PassivTower

Sustainable housing for the high density city

Allies and Morrison

Contents

Introduction

Research study
Interdisciplinary collaboration

This research and development paper has been commissioned by Allies and Morrison, in collaboration with a number of the industry's leading experts in Passivhaus design at scale. In looking to address a growing need for greater building performance transparency, the project aims to explore the Passivhaus standard on a scale not yet tested and identify key challenges in its implementation in the housing sector in London and other cities facing housing shortages.

Establishing a well balanced team, with experience in the delivery of Passivhaus projects at scale was an important first step in the project's initiation. The Passive House Academy (PHA) brought significant experience from their role on the Cornell Tech Passivhaus tower in New York, which currently holds the title of the world's tallest Passivhaus development. PHA provided invaluable insights into the opportunities and pitfalls when implementing large scale Passivhaus projects and undertook the unenviable task of creating the world's largest know Passive House Planning Package (PHPP) file.

Buro Happold Engineering took on the challenge of rethinking the function and scale of building services, in a building typology that could potentially have very different requirements to that of the typical new build residential tower in the London climate. Gardiner and Theobald also provided insights into estimate capital and operational costs at each design iteration. Their insights into potential supply chain challenges was invaluable and provided an important grounding throughout the project.

Over the course of a year, each contributor to the project tackled an endless stream of estimated performance data, developed throughout the project, converging a number of thought provoking conclusions leading up to the proposal for the **PassivTower**.

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Why Passivhaus?

Addressing industry challenges

The performance gap

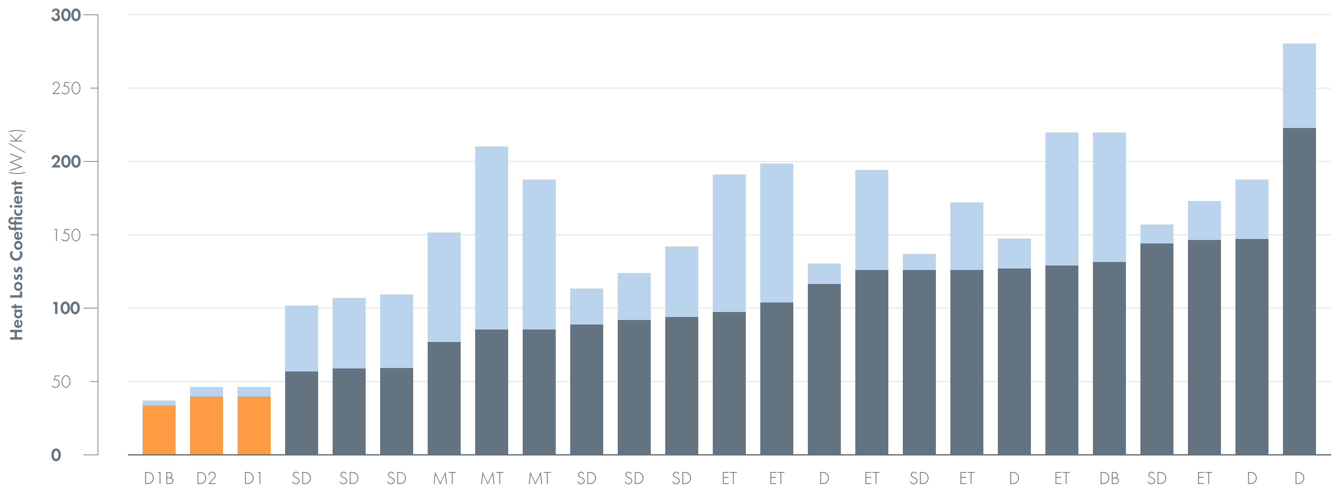


FIGURE 1 Review of post occupancy building performance across a number of residential typologies and the associated 'performance gap'
Source: Centre for Built Environment, Leeds Metropolitan University

The 'Performance Gap' is a term that seems to have developed an unfortunate association with the UK construction sector and poses one of the biggest challenges to the industry in the coming years. This is a complex and multifaceted problem; however in the vast majority of cases, the issues can be traced back to information losses between design, construction and operation stages, where the quality of design intent is all too often not materialised on site.

In tackling this issue, the industry is looking to firstly, improve the methods in which we simulate and predict building energy performance in the design stages. Secondly, there needs to be a far greater emphasis put on the importance of build-ability reviews during design stages and the monitoring of site quality during the construction stages. Both challenges are ingrained in the approach of Passivhaus and there are many lessons to learn from the methodology of this standard. The use of PHPP from conceptual design, all the way through to the certification process post construction, ensures all parties are aware of strengths and weakness within a scheme.

In extensive research carried by Innovate UK on building performance in residential schemes across the UK, it was concluded that the identified performance gap in Passivhaus dwellings is significantly lower than conventional new builds. This is also confirmed in research carried out by Leeds Metropolitan University, highlighted in **FIGURE 1**, where varying residential scales and typologies were analysed post occupancy. The increased certainty in realised performance figures associated with the Passivhaus standard is widely attributed to the use of PHPP building simulation and the rigorous on-site quality procedures that must be adhered to in achieving the standard.

As clients are increasingly looking towards Post Occupancy Evaluation (POE) as a means of measuring actual building performance, there is a growing requirement for all players in the construction industry to monitor these parameters throughout design and construction stages, and deliver buildings to the quality expected by end users.

Passivhaus and future trends

Increased transparency

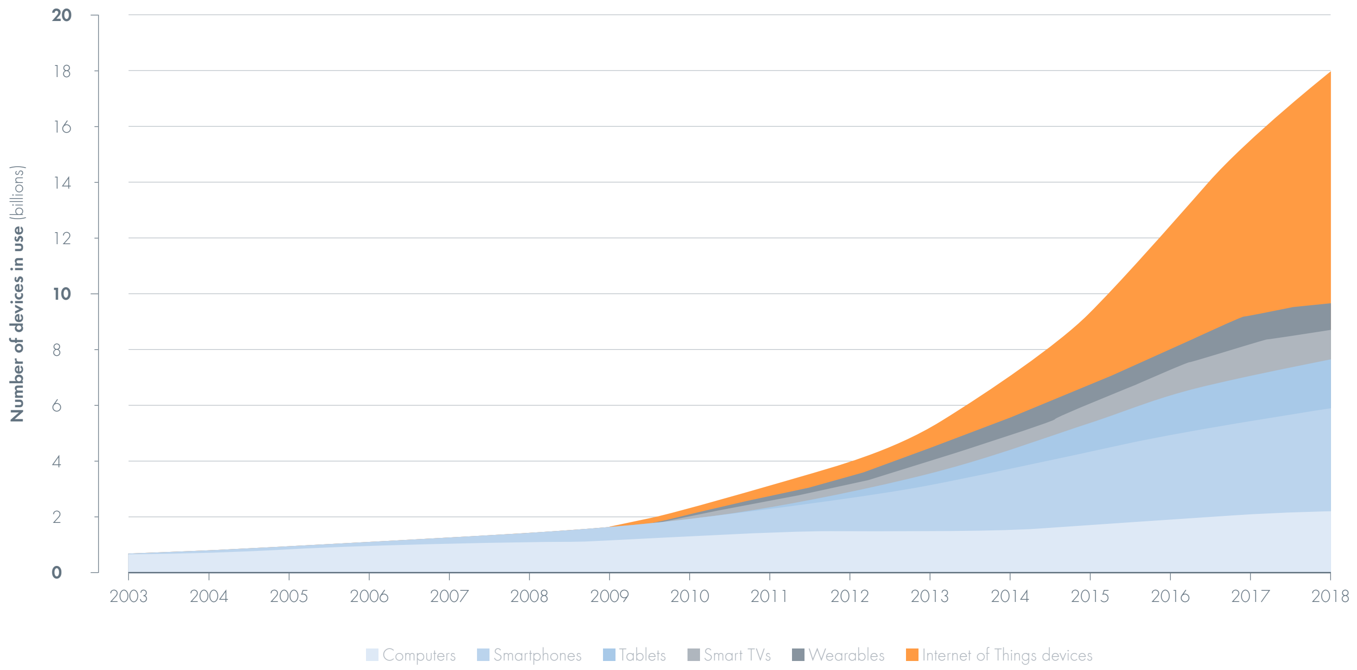


FIGURE 2 Predicted increase in the number of devices entering the market in the next two years.
Source: Gartner, IDC, Strategy Analytics, Machina Research, Company fillings, Bill estimates.

In assessing the potential of the Passivhaus standard on future developments in cities like London, it is important to understand changes to the housing market and assess the potential influence of technology in measuring the performance of a building. This is particularly prevalent in the emergence of 'smart home' technology and ease at which previously complex data is now available to the mass market. As **FIGURE 2** illustrates, the predicted increase in sales for sensory or 'Internet of Things' technology is greater than smartphones, tablets and wearable technology combined. Whilst the estimated influence of these 'disruptive' tools remains unclear, there is little doubt that the failings the industry, highlighted in the previous section, below difficult to conceal in an increasingly consumer-focused housing market.

As internal air temperatures, air quality and energy use is monitored on a live basis, the occupant now is fully aware of how their home performs. In going a step further, this information can now easily be shared and compared to a point where homes delivered by developers can be rated through interrogation of real data. This has numerous implications on how the housing market operates, with an increased emphasis on the ability of the supply chain to deliver accurate building performance figures from design through to use.

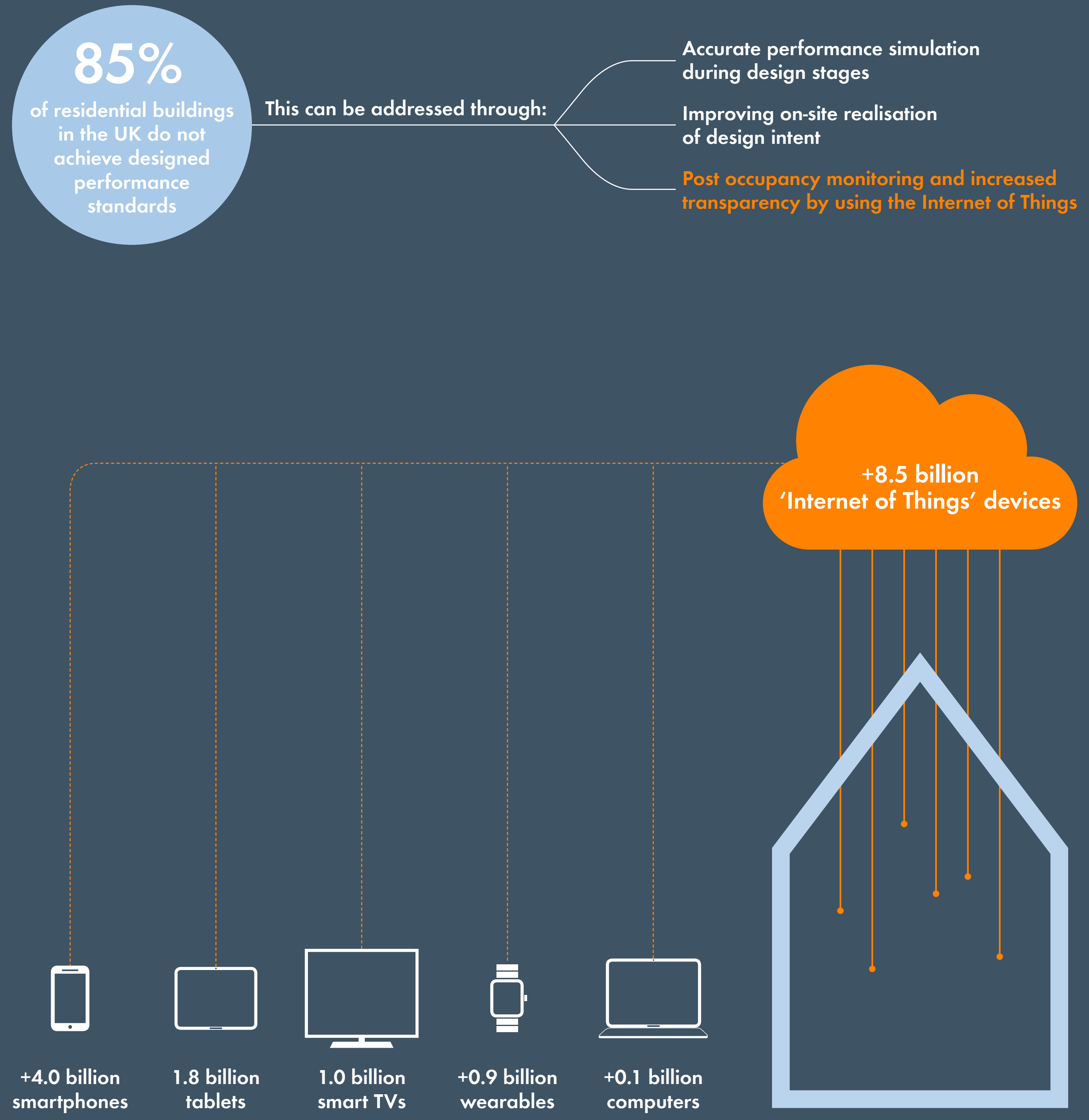


FIGURE 3 Devices which can measure the performance of homes

PassivTower
Study objectives

High density residential
Analyse the potential of implementing the Passivhaus standard at a scale not yet achieved, yet at a scale that is relevant to the residential market.

Architectural aesthetic
Challenge the sustainable design ethos of the Practice, whilst looking to minimise any compromises on architectural quality.

Building performance
A detailed comparative review of the Passivhaus standard against the defined base scheme and analysis of how buildings of this scale perform in terms of energy.

End-user engagement
Review the implications of producing Passivhaus standard apartments in real world scenarios and on the end-user.

Capital and operational costs
High-level review of potential additional construction costs in producing Passivhaus and whether this is offset through analysis of operational costs over 60 years.

London housing market
High-level review of the potential market value of Passivhaus in London.

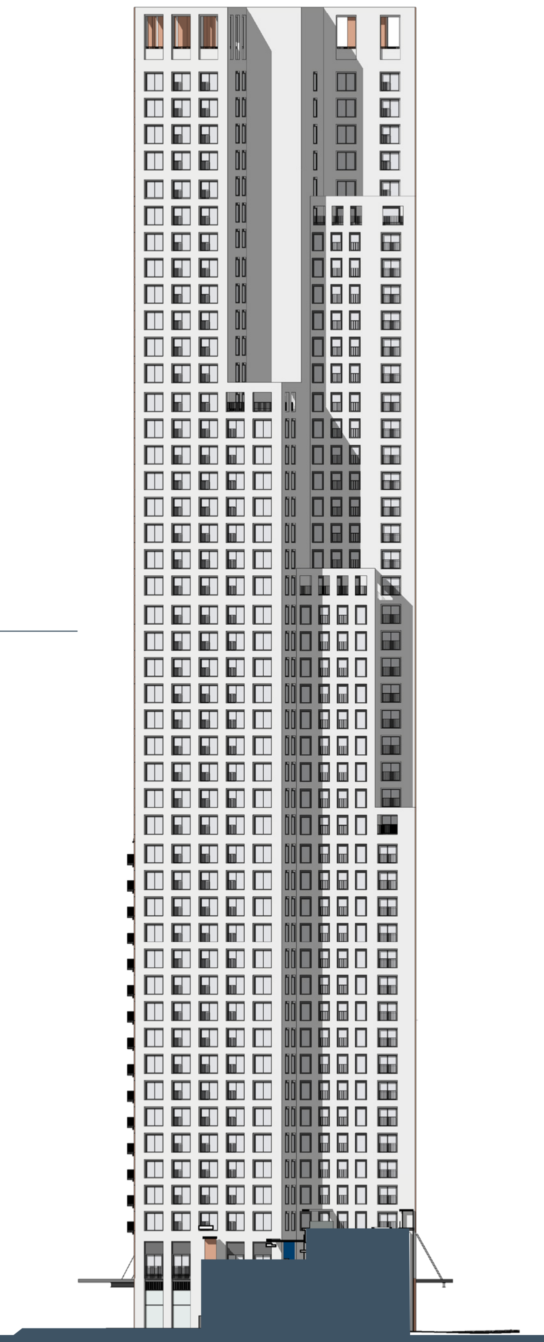
Future urban development
Analysis of the potential role of Passivhaus in the wider discussion of sustainable cities of the future.

