

# Passivhaus: the route to zero carbon?



*Passivhaus Classic + renewables*

**NET zero**



*Notional Building Regs zero carbon*

**NOT zero**

Sponsors



# Passivhaus: the route to zero carbon?

## Contents

Executive Summary	2
Introduction	3
Embodied carbon or operational carbon?	3
Are we talking about carbon or energy?	4
How do Buildings use energy?	4
Zero Carbon is simple, right?	5
The Performance Gap	6
Seasonality of Renewable Energy	7
How much renewable energy can we produce?	8
Grid Capacity and Peak Demand	8
Reducing Demand and Closing the Gap	9
Comparing Zeros	11
On or off site renewables?	13
Conclusions	14
Appendix 1 – Defining a Baseline	15
Appendix 2 – The Performance Gap	16
Appendix 3 - Passivhaus Buildings Emission Rates	18

## Figures

FIGURE 1 - AVERAGE NEW BUILD ENERGY DEMAND - CURRENT SITUATION AND FROM 2020 WITH AN ASHP .....	5
FIGURE 2 - AVERAGE NEW BUILD ENERGY DEMAND - IMPACT OF THE PERFORMANCE GAP .....	6
FIGURE 3 - AVERAGE NEW BUILD ENERGY DEMAND - IMPACT OF STORAGE LOSSES .....	8
FIGURE 4 - AVERAGE NEW BUILD ENERGY DEMAND VS PASSIVHAUS .....	10
FIGURE 5 - COMPARISON OF ZERO CARBON SCENARIOS WITH ONLY REGULATED ENERGY CONSIDERED.....	11
FIGURE 6 - COMPARISON OF ZERO CARBON SCENARIOS WITH ALL ENERGY CONSIDERED.....	12

## Acknowledgements

The Passivhaus Trust would like to thank the following individuals for their contribution to this paper: Nick Grant, Alan Clarke, Mark Siddall and Laura Soar.



## Executive Summary

There are clear imperatives to reduce the carbon emissions resulting from the built environment. However, we are currently not achieving any significant year-on-year reductions and, unless new policies embodying new standards, incentives and penalties are put in place, we are unlikely to do so.

Setting a Zero Carbon target for our new housing would be a clear and bold step to achieve genuine emissions reductions and many cities and regions are moving towards this goal.

However, understanding what this actually means and how to achieve it is far from clear.

Examining data from Energy Performance Certificates (EPCs) as well as monitored data from real buildings, shows us that, there are three problems with adopting a net zero emissions approach:

1. There is a performance gap between predicted heating energy demand and actual energy use
2. There is a seasonal disparity between energy demand (heating in winter) and renewable energy generation (solar PV in summer alongside wind in the autumn and winter). This indicates a need for inter-seasonal energy storage which will result in storage losses
3. There are limits to how much renewable energy can be deployed and managed through the national grid

As a result of these problems, a notionally zero carbon home (according to Part L calculations), would not have zero CO<sub>2</sub> emissions, but would still emit 18 Kg CO<sub>2</sub>/m<sup>2</sup>.year, and an average 68m<sup>2</sup> new home in the UK would need 28 solar panels to actually achieve zero net operational carbon emissions, far greater than the amount of roof space it has available.

Extrapolating this to a national level shows that this model of zero carbon is not achievable as the increased grid capacity, storage capacity as well as the space and cost of the renewable generation required to support this is simply not achievable.

In contrast, an equivalent Passivhaus would need only 14 solar panels, dramatically reducing the requirement for grid and storage enhancements and halving the amount of renewable generation capacity required. Reducing the heating energy demand through a fabric first approach is therefore the only practical way to achieve zero carbon homes in reality.

If the zero carbon 'boundary' is expanded beyond the individual building to the national level, then achieving a net zero operational carbon built environment is possible if the fabric efficiency levels of our new homes are increased to Passivhaus levels.



## Introduction

The UK's 2030 and 2050 Climate Change targets now look unlikely to be achieved with predictions showing that Buildings emissions will not reduce significantly given current trajectories<sup>1</sup>. A recent report from the Committee on Climate Change concluded that emissions from the UK homes were no longer decreasing and that current policies will not deliver any further significant reductions<sup>2</sup>. The Government has recognised that action is required, and the Prime Minister's 2018 Jodrell Bank announcement has resulted in a Building Mission target of 50% energy use reduction in new buildings by 2030<sup>3</sup>. Scotland has already signalled its intent in this area and is seeking to move towards a Zero Carbon building standard using Building Regulations as a mechanism and in line with recommendations in the Sullivan report<sup>4</sup>.

All our new buildings must be designed to meet the energy requirements set out in Building Regulations Part L. However, this standard is based on a series of percentage reductions in emissions relative to the building's particular shape/size and so no specific level of emissions is currently being mandated. This method actually benefits inherently inefficient building shapes and so does not penalise poor design. Given the imperatives above, it is also clear that current targets do not go far enough in reducing energy use.

There is therefore considerable interest in using targets based on specific emissions levels and thus setting a Zero Carbon standard, which would result in buildings that produce zero net emissions over their lifetime. However, defining what is meant by a Zero Carbon standard is far from straightforward and could potentially encourage behaviour which would actually increase our overall emissions.

This paper therefore examines the validity of Zero Carbon as a concept and then goes on to suggest how Passivhaus might be used as part of a Zero Carbon strategy.

## Embodied carbon or operational carbon?

Our ultimate aim must be to look holistically at carbon emissions in the built environment and determine the most effective way to reduce them. This suggests that we should be considering both embodied carbon<sup>5</sup> and operational carbon<sup>6</sup>.

The calculation methods and sources of information for embodied carbon within construction materials are evolving rapidly and will allow us to model operational and embodied carbon alongside each other. However, the way in which we 'trade' carbon between operational and embodied is not yet established. For example, adding more insulation results in higher embodied carbon, but lower operational carbon. However, it also results in greater comfort levels within the building which has no carbon implication but makes the building function better. The insulation also enables smaller plant sizing, which reduces embodied carbon. Establishing whether more insulation is the best course of action therefore needs to bring in other factors beyond just emissions levels and thus leads to significant complexity. As this paper will show, we continue to build homes which are inefficient in operation and, unless we correct this first, operational carbon will remain the dominant factor for many years to come.

---

<sup>1</sup> Reducing UK emissions, 2018 Progress Report to Parliament, Committee on Climate Change, June 2018. Chapter 3.

<sup>2</sup> UK housing: Fit for the future?, Committee on Climate Change, February 2019, Page 28

<sup>3</sup> <https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/missions> accessed 12/12/18

<sup>4</sup> 'A Low Carbon Building Standards Strategy for Scotland 2007', Updated 2013

<sup>5</sup> Embodied carbon refers to the carbon emissions relating to the construction of a building, including the carbon emissions resulting from the manufacture and transport of the materials used.

<sup>6</sup> Operational carbon refers to the carbon emissions generated during the building's lifetime relating to its use and principally arising from the building's energy demand



This paper will therefore look exclusively at operational carbon and seek to determine how we can achieve net operational zero carbon emissions in the built environment, whilst acknowledging that embodied carbon will need to be considered alongside this as it becomes more dominant and our methods of assessing trade-offs become more mature.

