Business case for exceeding the Greater London Authority energy plan

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Abstract

Zero carbon standard and carbon offsetting tax has been applied from October 2016 to all new residential developments in London, setting an economic challenge to housing providers and developers. Prior to that, residential developments were required to achieve at least a 35 per cent reduction in regulated carbon dioxide emissions compared to the Part L 2013 on-site. This technical insight, therefore, will demonstrate how exceeding the Greater London Authority (GLA) compliant design from 35% carbon emissions below Part L to Passivhaus (PH) standard (currently the leading international low energy design standard) can enable housing providers and developers to effectively tackle this challenge.
The paper establishes an elemental Capital and Life Cycle Cost (LCC) saving analysis for a 25445 m^2 residential development in London, over a 30-year period, to compare the cost variance of a minimum GLA compliant design – 35% carbon emissions below Part L – with a PH design. The outcomes of the case study indicate that building to PH standard can save approximately £889K (£32 per m^2) at the construction stage while the LCC savings will be over £1.5M (£55 per m^2) circa compared to the GLA design compliance.

Keywords Life Cycle Cost (LCC), Zero Carbon Standard, Greater London Authority (GLA), Passivhaus (PH) Standard, Carbon Offsetting Tax

1.0 Introduction

1.1. The Challenge – Greater London Authority (GLA) compliant design

The London Housing Supplementary Planning Guidance (SPG) stated that from October 2016 zero carbon standard and carbon offsetting tax will be applied to all new residential developments. This target was set to align with the then expected introduction of ‘zero carbon homes’ through Part L of the Building Regulations. However, on July 2015, the government announced that ‘it does not intend to proceed with the zero carbon Allowable Solutions carbon offsetting scheme, or the proposed 2016 increase in on-site energy efficiency standards (1).

Residential developments in London are required to achieve at least a 35 percent reduction in regulated carbon dioxide emissions compared to the Part L 2013 on-site. The remaining regulated carbon dioxide emissions, up to 100 per cent, are to be offset through a cash in lieu contribution to the relevant Borough, in order to secure delivery of carbon dioxide savings elsewhere (2).

This new target will be setting an economic challenge to the housing providers and developers. Therefore, the industry needs now, to find an economically viable and efficient way of delivering the GLA carbon emission target.

In addition, GLA carbon emission target's dependency on achieving a percentage carbon reduction might not encourage designing to reduce energy consumption and increase thermal comfort in buildings. While, consideration also should be given to the provision of thermal comfort and good indoor air quality to occupants and it is not necessarily achieved by means of high carbon reduction targets and policies.

1.2. The Solution – Passivhaus and Modular Construction

Passivhaus (PH) standard which is currently the leading international low energy design standard, has set an energy target per square metre per year for all buildings. The target results in following a simple aim of achieving, by good design, optimum internal comfort for the lowest possible energy consumption (3).
While (i) an overwhelming evidence of affordable, low energy, sustainable housing in other European countries provided by following Passivhaus principles and (ii) energy bills in the UK are rising rapidly, Passivhaus is still relatively a new concept in the UK and the number of Passivhaus schemes completed to date in the UK is low when compared to other European countries.

One of the main drawbacks in adopting Passivhaus and other higher building standards in the UK is the market uncertainty about additional capital costs of building to a higher compliance standards (4; 5). The outcome of the '*Passivhaus Capital Cost Research Project'* by Passivhaus Trust indicates that meeting Passivhaus standard attracts an uplift mainly in preliminaries and design fees. These fees are attributed by respondents to additional design fees, additional airtightness testing and Passivhaus certification, supervision, hard prelims, Construction Management Fee and Contingency (5). Other countries, however, have managed to reduce these costs by using pre-fabricated and modular method of construction (6).

As a result, Passivhaus standard and off-site construction could be a long term and economically viable solutions to the UK housing providers and developers.

1.3. Objectives of the analysis

This research establishes an elemental Capital and Life Cycle Cost (LCC) saving analysis for a residential development in London, over a 30-year period, to compare the cost variance of a Greater London Authority (GLA) minimum compliant modular design –35% carbon reduction compared to Part L– with a modular Passivhaus (PH) standard compliant design.

2.0 Background

2.1. GLA Compliance

From October 2016 a new section in the GLA's London Plan Policy has called for residential developments to become zero carbon. Residential developments are required to go beyond the 35 per cent reduction in regulated CO_2 emissions through on-site measures and *now* carbon offset payments to the local authority, too.
The emission reduction targets the GLA had been applying to applications in order to achieve zero carbon emission target are as follows (2):

- Stage 1 schemes received by the Mayor on or after the 1st October 2016– Zero carbon (as defined in section 5.2 of the Housing SPG) for residential development and 35% below Part L 2013 for commercial development.