BUROHAPPOLD ENGINEERING

PHA Passive House Academy

Allies and Morrison

GT GARDINER &THEOBALD



Passivhaus core principles

Fabric first design

The principles of Passivhaus were first developed in Germany in the 1990's and had a primary focus on occupant comfort, minimal energy requirements and use of high quality materials. In the implementation of the Passivhaus standard, there is a meticulous attention to detail required and an increased emphasis on construction quality. To ensure the quality of the design intent is maintained throughout the construction process, the Passivhaus Institute has developed a rigorous certification process that analyses the predicted performance of the building, to the specific climate conditions of the site.

Whilst the various components of the Passivhaus standard are based on the buildings energy performance, these metrics are very much based on the performance of the building envelope itself. Right from project inception, the U-Value performance of the base floor, external walls, roofs and openings must be considered holistically. In parallel, the interfaces between each building component should be designed in a manner that completely removes thermal bridge and ventilation heat losses. As a result, the external envelope of the building enfolds the internal layouts in a thermally robust and airtight barrier to the elements. In providing a constant supply of fresh air to the interiors, a Mechanical Ventilation with Heat Recovery (MVHR) unit must be provided. This system must also provide a high degree of heat recovery from the exhausted air (75%).

Throughout the design process, the Passive House Planning Package (PHPP) is used as a central source of project data and provides a transparent overview of the interconnected systems within a building. This building performance analysis tool is used both but the design team as a performance verification tool and by the Passivhaus standard assessors as part of the verification process.

Fabric First Principles

Building envelope
Continuous unbroken layer of insulation
U-values < 0.15 W/m²k

MVHR
Mechanical ventilation with heat recovery;
heat recovery efficiency > 75%

Thermal bridges
Detail to remove thermal bridges from the envelope
linear heat coefficient < 0.01 W/(mK)

Solar gains
Carefully balanced glazing percentages
and glazing specifications

Airtightness
Continuous unbroken airtightness line < 0.6 ach (n50),
approximately 1.5 m³/m²/hr (q50)

Performance based standard

Primary energy demand ≤ 120 kWh/m²/yr

Space heating demand ≤ 15 kWh/m²/yr

Space cooling demand ≤ 15 kWh/m²/yr

Airtightness ≤ 0.6 air changes/hr @ n50

Comfort – no more than 10% of annual hours over 25°C

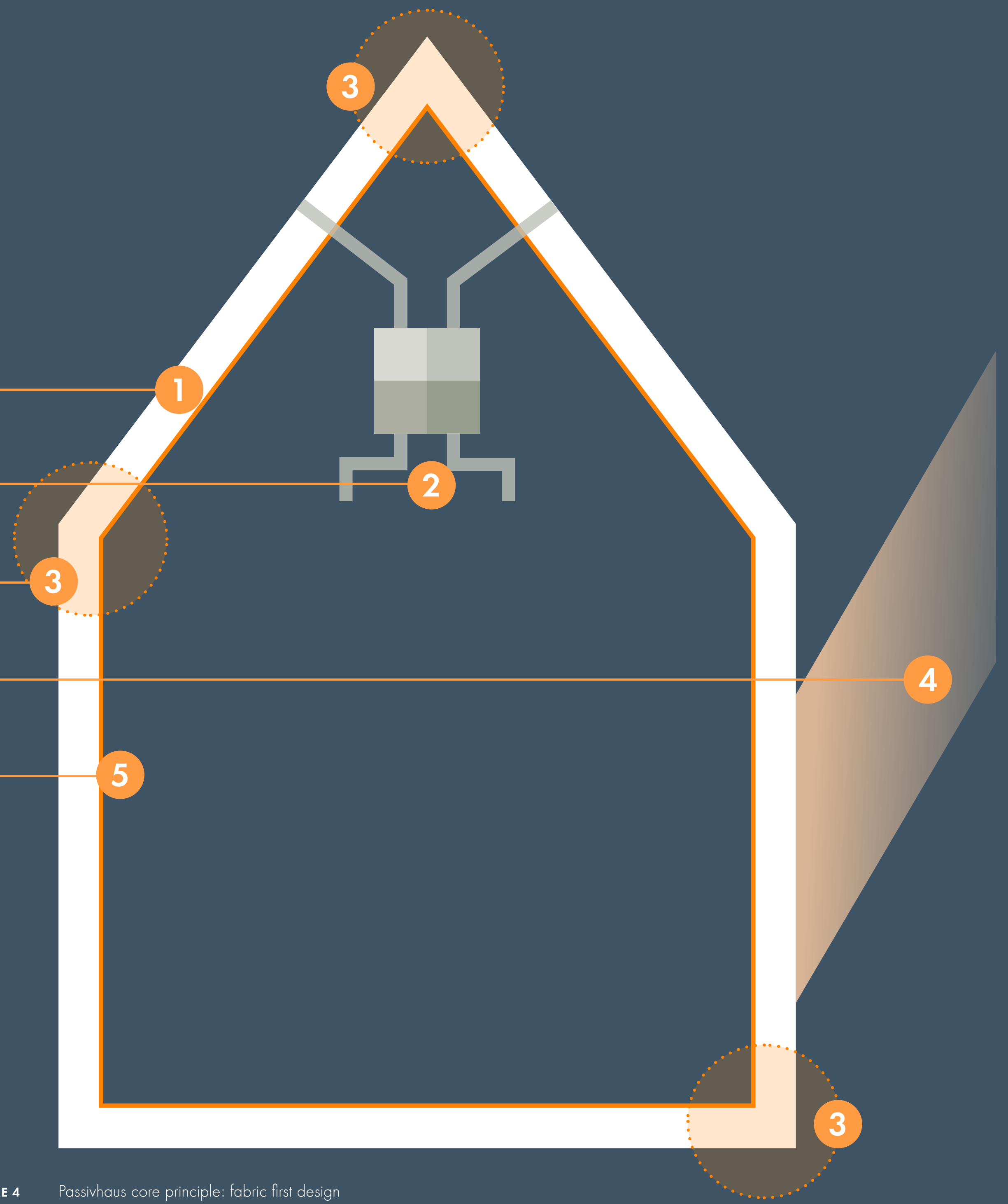


FIGURE 4 Passivhaus core principle: fabric first design

High density Passivhaus

PassivTower
Research parameters

Baseline scheme
In challenging the scope of this research project, the baseline scheme we have selected represents a nominal residential tower development with 44 levels, 335 units and an estimated occupancy of 922. The base scheme design looked to exceed current building regulations and achieve Code for Sustainable Homes Level 4+ and BREEAM Excellent standards. The development has a target completion date in 2024 and the climate data utilised in the Passivhaus scheme assumes increased temperatures over the next 30 years. Each apartment from level 01 to level 16 has a projecting balcony, with all apartments on the upper levels containing recessed balconies.

Analysis methodology
As outlined in the objectives, the purpose of this report is to compare the baseline buildings' performance with an adjusted Passivhaus scheme. To ensure a structured comparison is maintained, the Passivhaus scheme assumes the same parameters as the base scheme and both buildings have been analysed using the Passive House Planning Package (PHPP) software. The goal is to ensure that the same level of architectural quality can be achieved when compared to the base scheme.

Feasibility review
As noted in the objectives, the project looked to test the feasibility design, constructing and operating a Passivhaus at this scale in the London climate. Whilst this project is intended to be research only, it is hoped that the rigorous and tested method of performance data collection through PHPP will develop a fabric first design ethos at Allies and Morrison and provide a wealth of knowledge on the behaviour of high performance buildings at this scale.

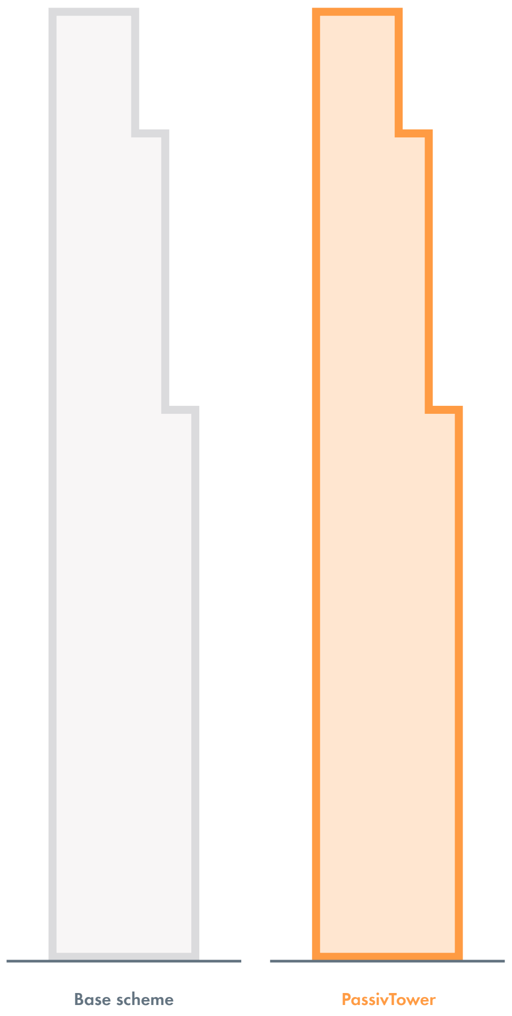


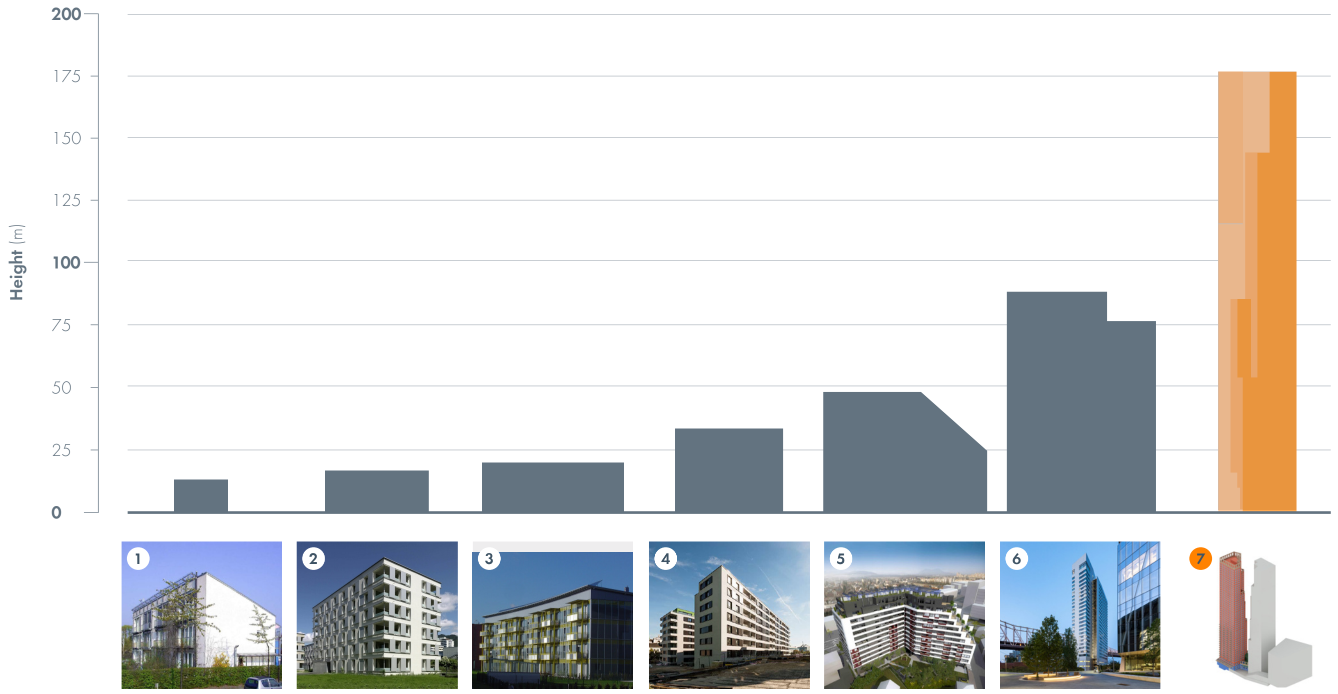
FIGURE 5 Location map of notable Passivhaus schemes

Whilst the buildings reviewed as part of the precedent study were at considerably different scales to the base scheme and proposed PassivTower project, the figures gave a good insight into the envelope performance requirements we would need to consider going forward. Perhaps the most surprising factor were the similarities between proposed envelope u-value requirements on the base scheme and the very similar pattern of performance levels included in the precedent schemes. In contrast, it was also evident from the precedent study data that significant improvements in glazing u-values, airtightness levels and thermal bridge heat energy losses would need to be made if the research initiative were to meet the Passivhaus standard.

Unsurprisingly, there is a clear correlation between the fabric performance specification of the precedent studies and the building performance figures estimated during the certification process. For the research scheme to reduce its energy demand to these comparative levels, it was clear that the focus of the research project would not necessarily need to look at increasing envelope insulation levels and subsequently losing internal net area. It quickly became apparent that the main focus of this project would likely centre on the specification of high performance components and meticulous analysis of construction sequencing and airtightness strategies.

Passivhaus at scale

New ground for Passivhaus



	Passivhaus, Darmstadt Germany, 1991	Max Haller Strasse V111 Austria, 2009	MFH Solar City Haus 1 Austria, 2004	Wien Passivhaus Austria, 2011	ESH Passivhaus Slovenia, 2014	Cornell University USA, 2017	Residential Tower (Base Scheme)
GEA	191m²	4,200m²	2,635m²	18,500m²	13,200m²	13,200m²	36,000m²
Units	4	50	24	183	128	352	338
TFA	156m²	3,100m²	1,884m²	16,285m²	10,836m²	18,426m²	27,000m²
A/V Ratio	0.55	0.36	0.39	0.34	0.31	0.22	0.24

FIGURE 6 Review of precedent building heights, height of world's tallest Passivhaus in New York and proposed scheme in London

Precedent and base scheme analysis
Building envelope performance

Whilst the buildings reviewed as part of the precedent study were at considerably different scales to the base scheme and proposed PassivTower projects, the figures gave a good insight into the envelope performance requirements we would need to consider going forward. Perhaps the most surprising factor was the similarity between the proposed envelope u-value requirements on the base scheme and the very similar pattern of performance levels included in the precedent schemes. However, it was also evident from the precedent study data that significant improvements in glazing u-values, airtightness levels and thermal bridge heat energy losses would need to be made if the research initiative were to meet the Passivhaus standard.

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FIGURE 7 Comparison of precedent building envelope u-values against base scheme

Project results

Project results
Passivhaus standard and building physics

In what we believe to be the largest recorded project to be evaluated by PHPP, the volume of data generated by both the base and PassivTower schemes was significant. As the team looked to tackle the daunting task of sifting through thousands of building performance metrics, we looked to identify a number of major differences between the base scheme and PassivTower.