Thus, where this paper refers to zero carbon, we are referring to zero net operational carbon.

## Are we talking about carbon or energy?

Whilst our aim must, of course, be to reduce carbon emissions, purely focussing on emissions without looking at energy efficiency could potentially lead to perverse decisions. The carbon emissions resulting from a building can vary over time as the carbon factors associated with different energy sources change. These can vary over the long-term (years) or short-term (hours) as the energy sources supplying the national grid vary. The type of building services employed also have a significant impact on the level of resultant emissions and during the lifetime of the building, upgrading and replacing various building services systems will therefore change the amount of carbon that is related to the building's use. Accurately measuring and predicting carbon use thus becomes complex and based upon a number of assumptions – which become less robust the further into the future we look.

In contrast, the energy demand of a building will be relatively consistent throughout its life, with the most significant variations due to occupancy habits and climate. If the energy demand of the building is minimised in the first place, then subsequent reductions in emissions arising from a reduced carbon factor are a welcome bonus. For these reasons, this analysis will focus on energy use as the primary metric but will relate this back to carbon emissions where appropriate.

## How do Buildings use energy?

Before we look at how we might achieve a zero carbon building, it is useful to understand what type of energy demands occur in buildings. To help us then look at how these demands could be reduced, we should also consider how these categories relate to the design of the building as well as the way in which it is used by the occupants<sup>7</sup>. Any building's energy demand can be broken down as follows:

Category	Includes	Affected by Design	Affected by Occupancy Habits	Type
Heating / Cooling	Energy needed to maintain the building at a comfortable temperature	Significantly	Moderately	Regulated
Hot Water	Energy needed to provide a supply of hot water for washing and cleaning	To a limited degree	Significantly	Regulated
Lighting and Auxiliary electricity	Energy need to provide lighting and run the pumps/fans to support heating/cooling/hot water systems	Moderately	Moderately	Regulated
Appliances, specialist uses and 'plug loads'	Appliances, computers and all other electrical loads	To a limited degree	Significantly	Unregulated

In the UK, the first three categories make up what is known as 'Regulated Energy' and these are the only energy uses considered by the Standard Assessment Procedure (SAP) which is used to calculate Energy Performance Certificates (EPCs), as used in the UK Building Regulations. Appliances and plug loads are considered to be 'Unregulated Energy' and are not calculated.

<sup>7</sup> Commonly referred to as 'Occupancy Habits'



## Zero Carbon is simple, right?

Buildings need energy to provide a habitable environment for their occupants, as outlined in the previous table. Whilst we can take steps to be more efficient in the way we use energy, we will never be able to reduce our actual usage to zero. To achieve zero net emissions, we therefore need to be able to offset our actual energy use with energy derived from renewable energy sources. This would seem to make it straightforward to define Zero Carbon – all regulated and unregulated energy must be offset by renewable energy.

However, how much carbon we use is also related to what type of energy we use and how that energy is generated. The UK national strategy is to ‘decarbonise’ the electricity grid by introducing more renewable energy sources. This has already had a significant impact and the current emission factor for grid electricity of 0.519KgCO<sub>2</sub>/kWh is set to reduce to 0.233KgCO<sub>2</sub>/kWh from 2020. This almost equates to the emission factor for natural gas of 0.210KgCO<sub>2</sub>/kWh.

Using a heat pump will reduce actual electricity consumption for heating and hot water by at least half compared to direct electric<sup>8</sup>. Thus, it would seem that simply switching from gas to heat pumps to capitalise on grid decarbonisation would, in itself, significantly reduce emissions. Might this be enough to get us close to zero carbon?

The chart below shows the breakdown of annual energy demand for a 68m<sup>2</sup> house<sup>9</sup> built to Building Regulations standards<sup>10</sup> first using a gas boiler for heating and hot water (current situation) and then with the same house using an Air Source Heat Pump applying 2020 emissions factors. These demands are then set against the generation from 16 solar panels<sup>11</sup>.

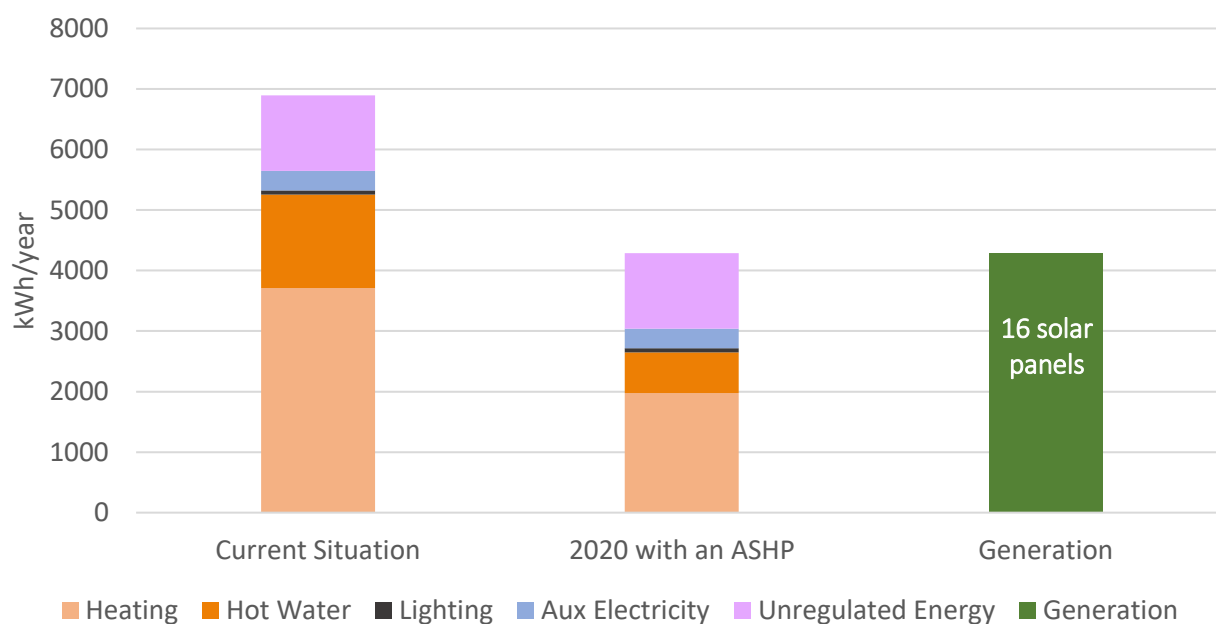


Figure 1 - Average new build energy demand - current situation and from 2020 with an ASHP

<sup>8</sup> Heat pumps will produce hot water with a Coefficient of Performance (COP) of somewhere between 1.5 and 4 depending on heat pump type and system design. For example, a heat pump with a COP of 2 will produce 2kWh of hot water using only 1kWh of electricity.

<sup>9</sup> The average UK new-build house size is now 68m<sup>2</sup> – see [https://www.labc.co.uk/news/what-average-house-size-uk?language\\_content\\_entity=en](https://www.labc.co.uk/news/what-average-house-size-uk?language_content_entity=en) accessed 30 Jan 2019

<sup>10</sup> Using the baseline emissions data derived in appendix 1, a Passivhaus Planning Package (PHPP) model has been used to calculate that the equivalent space heating demand for an average Building Regulations property is 54 kWh/m<sup>2</sup>.year

<sup>11</sup> Based on 300Wp panels, unshaded, south facing, located in the East Pennines.



