OPDC
OLD OAK AND
PARK ROYAL
DEVELOPMENT
CORPORATION

Energy, Overheating and Daylight in Tall Buildings Study

LOCAL PLAN SUPPORTING STUDY

2018

MAYOR OF LONDON

16. Energy, Overheating and Daylight in Tall Buildings Study

Document Title	Energy, Overheating and Daylight in Tall Buildings Study
Lead Author	Buro Happold
Purpose of the Study	• To understand the viability and technical feasibility of meeting and surpassing the draft new London Plan aspirational targets for passive energy performance in tall developments and high density areas. • • To understand the trade-offs between meeting passive carbon targets, good daylight and overheating standards in tall buildings.
Key outputs	• The document demonstrates that it is feasible and viable to meet the draft new London Plan passive building standards for most types of development. • The document provides guidance on the approach developers should take to optimise daylight, overheating and carbon performance in tall buildings.
Key recommendations	• Developers should comply with draft new London Plan energy policies, prioritising energy efficiency first by aiming to achieve 10% carbon reduction over Part L of the building regulation for residential and 15% for non-residential through energy efficiency. • Developers of non-residential development should model operational energy performance at the design stage to identify and address potential gaps in performance. • Developers should ensure that they model overheating risk using the most up to date modelling techniques set out in the draft new London Plan for residential and non-residential development. In non-residential development developers should demonstrate how the GLA cooling hierarchy has been used where cooling is provided. • Development should achieve an average daylight factor of 1.5 or more in all living spaces in residential development and demonstrate how the design optimises daylight in non-residential development. • Developers should demonstrate how proposed designs balance consideration of carbon, daylight and overheating.
Key changes made since Reg 19 (1)	New Study
Relations to other studies	Outputs cross-relate to the Environmental Standards Study and Environmental Modelling Framework Study
Relevant Local Plan Policies and Chapters	• Design Policy D6 (amenity) • Environment and Utility Policies EU4 (air quality), EU9 (Minimising carbon emissions and overheating) and EU10 (Energy systems)

Energy, daylight and overheating study in tall buildings

Analysis Report

0041413

22 May 2018

Revision 04

Revision	Description	Issued by	Date	Checked
00	First draft for review by OPDC	GE, MJ and RB	29/03/18	JG
01	Second draft for review by OPDC	JG	20/04/18	DP
02	Draft final report – with added appendices and analysis findings	JG	04/05/18	DP
03	Final review	JG	16/05/18	DP
04	Final Copy	JG	22/05/18	DP

author	**Jon Gregg**
date	**22/05/18**
approved	**Duncan Price**
signature	
date	**22/05/18**

C:\Users\dprice1\Desktop\180521 JG 0041413 Energy, daylight and overheating study in tall buildings_Analysis report_Rev 04_dp.docx

This report has been prepared for the sole benefit, use and information of Old Oak Common and Park Royal Development Corporation for the purposes set out in the report or instructions commissioning it. The liability of Buro Happold Limited in respect of the information contained in the report will not extend to any third party.

The information contained in this report has been produced as a strategic high-level report, based on the evidence provided by OPDC but does not constitute an exhaustive list of recommendations applicable to policy development and design guidance approaches covered within its scope. Buro Happold has, exercising reasonable skill and care, provided general principles/guidance as part of this report. However, this should not be interpreted as a detailed set of requirements for any buildings covered within the scope of this report. Each individual building covered within the scope of this report will require a separate study/evaluation.