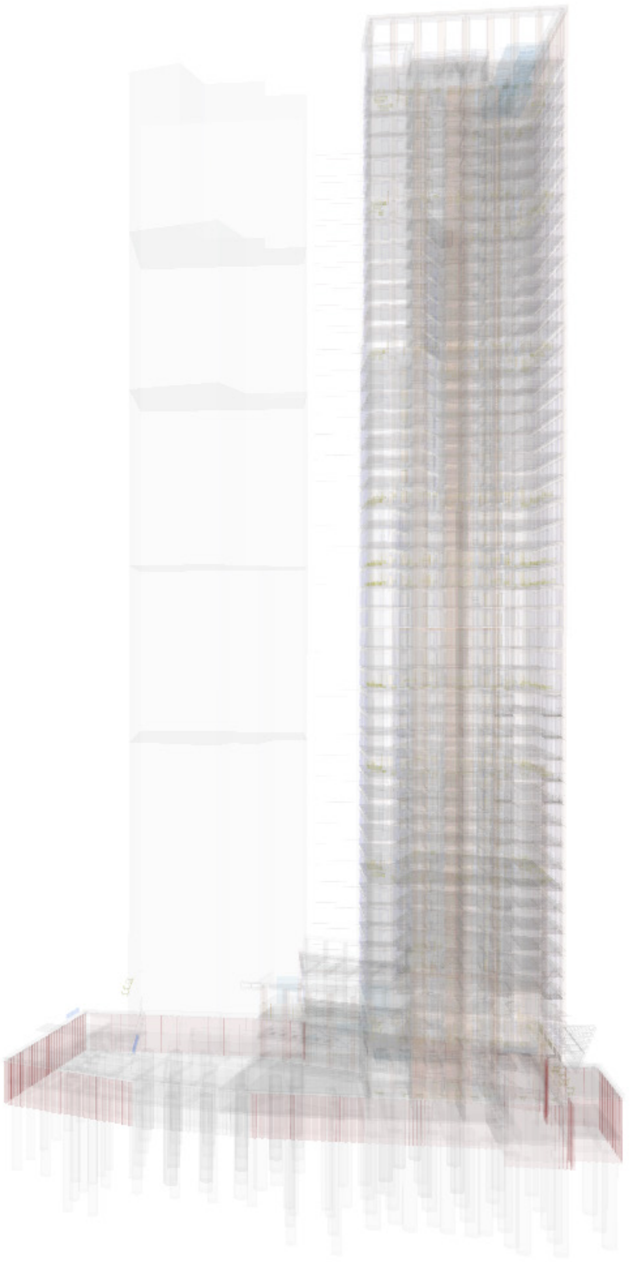
The objectives of this study were not just focused on the Passivhaus Standard criteria, but on the performance of the building across a number of key parameters. We looked to gain an insight into the behaviour of buildings at this scale when subjected to the rigorous building standards of Passivhaus and how this may affect the occupant. The following criteria reviewed were then.

Primary energy demand
The total energy to be used for all domestic applications (heating, hot water and domestic electricity, per kWh, per square meter).

Heating and cooling energy demand
Energy required to heat or cool living spaces must not exceed 15 kWh per square meter of net living space.

Airtightness
A maximum of 0.6 air changes per hour at 50 Pascals pressure, as verified with an on-site pressure test (in both pressurised and unpressurised status).

Comfort criteria
Thermal comfort must be met for all living spaces during winter and summer, with not more than 10% of the hours in a given year estimated over 25°C.



Project parameters
Passive House Planning Package (PHPP) – Building envelope

At the outset of the project, the team had identified the use of Building Information Modelling (BIM) as an essential component in the iterative design process. In looking to manage the enormous amount of data produced by PHPP, whilst allowing the team the flexibility to test various design options quickly, the team began by modelling both the base and PassivTower schemes in Design PH. Whilst the connection of SketchUp with Excel spreadsheets is not generally associated with BIM workflows, the direct link between the massing in the model and component quantities data in PHPP proved to be an efficient and transparent way of working.

Through the Design PH and PHPP connected workflow, the team were also able to review, in detail, the influence of the neighbouring tower in terms of solar shading and loss of energy gains. Through a series of iterative design alterations to the PassivTower window specifications and reveal depths, we looked to mitigate the relatively low solar gains on the northeast facade in particular.

At each iteration of the design, the team were cautious to challenge the figures produced by the PHPP and review the assumptions behind the calculations. Whilst regarded a reliable and robust tool in calculating energy performance in low density residential buildings, the use of PHPP on a building of this scale seemed to push the capabilities of the tool in a number of areas. As the project progressed, the Passive House Institute (PHI) were consulted on a number of occasions with queries ranging from the accuracy of the London zone climate data, to the accuracy of internal heat gains calculations. Any deviations from standard calculations are detailed in the individual sections below.

Before we considered reviewing the building performance data in detail, we first had to get to grips with the quantities of components and building systems that must be considered in a building of this scale, as illustrated in FIGURE 8. In addition to the results of the overall comparative study between the base and PassivTower schemes, also looked to review specific influences on building our research performance under the following headings;

Glazing performance – Analysis of heat gains and losses through window components and the use of triple glazing in high density residential schemes.

Internal heat gains (IHG) – A review of IHG generation and the risk of overheating in a large building a thermally sealed building envelope.

Mechanical heat ventilation with heat recovery (MVHR) – This section looks to challenge assumptions on where MVHR units are located in a typical apartment and illustrate the consequences of long insulated duct runs.

Ambient of thermal bridge losses – comparative review of heat energy losses in the base scheme and the reduced losses in the PassivTower scheme.

Airtightness – Analysis of the influence of building envelope airtightness on ventilation heat losses in high density buildings and a review of the challenges this poses within the UK construction industry.

Rethinking heat demand – Challenging traditional methods of space heating to match the reduced heat energy demand of the PassivTower.

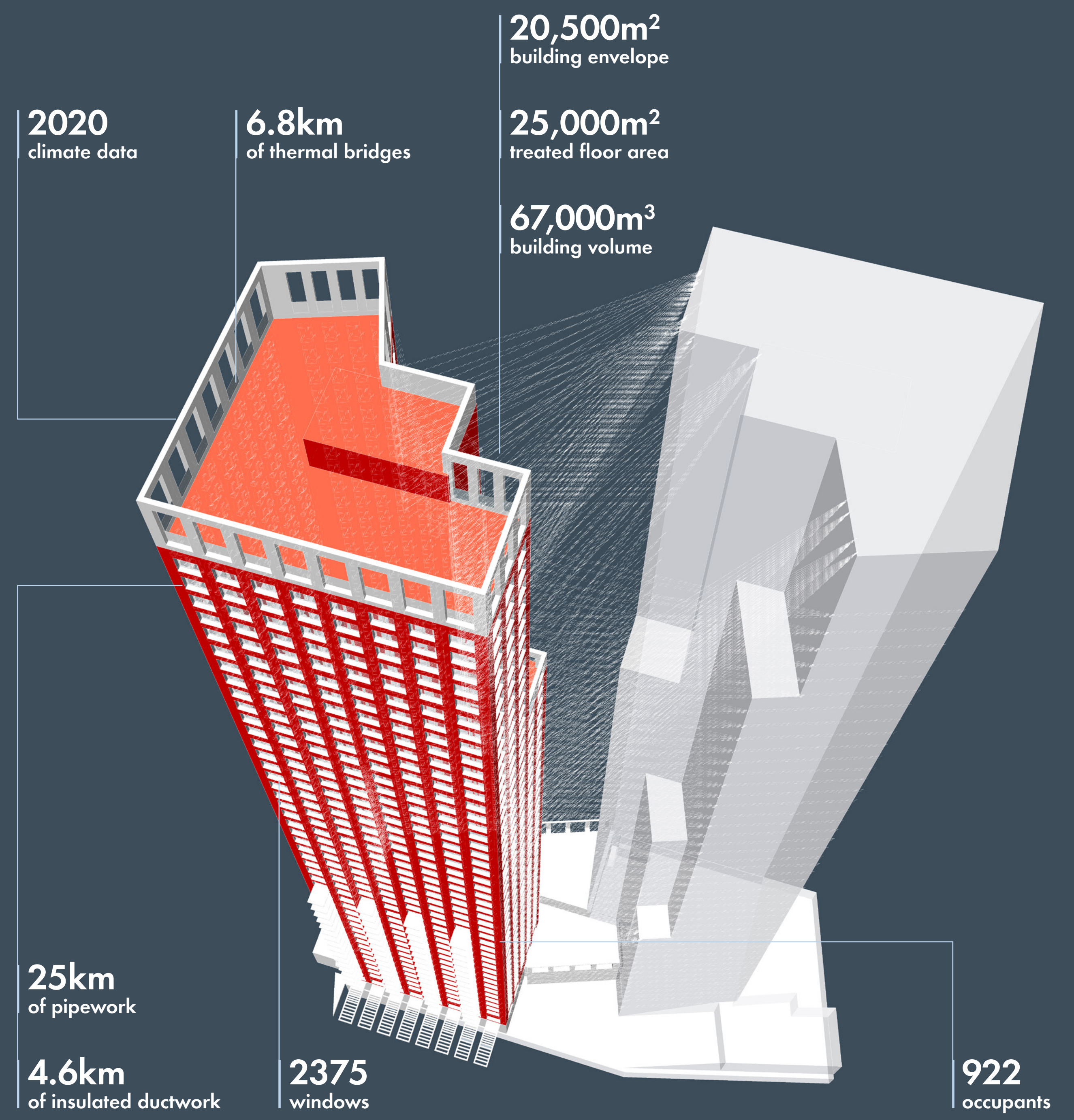


FIGURE 8 Tower modelled in Design PH, including adjacent shading with key building metrics

Building comparison
Primary energy, heating and cooling demand

With the inclusion of a number of recommended adjustments to the specified components, construction techniques and building services from the base scheme, we were able to demonstrate that the proposed PassivTower project would likely achieve the Passivhaus Standard if continued to completion. This conclusion is based on a number of assumptions, relating to the reliable supply of materials and adequate construction skills. These will be discussed in further detail in the next section.

As illustrated in **FIGURE 10**, the PassivTower project has performed marginally better in terms of Cooling Energy Demand. The reduced requirement for active cooling can primarily be attributed to the reduction in heat gains from glazing components and the increased insulation on the domestic hot water pipework throughout the building. As a result, the subsequent reduction in Primary Energy Demand was notable. As the control of internal temperatures is managed through increased passive measures, the energy required to supply active cooling can be reduced considerably. The PassivTower project also looked to prescribe low energy appliances and lighting, to ensure occupant energy use is kept to a minimum.

Perhaps the most significant conclusion from the study is the estimated 82% reduction in heat demand in the PassivTower scheme, compared to the heating requirements of the base development. This result also indicates an unusual scenario where the annual cooling demand for the building is estimated to be greater than the heating demand.

We have looked to expand on these figures in the following sections and review a number of assumptions in the methods of high density residential building delivery in the London market.

Cooling energy demand

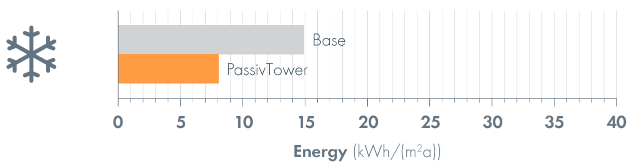


FIGURE 10 Comparison of cooling energy demand

Primary energy demand

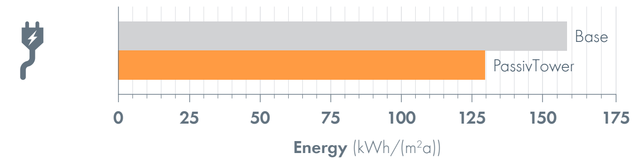


FIGURE 9 Comparison of primary energy demand

Heating energy demand

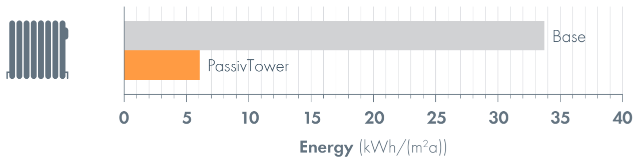


FIGURE 11 Comparison of heating demand

Energy Balance
Base vs PassivTower

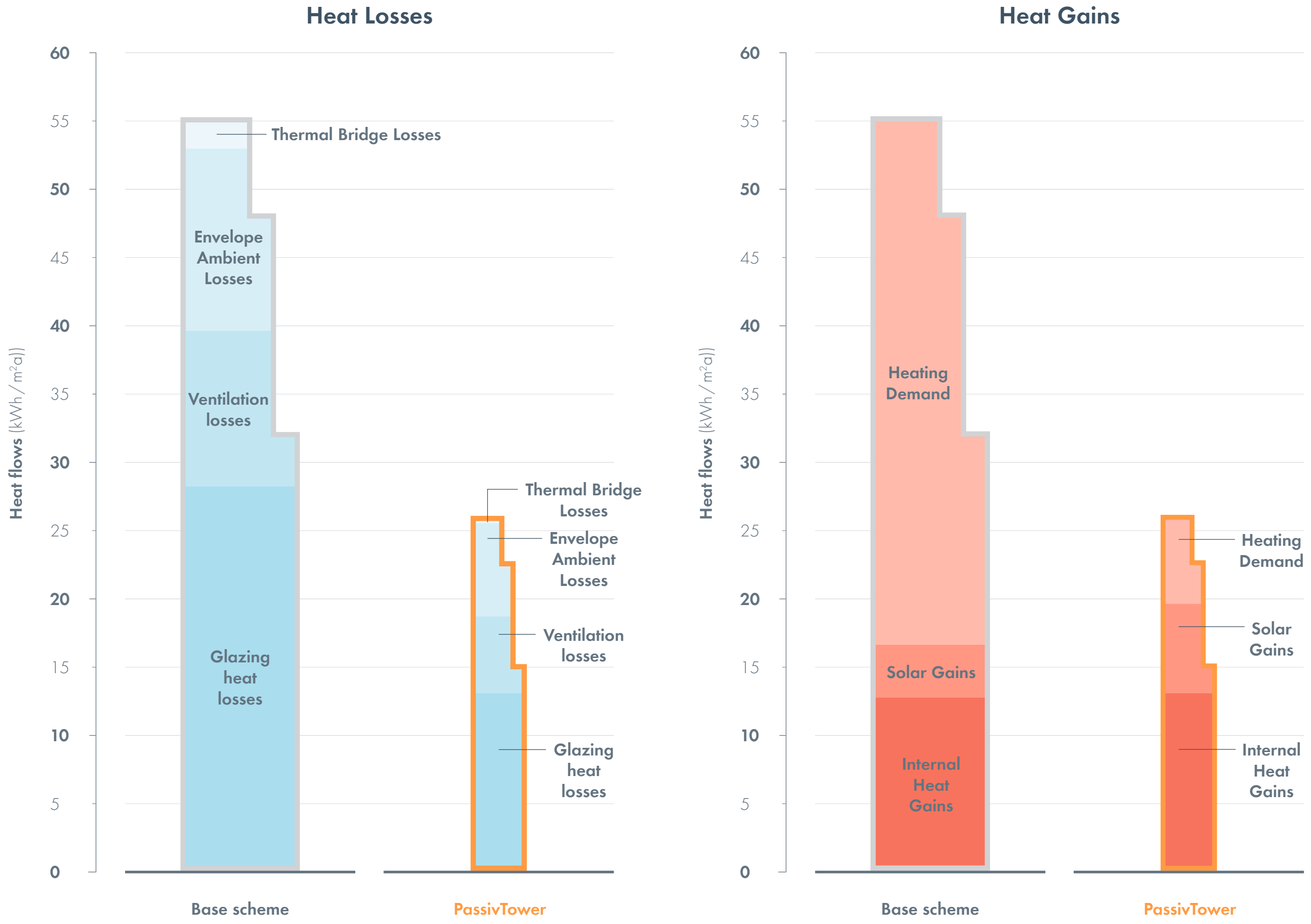


FIGURE 12 Comparison of heat losses and gains

Building physics
Ambient and thermal bridge losses

Perhaps one of the more surprising findings of the study, were the relatively minor interventions required to the base scheme envelope in looking to meet Passivhaus building performance standards. As discussed in the precedent study comparison, the U-values of the basement floor, external walls and roof elements remain unchanged. There are however, a number of interventions required to reduce the number of thermal bridge heat losses across the facade. For the purposes of allowing a detailed and meaningful study of weakness points in the base scheme facade connections, the team identified a number of key sections of a whole facade panel, to be reviewed as a comparative study between the base and PassivTower schemes as shown in **FIGURE 13**.