The total energy demand for our 2020 ASHP house is 4,300 kWh/year and with our 16 solar panels, the total generation is also 4,300 kWh/year. So, we would appear to have a Zero Carbon building. However, unfortunately, it's not that simple. If we are to get to true zero, we need to consider the Performance Gap, seasonality of renewable generation and associated storage losses, how much renewable energy we can realistically generate and the impact on the electricity grid.

## The Performance Gap

There is clear evidence that the actual energy performance of our new homes does not match with the design. Appendix 2 sets out the evidence and demonstrates that the average home is likely to use around 40% more energy than predicted, with heating demand sometimes 2 to 3 times greater. If we include the impact of the performance gap to reflect the way in which our buildings are actually performing, then our demand increases to 5,400 kWh/year, which requires 20 solar panels to offset<sup>12</sup>.

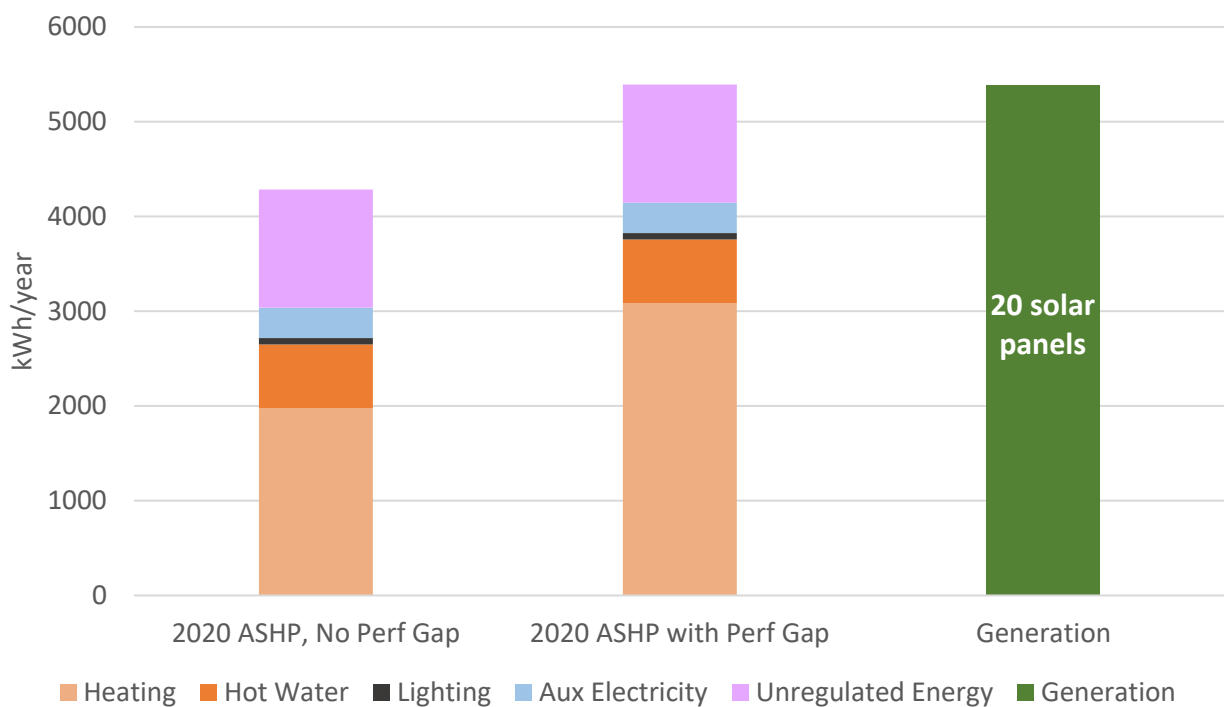


Figure 2 - Average new build energy demand - impact of the Performance Gap

In contrast, the quality assurance process that is part of the Passivhaus standard ensures that what is designed is what gets built and the actual energy performance of Passivhaus homes is, on average, exactly as predicted by the design stage modelling. In short, Passivhaus buildings do not suffer from a performance gap.

It could be argued that much of the data relating to the Performance Gap is now historical and we shouldn't be basing future policy on this basis. Whilst there is no one single root cause of the gap, much of it is due to quality control on site – ensuring high quality construction and that the right materials are used in the right places. To achieve this, we need more robust assurance regimes, incentives for better buildings and penalties for those that do not perform. Unless policies are put in place to achieve these, then it is reasonable to assume that we are likely to see the Performance Gap endure in our new homes for some time to come.

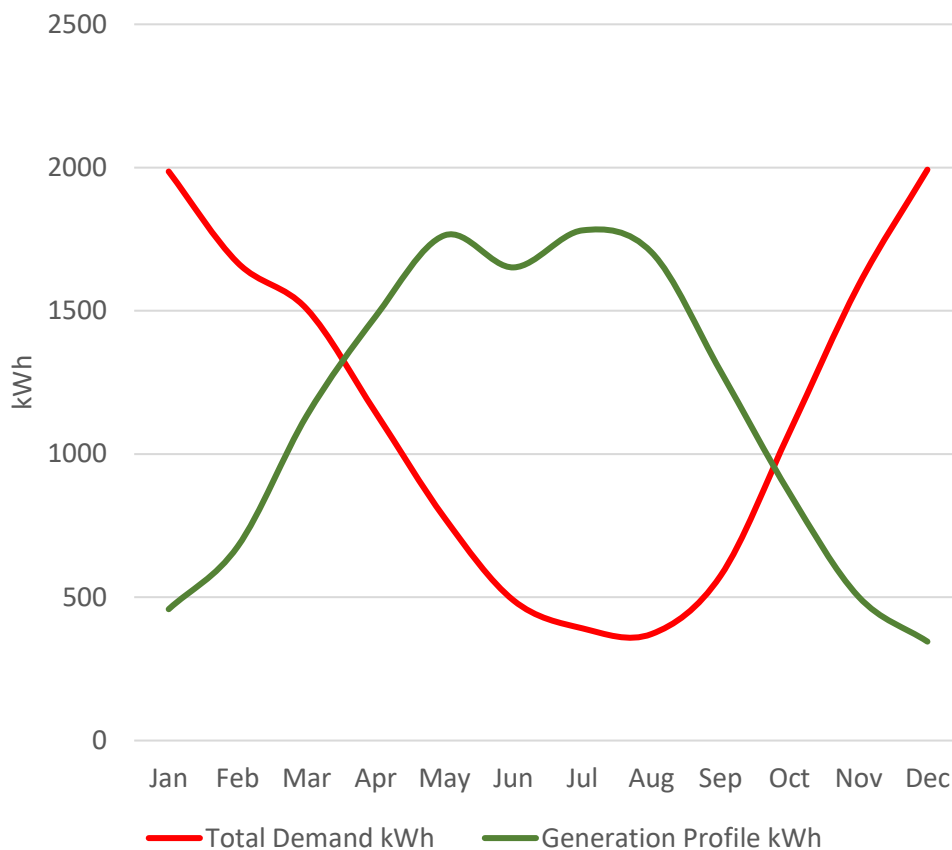
<sup>12</sup> Including the impact of the performance gap increases space heating demand to 84 kWh/m2.year



## Seasonality of Renewable Energy

So, is our building now Zero Carbon? Our primary sources of renewable energy are wind, tidal and solar, all of which fluctuate daily and with the seasons. However, solar energy is more predictable and thus we will use this to illustrate the problems associated with seasonality.