Contents

1 Executive summary 9

2 Introduction 13

3 Policy context 14

4 Challenges OPDC faces in meeting the Draft New London Plan policies 16

5 Approach adopted to test the technical feasibility and cost implications 17

6 Results 19

7 Conclusions 30

8 Further energy considerations 31

9 Policy and guidance recommendations 32

10 SPD Checklist 33

11 Appendix A - Study Process 34

12 Appendix B – Costing approach 40

13 Appendix C - Analysis findings 42

14 Appendix D - Meeting carbon reduction targets with Future Carbon factors 64

15 Appendix E - What is the potential performance gap and how to minimise it 69

16 Appendix F - Impact and consideration of demand management technologies 72

17 Appendix G - Social assessment 74

18 Appendix H - Modelling variables 76

19 Appendix I – Application of Passivhaus certification in Tall buildings 77

20 Appendix J - Industry engagement throughout study 78

21 Appendix K - Costing variables 79

22 Appendix L - Specifications to balance all factors by orientation and unit type 81

Glossary

Term	Definition
£/tCO_2/unit	The capital cost of reducing one tonnes carbon emissions reduction on a dwelling basis.
2020 or 2050 DSY future weather files	2020 or 2050 Design Summer Year weather files, as outlined in the CIBSE TM49 document, projected to account for future climate change for a time frame centred around the decade notation (i.e. 2020 files account for 2010-2040, and 2050 from 2040-2070). These weather files account for more extreme peak temperatures as well as high frequency of occurrence (reduced return periods).
4th generation DH	A heat network that can provide buildings with a Low-energy space heating, cooling and hot water systems, which utilises waste heat recycling and integration of renewable heat with low flow and return temperatures (70 degrees flow to 40 degrees return).
ADF	Average Daylight Factor measured in (%)
ASHP	Air Source Heat Pump is a heating or cooling generation unit. It utilised the ambient air temperature to pre-heat gas, which is then compressed to increase the temperature. This heat can then be used for space heating or hot water. The heat pump can work in reserves and moves unwanted internal heat to the ambient air, acting as an air conditioning system.
Be clean/ 'Clean' measures	Carbon savings from communal heating systems powered by local energy resources (such as secondary heat). This includes CHP, Heat pumps and other communal heating systems.
Be green/ 'Green' measures	Carbon savings from bolt on renewables. This can include but not limited to Solar PV, Solar Thermal, Biomass heating and wind turbines.
Be lean/ 'Lean' measures	Carbon savings from energy efficiency and demand reduction. This includes both passive and active measures within a dwelling/building however excludes communal heating systems.
BEIS	The Department for Business, Energy & Industrial Strategy (formally DECC)
BER	Building CO_2 Emission Rate is a measure of the CO_2 emissions produced by a non-residential space on an m^2 over an annual basis from a Part L 2A complaint calculation. This is created based upon the design geometry along with input system parameters as per the as designed performance.
BMS	Building Management Systems that provides centralised control of building services systems.
BMUs	Building Management Units located on the roofs of tall buildings and used for access, maintenance and window cleaning
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method is a voluntary certification system for non-domestic buildings in UK covering a wide range of environmental and sustainability categories.
Carbon offsetting	Carbon Offsetting is a mechanism for applicants to commitment to ensure the shortfall of carbon emissions emitted from site is met through off-site means. This is facilitated through a fund (controlled and operated by the London Borough) paid into by the applicant or by directly offsetting with measures identified by the applicant.
CHP	Combined Heat and Power is an energy generation unit, producing useful heat and electricity. Normally a gas engine is used.
CIBSE AM10	CIBSE Application Manual 10 Natural Ventilation in Non-Domestic Buildings
CIBSE Guide A: thermal comfort criteria	CIBSE Guide A: Environmental Design Table 1.5 Recommended comfort criteria for specific applications, outlines winter and summer operative temperature ranges to be met for different building and space types if air-conditioned is provided.