Through iterative analysis of key junction details with thermal bridge analysis software, we were able to identify a number of weaknesses within the details. The use of Glass Reinforced Concrete (GRC) brick faced panels posed many challenges in terms of construction sequencing and a considerable effort was required in addressing the transfer of heat through the window / GRC panel connection. To mitigate this, PIR infill insulation was added to the panel itself and loose mineral wool insulation was proposed to be pumped into the void space located on the internal face of the panel / slab connection.

FIGURE 13 shows heat conduction through the base scheme facade / intermediate floor junction. The corresponding detail for the Passivhaus scheme shows the effect of removing the outer layer of mineral wool from the GRC and replacing with loose wool in the internal void section. The resultant thermal bridge calculation showed dramatic improvements in the heat-flow though this particular section. In translating the thermal bridge analysis results into PHPP, a series of complex individual calculations were made of each variation of wall construction within a typical bay of the facade. The addition of these calculation thermal bridges was then added to the PHPP file through a combination of specificity identified junctions in the 'Areas' tab and inputting 'U-value supplements' to account for thermal bridges within typical construction build-ups. In reviewing these figures in both schemes, we have demonstrated that the PassivTower adjustments are estimated to have removed 81% of thermal bridge energy losses that were identified in the base scheme.

Base scheme
PSI Value – 0.514 W/(mK)

PassivTower
PSI Value – 0.269 W/(mK)

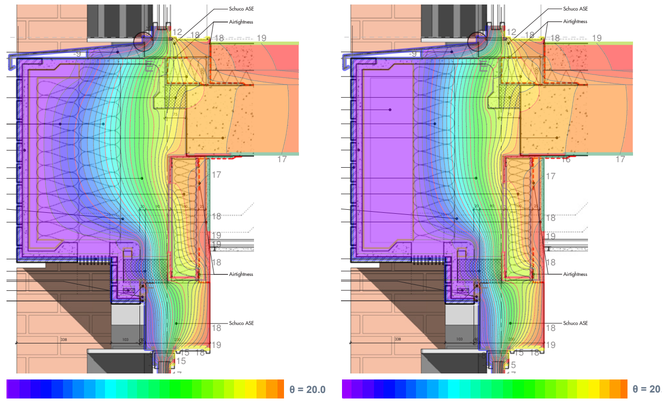


FIGURE 13 Thermal analysis studies of a typical glazing panel head / GRC panel connection between the base (left) and PassivTower (right) details

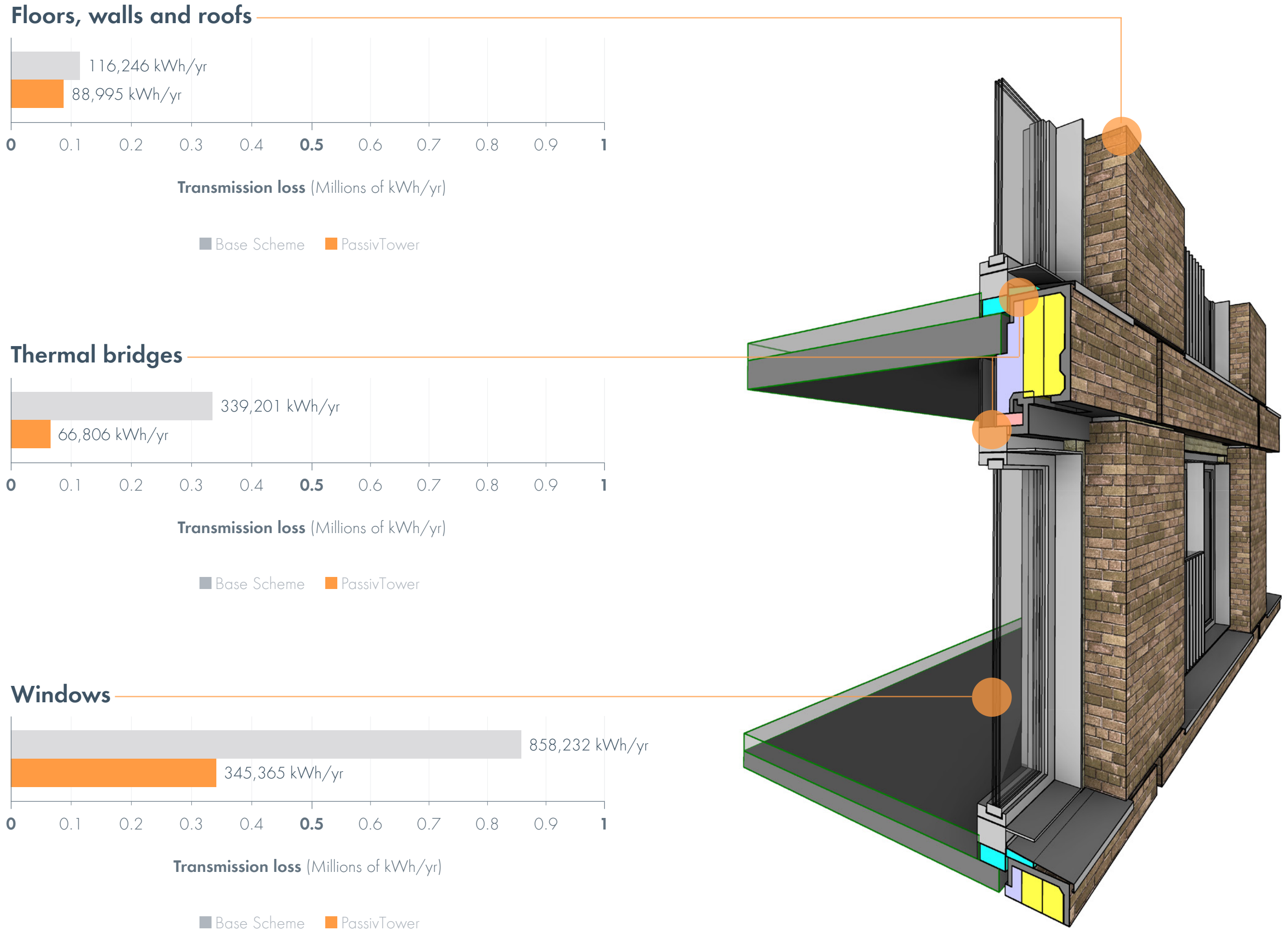


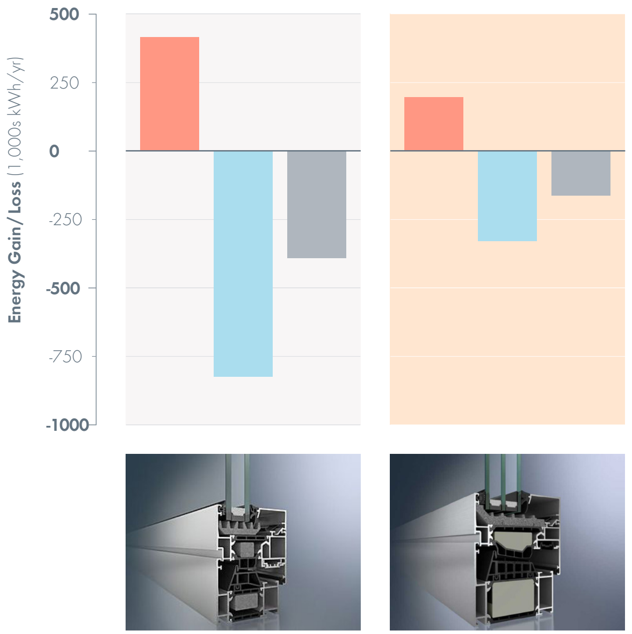
FIGURE 14 Comparison of transmission losses between the PassivTower and Base Schemes

Building physics
Glazing performance

The implementation of the Passivhaus standard has traditionally gone hand in hand with the use of triple glazed window components in the majority of European climate zones. This is primarily due to the fact that Passivhaus requires a continuous thermally connected layer across the building envelope, including the window units. The significant density of the PassivTower and favourable form factor (ratio of building volume to thermal envelope area), our early findings highlighted the fact that the Passivhaus standard could potentially be achieved without upgrading the originally specified double glazed window units in the baseline scheme.

This said however, the graphs opposite highlight the substantial benefits of specifying carefully selected triple glazed units. Whilst there is certainly a drop in solar gains when using the triple glazed system, the overall reduction in net losses contributes over 40% to the reduction in the heat demand highlighted in the results section. It is also important to highlight the fact that the AGC iPlus glazing was chosen primarily for its low g-value of 0.42. This is a crucial design choice as any increase on this value would result in increased pressure on the active cooling, and subsequently increased primary energy requirements. Whilst there were more aesthetically favourable glazing units on the market, the vast majority had g-values of 0.55 and over and could not be considered in the PassivTower scheme.

The team considered a number of triple glazed sliding partition systems that met the aesthetic criteria set in the base scheme. The vast majority of those reviewed however, had g-values of 0.55 and over and were not considered an option.



Schuco AWS 70 HI Base scheme	Schuco AWS 90 SI+ PassivTower
Frame U-Value	**Frame U-Value**
1.7 W/m²K	0.80 W/m²K
Glass U-Value	**Glass U-Value**
1.1 W/m²K	0.59 W/m²K
Installed U-Value	**Installed U-Value**
1.95 W/m²K	0.59 W/m²K
G-Value	**G-Value**
0.41	0.42

● Solar Gains ● Heat losses ● Net losses

FIGURE 15 Comparative review of building performance with double and triple glazed units

When looking at the total energy balance of the PassivTower scheme, we can see that 25% of the building's heat requirements are met through solar gains alone. In stark contrast, we can also see that 50% of the buildings heat losses are associated with losses through glazing units. Despite this, we have made significant improvements to the thermal performance of glazing units from the base scheme specification, yet they remain the weakest link in terms of the overall envelope performance.

As illustrated in **FIGURE 15**, energy gains and losses associated with each glazing unit are heavily influenced by the orientation of the building itself. In reviewing the performance of 335 units within the building envelope simultaneously, it is important to consider the orientation of each façade of the building and the overall heat losses/gains associated as a whole. Through PHPP analysis, we were able to identify challenges within the orientation of the building and mitigate the clear differences between north and south façades through alternative passive measures. These included reducing the reveals on glazing units on the north west façade and retaining shading components on the heavily glazed ground floor façades.

These figures also highlight the importance of integrating a sensible glazing percentage across each façade. In maintaining an architectural language of uniformity, glazing percentages on the south facing elevations were restricted to approximately 40%. It must also be noted that despite the importance of glazing as a form of heat energy generation, achieving strong daylight levels in each apartment was the main priority. This was particularly challenging on the inward facing facade and a number of adjustments were made to internal layouts to improve daylighting performance.

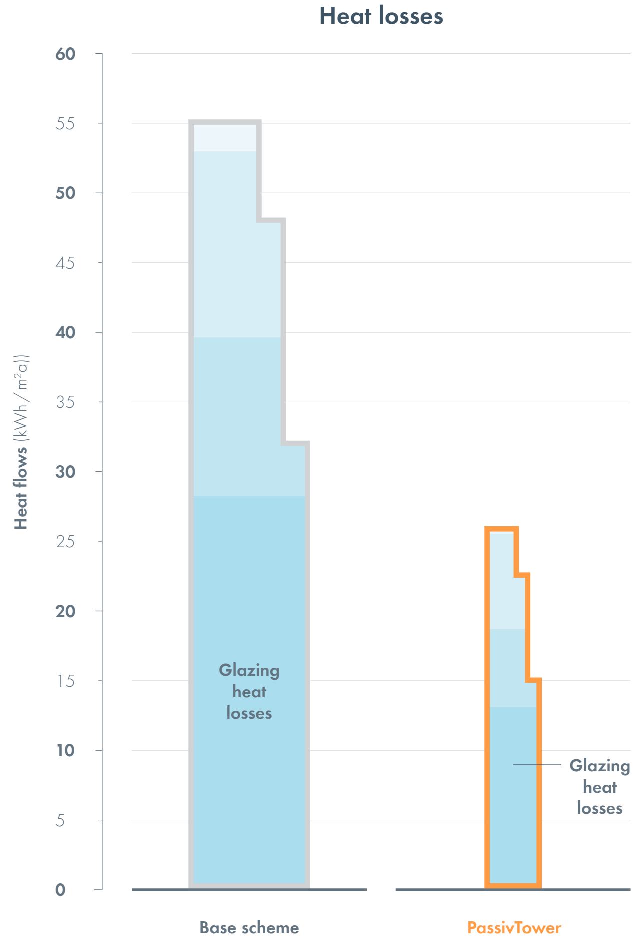


FIGURE 16 Transmission of losses as a percentage of overall building heat losses

Building physics

Internal heat gains

As demonstrated in the previous sections, the Passivhaus standards 'fabric first' approach to building envelope design has clear advantages in terms of harnessing generated heat energy efficiently. In the case of the PassivTower however, it is clear that this can retain high levels of internally generated heat energy. Within the thermal fabric of the building, there are 336 apartments generating a significant amount of heat energy. The source of this heat can vary from the domestic hot water circulation pipework, to lighting and appliances and even to the occupants themselves. As **FIGURE 17** highlights, over 50% of the building's energy requirements are supplied through effectively uncontrolled internal sources. As active cooling was part of the baseline scheme, this overheating figure was not relevant in meeting the Passivhaus standard, however energy use associated with the active cooling was also a limiting factor in the PassivTower scheme, and an important criteria to monitor.

The calculated figures have already taken into account an increase in insulation levels on the DHW pipework from the base scheme thickness of 33mm to 50mm. Whilst this poses many advantages during the winter months, this heat during the summer and adequate methods of purging must be considered in the design. We have also assumed a low energy specification for lighting and appliances as this is essential in minimising the heat energy generated in each apartment.

To highlight the inherent risk of overheating in the Passivhaus tower, we analysed the estimated external and internal temperatures over the course of a year, if active cooling was removed from the scheme. The Passivhaus standard comfort criteria is based on an internal temperature threshold of 25°C and a requirement not to exceed this temperature for more than 10% of the year. PHPP calculations estimated that the PassivTower scheme would overheat 32% of the year and perhaps more surprisingly, the base scheme would overheat an astonishing 38% of the year.

While the Passivhaus scheme has a greater ability to hold heat within the fabric, the base scheme has considerably higher solar energy gains and heat energy from the DHW network. The use of active cooling in residential buildings in London is often viewed as a luxury, however in the case of both the baseline and Passivhaus schemes, the analysis suggests the removal of the active cooling systems would be detrimental to the internal comfort of the apartments.

While it is clear active cooling is a necessity, it is imperative that passive measures are also allowed within the design. The long standing myth that operable windows are not permitted in Passivhaus is simply not the case and PHPP has the ability to include natural ventilation calculations as additional night cooling.