Our analysis thus far has assumed that all the generated energy can be used to directly offset demand. However, the majority of solar energy is generated in the summer, but the peak demand from the house is in the winter. The chart below shows the demand and generation profiles of the same house over the course of the year.



This shows that much of the energy generated during the summer months will need to be stored and used in the winter months to support the heating demand. This would require some form of long-term inter-seasonal storage. Whilst these technologies do exist, and more are under development, they are not that efficient and thus a significant amount of the energy generated will be lost during storage. If we include these storage losses<sup>13</sup>, then the picture is very different:

<sup>13</sup> Calculated using the Passivhaus Primary Energy Renewable Factors





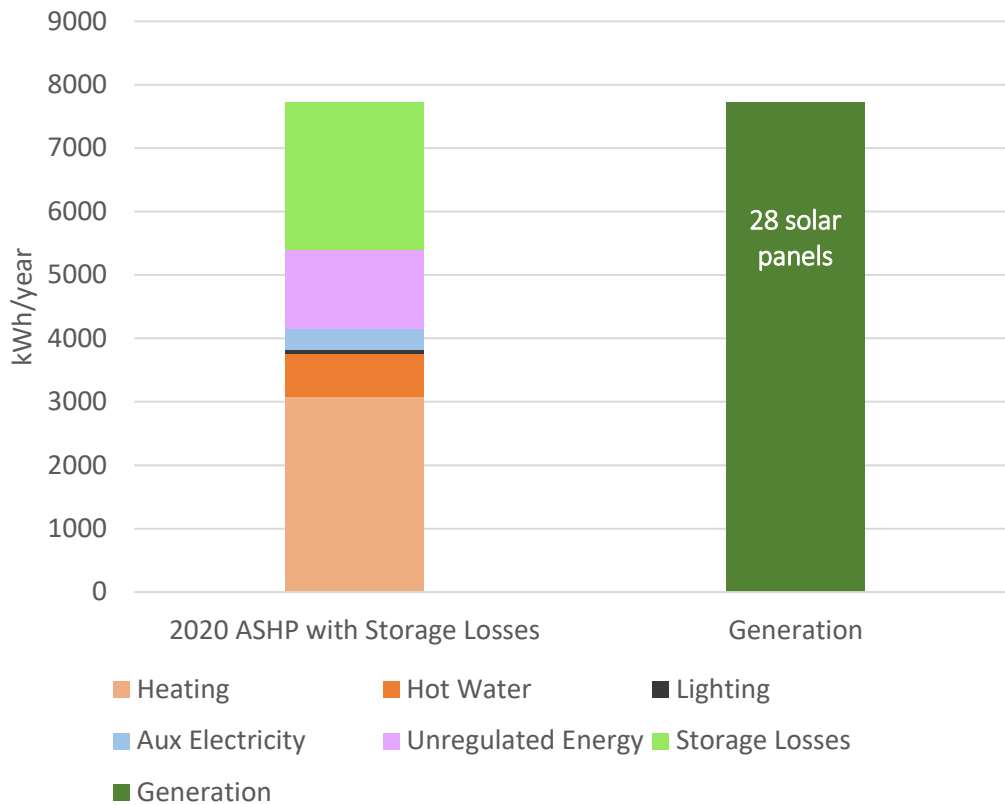


Figure 3 - Average new build energy demand - impact of storage losses

The overall energy demand of the building is now 7,700 kWh/year – 80% more than we had previously calculated. To actually make this building Zero Carbon, we now need to add another 8 solar panels – that’s 28 solar panels in total, needing an area of 45m<sup>2</sup>, just to make one house Zero Carbon. That’s nearly 50% more than the area of the building footprint.

## How much renewable energy can we produce?

In theory, we have achieved a Zero Carbon home, but is this 45m<sup>2</sup> of solar panels for a single dwelling reasonable? It is significantly more than we can achieve on-site and thus some or all of this generation will need to occur offsite. However, the finance and space available to install renewable energy resources is finite and we cannot simply assume that we can keep adding more renewable capacity until we reach zero carbon. In 2017, renewable energy formed 29% of the UK’s electrical generation and amounted to 99TWh<sup>14</sup>. Even assuming that **all** this energy was available for the domestic sector, this would be enough to offset only 13M homes at this level of demand. There are 25 million homes in the UK.

## Grid Capacity and Peak Demand

As the grid is decarbonised, there is an increasing case to use more electricity for heating purposes. This is particularly compelling when using heat pumps, as the running costs can become comparable to gas. Thus, heating loads which were previously satisfied by gas will need to be met from the electricity grid.

<sup>14</sup> Digest of UK Energy Statistics (DUKES): renewable sources of energy, Chapter 6 (Updated July 2018)



Whilst this is good for emissions, it is not good for the grid as it must be enhanced to deal with both greater overall capacity and a much higher peak load (as heating demands will tend to be at the same time for all dwellings).

It is estimated that, without improving current levels of fabric efficiency, the additional grid capacity required to accommodate new homes with heat pumps is up to 43TWh, with an additional peak load demand of up to 16GW<sup>15</sup>. So, that would take up nearly half of our current renewable generation of 99TWh and require a 26% increase in the grid's peak load capacity<sup>16</sup>. This is a significant increase in overall capacity and the grid's generation and distribution infrastructure will need to be upgraded accordingly which will be both expensive and will take time to implement.

If this upgrade process does not keep pace with demand, in areas where loads are too high, then we may see situations where the grid is unable to support demand and thus projects are forced to use gas as their fuel source.

However, if the heating loads are significantly reduced, as we have demonstrated above, then the peak load will also be reduced and the demand on the grid reduced accordingly, allowing us to switch to electrical heating and thus realise the reduced emissions that the decarbonisation strategy envisages.

## Reducing Demand and Closing the Gap

So, the seemingly simple route to Zero Carbon of balancing energy demand against renewable supply isn't really viable at a national level. The more energy we need to offset, the greater the effect of the seasonal imbalance and thus the greater the amount of renewable energy that needs to be generated and the greater the demand on the grid. We therefore need to return to our energy uses and see what can be done to reduce that first, before we address renewable energy generation.

The emissions associated with heating/cooling can be significantly reduced by amending the building design. This is the primary focus of the Passivhaus standard which reduces thermal losses by improving the building fabric and ventilation heat recovery. Significant reductions can be achieved as, even in new homes, this is typically the largest area of demand by some margin. This is also the area primarily affected by the performance gap.

Hot water demand can be reduced to some extent by good design – efficient layouts which reduce distribution losses. The net emissions can also be reduced by using heat pumps which, given the increasing de-carbonisation of the electricity grid, now result in significantly fewer emissions than a gas boiler equivalent.