CIBSE TM49	Chartered Institution of Building Services Engineers Technical Memorandum 49 - Design Summer Years for London, May 2014 outlines the background to the baseline DSY 1,2 and 3 weather files as well as the future climate predictions.
CIBSE TM52	Chartered Institution of Building Services Engineers Technical Memorandum 52 - The Limits of Thermal Comfort: Avoiding Overheating in European Buildings outlines thermal comfort judgement criteria for assessment in both residential and non-residential buildings.
CIBSE TM54	Chartered Institution of Building Services Engineers Technical Memorandum 54 - Evaluating Operational Energy Performance of Buildings at the Design Stage
CIBSE TM59	Chartered Institution of Building Services Engineers Technical Memorandum 59 - Design methodology for the assessment of overheating risk in homes provides guidance on how to apply the TM52 criteria and TM49 weather files to residential dwellings.
CO_2 emissions or Carbon	Carbon Dioxide Emissions measured in kilograms (kg)
DCLG	Department for Communities and Local Government
DECC	Department of Energy and Climate Change (Now known as BEIS)
DECs	Display Energy Certificates show in-use energy data from the previous years. They show gas, electricity and other meter consumption and provide rating (A to G) based on energy consumption.
DER	Dwelling CO_2 Emission Rate is a measure of the CO_2 emissions produced by a dwelling on an m^2 over an annual basis from a Part L 1A complaint calculation. This is created based upon the design geometry along with input system parameters as per the as designed performance.
DHN / DH	District Heat Network or District Heating is the application of transferring hot water through distribution pipework from a centralised heat generation plant, otherwise called an energy centre. Other names include Energy Networks, Heat network or District Energy.
DHW	Domestic Hot Water used for baths, showers and taps.
DLF	Distribution Loss Factor is used within Part L calculations to increase the heat energy delivered of a communal heating system to account for system losses.
DSM or DSR	Demand Side Management or Demand Side Response is where levels of energy demand are changed (increased, reduced or shifted) at a particular moment in time in response to an external signal (such as a change in price, or a message).
DSY 1	Design Summer Year 1 is a near-extreme weather files of April–September average temperature (middle of the upper quartile) with a return period of 9 years. Weather data from London Heathrow Airport (LHR) from the year 1989 representing a moderately warm summer. CIBSE TM59 asks for compliance with this weather file.
DSY 2	Design Summer Year 2 based on the 2003 year, represents a more extreme year with two-week extreme heat wave with a return period of 19 years. CIBSE TM59 suggests that design should consider risk of this weather file, however it is not strictly required to show compliance.
DSY 3	Design Summer Year 2 based on the 1979, represents a more extreme year with a more persistently warm summer return period of 27 years. CIBSE TM59 suggests that design should consider risk of this weather file, however it is not strictly required to show compliance.
Dual aspect	Where a dwelling or building has two external walls, which can be either adjacent or opposite.
EPCs	Energy Performance Certificates are required for all buildings when they are constructed, sold or rented out based upon the compliance modelling undertaken for Part L. The certificate provides rating (A to G) based on energy costs.
EVs	Electric Vehicles
FM	Facilities Management
Fully conditioned	A fully conditioned strategy refers to a building with MVHR or other auxiliary systems for ventilation providing fresh air. Fixed mechanical cooling to condition air to required temperatures all year round.
GLA	Greater London Authority
GLA Carbon Baseline	The regulated CO_2 emissions assuming the development Notional building emissions (TER) with heating provided by gas boilers and that any active cooling would be provided by electrically powered equipment.
Glazing ratio (Window/floor) (GF)	A ratio of the glazing area as a % of net internal area of a dwelling or space. This takes into account unit depth and normalises the glazing ratio.
Glazing ratio (Window/Wall) (GR)	A ratio of the glazing area as a % of external net façade area, excludes servicing voids and slab edges. If "glazing ratio" is quoted in the report, Window/Wall is being referenced. If Window/floor is being referenced specific notation will be provided.