Internal heat gains

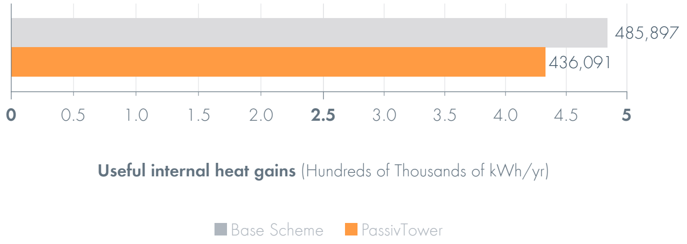


FIGURE 17 Comparison of internal heat gains

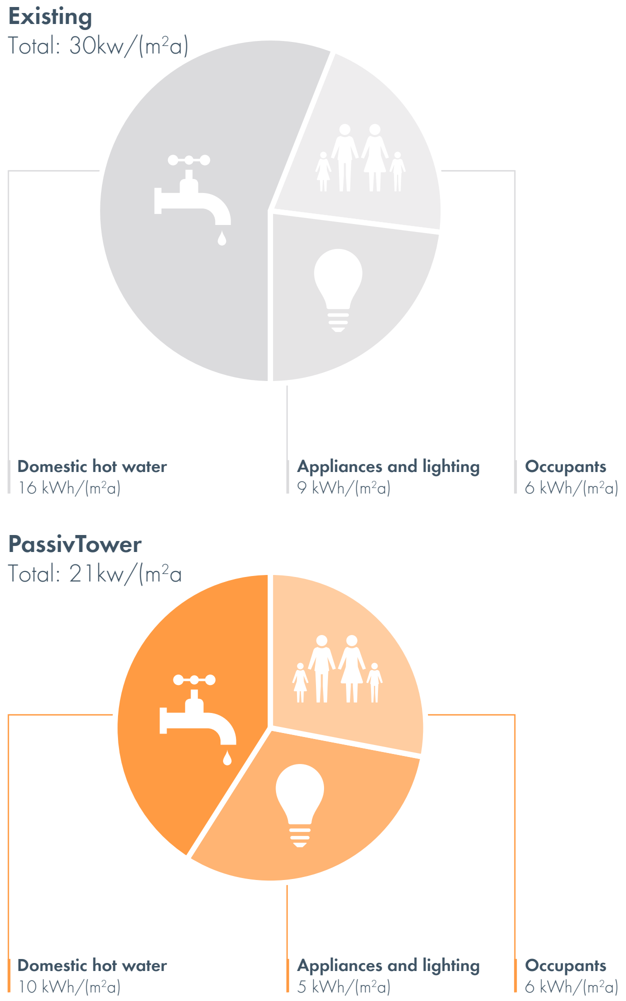


FIGURE 18 Internal heat gain sources

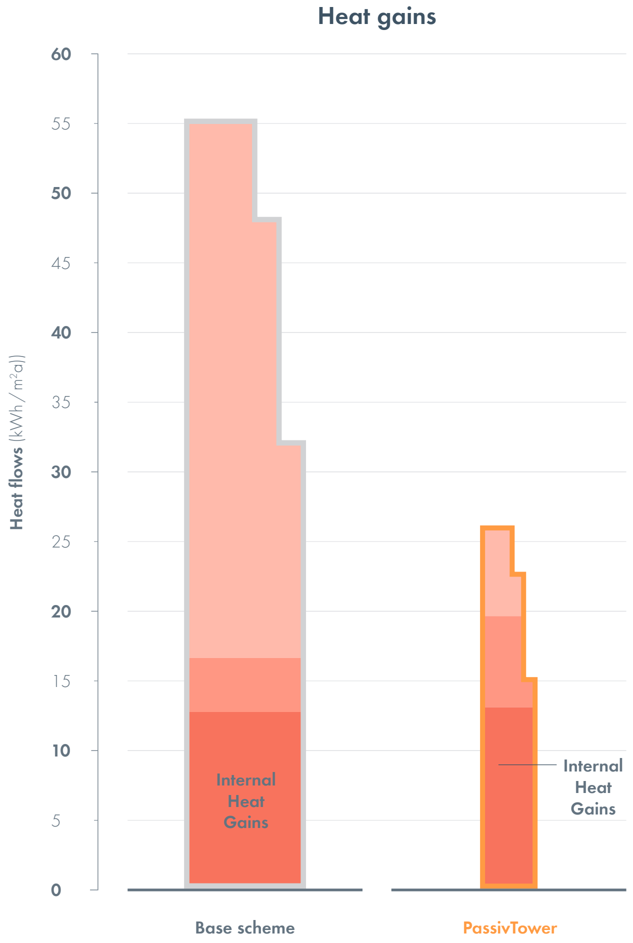


FIGURE 19 Internal heat gains as a proportion of overall building heat gains

Building physics
Ventilation losses (airtightness)

Potentially the most challenging aspect of Passivhaus design is the stringent airtightness levels required in meeting the standard. It doesn't help that the Passivhaus standard uses a scale based on Air Changes per Hour (ACH), whilst UK building regulations are based on the amount of air that passes through the building envelope each hour ($m^3/m^2/hr$). For the purposes of clarity, we have converted ACH figures in the PHPP calculation tool to the airtightness scale used in UK building regulations.

As the demonstration of a buildings airtightness levels can only ever be achieved through careful implementation on-site, it is difficult to fully appreciate the challenges in achieving airtightness levels as low as this. It is important however, to review an airtightness figure as low as 0.65 $m^3/m^2/hr$, in the context of the UK construction industry skills level, suitable procurement routes and the realities of test airtightness levels in 335 apartments over 45 levels.

Whilst these ultra low airtightness levels are regularly achieved in central European developments, it would be unwise to assume that construction skills levels in the UK are comparable. As **FIGURE 20** indicates, the regulation of airtightness levels across a number of EU countries would suggest that the UK construction industry does not yet have the incentive to meet low levels of airtightness required by the Passivhaus standard.

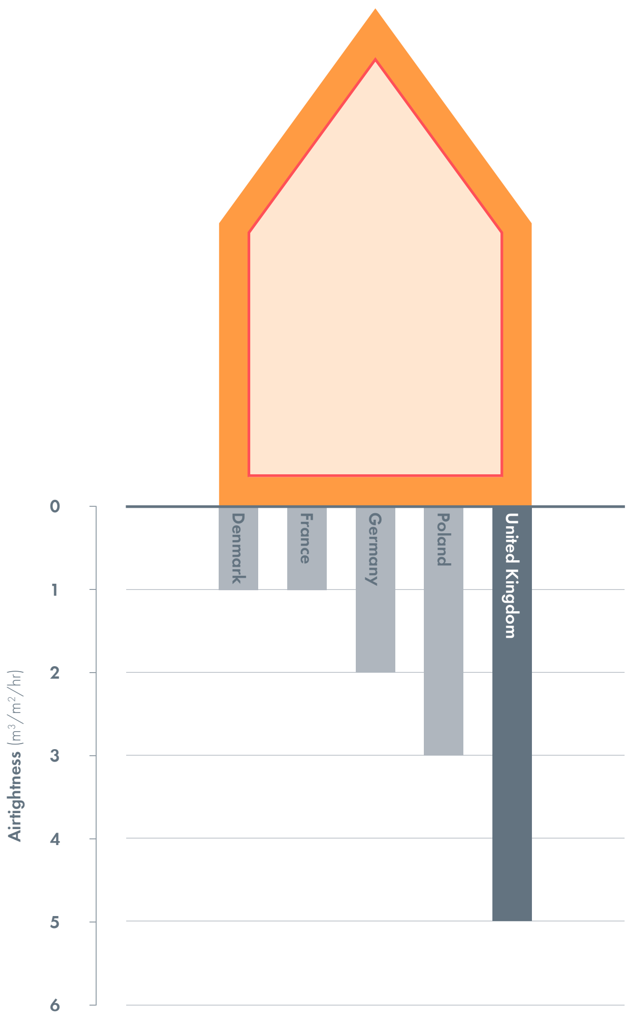


FIGURE 20 Comparative review of airtightness regulation standards for new builds in European countries (Source: Indoor Air Quality, Thermal Comfort and Daylight, BPIE)

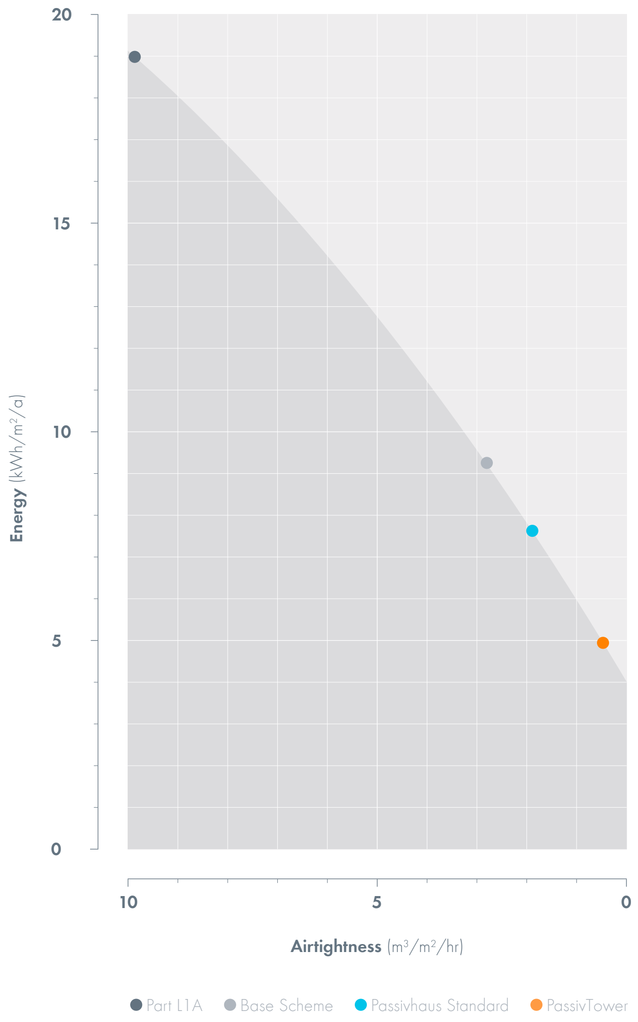


FIGURE 21 Heat energy lost through ventilation compared to airtightness levels

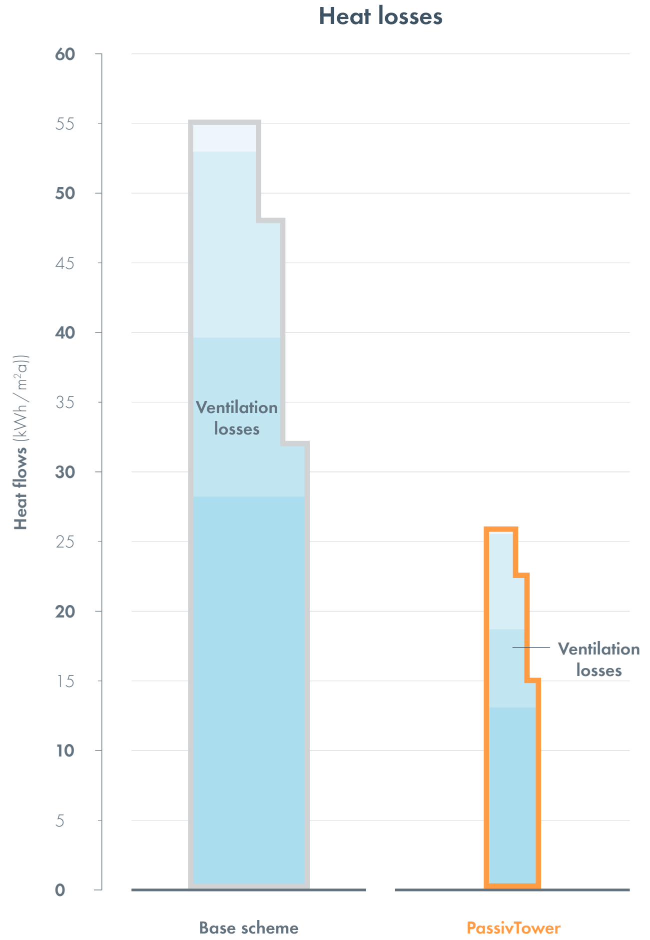


FIGURE 22 Ventilation losses as a percentage of overall building heat losses

Building physics
MVRH

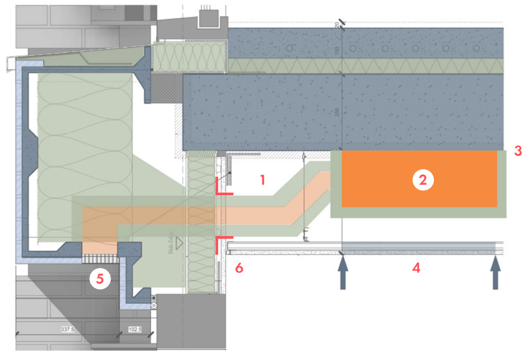
As was designed in the base scheme, the most logical position to place an apartment MVHR unit is in the storage space often adjacent to the entrance door. Through analysis of the of the heat readings of the MVHR unit itself and the subsequent influence over the heat demand of the apartment, we sought to challenge this design assumption.

In maintaining the thermal performance of the apartment under the Passivhaus standard, the efficiency of the ventilation heat recovery must not drop below 75%. Typical MVHR units available on the market will often boast efficiencies over 90%, however this does not take into account the lengths of both insulated extract and intake ducts that must connect with the facade. As **FIGURE 23** indicates, a typical apartment within the base scheme required insulated ductwork to connect to the facade. This is estimated to have reduced the heat recovery performance of the unit from 85% to 68%.

In contrast, the relocation of MVHR unit as close as possible to the facade in the PassivTower scheme has resulted in a heat recovery efficiency figure of 80%. This has halved the amount of heat energy lost to MVHR inefficiencies from 208,600 kWh/yr to 114,500 kWh/yr. In relocating the MVHR unit across all 336 apartments, the length of insulated ductwork required has been reduced from 4.6km to just 1.1km. Apart from the fact that this has cost saving implications in terms of ductwork alone, it also reduces the time spent on site in connect each of these units to the facade.