Unregulated energy use is, by its nature, more difficult to reduce. Occupants can be encouraged to behave differently, but this may not have a significant effect. In different usage classes (e.g. healthcare, industrial, office), the unregulated energy uses will be specific to the nature of the building use and will vary widely across different classes. Again, sensible design may help to reduce this.

To illustrate the impact of reducing energy demand, let us return to our 68m<sup>2</sup> house, but now redesigned as a Passivhaus building using an air source heat pump for heating and hot water<sup>17</sup>. The result is a significant reduction in heating demand, even with hot water, auxiliary electricity and plug loads remaining the same. The house would now need 3,700 kWh/year of renewable energy to be Zero Carbon – that's 14 solar panels,

---

<sup>15</sup> UK housing: Fit for the future?, Committee on Climate Change, February 2019, Page 64

<sup>16</sup> 2017 Grid Peak Load capacity was 59.4GW, taken from the National Grid Future Energy Scenarios data for 2018

<sup>17</sup> Using proposed SAP 10 carbon factor of 0.233 kgCO<sub>2</sub>/kWh for electricity



or 22m<sup>2</sup>. A 100% reduction from the Building Regulations equivalent. The 99TWh of renewable electricity available nationally could now make over 26M homes Zero Carbon.

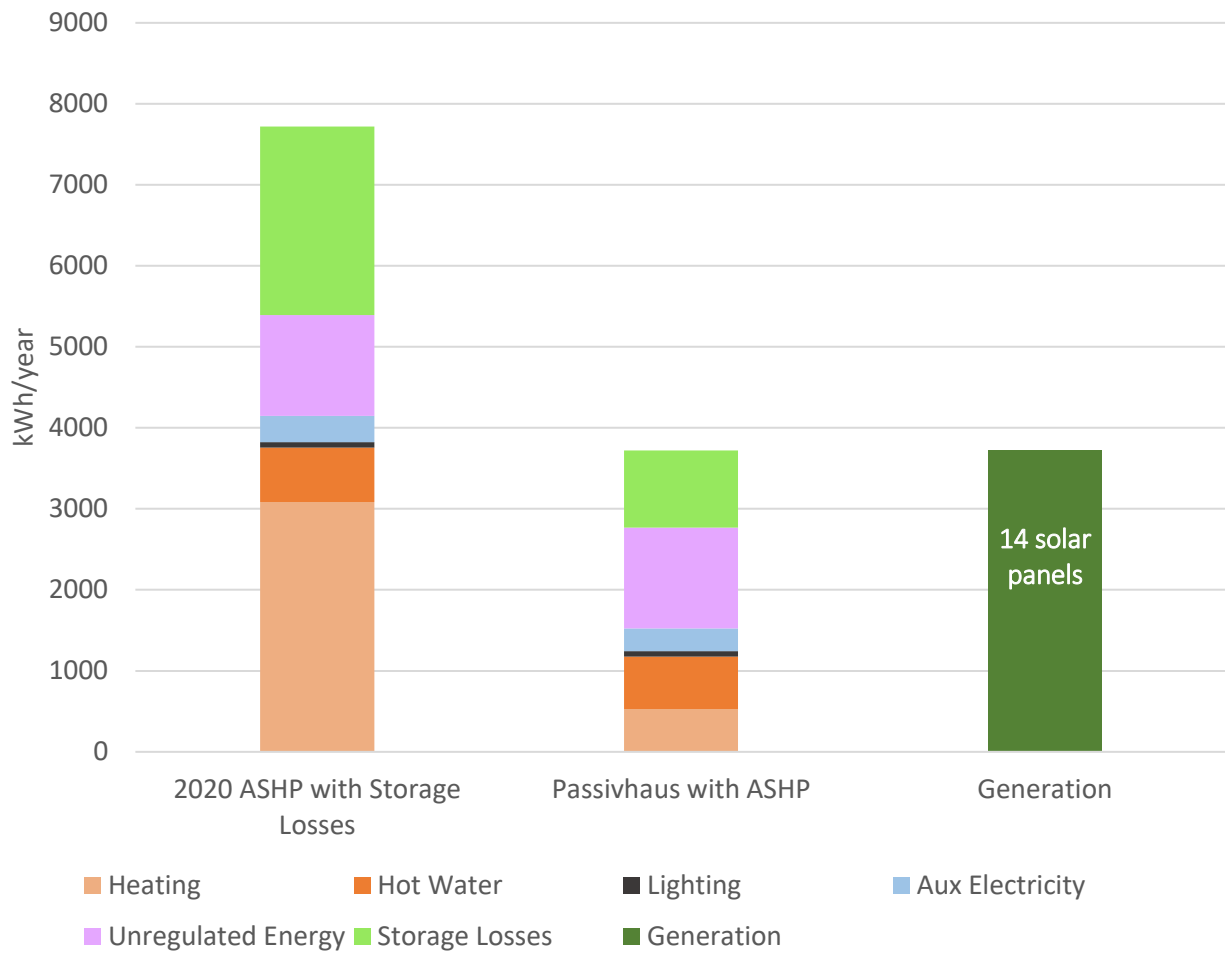


Figure 4 - Average new build energy demand vs Passivhaus



## Comparing Zeros

In setting a definition for Zero Carbon, it is clear that factors such as the performance gap and storage losses need to be taken into account to ensure that a realistic assessment of net emissions is made.

There are therefore a number of potential Zero Carbon ‘scenarios’ which will all result in different levels of net emissions. To provide an illustrative comparison, the following scenarios have been considered, assuming that we offset only the regulated energy:

<b>Scenario 1</b>	Current situation – existing carbon factors, assuming a gas boiler and including the performance gap. Renewable energy sufficient to offset regulated energy (i.e. what is currently considered a Zero Carbon dwelling)
<b>Scenario 2</b>	2020 Carbon Factors with an ASHP and renewable energy sufficient to offset regulated energy (i.e. a Zero Carbon home from 2020 onwards) if nothing changes
<b>Scenario 3</b>	2020 Carbon Factors with an ASHP, but with Part L requiring a further 19% reduction in TER <sup>18</sup> . Renewable energy sufficient to offset regulated energy.
<b>Scenario 4</b>	Passivhaus with ASHP and no generation
<b>Scenario 5</b>	Passivhaus with ASHP and sufficient generation to offset regulated energy

The chart below shows the net emissions arising from each of these potential definitions of Zero Carbon, alongside the area of solar panels that would be required to satisfy each scenario and the increase in grid capacity that would be required.