According to the SPG, design proposals should make the fullest contribution to minimise carbon dioxide emissions in accordance with the following energy hierarchy (2):

- Be Lean – Use less energy
- Be Clean – Supply energy efficiently
- Be Green – Use renewable energy

2.2. Passivhaus Standard

Passivhaus is defined as a building in which thermal comfort can be provided solely by heating or cooling of the fresh airflow that is required for good indoor air quality (7). Developed in Germany in the early 1990s, the Passivhaus standard strengths lie in the fabric first approach; build a house that has an excellent thermal performance, exceptional airtightness with mechanical ventilation to provide adequate fresh air to the occupants. The standard can be applied not only to residential dwellings but also to commercial, industrial and public buildings (8). Table 1 presents the minimum requirements and performance targets to meet the Passivhaus standard (7).

Element	Minimum criteria
Air-tightness	0.6 ach @ 50Pa (n_{50})
External Walls	0.15 W/m^{2}K
Roof	0.15 W/m^{2}K
Ceilings	0.15 W/m^{2}K
Wall to unheated areas	0.15 W/m^{2}K
Window U-Value install	0.85 W/m^{2}K
Window g-value	0.5
Primary energy demand	120 kWh/m^2/yr
Space Heating requirement	15 kWh/m^2/yr

Table 1: Minimum requirements and performance target to meet Passivhaus standard

2.3. Life Cycle Costing (LCC)

Whole Life Cycle Cost (WLCC) assessment is essential to fulfil the Construction 2025's 33% cost reduction target and to align design and construction with operational asset management (9). This particularly arises when making decisions on M&E services due to several potential investment opportunities and the importance of finding the most cost-effective long-term choice.

WLCC is an effective, yet complex process to undertake and considers the total expenditure of a project over four stages: (i) Externalities, (ii) Non-Construction, (iii) Life Cycle Cost and (iv) income Costs.

For the purpose of this paper, Life Cycle Cost (LCC) assessment –including Construction, Operation, Maintenance and Replacement Costs– has been carried out (10). The costs that have been included in the LCC assessment are indicated in Figure 1 next page.

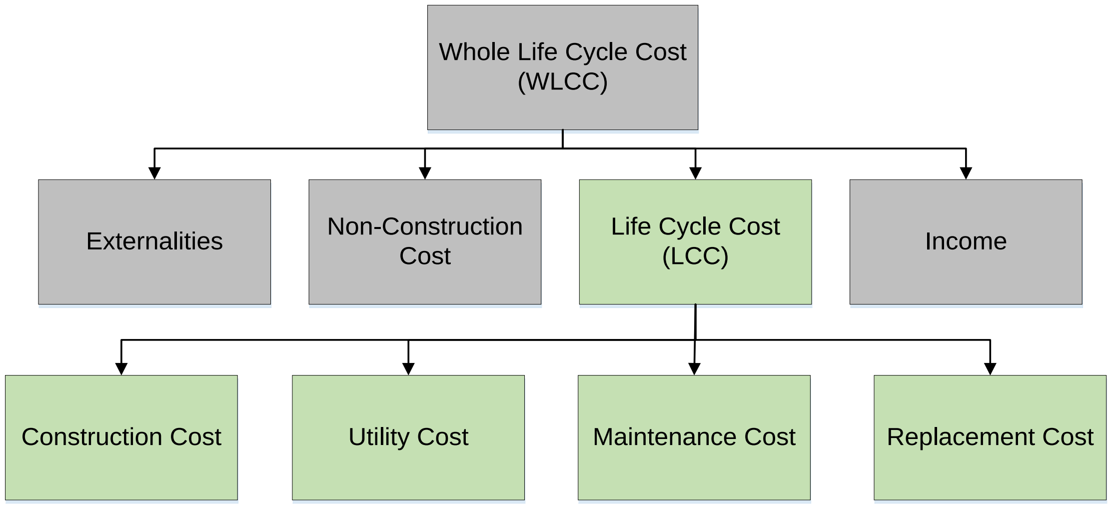

Figure 1 - WLC and LCC elements and scope of analysis (10)

3.0 Basis of Comparison

The analysis has been carried out for an £80M, 440 residential units (in five blocks) development with the Net Internal Area (NIA) of 27514 m^2 including affordable housing and 2069 m^2 of flexible commercial / community floor space. The case study has been modelled to meet the following scheme design options:

1. Greater London Authority (GLA) Compliant design and
2. Passivhaus Compliant Design (which also complies with GLA requirements)

Tables 2 and 3 compare the requirements for *certification to the Passivhaus classic standard* to the *GLA compliance*. Passivhaus standard values and requirements also comply with the 35% carbon reduction required by the GLA.