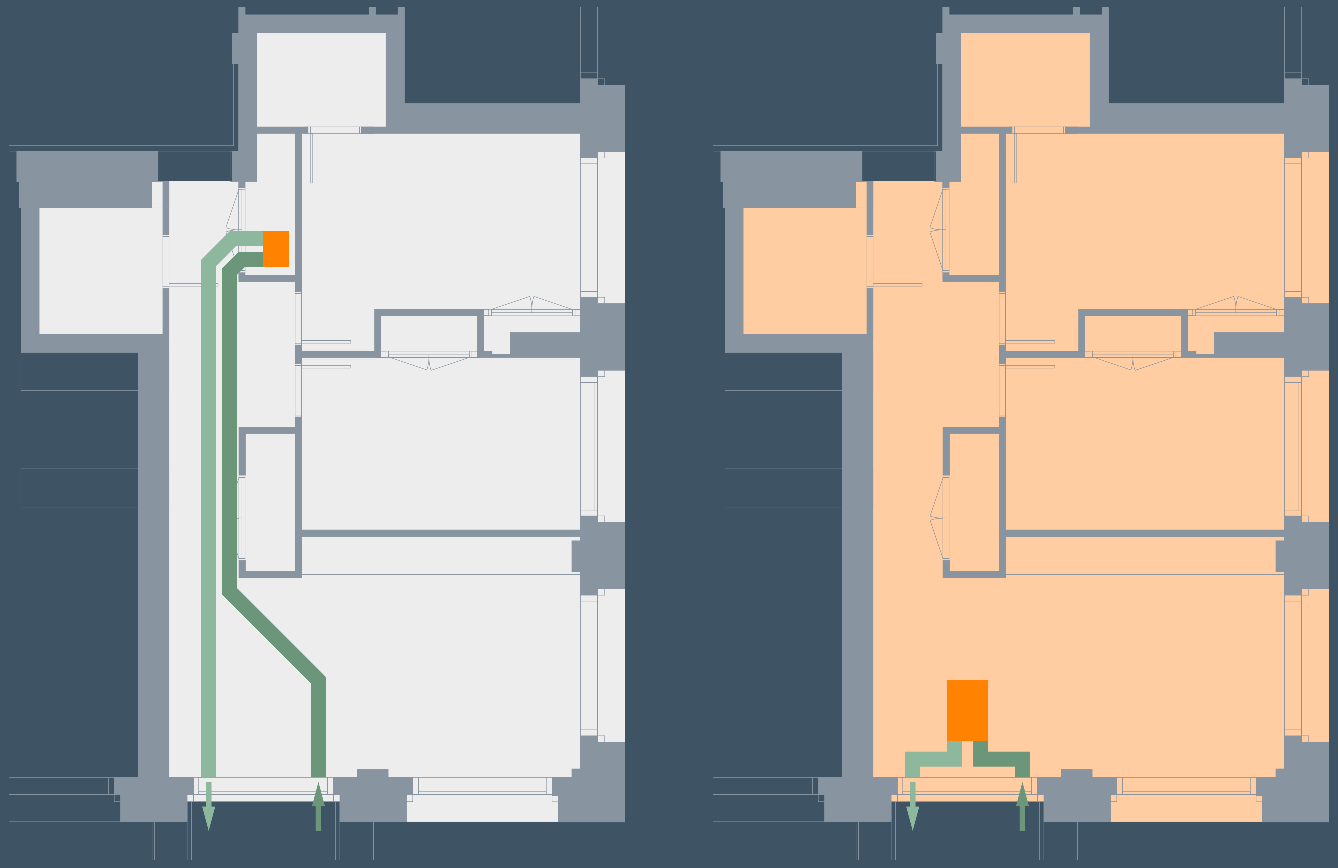
The specification of the unit itself was changed to allow slimmer unit to be placed in the ceiling void. We also allowed for 50mm of acoustic insulation to ensure noise from the unit did not interfere with the quality of the living space. Whilst this simple design change has halved the amount of heat energy lost through MVHR inefficiencies of each apartment, consideration must be made to the fact that an access hatch would be required in the ceiling to change filters on a six monthly basis. This is not an ideal solution in looking to create quality internal living spaces and the team plans to investigate alternative solutions in the coming months.

The study also looked at the implications of increasing the insulation levels on the ductwork from 25mm to 50mm. This had minimal influence on the overall energy savings however, primarily do to the fact the duct lengths in the PassivTower scheme are much shorter and the increase in insulation did not warrant the on-site cost increases.



1 Increased duct insulation
2 Ceiling based MVHR
3 Acoustic insulation
4 Ceiling access hatch
5 Intake / extract vent
6 Airtightness barrier

FIGURE 23 Typical MVHR unit



Base scheme

Passivhaus

FIGURE 24 Change in MVHR position and reduction in insulated ductwork

Building physics
Rethinking heating supply

In reducing the heat demand of each apartment from 33 kWh/m^2/a to 6 kWh/m^2/a, it is clear that the strategy to supply heat through underfloor heating in the base scheme must be reconsidered. In taking the analysis a step further, we were able to determine that the supply of heat would only be required during periods of prolonged cold weather.

With the significantly lower heat demand requirements, we were able to remove all the underfloor heating systems, with an estimated cost saving of £1.5m. This heat source was then replaced with a simple electric post heater to the MVHR. Whilst wall wall-mounted radiators could also have been included here were, we felt there was an opportunity to allow for increased freedom in internal space planning.

In making the decision to use a post heater as the primary heat supply, the team had to consider how this would influence the Primary Energy Demand figures. In moving from water based heating to electrically supplied heating, there was an uplift of the estimated electricity demand as illustrated in **FIGURE 25**. Whilst the PassivTower was still meeting the Passivhaus criteria, the use of the heating systems would have to be carefully managed by the end user.

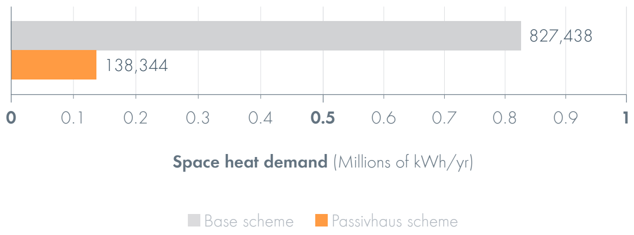
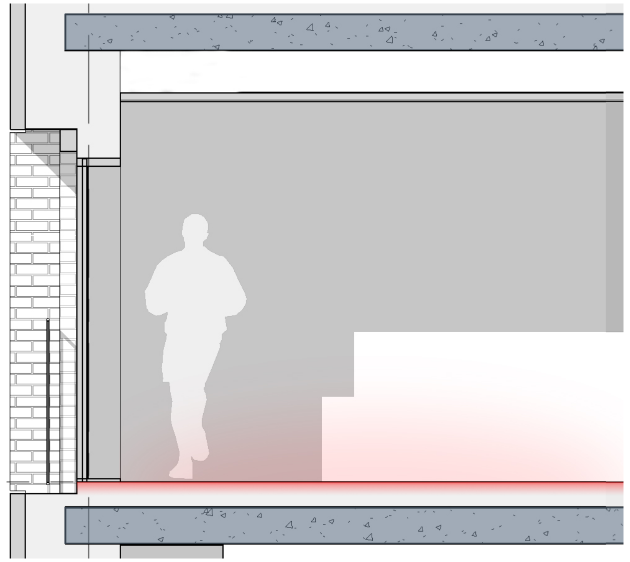
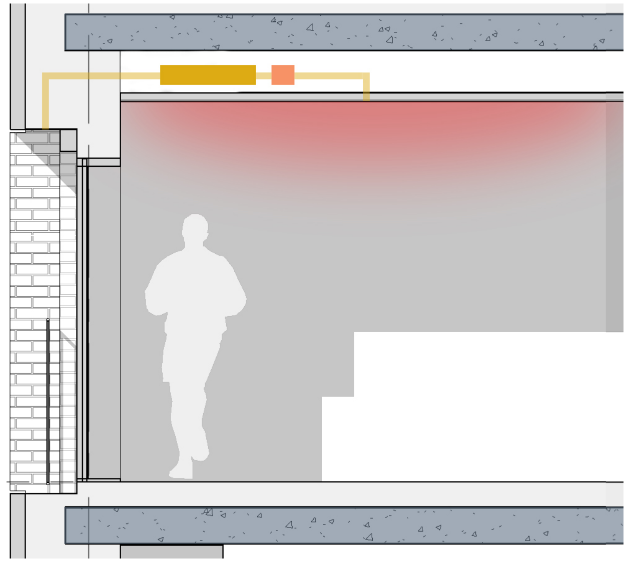


FIGURE 25 Comparison of space heat demand between the PassivTower and base scheme



Base scheme
Underfloor heating supplies **33 kWh/m^2/a** heat energy demand



Passivhaus scheme
MVHR post heater matches **6 kWh/m^2/a** heat energy demand

FIGURE 26 Ultra low heating demand allows for a radical approach to supplying heat

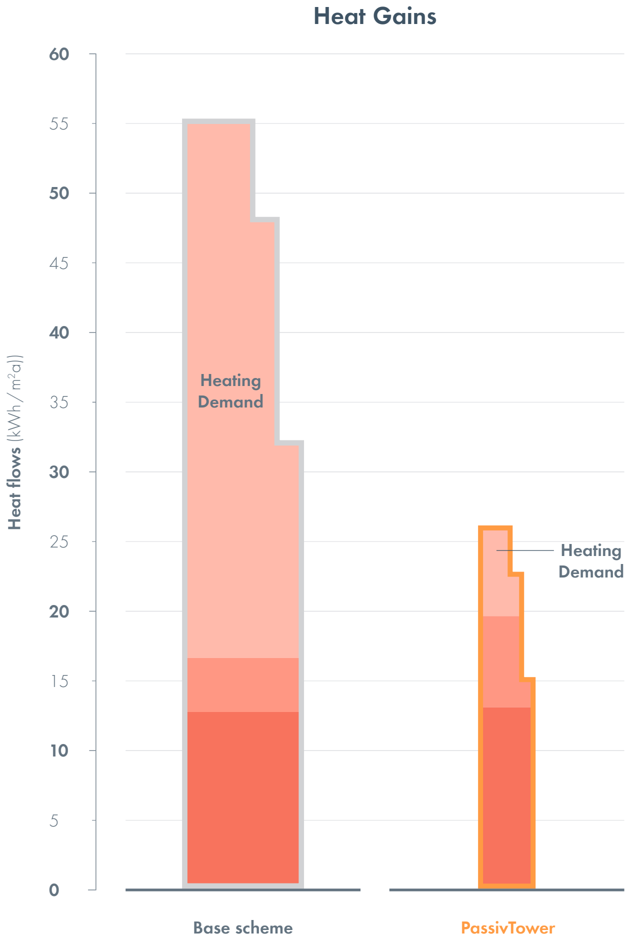


FIGURE 27 Remaining heat demand as a percentage of overall building heat gains

Opportunities for Passivhaus at scale

Applying Passivhaus at scale

Meeting industry challenges

The Farmer Review of the UK Construction Labour Model, *Modernise or Die* was released in 2016 and identified a number of alarming threats to productivity within the industry in the coming years. Particular focus was put on the fragmentation of procurement, aging demographics, declining skill levels and perhaps most alarmingly, the significant shortfall in R&D investment required in maintaining the competitiveness of the industry.

With productivity within the industry continuing to fall and the profit margins of the main contractors suffering as a result, it can be difficult to elevate the question of construction quality, high performing buildings and sustainable methods of housing delivery. There is an urgent requirement to establish housing construction models that encourage integrated and collaborative delivery team approaches, as opposed to the 'race to the bottom' tendering process. Essential to the feasibility of projects such as the PassivTower, would be a model where the risk of utilising new methods of construction is shared unilaterally and the entire team is incentivised / motivated in achieving quality on site.

We must also look at the feasibility of the PassivTower project in the context of current building performance regulations and the uncertainty that the Brexit process may bring to industries' obligations in meeting EU Carbon Emissions targets. Is carbon an appropriate method of measurement when looking to regulate building energy performance, or should the UK be more aligned with other EU nations in regulating energy use?

We will also briefly look at global adoption of the Passivhaus Standard in climate zones similar to the UK and consider how successful local and city authorities have been in integrating the standard with building regulation.

Changing landscapes

Measuring carbon or energy?

To understand the progression of building regulations in the UK over the past 15 years or so and the methods in which we measure building performance, we can look to the framework set by the European Union. In response to the carbon emissions targets set by Climate Change Act 2008, the European Directive set Regulation 23 to all EU member states, declaring all new builds must achieve the 'Nearly Zero Energy Buildings' target by 2021.

With the building stock accounts for approximately 36% of all carbon emissions produced in Europe, the regulation of building energy efficiency clearly has an important role to play in achieving 2050 targets. Whilst the vast majority of EU member states have looked to address this challenge through the regulation of building energy performance, the UK is one of the few that have opted to develop a series of building regulations and targets that focus on both energy performance and carbon emissions. This is an important differentiation in building performance metrics, as the consideration of energy supply in tandem with envelope performance does not typically incentivise the 'fabric first' approach of energy based standards such as Passivhaus.

The construction industry in the UK has been able to offset inadequacies in the building envelope, with alternative solutions such as renewable energy and carbon offset funds, whereas the stringent construction standards required in northern and central Europe must be met.

As the UK removes itself from EU directive requirements in the coming years, there is a growing concern that the effectiveness of national regulation on building performance standards may suffer. With the majority of EU countries targeting Nearly Zero Energy Building targets for 2021, the UK may find itself struggling to compete in the delivery of sustainable buildings in the global market. There are a number of case studies emerging from local authorities such as Norwich Council, that have looked to take the initiative and exceed the required building regulations through the implementation of the Passivhaus standard in social housing developments. Their innovative framework approach to construction procurement has allowed for a marked improvement in the quality of construction techniques on site and incentivises building objectives such as low airtightness levels in particular, that are rarely aspired to in most developments.