g-value	A measure of the total solar gain transmitted through a glass element as a proportion of total solar radiation onto the external face of the glass. A high g-value allows more solar gain in than a low g-value, which can provide benefits in winter but drawbacks in the summer.
HIU	Heat Interface Unit which is situated within a dwelling or non-residential tenant space that provides a hydraulic separation on a communal heating system. From this unit metering and dwelling side control is provided.
HS2	High Speed Rail 2
ICT,	Information Communication Technology
iPHA	International Passive House Association
kg/m^2/year	A unit of BER/DER and TER to dictate the quantity of Carbon emissions either produced tor savings on an internal m^2 basis over a year as calculated by Part L calculations.
kgCO$_2$/kWh	The kilograms of Carbon Dioxide Emissions emitted or saved to produce or save a kilowatt hour of energy.
kWh	A unit of energy to dictate the power and time of consumption. A kilowatt hour is equal to one kilowatt of power being used for one hour of time. This can denote both energy consumption and a demand.
kWh/m^2	Dictates the energy consumption or demand on a normalised per metre squared basis of net internal area.
kWp	The peak electrical power installed of solar photovoltaic panels.
LCC	Life Cycle Costs
LED lighting	Light Emitting Diode lightings
LLDC	London Legacy Development Corporation
lumens/W	Lumens of light produced per circuit watt of electrical power required for a light fitting
LZC	Low/zero carbon energy sources
M&E	Mechanical and Electrical services, including air handling, heating, hot water, lighting and small power.
m^2	Metres squared as an area measurement
m^3/m^2.h	A measure of the air tightness at 50 Pascal pressure. It indicated the volume of air leakage per hour per metre squared of façade.
MEV	Mechanical Extract Ventilation
Mixed mode or assisted ventilation strategy	A mixed mode strategy refers to a building with MVHR or other auxiliary systems for ventilation providing fresh air. Fixed mechanical cooling can be provided but only to mitigate overheating or adverse thermal comfort in summer peaks. In this condition cooling is not included within Part L modelling but will be considered in operational energy modelling.
MVHR	Mechanical Ventilation and Heat Recovery,
MWh	1000 kilowatt hours
Natural ventilation	A natural ventilation strategy refers to a building with no mechanical fixed cooling or auxiliary ventilation systems. Baseline ventilation rates are met by operable windows, passive vents and cross ventilation.
NLA or NIA	Net Lettable Area or Net Internal Area
O&M Manuals	Operation and Maintenance manuals provide guidance and instruction on how to run building systems post construction.
on-site carbon savings	The carbon reductions from Lean, Clan and Green measures combined, before carbon offsetting has been accounted for, beyond the GLA carbon Baseline.
OPDC	Old Oak and Park Royal Development Corporation
Part L	Building Regulation Approved Document Part L: Conservation of fuel and power. Part L 1A is applied for residential dwellings and Part L 2A for non-residential spaces (including communal areas and entrances ways of communal residential blocks)
Passivhaus standard	An energy performance standard that looks to reduce energy demands for residential and non-residential buildings providing low overheating costs. The standard outlines prescribed fabric performance as well as energy demands. The standard applies the use of Passive House Planning Package, which differs from the PART / SAP calculations.
PIR	Polyisocyanurate rigid thermal insulation
PV	Solar photovoltaics panels used to produce electricity from the sun's energy.
QS	Quantity Surveyor
RHI	Renewable Heat Incentive is a UK government scheme to incentivise the use of heat derived from renewable sources. Payments are provided by the government per unit of heat for both non-domestic and domestic uses. The rate or tariff paid is dependent upon the technology and heat source.
SAP	Standard Assessment Procedure is a steady-state calculation methodology for residential energy modelling. Compliant software uses this methodology for Part L calculations to provide Dwelling emissions rates.
Single aspect	Where a dwelling or space has only one external wall
SPD/ SPG	Supplementary Planning Document or Guidance
tCO$_2$	Tonnes of Carbon Dioxide Emissions
TER	Target Emission Rate is the annual emissions produced by a notional dwelling/building on an m^2 over an annual basis from a Part L 1A or 2A complaint calculation. The notional dwelling matches geometry of an actual dwelling/building and uses fixed glazing design and facade/systems performance.
Thermal comfort	That condition of mind which expresses satisfaction with the thermal environment, as defined by BS EN ISO 7730.
UDI	Useful Daylight Illuminance is a measure to maximise the useful lighting between 100 -2,500 lux within a space
U-value	Heat transfer coefficient of a material, the lower the value the better the insulating properties of that material are
VAT	Value Added Tax
VLT	Visual Light Transmittance - A measure of the total visual light transmitted through a glass element as a proportion of total visible light onto the external face of the glass
W/m^{2}K	Is the unit provides for the U-value of material and denotes the heat loss through an element at a given temperature difference.
Zero Carbon	As defined by the GLA, are developments where at least a 35 % reduction in regulated carbon dioxide emissions (beyond Part L 2013) on-site is achieved. The remaining regulated carbon dioxide emissions, to 100%, are to be off-set through a cash in lieu contribution to the relevant borough to be ring fenced to secure delivery of carbon dioxide savings elsewhere.
λ-value	Lambda value measured in W/mK is a measure of the insulating capacity of a material. The lower the value the better the material is at insulating.