Elements	Recommended design values to meet GLA planning requirements	Recommended design values to meet Passivhaus Plus GLA Compliance
Air-tightness	3 m^3/m^2h @ 50Pa (n_{50}) equivalent to 0.6 ach @ 50Pa (n_{50})	0.6 ach @ 50Pa (n_{50})
External Walls	0.15 W/m^2K	0.15 W/m^2K
Roof	0.15 W/m^2K	0.15 W/m^2K
Ceilings	0.14 W/m^2K	0.15 W/m^2K
Wall to Unheated Areas	0.18 W/m^2K	0.15 W/m^2K
Window U-Value	1.40 W/m^2K	0.85 W/m^2K
Window g-Value	0.5	0.5

Table 2: Fabric and airtightness requirement to meet 'GLA' and 'PH plus GLA' Compliance for the case study building

Recommended Building Services Strategy		GLA planning	Passivhaus standard
Heating system	**System**	Via Communal Boilers, 95% Efficiency and Combined Heat and Power (CHP) Heat Interface Units (HIUs) in each dwelling	Via Communal Boilers, 95% Efficiency and Combined Heat and Power (CHP) for Hot Water only
	Emitters	Radiators	infrared Panel Heaters
	Controls	Time and Temperature Zone Control	Time and Temperature Zone Control
	Water Heating	from Heating System	from Heating System
Ventilation		Mechanical Ventilation with Heat Recovery	Mechanical Ventilation with Heat Recovery
Renewables		Photovoltaic Panels to serve the commercial and communal areas	-

Table 3: Building Services Strategy to meet 'GLA' and 'Passivhaus standard plus GLA' compliant design

GLA compliance, similar to Passivhaus standard, focuses on improving the building's fabric and efficiency of services to achieve best practice U-values over and above current Building Regulations. Therefore, the major difference between the GLA Compliance and Passivhaus scheme's fabric strategy is on the triple-glazed windows.

In addition, 35% CO_2 reduction (required by GLA compliance) for the whole development could be achieved by the Passivhaus scheme without a need for installing PV panels. However, a separate cost basis analysis would be required to determine if adding PV panels to the PH scheme could provide any benefits to the developer.

4.0 Results

Please note that the costs presented are mainly focused on the specific elements that differentiate the two strategies to report on the net savings/additional costs of building to Passivhaus Standard in London.

4.1. Capital Costs

For the purpose of this study, the capital costs are provided by the design team (the Building Services Consultant, the Passivhaus Consultant and the Quantity Surveyor), BCIS databases and manufacturers' product data. Cost of the following elements are compared for the two different design schemes:

- Capital Costs of Fabric and glazing
- Mechanical and Electrical (M&E) Installations
- Preliminaries

Figure 2 demonstrates the capital cost savings and extra expenditure when building to Passivhaus standard. Please see Table 4 for more details of analysis and the capital cost variance for the two options.

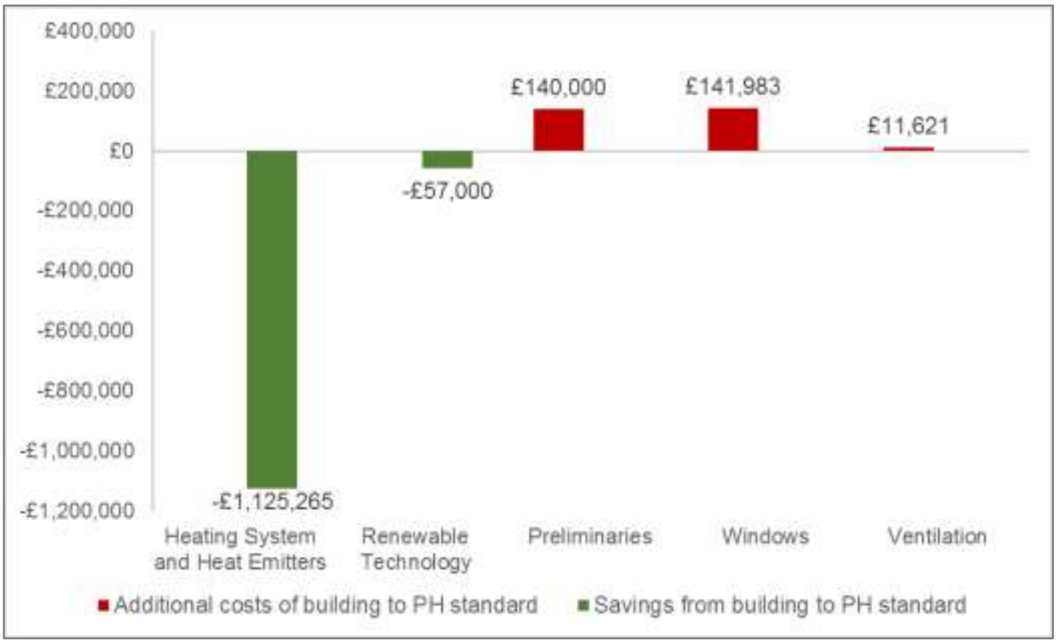

Figure 2 - Capital Cost variances for the Fabric and M&E Installations from building to Passivhaus Standard

As can be concluded from Table 4 (see next page), it is projected that incorporating Passivhaus standards, whilst achieving the GLA carbon reduction target, will result in approximately £889K savings in the Capital Costs. The estimations and assumptions are for a pre-fabricated and modular method of construction.