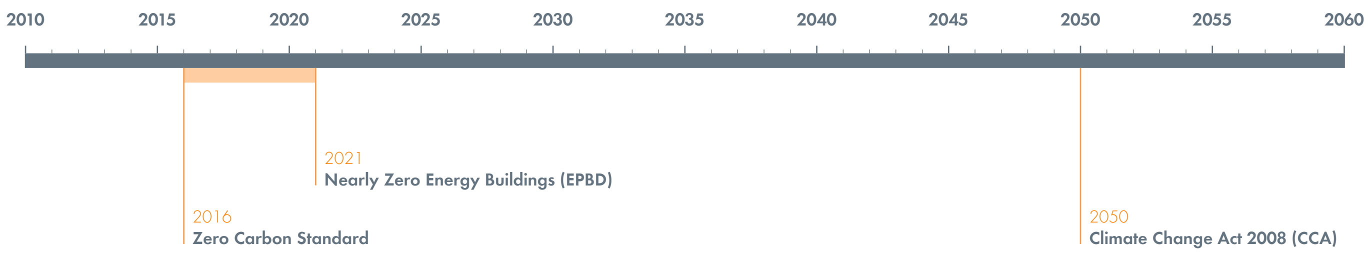


FIGURE 28 Future chronology for sustainable buildings

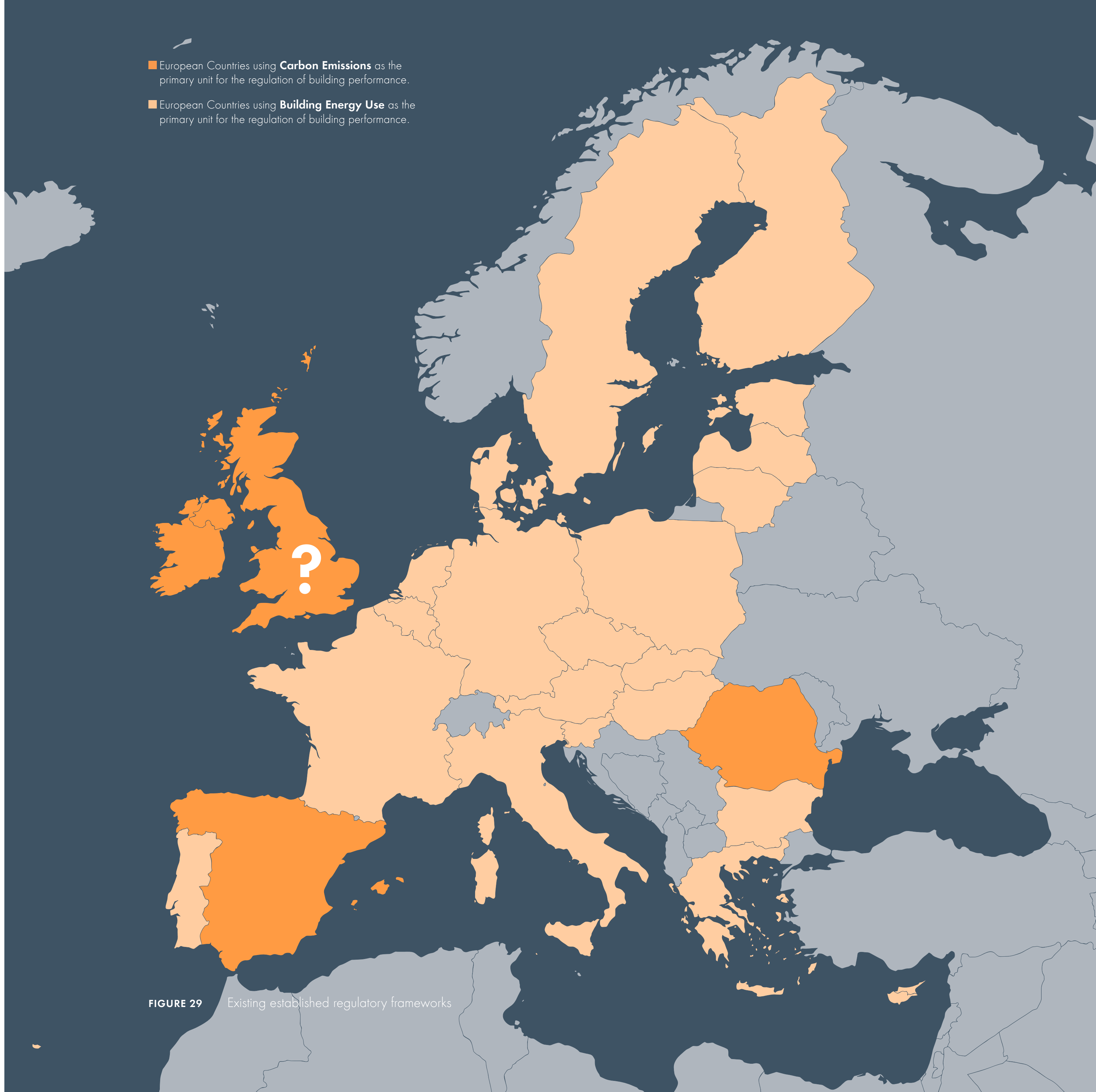


FIGURE 29 Existing established regulatory frameworks

Methods of measurement

SAP and PHPP

Whilst Passivhaus does not consider carbon emissions in terms of certification, it is important to briefly review the results under the measurement structure implemented in the UK. The majority of councils in London are now enforcing the 'offset payment' approach to schemes falling short of the 35% improvement on carbon emissions calculated in accordance with Part L1A 2013 regulations. In this case of the base scheme, this target was set at a challenging 65% reduction. With the offset payment calculation based on £60 per tonne of CO_2 over 30 years, there is a clear incentive to reduce the percentage reduction. As **FIGURE 30** and **FIGURE 31** highlight however, the method of calculation perhaps requires further review. In comparing the standard SAP assessment tool with PHPP, there are significant differences in the estimated annual CO_2 emissions produced. Whilst this report does not intend on claiming that the PHPP calculations are an accurate representation of building carbon emissions in reality, we do question whether the continued use of SAP as a building performance estimator is appropriate.

To illustrate the estimated carbon emissions of the PassivTower, in the context of a number of regulatory frameworks in London, **FIGURE 32** shows the CO_2 (tonnes)/year/m² of each building. Through use of publicly available data in the form of Display Energy Certificates (DEC), we were able to develop a number of comparative parameters.

Whilst it is probably an unfair assessment on many levels, given the variety of scales, typologies and building ages, there is a significant difference in the carbon emissions figures from these institutions responsible for building performance regulation in the UK and the proposed PassivTower scheme. As the industry's minimum building performance targets are set within these various departments, there is perhaps greater scope for regulatory bodies to lead by example.

SAP Calculation

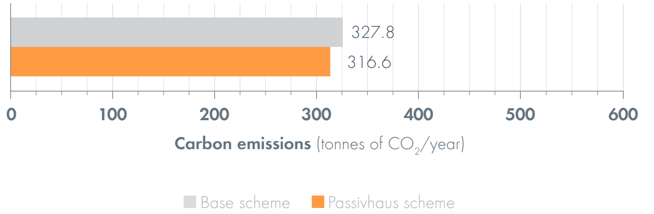


FIGURE 30 Carbon emission reductions using SAP calculations

PHPP Calculation

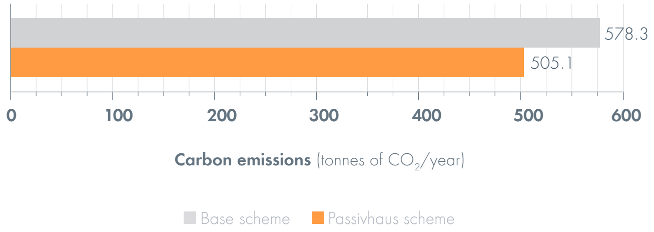


FIGURE 31 Carbon emission reductions using PHPP calculations

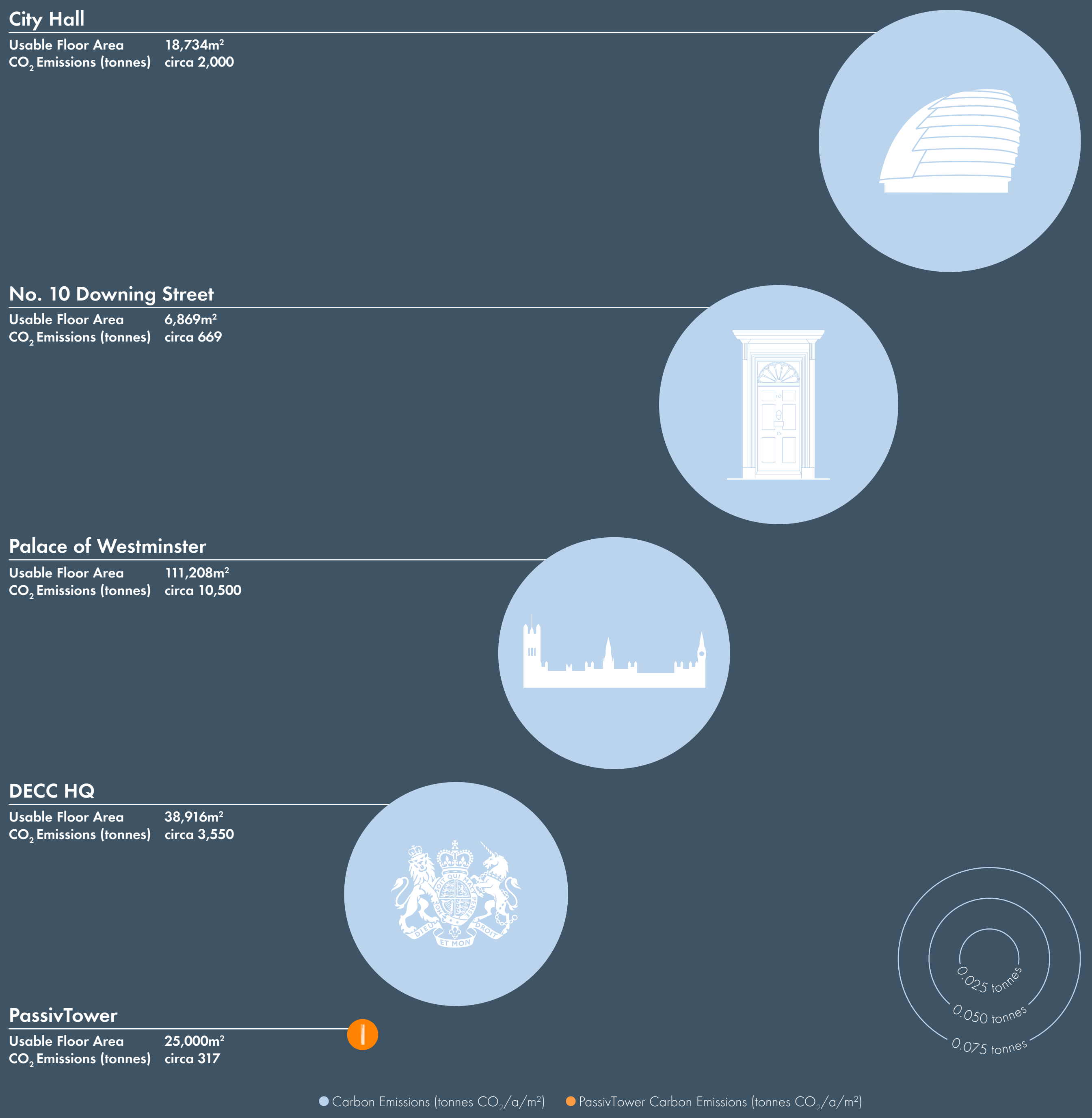


FIGURE 32 Comparative review of No. 10 Downing Street, Department of Climate Change, City Hall, Palace of Westminster and proposed Passivhaus tower in terms of treated floor area and carbon emissions.
Source: Energy Performance of Buildings Data, England and Wales. All figures from 2016

Rethinking energy
Decarbonised energy

As building regulations are slowly looking to push housing developments towards zero carbon standards, high density residential schemes such as this are at a distinct disadvantage. Without compromising on architectural quality, it is extremely difficult to generate sufficient energy through renewables to match the demand of a 48 storey tower. Whilst the limited space on the roof was utilised for photovoltaic panels, the maximum contribution to the primary energy demand was estimated at approximately 7%.

In creating a viable solution to this problem, we must look to the potential Passivhaus as part of the micro urban and neighbourhood scale as a first step. Through the principles of fabric first design, we can now revise our approach to energy supply to a series of building blocks. With a collective reduction in heat energy requirements of up to 80%, these developments now have the potential to include site integrated renewable energy, with aspirations of completely offsetting the energy requirements of each apartment. This alternative approach to energy supply challenges many of the urban design principles relating to energy generation and distribution to apartments.

The Greater London Authority has set a goal of achieving 25% of energy produced from decentralised sources by 2025. This includes the support of community energy models and a number of initiatives that look to create a more competitive energy supply industry. It is clear that there still must be an economic benefit to the end-user in making the necessary investment in decentralised energy sources. With Passivhaus as a base, there is a unique opportunity to review the traditional mixed use models, and investigate the feasibility of including innovative integration of small scale industrial units and residential developments, or district scale use of ground and air source heat pumps.

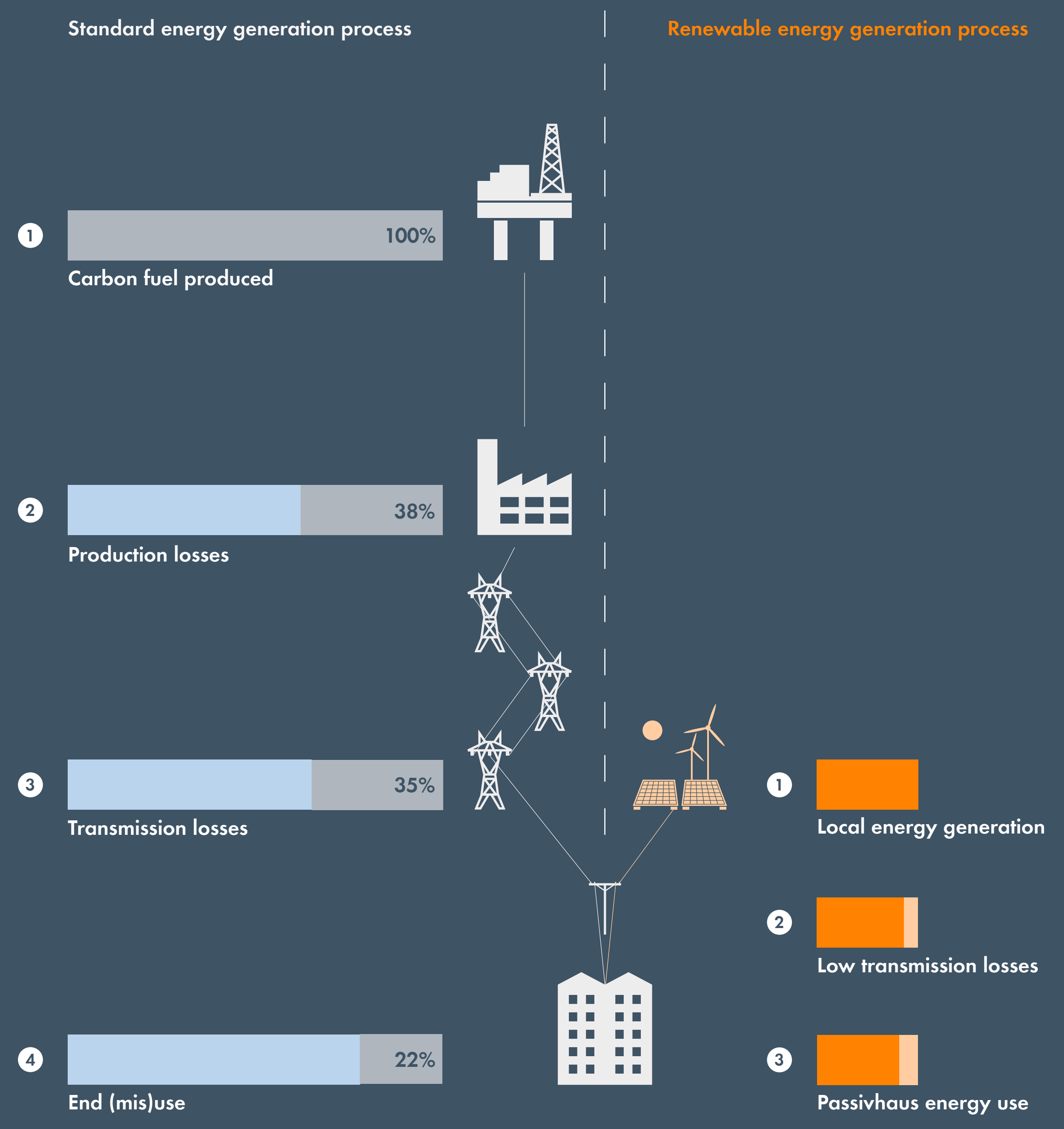


FIGURE 33 Illustration on the left shows the estimated losses in energy from generation to end use. Image on the right is a proposed alternative that embraces the advantages of renewable energy.

Global appeal
Suitable climate conditions

From its origins in 1990's central Europe, the Passivhaus Standard has since grown considerably. Recent years have seen the standard adopted across the globe, with over 60,000 Passivhaus units now certified.

With many projects ongoing internationally, the practice sees a value in adopting a global and legislation agnostic building performance standard. Whilst local building regulation will set the criteria for quality on any project, there is an opportunity to aspire to a global benchmark with the Passivhaus Standard. Local climate conditions become the initial reference point for the design and an understanding of the sites environmental considerations must be understood from the offset. As the map illustrates, there are certain climates that support the Passivhaus Standard better than others. Cool and warm temperate climate zones are particularly suitable to the Passivhaus standard and the relatively mild winter temperatures of the London micro-climate (in comparison to central Europe) ensure we are well placed in avoiding the extreme temperatures that may challenge the Passivhaus Standard.

As the Passive House Database continues to grow with each certification, we can now generate an accurate picture of what building envelope performance criteria may be required at specific points on the globe. In linking this data into our early conceptual design process, decisions on building orientation, envelope u-value requirements, glazing percentages and airtightness levels can be made based on proven data.

Whilst most Passivhaus projects are still located in central Europe, the rapid rise of global Passivhaus organisations has seen the standard spread. We have also indicated on this map, a number of national and local authorities that are adopting the Passivhaus Standard and integrating the criteria into building regulation, as well as major global cities that are in a Passiv friendly climate zone. As these authorities look to dramatically improve the energy performance of existing and new housing stock, they have looked to the track record of Passivhaus as a reliable standard to aspire to. With the largest Passivhaus house scheme to date completed in New York, there is now growing evidence to suggest that the Passivhaus standard is not only achievable in high density residential buildings, but delivers high quality homes.