1 Executive summary

1.1 Forward

The Draft New London Plan sets ambitious new energy efficiency targets for major development. As a Mayoral Functional Body, that is delivering one of the biggest and most high-profile developments in London, OPDC wants to understand the technical feasibility and cost implications to developers of meeting and exceeding these standards in tall buildings. In addition, it also wants to understand how best to optimise design for energy, daylight and overheating and balance trade-offs.

BuroHappold was commissioned by OPDC to test the technical feasibility and financial implications of meeting the Mayoral targets for passive energy performance in tall buildings that form part of the masterplan for the Old Oak and Park Royal area.

BuroHappold carried out extensive modelling of a typical block that included a 30-storey tower with shoulder developments, a plinth with commercial and retail development (see figure 1-1 below). Parametric modelling was undertaken on this typical block that included a number of apartments on different floors and orientations, different window and balcony layouts etc., covering both residential and non-residential development. In total eighty six thousand scenarios were modelled to understand the challenges faced across different aspects of a block.

The study has concluded that it is can be challenging to meet the new ambitious London Plan targets for energy efficiency, daylight and overheating but through good design and careful modelling, it is possible to go a long way to resolving conflicting requirements without imposing significant cost burden.

In residential development, the proposed target for energy efficiency is generally achievable but will probably need widespread adoption of triple glazing, mechanical ventilation with heat recovery and good levels of air tightness. Careful detailing to minimize thermal bridging and attention to long term management and maintenance will also be required. The extra capital costs beyond typical London Practice are estimated to be between £850-£1500 for a one and two bedroom unit. These are similar to those calculated for the GLA as part of their viability appraisal for the draft London Plan.

To design new development to maximise daylight whilst minimising the risk of overheating will require careful modelling and a range of responses depending on orientation, vertical position within a tall building and shading from surrounding buildings.

A number of elements will need to be optimised including glazing areas, window type, glazing location and solar control such as balcony type/position, and glazing g-value. Other design approaches that can be adopted include careful positioning of openable windows and doors to promote ventilation, careful use of thermal mass and night time cooling.

A nuanced approach will be needed within a building to respond to the different levels of daylight, wind speed, overshadowing, single or dual aspect, depth of apartment or workspace and other conditions which vary depending on orientation of the façade, relationship to other buildings and floor level.

Varying the response to energy, daylight and overheating on a building can increase capital cost. However, it is important as the impact on wellbeing and health of an apartment or workspace that is prone to overheating or doesn't receive sufficient daylight can be significant.

Developers also need to take account of the risk of climate change and ensure conditions within buildings are comfortable under future climate scenarios where overheating is predicted to become a major issue. Overheating strategies will need to minimise energy consumption for cooling in line with the draft London Plan. The analysis has shown that it is challenging for naturally ventilated non-residential spaces to avoid overheating under future climate conditions and efficient cooling systems should therefore be deployed.

For non-residential buildings, the energy efficiency target is achievable for the office and retail units tested and there was found to be no correlation between energy efficiency and capital costs, suggesting that costs can be minimised through good design. However, analysis commissioned by the GLA has shown that energy use in non-residential buildings is highly variable so feasibility will need careful testing on a project-by-project basis.