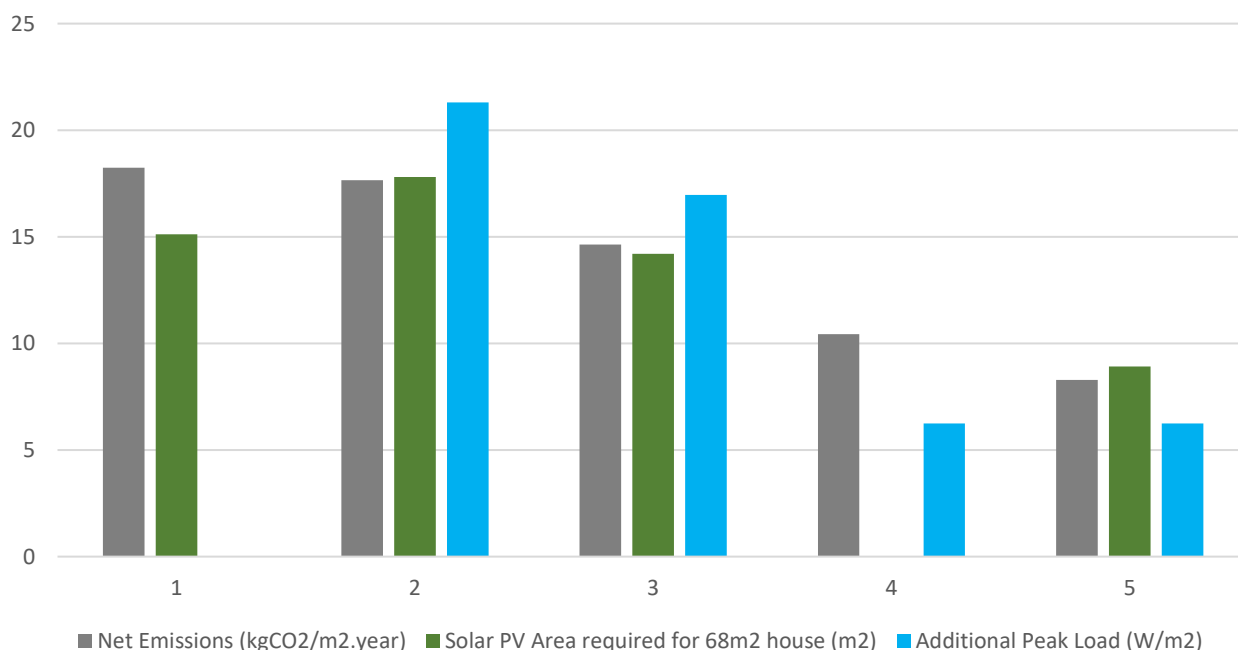


Figure 5 - Comparison of Zero Carbon scenarios with only Regulated Energy considered

This analysis shows that a Passivhaus using an ASHP and no renewable generation has significantly lower net emissions (circa 10 kgCO<sub>2</sub>/m<sup>2</sup>.year) than any of the Building Regulations scenarios with their regulated energy fully offset – i.e. what would currently be classed a Zero Carbon home. In other words, if a further 19% reduction in TER is implemented, and we fit Air Source Heat Pumps alongside sufficient solar panels to offset all regulated energy, the resultant dwellings will still result in higher emissions than an equivalent Passivhaus with no solar generation.

<sup>18</sup> Target Emissions Rate (TER) – this is the emissions rate as determined by SAP, based on a percentage reduction on 1990 emissions levels for an equivalent building. A 19% reduction on existing levels was proposed in 2018 by the UKGBC.



However, none of these scenarios actually achieves net zero carbon, as unregulated energy and storage losses have not been included when calculating how much renewable energy is required. Once these are included, each scenario can be modified as follows:

<b>Scenario 1b</b>	Current situation – existing carbon factors, assuming a gas boiler and including the performance gap. Renewable energy sufficient to offset all energy.
<b>Scenario 2b</b>	2020 Carbon Factors with an ASHP and renewable energy sufficient to offset all energy including storage losses.
<b>Scenario 3b</b>	2020 Carbon Factors with an ASHP, but with Part L requiring a further 19% reduction in TER. Renewable energy sufficient to offset all energy including storage losses.
<b>Scenario 4b</b>	Passivhaus with ASHP and no generation.
<b>Scenario 5b</b>	Passivhaus with ASHP and sufficient generation to offset all energy including storage losses.

The chart below shows the amended results.

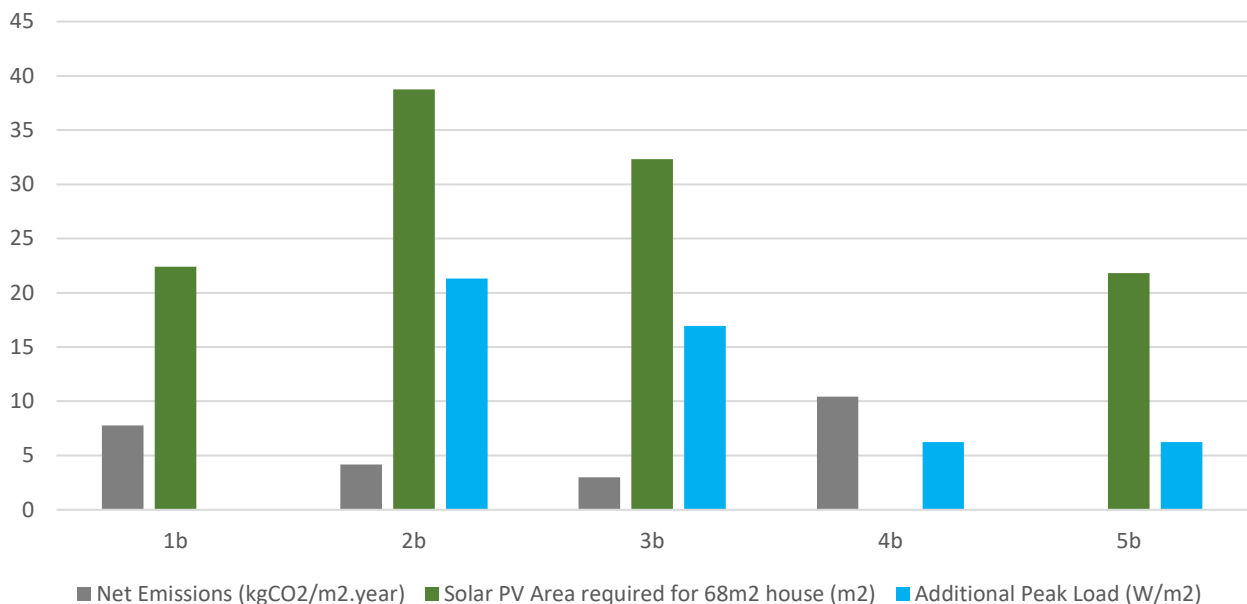


Figure 6 - Comparison of Zero Carbon scenarios with all energy considered

This time, the results show that the proposed move to a notional net zero building (using an ASHP and reducing the TER by 19%) will still have emissions of 3 kgCO<sub>2</sub>/m<sup>2</sup>.year, which would require 32m<sup>2</sup> of solar panels to offset. In contrast, the Passivhaus fitted with 22m<sup>2</sup> of solar panels lowers emissions to actual zero. Of all the scenarios modelled, this is the only actual zero carbon building.



## On or off site renewables?

The discussion to this point has not discriminated between on-site or off-site renewable generation. The concept of a Zero Carbon building tends to draw the system boundary<sup>19</sup> around the building itself (or at least the site), thus implying that the renewable energy required should come from the site.