Comments below are provided by the design team on the above cost elements and figures:-

Capital Expenditure	Approx. Cost Savings of building to Passivhaus Standard (Approx. £)	Extra Cost of building to Passivhaus Standard (Approx. £)
Facades	£0	£0
Building Fabric	£0	£0
Windows	£0	+£141,983
Airtightness	£0	£0
Ventilation	£0	+£11,621
Heating and Hot Water (Includes boiler house pipework, valves, gas supply, pressurisation unit, expansion vessel, flue, HIUs and controls)	-£1,042,828	£0
Heat Emitters	-£82,437	£0
Renewable Technology	-£57,000	£0
Preliminaries	£0	£0
Additional risk allowance	£0	£0
Additional air tightness testing	£0	£0
Certification fees	£0	+£140,000
Main contractors preliminaries on above	£0	£0
Total Extra cost of building to Passivhaus standard	**-£888,662** (1.1% of the total construction value)	

Table 4: Analysis of the Capital Cost variances for Fabric and M&E Installations from building to Passivhaus Standard

1. Building Fabric

1.1. High level of building fabric U-Values are applied to achieve the London Plan (Be Lean) and therefore there will not be significant cost implications when improving the U-Values to meet PH standard. See Table 2 for Fabric strategy comparison.

1.2. Additional costs are attributed to triple glazing to achieve Passivhaus as opposed to Standard double glazing. The cost difference are provided according to a triple glazed manufacturing quotation.

1.3. As this is a pre-fabricated modular construction method, it is expected that the work will be undertaken with accuracy and care. Given that the proposals for sealing the pre-constructed units together are relatively straightforward and repetitive, there is no reason to think that the slightly higher airtightness standard for the GLA compliance will not be exceeded or impose any additional demand on the installation or additional costs (11).

2. M&E Installations

2.1. Airtightness necessities for both ‘GLA’ and ‘PH’ requires balanced mechanical ventilation systems to avoid overheating and therefore the only cost variance is between certified ventilation unit and non-certified ventilation units. The cost difference has been provided by a manufacturer.

2.2. In terms of heating plant and heat output, building to PH standard will result in:-

- A reduction in boiler plant capacity from 2 MW to 1.6 MW and
- A reduction in heat output from typical 1.8 kW to 0.8 kW due to savings in size and quantity of heat emitters.

2.3. With Double glazed windows applied to the GLA compliant design, installing PV panels is essential to meet the GLA target (35% carbon reduction at the time of this study). With Triple glazed windows, the GLA target could be met by incorporating Passivhaus standards and without the need for renewable technology.

It should be noted that as this development is a mixed-used residential and commercial development, savings from PV will be applied to the commercial and communal areas rather than the residential areas. Therefore, the energy costs will not be effected by the PV panels.

3. Preliminaries

3.1. For a traditional construction, the quantity surveyor would allow an extra cost of 500K for risk allowance. Due to the nature of the project (modular and pre-fabricated) this risk applies to both schemes and therefore this cost has not been considered in the calculations.

3.2. It should be noted that for a typical on-site traditional construction, an additional management and supervision cost associated with both the main contractors and subcontractors, having to employ additional staff to monitor Passivhaus compliance, would apply to the project. These costs would include supervision (4%), hard prelims (8%), Construction Management Fee (2%), Contingency (5%), and inflation (2%). The total cost of these compounded which should be applied to the net additional cost is 23.5%. For this case study these costs were calculated to be approximately £1.1M (£40 m^2) if the PH design was built traditionally.

However, as can be seen from Table 4, this extra cost can be offset by savings in the heating system.

4.2. Utility Costs

4.2.1. Modelling

For the purpose of estimating annual utilities costs for the two schemes, the energy consumption figures are generated from the Standard Assessment Procedure (SAP) to facilitate an overall Life Cycle Cost. The SAP results for the Passivhaus option are compared and validated with the Passivhaus Planning Package (PHPP) provided by the project's Passivhaus consultant.

4.2.2. Energy Prices

It is inherently difficult to predict life time energy costs due to unpredictable future fuel prices. In reality, energy prices will not remain constant over time. However, historic data can be used to adjust this uncertainty and predict a range of probable future fuel prices (12; 13). To predict future fuel prices, 30 years (1986-2016) of gas and electricity price indices (The percentage for escalation) datasets have been drawn from BCIS historic data (14). Accordingly, the inflation rate of 3% and 2.8% has been considered for gas and Electricity prices respectively and the projected energy costs have been discounted to the present value using a discount rate of 3.5%.

It should be noted that these estimates may change as the design develops. This may be either due to changes in the GIA of the building, or due to the adjustment of the benchmark £/m^2 rates based on an increase in the level of information available which will enable refining the estimates.

4.2.3. Energy Costs

The savings (when building to PH standard compare to the GLA compliance) are mainly attributed to the space heating consumption (by gas). Figure 3 compares the heat consumption of the GLA Compliant Building and a Passivhaus Compliant Building over 30 years of running the building. Table 5 provides a comparison between the GLA Compliant Building and a Passivhaus Compliant Building energy costs over a 30-year period.