On both residential and non-residential developments, balancing energy, daylight and overheating will require project specific modelling to inform early stage design choices. In some circumstances, it will be possible to meet all the targets together, however in other circumstances there will need to be a trade-off between daylight and overheating that can also impact on energy use. Evidence should be submitted at planning stage to highlight potential risks and demonstrate how the design has optimised performance for all three performance standards.

1.2 Introduction

As one of the Mayor's functional bodies, Old Oak and Park Royal Development Corporation (OPDC) recognises that high quality development and excellent energy performance must be met, but to what extent? Carbon performance needs to be balanced with other important objectives including health and wellbeing. Developers also need to ensure they are meeting carbon, daylight and overheating standards. The primary aim of this project is to assess whether it is technically feasible to meet the GLA's Draft New London Plan energy efficiency targets in tall buildings and to understand cost implications of doing so. An important secondary aim is to understand how best to optimise carbon, daylight and overheating requirements.

1.3 Policy context

The OPDC as a Mayoral Development Corporation, as a minimum is seeking to comply with the New London Plan requirements within local policy documents. There is also an expectation from the Mayor that functional bodies will set new standards in zero carbon and high quality development where viable. This is outlined in the London Environment Strategy, Draft for Public Consultation, Aug 2017, Chapter 11 GLA group operations – leading by example. It states the following:

"Mayor and the organisations he directly controls and has oversight of should lead by example"

"The GLA group will lead by example in its own operations by tackling environmental challenges and procuring responsibly – delivering, driving and enabling best practice. They can be powerful demonstrators of best practice or new technologies and use their scale to help drive down costs to enable others to follow suit"

"Specific examples within the strategy where the GLA group will be expected to show leadership include but are not limited to: meeting a 60 per cent reduction in GLA group CO2 emissions on 1990 levels by 2025"

To meet this, the GLA has introduced new energy targets including efficiency targets within the Draft New London Plan. These are ambitious and will stretch developers whilst recognising that there will be a learning rate for the industry, reflected in the choice of words within the policy:

Policy S12 Minimising greenhouse gas emissions
B Major development should include a detailed energy strategy to demonstrate how the zero-carbon target will be met within the framework of the energy hierarchy. Developers will be expected to monitor and report on energy performance.

C In meeting the zero-carbon target a minimum on-site reduction of at least 35 per cent beyond Building Regulations[1] *is expected. Residential development should aim to achieve 10 per cent, and non-residential development should aim to achieve 15 per cent through energy efficiency.*

The policy is being introduced in response to anticipated changes to the Standard Assessment Procedure (SAP), which has been adopted by government as the UK methodology for calculating the energy performance of dwellings. It is anticipated that proposed amendments to the latest version of SAP, introduced in late 2018 or 2019, will significantly reduce the benefit of gas CHP. Gas-fired CHP has been the lynchpin of heat networks and low carbon strategies in major mixed-use developments in London. Revised SAP calculations will impact on gas-fired CHP because:

- They change the CO_2 emissions of mains power supply to reflect the decarbonisation of the grid.
- The default distribution loss factors (DLF) associated with communal heating networks have been revised up to reflect evidence from actual performance.

In 2017, the GLA commissioned a series of studies to understand the implications of these changes on developments in London. They concluded that there would be a significant reduction on the reported carbon benefit of CHP and district heating. Therefore, many developments will struggle to meet the 35% on-site carbon reduction target prescribed in the London Plan. The new energy efficiency targets are intended to compensate for this by placing greater importance on delivering passive carbon reductions.

OPDC is in the process of updating its new Local Plan. It wants to understand how feasible it is to achieve the targets set out in the Draft New London Plan and what the cost to developers would be. As a Mayoral body seeking to lead by example, it wants to understand how far it can reasonably go in adopting and pushing beyond these targets.

1.4 Challenges OPDC faces

Dense developments like Old Oak can prove challenging from an environmental design perspective.