However, some sites and building may not be suitable for solar generation and, even using the Passivhaus scenario above, many buildings will simply not have sufficient roof area. Our example above showed that even taking fabric efficiency to Passivhaus levels, we still need 22m<sup>2</sup> of solar panels for a 68m<sup>2</sup> dwelling. If this dwelling was part of a multi-storey block of similar dwellings, it is clear that it would be impossible for the site to provide sufficient renewable generation. Thus, any achievable Zero Carbon scenario on a regional or national scale will need to utilise off-site renewable generation.

If that is the case, then it would seem sensible to move our system boundary to encompass all buildings and all sources of renewable energy and then simply choose the most cost-effective means of generation, whilst maintaining a balance across the various sources.

With the demise of the Feed in Tariff, the cost per kWh of small domestic solar arrays is now far more than for large arrays and the cost of generation from onshore wind is even cheaper<sup>20</sup>.

It would therefore seem that the most effective means of providing the renewable energy required to make our Zero Carbon strategy work, would be for new-build projects to pay a contribution towards the construction of national or regional renewable energy projects rather than be mandated to provide on-site generation.

Whilst to be truly zero carbon, a project should result in the creation of enough generation capacity to match the increased demand, in certain situations, it may also be appropriate to consider Offset schemes where financial contributions are provided to pay for carbon saving schemes elsewhere.

---

<sup>19</sup> Concept of the system boundary for Zero Carbon drawn from 'Is net Zero the right target for buildings?', Nick Grant, Hannover Passivhaus Conference, May 2012

<sup>20</sup> See <https://www.bbc.co.uk/news/business-45881551> accessed 20 Jan 2019



## Conclusions

This analysis has shown that Zero Carbon targets don't necessarily result in Zero emission buildings and that, when considering how to define a Zero Carbon building, it is essential to take into account the complete picture of how the building will use energy as well as the impact of the seasonality of renewable generation.

The results show that a Passivhaus Classic building, with no generation capacity, will generate significantly lower emissions than a notional Zero Carbon building<sup>21</sup> - which isn't Zero Carbon anyway as its emissions will be around 18 KgCO<sub>2</sub>/m<sup>2</sup>.year.

The analysis shows that Passivhaus is the only realistic way to achieve Zero Carbon without massive renewable energy expansion coupled with a significant investment in grid capacity.

However, even when using Passivhaus as a mechanism to significantly increase efficiency, achieving a Zero Carbon built environment is only really viable if the system boundary is extended beyond individual buildings.

Recent reports have forecast that we now only have a few years left to reduce emissions enough to avoid a catastrophic rise in global temperatures. Significantly reducing the emissions of our buildings is vital if the UK is to make a meaningful contribution and would lead by example when many countries are also struggling to understand how to reduce emissions sufficiently.

---

<sup>21</sup> As calculated using SAP2012 methodology



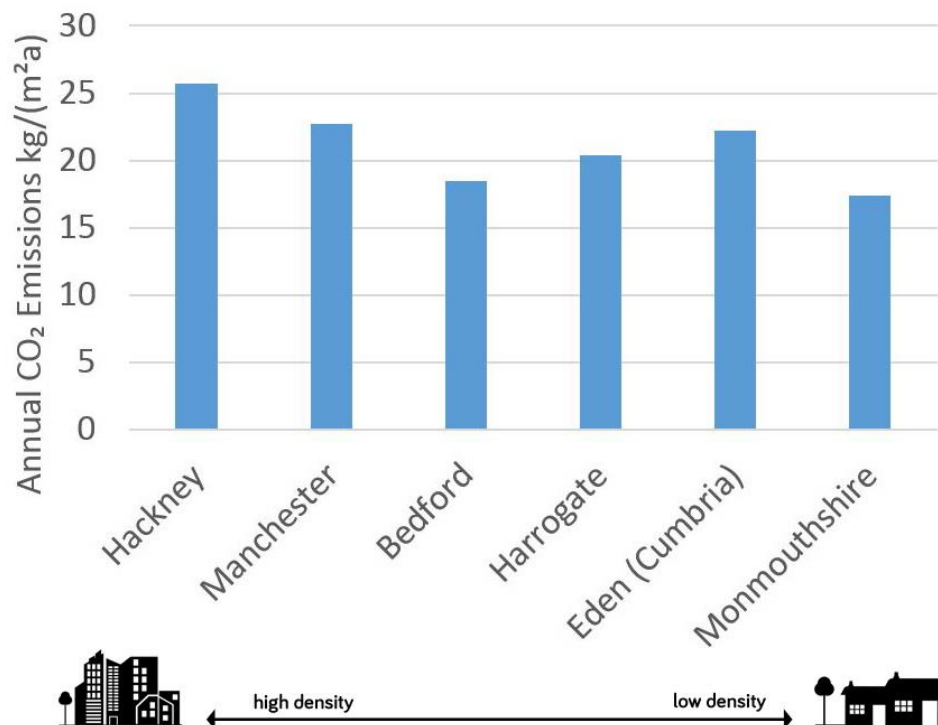
## Appendix 1 – Defining a Baseline

The UK is building around 170,000 to 200,000 new homes per year<sup>22</sup>. All these homes are designed to meet the energy standards required in Building Regulations Part L1A, but yet, because of the way in which the energy criteria are set, the emissions resulting from a typical new build dwelling are not evident.

Energy Performance Certificate (EPC) data from all new build dwellings from 2008 to 2016 is now available. EPC data includes a predicted emissions level, measured in kgCO<sub>2</sub>/m<sup>2</sup> for each dwelling<sup>23</sup>. Subsets of this data have been analysed to derive an average emissions level across all new build dwellings. The methodology for this analysis was as follows:

- Total of 9970 dwelling samples
- Lodgement dates of 2015 to 2016 selected to ensure that the current SAP version was in force
- Dwellings selected from a mixture of dense urban, urban and rural locations
- Predicted CO<sub>2</sub> emissions rates averaged across all dwellings

The results of this analysis are shown in the chart below.



The results show a fairly consistent predicted emissions rate across all dwelling areas and types. The overall average was 21 kgCO<sub>2</sub>/m<sup>2</sup>.year.

<sup>22</sup> <https://www.gov.uk/government/statistical-data-sets/live-tables-on-house-building> accessed 12 Dec 18

<sup>23</sup> Calculations relating to this data are based on SAP 9 emission factors of 0.519 kgCO<sub>2</sub>/kWh for electricity





## Appendix 2 – The Performance Gap

Monitoring data from new-build houses has consistently shown that the energy use predicted at design stage is frequently exceeded during actual use – in many cases by a significant margin. In 2015, a team at the Centre for the Built Environment at Leeds Metropolitan University (now Leeds Beckett) presented evidence that the performance of new build houses ‘as constructed’ often differs widely from performance ‘as designed’.<sup>24</sup> One of the main contributors to this ‘performance gap’ was found to be heat loss, which ranged from 10% - 125% of that predicted in the design calculation.

More recently, Innovate UK’s Building Performance Evaluation Programme, which looked at 76 low carbon homes to assess how well they achieved their performance targets, found that actual carbon emissions from these homes were on average two to three (2.5) times higher than design estimates<sup>25</sup>. This average encompassed a wide range, with the worst performing home consuming 29 times more than the design estimate for regulated energy alone. It should be noted that the buildings studied all aimed at better-than-average energy performance.