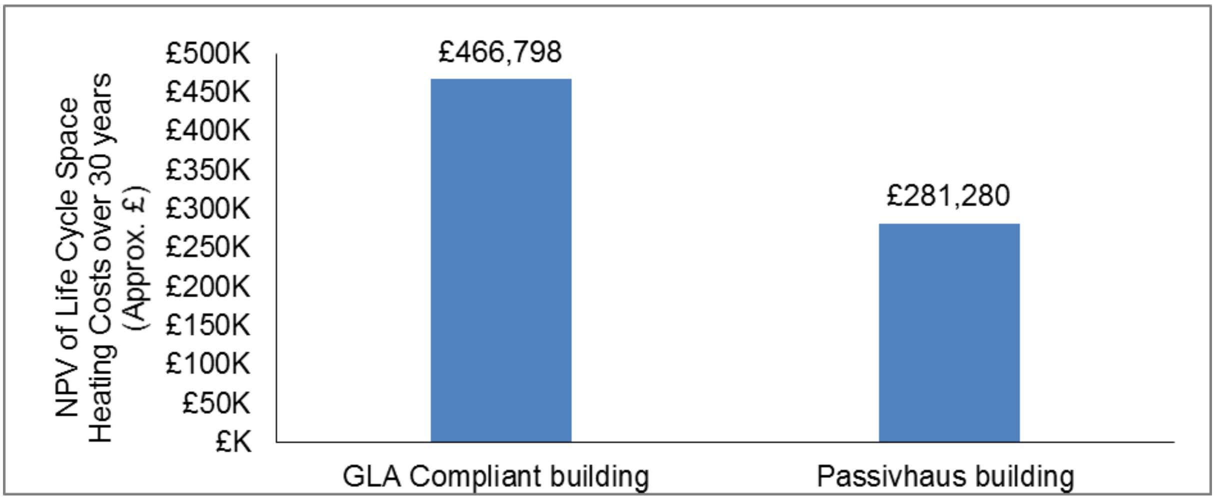

Figure 3 – Approximate NPV of Life Cycle Heating Costs over 30 years - Comparison between the GLA Compliant Building and a Passivhaus Compliant Building for the residential area.

<table>
<tr><th rowspan="2">Elements</th><th colspan="2">Annual Costs</th><th colspan="2">Total Life Cycle Costs over 30 years</th><th colspan="2">Total NPV of the Life Cycle Costs over 30 years</th></tr>
<tr><th>GLA Compliant Design</th><th>PH Design</th><th>GLA Compliant Design</th><th>PH Design</th><th>GLA Compliant Design</th><th>PH Design</th></tr>
<tr><td>Space Heating</td><td>£16K</td><td>£9K</td><td>£811K</td><td>£489K</td><td>£467K</td><td>£281K</td></tr>
<tr><td colspan="7">Whole Development –Total Space Heating Cost Savings from Building to Passivhaus Standard</td></tr>
<tr><td colspan="2">Annual Savings</td><td colspan="3">Life Cycle Cost Savings over 30 years</td><td colspan="2">NPV of Total Savings</td></tr>
<tr><td colspan="2">£7K</td><td colspan="3">£322K</td><td colspan="2">£185K</td></tr>
</table>

Table 4: Approximate Heating Costs for the residential buildings - Comparison between the GLA Compliant Building and a Passivhaus Compliant Building for the residential area.

As shown in Figure 3, the energy costs for space heating and hot water will reduce by 40% when building to Passivhaus standard compared to the GLA compliant building. In total building to Passivhaus standard results in approximate NPV savings of £185K in the total Space Heating costs over 30 years of running the building.

4.3. Carbon Emissions and Carbon off-setting tax

As mentioned before, the London Plan policy seeking 'zero carbon' homes and allowable solutions remains in place to ensure the development industry in London is prepared for the introduction of 'Nearly Zero Energy Buildings' by 2020.

The Mayor's SPG requires London planning authorities (LPAs) to develop and publish a price for CO_2 based on either a nationally recognised carbon dioxide pricing mechanism, or the cost of reducing off-setting CO_2 across the LPAs' area. In London 15 out of 22 LPAs that apply offsetting have relied upon the price for carbon referenced in the SPG (i.e. £60 x 30 years = £1,800 per tonne of CO_2 offset). The remaining seven LPAs applying offset have adopted varying prices (15).

The carbon emission factors of 0.184 $kgCO_2/kWh$ for gas and 0.446 $kgCO_2/kWh$ for electricity were used to estimate and compare the carbon-offsetting cost variance of building to GLA compliance compared to the Passivhaus standard. The figures are suggested by Department for Business, Energy and Industrial strategy (16).

Table 5 below compares the carbon offsetting tax required to be paid by the developer for both schemes. It should be noted that the building meets 35% reduction when built to the GLA standard and the remaining carbon tax applied to the residential area only. Therefore, calculations in this section is based on the carbon emissions from energy consumptions in the residential areas.