Tall buildings and closely-packed development create issues with high energy density, heat loss from heat networks, limited roof space for solar renewables, deep floor plans, single aspects apartments, high solar exposure on south and west facing facades, floor-to-ceiling glazing and poor daylighting in low level and over-shaded areas.

Mixed-use development, especially close to busy roads, rail lines and industrial areas where noise and air pollution can be poor can pose a challenge for natural ventilation in lower exposed parts of a development.

The environmental design of building in dense areas and their context, including the degree of shading on different facades depending on orientation, overshadowing by neighbouring buildings and sources of noise and air pollution for example need to be carefully considered through the design process in order to meet the high environmental standards sought by the Mayor.

1.5 Approach

To address the challenges of meeting and balancing carbon, daylight and overheating, we have tested and modelled different ways in which a typical dense urban block with a tower selected from the masterplan being developed by AECOM for Old Oak North (see Figure 1—1), could achieve the standards set out in the draft London Plan. The selected block includes all the key challenges that are likely to occur in blocks across the masterplan.

All the key parameters likely to have a significant impact on energy, overheating and daylight of tall buildings have been modelled. These include balcony types, glazing ratios, orientation and a range of fabric and building services measures such as U-value, g-value, air-tightness, thermal bridging and ventilation type.

These were used as inputs for a parametric modelling exercise that was carried out to understand the impact different design parameters are likely to have on building performance. 86,000 combinations of measures were modelled. The results were analysed in detail and key insights identified. Conclusions were drawn on the sensitivity of different parameters. This allowed us to identify the key factors that contribute to achievement of good environmental standards in tall buildings.

The outputs from the model are intended to inform policy and highlight typical challenges and potential solutions in achieving the London Plan, as well as Local Plan passive energy, daylight and overheating targets for tall buildings. Each project will need to carry out its own tests and identify the best way to meet these targets.

---

[1] Building Regulations 2013. If these are updated, the policy threshold will be reviewed

Figure 1—1 Example high density development

1.6 Conclusions

Carbon

For the residential and non-residential units tested, it is technically feasible to meet the energy efficiency targets set out in the Draft New London Plan (2017) subject to careful design. However, it should be noted that energy use in non-domestic buildings can be highly variable depending on use, fit out and other variables. Some non-residential buildings therefore may find it more difficult to meet the targets.

Our modelling suggested that achieving a 10% improvement over Part L for residential development as per the London Plan is possible. Going beyond this will be very challenging. Therefore, the requirement should be to meet the London Plan ambition unless trade-offs are necessary for other reasons, such as providing good daylight in shaded locations.

For non-residential development, meeting and going beyond the 15% improvement over Part L through passive measures will be possible on some but not all development. The London Plan target should therefore be required unless developers can show they have tried but can't find a feasible way to meet the target.

For residential developments, the capital cost uplift of meeting the target is comparable to that identified in the GLA evidence base, suggesting no material difference to the viability assessment carried out in support of the Draft New London Plan. However, OPDC will need to test the overall viability of its own Local Plan.

For non-residential office and retail units, the analysis found no direct correlation between capital costs and energy efficiency, suggesting that the targets in these use-types can be met through good design rather than increased expenditure. However, as noted above, the high variability of energy use in non-domestic building makes it difficult to draw general conclusions on the cost implications for all use types.

Daylight

The analysis has shown that for the indicative development type examined, good daylight can be provided to exposed residential and non-residential units.

However, where sky views may be partially limited (e.g. lower down the building where overshadowed or in other locations with close adjacent buildings), daylight levels are much harder to achieve, particularly for non-residential units. In these spaces, there will be a cost uplift to achieve good daylight.

Overheating

Overheating was found to be a significant challenge. In residential development, the problem is particularly acute in south and west facing units and dual aspect units with long hours of solar exposure. A range of measures have been identified to mitigate the risk but these will need to be examined on a case-by-case basis through detailed modelling.

In non-residential development, there is significant risk of overheating in naturally ventilated buildings under future climate conditions. The GLA's cooling hierarchy should be followed to maximise the opportunities for passive cooling before applying mechanical cooling. Overheating will need to be modelled using CIBSE TM52 methodology to understand and where necessary adopt measures to address this risk.