Passivhaus Trust
The UK Passive House Organisation
PASSIVHAUS Austria
PASSIVEHOUSEINSTITUTE NEW ZEALAND
AUSTRALIAN PASSIVE HOUSE ASSOCIATION
Passive House Institute
PASSIVE HOUSE ASSOCIATION OF IRELAND
NYPH NEW YORK PASSIVE HOUSE
PASSIVEHOUSE CANADA Build better. Feel better.

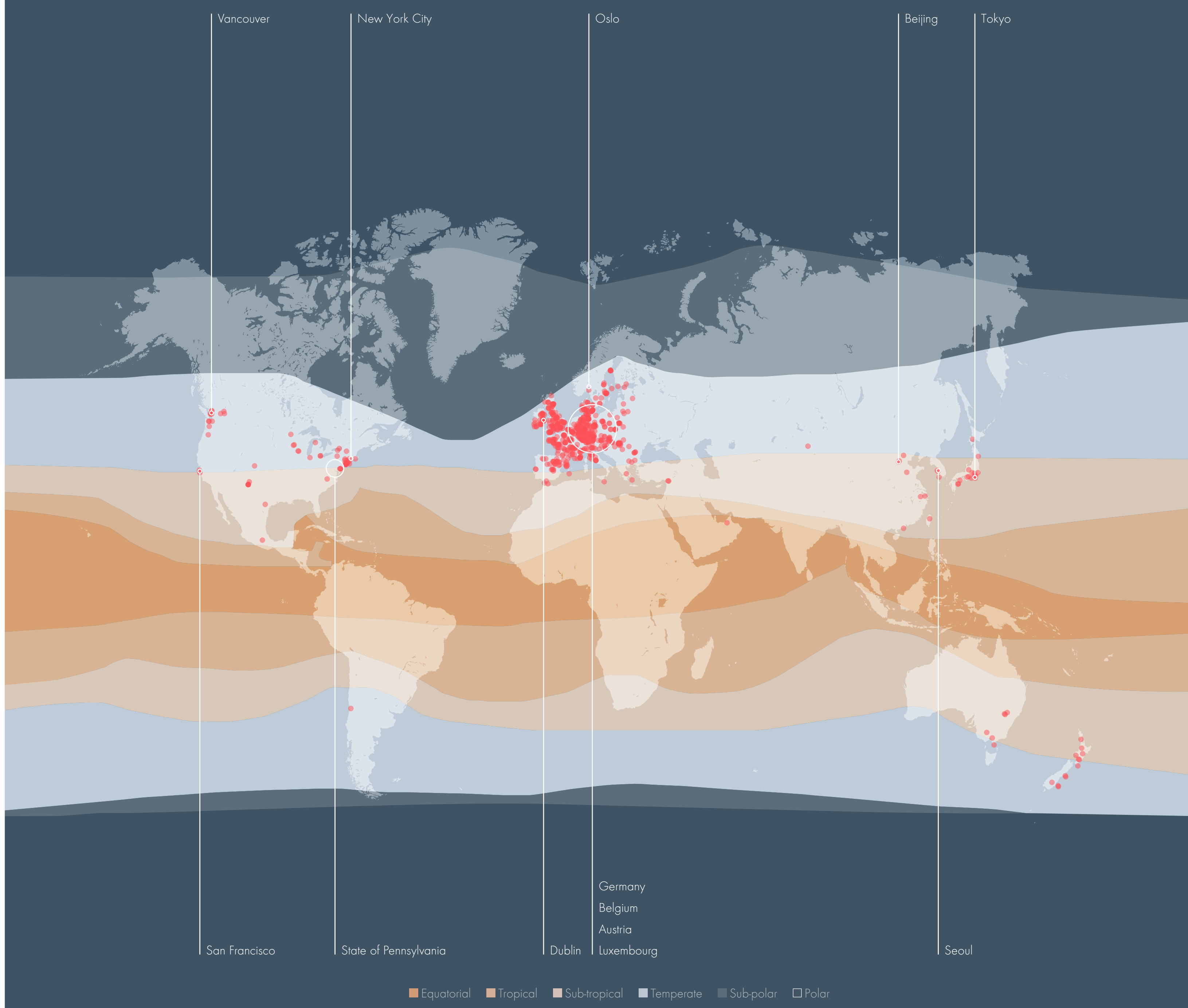


FIGURE 34 World climate zones and passive projects

What’s next?

What’s next?

This research project finds itself at the intersection of two seemingly unrelated issues, offering the possibility for a solution to both. First, is the sustainability crisis all societies face and the national, transnational and global targets that have been set to reduce energy. Then there is the shortage of housing. London and many larger cities are facing an acute lack of housing, especially for younger populations. Whilst the daunting challenge of retrofitting the existing building stock is likely to be the main challenge to upgrading the energy performance of housing stock, finding a proven method of delivering new sustainable housing, urgently needs industry consideration. The PassivTower could offer a solution.

Design at the heart

Whilst the building performance credentials of Passivhaus are to commended, the quality of the resultant architecture can often be less than inspiring. At the outset of this project, one of the core challenges was to minimise the impact of implementing the Passivhaus standard on the original design intent. At numerous points within the redesign, there were opportunities to push the building performance even further, however this was at the expense of the architectural language and quality of space that must remain at the core of the project objectives.

This said however, we successfully retained a number of key design objectives such as the deep window reveals, glazing percentages on each facade that produce strong daylight levels, brick finished GRC panels and we removed the requirement for any radiators or underfloor heating. Certain decisions that may require further consideration include MVHR ceiling hatches in apartment leaving spaces and potential options that look to combine hot water energy demand with air heat recovery systems.

As the London housing market looks to tackle the ongoing housing shortage, building at scale could address many of the market and sustainability challenges. The Passivhaus standard has never been attempted at the scale proposed by this project. As the findings of this report highlight however, it could be argued that the sheer scale of the proposal reduces many of the traditional challenges associated with the Passivhaus Standard.

FIGURE 35 Can Passivhaus at scale be beautiful?

What's next?

Could Passivhaus place design at its heart?

FIGURE 36 How can we incorporate elements of exemplary housing design into Passivhaus at scale. From left to right: Aldgate Place, incorporates many of the same design principles in the base scheme; generous balconies in an individual flat at Highbury Square; contextual contemporary design at Lock Keepers, a Peabody development in Bromley-by-Bow; and window and eave detail at Ash Court, a residential building for Girton College, Cambridge.

What's next

Constructing Passivhaus at scale

The Passivhaus Standard criteria does not look to specify specific construction techniques and there are a wide range of examples of the standard being achieved using masonry, timber and concrete frame construction. For the purposes of comparison between the base and PassivTower schemes, the original GRC panels with brick slips was retained. This form of construction supported the overall construction strategy of minimising the number of trades on site and the time required in assembling the facade components.

The emergence of off-site construction techniques into mainstream project delivery has become increasingly apparent in recent years and this is primarily driven by the need for quicker delivery housing units to meet the growing market demand. Off-site facilities from organisations such as Legal & General, Laing O'Rourke, Mace, Vision Modular and China National Building Material Company, have all invested heavily in establishing themselves in the UK market and have committed to increasing the delivery of units.

In reviewing differences in capital costs between both schemes, initial estimations have suggested that construction and material cost could be up to 12.5% more for the PassivTower. When we take a closer look at this figure, a significant portion of this uplifted cost is attributed to the ultra low airtightness levels specified and the associated costs procuring a supply chain with the skills to deliver. As identified in the previous section on airtightness analysis, there is a significant challenge within the UK construction industry to provide the skills and experience needed to achieve these standards and the obvious alternative is to move the assembly process to controlled off-site facilities.

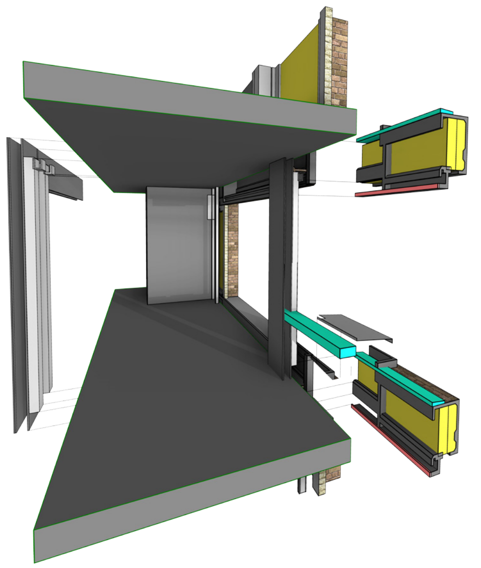


FIGURE 37 Adopting off-site construction techniques is one potential option in mitigating the risk of ultra-low airtightness implementation

Whilst there are clear advantages to the management of airtightness strategies through machine enabled assembly lines, the use of Design for Manufacturing and Assembly (DfMA) techniques poses many challenges to the traditional design approach. Building Information Modelling would certainly be an important tool in looking to review component interfaces, however the use of 'I' in BIM could have particular advantages to the implementation of Passivhaus at this scale. The inclusion of site specific data in the model, such as component sequencing, airtightness QA checks and photographic logging of as-built assemblies, ensures the quality of information between design and construction is maintained.

End-user engagement

Whilst the Passivhaus standard has consistently demonstrated its ability to simulate the performance of a building throughout the design process, the variable that is the end-user is difficult to estimate. In the case of the apartments contained within this Passivhaus tower, engagement with occupants is vital, as it is important to understand the implications of certain user interactions with the building and how it operates. The opening of windows and the influence this has on the overheating issues identified, the operation of the MVHR and ensuring the summer bypass is implemented during the cooling season and ensuring low energy lighting and appliances are used at all times are just some of the responsibilities that the occupants will have in ensuring the dwelling performs as intended.

Challenges remain in the skills base and in fabrication.

What's next?

A sustainable model to help meet the housing supply?
When considering an apartment that uses 80% less heat energy than a typical London new build, there are many interesting questions that arise in terms of sale market value. How to incentivise a developer to invest in the quality of the Passivhaus standard, when the benefits are passed to the purchaser?

One obvious consideration in addressing this question is to review the PassivTower in the context of the Private Rental Sector (PRS). As the developer retains a vested interest in the building over its life-cycle, the cost of operation and maintenance is of paramount importance. The associated incentive to produce a building that is resistant to fluctuating energy prices is clear. In the case of a building of this scale however, this model does not necessarily work economically. There is a significant sale market value uplift for an apartment at level 44, compared with level 01. In the case of a PRS model however, the rental revenue uplift does not hold the same value as height of the apartment increases.

A potential solution could be the development of a hybrid model which entails outright sale of an apartment to the buyer with energy supply, maintenance and operations remaining with the developer. This novel approach would allow the developer to sell heating and cooling at reduced market rates while profiting and also gaining new efficiencies through centralised MVHR systems. Projects such as these would become attractive to investors such as pension funds as it appeals to their need for long-term investments. The Passivhaus standards' emphasis on material and construction quality would also help to keep long-term maintenance costs down. What this signifies is that the PassivTower could be not just a way to reduce the ecological footprints for a global city with a growing population, but also an attractive delivery method for a city facing a mounting challenge in meeting its housing needs.

An ecological imperative for cities facing housing shortages.

FIGURE 38 London has more than 400 towers consented or in planning - could some of them be delivered as PassivTowers?

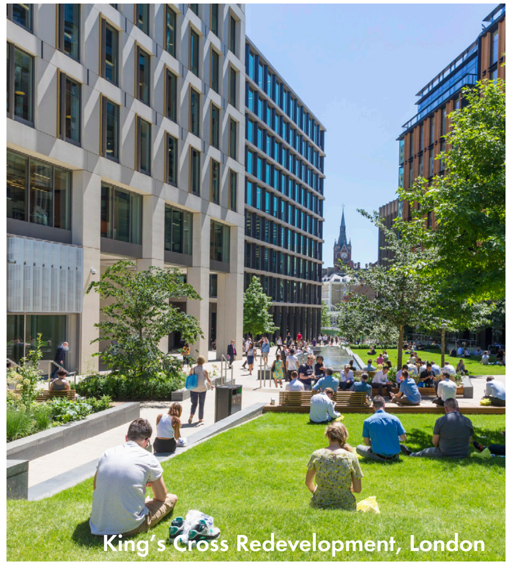
About Allies and Morrison

We are an architecture and urban planning practice with a reputation for well-crafted buildings and thoughtful place making.

Based in London, and working globally, we are designers who enjoy working from the scale of a single piece of furniture to the ambition of a citywide masterplan.

Our expertise spans across a wide area of work with particular strengths in urban, mixed-use projects, working for commercial, higher education, institutional and cultural clients. Working closely with local authorities and local communities, we believe cities can evolve and change by building on their historic form and identity rather than sacrificing it.

Our portfolio includes projects throughout the UK and Europe. We are also currently working on projects in the Middle East and in North America.


King's Cross Redevelopment, London


Queen Elizabeth Olympic Park, London


Royal Festival Hall refurbishment and South Bank public realm, London

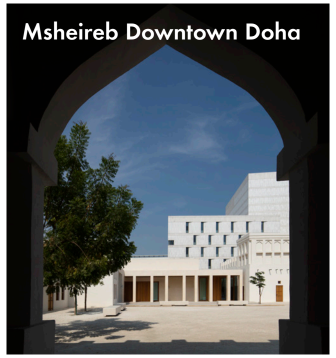

Yorkville, Toronto

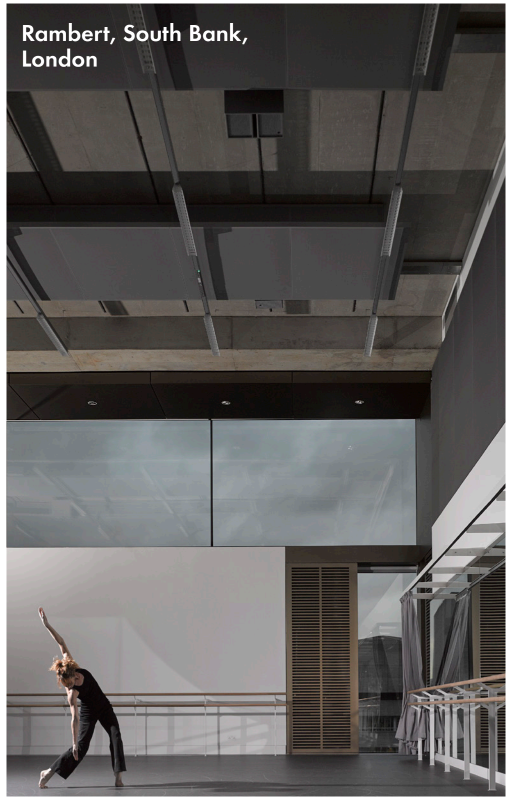

Irfan, Oman

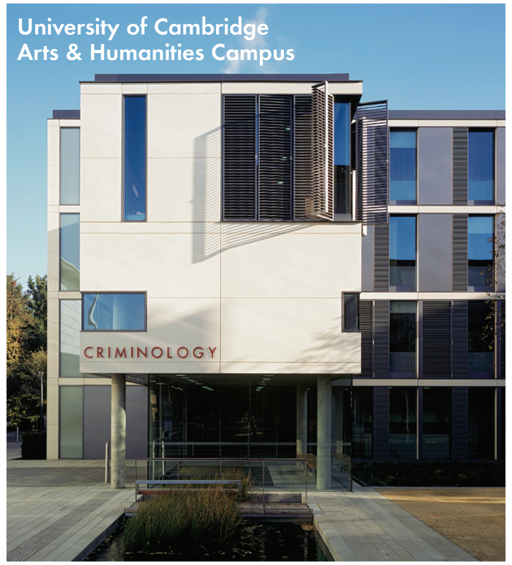

St Peter's College, University of Oxford


London College of Communication / Elephant & Castle Redevelopment


Brighton College


Msheireb Downtown Doha


Rambert, South Bank, London



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