Scheme	**Total annual CO_2 emissions (Tonnes)**	**Carbon Off-setting Cost (£)**	**Carbon Off-setting Cost (£/m^2)**
PH Standard	314	£565,957	£21
GLA Compliance (35% below Part L)	344	£619,746	£23
Savings from building to PH Standard	30	£53,227	£2

Table 5: Carbon off-setting tax for the regulated energy - Comparison between the GLA Compliant Building and a Passivhaus Compliant Building

As can be concluded from Table 5 above, it is projected that incorporating Passivhaus standards, whilst achieving the GLA carbon reduction target, will result in approximately £53K savings in the carbon tax.

4.4. Maintenance Costs

Manufacturers' data, New Rules of Measurements 3 (NRM3) published by the Royal Institution of Chartered Surveyors (RICS) – which deals with preparation of maintenance and replacement costs – as well as CIBSE Guide M – which provides detailed maintenance requirements along with the frequency of the required statutory and operational inspections– have been used for estimating the maintenance costs (17) (18).

For the majority of the M&E services installations, a similar amount of inspection and maintenance regimes will be required for both scheme design options.
As the development included both residential and commercial areas a site wide regulated carbon dioxide emissions and savings have to be submitted for planning. In order to meet the GLA Compliant building scheme, the design required a Solar PV panel installation to achieve the necessary carbon reduction target site wide whilst the Passivhaus scheme would not require Solar PVs to be installed. This additional installation against the GLA scheme would require regular maintenance. The Figure below provides a cost for keeping up with the regular maintenance over the 30-year period for both options.

As can be concluded from Table 6, it is projected that incorporating Passivhaus standards, whilst achieving the GLA carbon reduction target will result in an approximate NPV of £15K savings over 30 years of operating the building. The discount rate of 3.5% has been applied to the estimations.

<table>
<tr><th>Element</th><th colspan="2">Maintenance Life Cycle Costs Savings Over 30 years from Building to Passivhaus Compliance</th></tr>
<tr><td>Changing PV inverters</td><td colspan="2">£17,100</td></tr>
<tr><td>PV Inspection</td><td colspan="2">£9,300</td></tr>
<tr><td colspan="3">Total Maintenance Cost Savings from Building to Passivhaus Compliance over 30 years of running the building</td></tr>
<tr><td>Annual Saving</td><td>Life Cycle Cost Savings Over 30 years</td><td>NPV of Total Savings</td></tr>
<tr><td>£300</td><td>£26,400</td><td>£14,754</td></tr>
</table>

Table 6: Analysis of Maintenance Cost Implications for M&E Installations - Comparison between the GLA Compliant Building and a Passivhaus Compliant Building

4.5. Replacement Costs

For economic evaluation over the life cycle of a building, incorporating the building components' life expectancy is necessary. Due attention to this factor is even more crucial for building services as M&E services have a much shorter life expectancy when compared to other building components. BCIS has carried out a survey based on the experience of building surveyors. Surveyors were asked for the typical range of life expectancies for the components, and the findings of the survey were published in *The Life Expectancy of Building Components*, which is available in the *Component Life module of the BCIS Building Running Costs Online (BRCOL)* (14).

Replacement costs are estimated using the NPV of the original capital cost estimate, which is an industry standard approach. All Life Cycle replacement cost estimates and profiles are based upon an assessment of the expected service life of each asset/component and the likely replacement cost at the end of that service life.

Service life expectancies are estimated using BCM's databases, published data such as CIBSE, BCIS and manufacturers product and warranty data.
Figure 4 and Table 7 compare the Life Cycle replacement costs and savings for GLA and a Passivhaus Scheme.