By contrast, Passivhaus buildings have been consistently shown to perform, on average, at levels very close to their design intent. The post-occupancy research conducted by Leeds Met / Leeds Beckett University compared the performance of 33 dwellings using the co-heating test method<sup>26</sup> to evaluate the building fabric. Of these, six were Passivhaus dwellings, and these not only performed best at design stage, but also succeeded in effectively eliminating the performance gap.

In 2017, the Passivhaus Trust commissioned an independent report from the University of Bath<sup>27</sup> which examined post-occupancy data from a further 31 Passivhaus dwellings and concluded that, on average, they performed better than the design prediction of 15 kWh/m<sup>2</sup>.a.

The net result of this is that we can conclude that most new dwellings will consume significantly more energy than their SAP analysis would suggest, whilst a new-build Passivhaus will perform almost exactly as predicted by the PHPP modelling.

The size of the gap varies widely as has been shown above. However, determining an ‘average’ performance gap for overall emissions is problematic as the various studies have looked at individual elements such as heat loss variation as well as making comparisons between predicted unregulated energy and all in-use energy.

The Leeds Beckett analysis showed that the average difference between the whole house designed u-value and actual u-value was a factor of 1.6. This therefore gives us a ratio for conduction losses. This figure does not include ventilation losses. As the EPC data includes a measured ‘as-built’ value for air permeability, then the modelled ventilation losses should match the in-use results. However, data from the Innovate UK study<sup>28</sup> showed that airtightness levels were frequently above the initial as-built result when tested at a later date. For mid-range properties (3-5 ACH@50Pa), the average increase was 34%.

<sup>24</sup> Quantifying the domestic building fabric 'performance gap'. Johnston, D and Miles-Shenton, D and Farmer, D (2015) (<http://eprints.leedsbeckett.ac.uk/1054/>) accessed 3 Jan 19

<sup>25</sup> [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/497758/Domestic\\_Building\\_Performance\\_full\\_report\\_2016.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/497758/Domestic_Building_Performance_full_report_2016.pdf), Page 18, Accessed 3 Jan 19

<sup>26</sup> The co-heating test is a whole house heat-loss measurement that reliably assesses building fabric performance. Fan-assisted heaters are used to maintain an unoccupied house at a constant temperature of 25° for a period of typically 1-3 weeks during the winter months – the daily heat input can then be plotted against the interior to exterior temperature differential, giving a heat-loss coefficient as a static value in W/K.

<sup>27</sup> Rachel Mitchell, The Performance of Passivhaus in New Construction (Passivhaus Trust, July 2017)

<sup>28</sup> [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/497758/Domestic\\_Building\\_Performance\\_full\\_report\\_2016.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/497758/Domestic_Building_Performance_full_report_2016.pdf), Pages 24-27, Accessed 3 Jan 19



The emissions rates from the EPC data will include conduction losses, ventilation losses and domestic hot water use. If we take figures for the 'average' UK house, and assume that ventilation losses are 15% of the overall space heating demand<sup>29</sup>, then we get the following results:

Average household annual gas usage <sup>30</sup>	12,400 kWh
Average household size <sup>31</sup>	2.4 people
Annual domestic hot water usage <sup>32</sup>	2,045 kWh
Annual space heating demand (annual gas usage minus hot water usage)	10,355 kWh
Proportion of space heating demand relating to ventilation (15%)	1,553 kWh
Proportion of space heating demand relating to conduction losses (85%)	8,802 kWh

We can now work back and calculate the EPC design figures based on a 60% increase in conduction losses and a 34% increase in ventilation losses.

	Conduction Heat Loss (kWh/year)	Ventilation Heat Loss (kWh/year)	Domestic Hot Water (kWh/year)	Total (kWh/year)	Difference (%)
<b>BRegs Design</b>	5501	1159	2045	8705	0%
<b>BRegs In use</b>	8802	1553	2045	12400	42.4%

This indicates that an average building will consume over 40% more energy than its EPC modelling would indicate.

This has the effect of increasing our predicted average emissions rate derived in appendix 1 of 21 kgCO<sub>2</sub>/m<sup>2</sup>.year to 30 kgCO<sub>2</sub>/m<sup>2</sup>.year.

<sup>29</sup> Derived by setting the airtightness of a 200m<sup>2</sup> solid wall terraced property to 8 ACH@50Pa in PHPP

<sup>30</sup> DECC, National Energy Efficiency Data-Framework, Summary of analysis using the National Energy Efficiency Data-Framework (NEED), June 2015, Table 3.1

<sup>31</sup> <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2017> accessed 3 Jan 19

<sup>32</sup> Derived using the BREDEM formula to determine hot water usage per day (38 + 25\*N) where N is the number of people in the dwelling. The Energy Saving Trust publication, 'Measurement of Domestic Hot Water Consumption in Dwellings' (2008). Demonstrated a good correlation between this formula and actual hot water use.



## Appendix 3 - Passivhaus Buildings Emission Rates

To provide PHPP data which can be related back to SAP data, a theoretical building has been modelled in PHPP. This model has then been adjusted to different sizes, using TFA (treated floor area) as the key metric. Other metrics, including floor, wall and roof area, glazing, and pipe and ducting lengths, adjust relative to the TFA. As the TFA is altered, u-values of the building fabric are adjusted such that the sample building at every size has a total heating demand of 15 kWh/m<sup>2</sup>.a. This is the target heating demand a building must achieve to satisfy the Passivhaus standard and most Passivhaus buildings tend to end up quite close to this figure – i.e. very few are significantly lower than this.

Some other adjustments have been made to standard PHPP parameters, in order to enable the comparison with SAP calculations:

- **Climate data**  
EPC calculations use climate data for the East Pennines region to ensure consistency of EPC results, regardless of location. The theoretical Passivhaus buildings are therefore all located in the East Pennines.
- **Regulated energy**  
PHPP includes calculations for unregulated energy (appliances etc), while SAP does not. These have all therefore been set to zero within the PHPP model. Lighting, which is included in SAP calculations, has been included. This therefore means that the PHPP model is calculating the energy use of the same items (regulated energy items) as the SAP/EPC.
- **Carbon factors**  
To facilitate an equitable comparison between PHPP and EPC/SAP, a gas boiler has been modelled in the PHPP, using SAP 9 carbon factors. This aligns with what is likely to be the predominant configuration in a typical dwelling.

The output from the baseline model is a series of values for CO<sub>2</sub> emissions for a Passivhaus dwelling ranging from 13.9 kg/(m<sup>2</sup>.a) for a house with a TFA<sup>33</sup> of 50m<sup>2</sup> to 7.8 kg/(m<sup>2</sup>.a) for a house with a TFA of 250m<sup>2</sup>.

It is worthy of note that the average emission rate is 10 kg/(m<sup>2</sup>.a) which meets the Zero Carbon Hub threshold for Carbon Compliance as set out in their definition of the Zero Carbon hierarchy.

This theoretical analysis of Passivhaus buildings has been verified by making the same PHPP amendments to several certified Passivhaus buildings. These real buildings are overlaid on the theoretical chart as shown below and demonstrate a close correlation with the theoretical results.

---

<sup>33</sup> Treated Floor Area – effectively the usable floor area, typically between 90 and 95% of the Gross Internal Area.