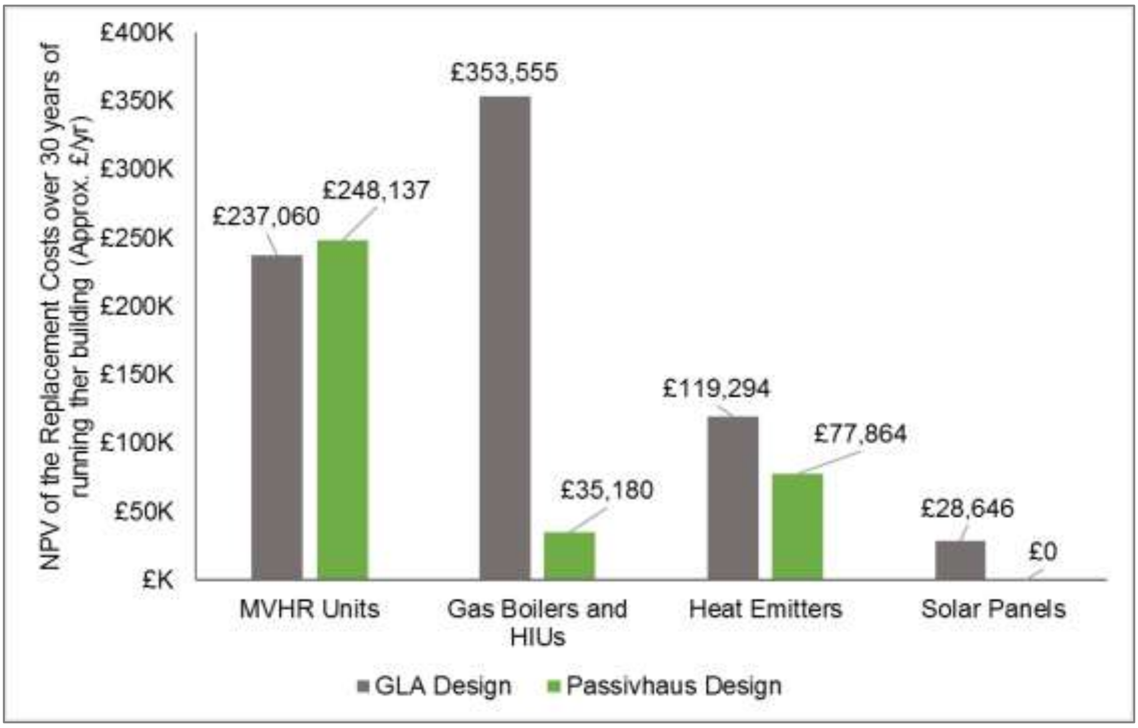

Figure 4 - Life Cycle Replacement Costs and Savings for GLA and a Passivhaus Scheme

Element	Life Span	Baseline (GLA Compliant) – Replacement Life Cycle Costs	Passivhaus – Replacement Life Cycle Costs	Replacement Life Cycle *Cost Savings for Passivhaus Scheme*
MVHR Units	15	£497,414	£520,656	-£23,242
Gas Boilers and HIUs	20	£703,500	£70,000	£633,500
Heat Emitters	20	£237,371	£154,934	£82,437
Solar Panels	20	£57,000	PV is NOT required	£57,000
Total Replacement Costs Saving from Building to Passivhaus Compliance				
Life Cycle Cost Savings over 30 years		**NPV of Total Savings**		
£749,695		£377,375		

Table 7: Life Cycle Replacement Costs and Savings for M&E Installations - Comparison between the GLA Compliant Building and a Passivhaus Compliant Building

It is projected that incorporating Passivhaus standards, whilst achieving the GLA carbon reduction target, will result in an approximate discounted saving of £377K over 30 years of running the building on replacement costs. The discount rate of 3.5% has been applied for the NPV estimations.

5.0 Summary and Total Life Cycle Cost savings

An elemental Life Cycle Cost (LCC) analysis has been undertaken for the proposed residential development in London based on the Stage 2 proposals for the following scheme design options:

- GLA Compliant Design
- Passivhaus plus GLA Compliant Design

The elemental Life Cycle Cost analysis has mainly focused on the specific elements that differentiate the two scheme design standards to report on the net savings/ additional costs over a 30-year period. The below categories under the LCC have been assessed within this paper for each of the above design standards.

- Construction Costs
- Utility Costs (Space Heating)
- Maintenance Costs
- Replacement Costs

From the analysis undertaken of the elemental Life Cycle Cost (LCC), the cost savings of developing the scheme to Passivhaus standard over 30-year period are summarised in Figure 5 and Table 8. Overall, building to Passivhaus standards with an off-site construction method will reduce the Life Cycle Costs by approximately £1.5M (£55/m^2). This equates to the approximately 2% of the total project costs.

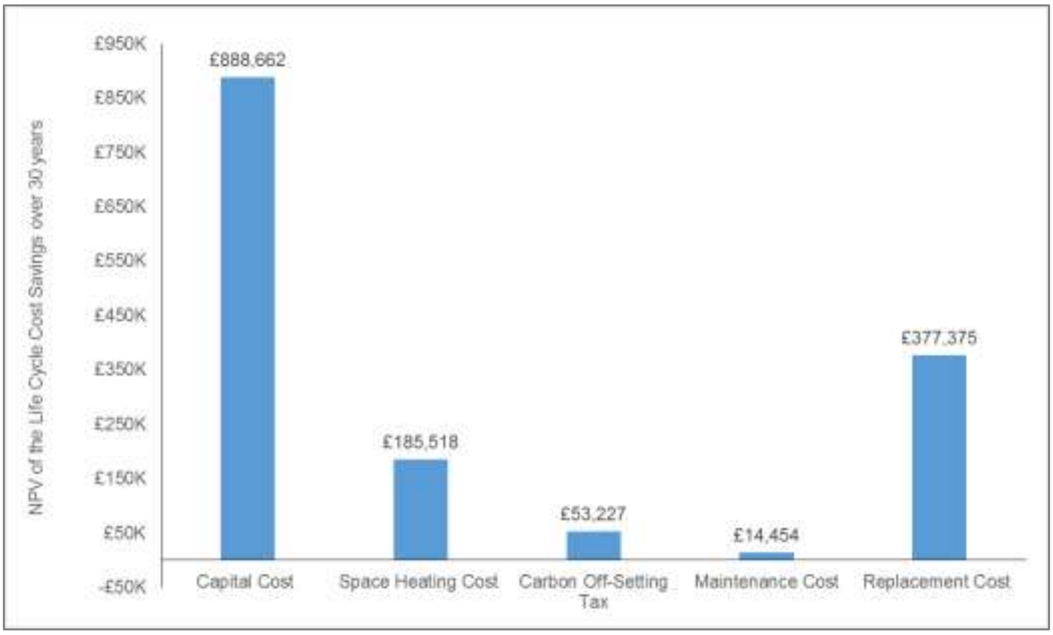

Figure 5 - Summary of Life Cycle Cost Saving

As can be seen from Figure 5, both the developer and future occupiers will benefit from building to Passivhaus standards during the building's life cycle.

It is projected that:-

- The developer will make an approximate saving of £889K (£32/m^2) cost saving from building to Passivhaus standards at the construction stage.

- The Passivhaus scheme will eliminate required regular maintenance and replacement costs of £15K for solar PV panels. Installing a renewable source of energy is necessary to achieve the GLA Compliant carbon reduction target.

- Installing triple glazed windows will decrease heating demand, reduce the capital cost of heat source and results in a significant reduction of £377K (£14/m^2) in replacement and maintenance costs.

- By a combination of energy efficient fabric and building services, for a Passivhaus scheme the entire development achieves an overall £185K (£7/m^2) reduction in space heating bills. In addition, 53K (£2/m^2) less carbon-offsetting tax will apply to the development.

Cost Savings Breakdown for a Passivhaus Scheme		
Element	**Life Cycle Cost Savings Over 30 years**	**Percentage of the Net Construction Value**
Construction Costs	-£888,662	1.1%
Maintenance Costs	£26,400	0.03%
Replacement Costs	£749,695	1%
Space Heating Costs	£322,331	0.4%
Carbon-Offsetting Tax	£53,227	0.07%
Summary of Total Cost Savings for a Passivhaus Scheme		
Total Life Cycle Cost Savings over 30 years	£2,040,315	2.6%
Net Present Value of Total Savings	£1,519,236	1.9%

Table 8 - Cost variance summary of a GLA Compliant Design compared to a Passivhaus Scheme

References

(1) HM Treasury and the Department for Business, Innovation & Skills (BIS). Fixing the foundations: Creating a more prosperous nation. s.l.: HM Treasury, July 2015.
(2) Greater London Authority. Housing Supplementary Planning Guidance (SPG). London: Greater London Authority, March 2016.
(3) Hines, Jonathan. Compare and contrast: Passivhaus and the UK building standards. Architecture Today. Architype, 24.10.2010. [Cited: 01.12.2016] http://www.architecturetoday.co.uk/?p=12101.
(4) Price, Sarah and Brown, Helen. Technical Insight, Whole Life costs of a Passivhaus. Encraft. [Online] 2014. [Cited: 01.10.2016] http://www.encraft.co.uk/wp-content/uploads/2014/02/Technical-Insight-February-2014-Whole-life-Costs-of-a-Passivhaus.pdf.
(5) Passivhaus Trust. Passivhaus Capital Cost Research Project. [Online] January 2015. [Cited: 01.12.2016] http://www.passivhaustrust.org.uk/UserFiles/File/Technical%20Papers/150128%20PH%20Capital%20Costs.pdf.
(6) Blankney, Rob. The Business Case for "Passive House". Local Impact Design. [Online] 04.2016. [Cited: 01.12.2016] http://www.neufenster.com/uploads/3/7/2/0/3720911/the-business-case-for-passive-house.pdf.
(7) Passivhaus Trust. What is Passivhaus. Passivhaus Trust. [Online] [Cited: 01.12 2016] http://www.passivhaustrust.org.uk/what_is_passivhaus.php.
(8) The Passivhaus Standard. Passivhaus. [Online] [Cited: 01.12.2016] http://www.passivhaus.org.uk/standard.jsp?id=122.
(9) HM, Government. Construction 2025. GOV.UK. [Online] July 2013. [Cited: 24 01 2017.] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf.
(10) BSI. Guide for life cycle costing of maintenance during the in use phases of buildings. s.l.: BSI Standards Limited 2013, 2013.
(11) Burton, Roger. E-mail message to the author. 10.08.2016.
(12) Ellingham and Fawcett. The option to refurbish. In new generation of whole life costing: property and construction decision making under uncertainty. London: Talor and Francis, 2006, pp. 140-141.
(13) Mohammadpourkarbasi, Haniyeh. The eco-refurbishment of a 19th century terraced house: energy, carbon and cost performance for current and future UK climates. Liverpool: University of Liverpool, 2015.
(14) RICS. BCIS Building Running Costs Online. Online tool: RICS, 2015.
(15) Hawkes, Jane Richardson. Review of Carbon Offsetting Approaches in London. London: The National Energy Foundation, 2016.
(16) Hill, Nikolas, Watson, Rebekah and James, Keith . 2016 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors. Department for Business, Energy & Industrial Strategy. London: Department for Business, Energy & Industrial Strategy, 2016.
(17). RICS. RICS new rules of measurement. 1. London: Royal Institute of Charted Surveyors (RICS), 2014.
(18) CIBSE. CIBSE Guide M. London: The Chartered Institution of Building (CIBSE), 2008.

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