Optimising environmental design

The modelling undertaken through the study has tested in detail the relationship between energy performance, overheating and daylight across a typical high-density block to understand the challenges of meeting all 3 objectives in different parts of the building (aspect, floor level, relationship to other buildings).

Design approaches have been described for optimising performance across the three areas, depending on orientation and location of units that may affect the degree of shading from surrounding buildings and access to daylight.

On south and west-facing elevations where it can be most challenging to balance all three conditions, the design of residential units will need to carefully optimise a range of design measures. These may include triple glazing, mechanical ventilation and heat recovery (MVHR), air tightness, thermal bridging, glazing area, glazing solar control (g-value), position of balconies and decisions about where to locate single and double aspect dwellings. Other measures which have not been explored but should be considered during detailed design include varying floor to ceiling heights to maximise daylight and views in the lower parts of the building, varying thermal mass, use of movable and external shading, and altering the depth of the window relief.

The analysis show that for the building being modelled, almost none of the naturally ventilated non-residential options simultaneously passed the criteria for carbon, daylight and overheating. This suggest that a conscious trade off may be required. Alternative solutions deployed could include mixed mode systems, mechanical ventilation or comfort cooling.

1.7 Policy recommendations

Based on the findings from the modelling, the following minimum requirements are proposed for inclusion within the OPDC Local Plan or Supplementary Planning Documents.

Residential

In order to reduce carbon emissions, development proposals should:

i). Comply with the London Plan energy policies in force at the time
ii). Achieve at least 10% carbon reduction through energy efficiency where possible

In order to deliver good daylight, development proposals should:

iii). Achieve average daylight factor of 1.5% in all habitable rooms where windows of residential units have an unobstructed sky view

In order to minimise overheating risk, development proposals should:

iv). Demonstrate that the design complies with CIBSE TM59, based on 2020 DSY weather files.
v). Demonstrate how the GLA cooling hierarchy has been followed to reduce and mitigate overheating risk

In order to optimise environmental design, applicants should:

vi). Demonstrate through modelling how the proposed designs aim to balance consideration of carbon, daylight and overheating.

Non-residential

In order to reduce carbon emissions, development proposals should:

i). Comply with the London Plan energy policies in force at the time
ii). Achieve at least 15% carbon reduction through energy efficiency where possible
iii). Carry out operational energy performance modelling at design stage, to identify the potential performance gap and look at ways to reduce it.

In order to deliver good daylight, development proposals should:

iv). Show how the design has sought to optimise daylight for different types of building use

In order to minimise overheating risk, development proposals should:

v). Ensure that the design complies with CIBSE TM52 criteria (if naturally ventilated) or CIBSE Guide A criteria (if mechanically cooled), based on 2020 DSY weather files
vi). Demonstrate how the GLA cooling hierarchy has been followed to reduce and mitigate overheating risk

In order to optimise environmental design, applicants should:

vii). Display through modelling how the proposed designs aim to balance consideration of carbon, daylight and overheating

A series of encouraged activities have also been described.

2 Introduction

2.1 Background

Old Oak Common and Park Royal Development Corporation (OPDC) was established as a Mayoral Development Corporation to oversee the largest regeneration project in Europe – a 650 hectare site in West London.

Old Oak and Park Royal is the only place where HS2 meets Crossrail. OPDC is seeking to use this opportunity to create a thriving new area in the city; somewhere people will aspire to live, work and play.

This will be a high density, residential-led, mixed-use development. OPDC's mission is to secure the maximum benefits for London and Londoners, by:

- transforming one of London's most inaccessible areas into a well-connected, world-class transport interchange
- providing new housing and commercial development, surrounded by sustainable and thriving neighbourhoods and valued amenity space
- protecting and improving Wormwood Scrubs.

There is an expectation (established in the Draft London Environment Strategy and reinforced in the new Draft London Plan) that Old Oak will set the highest quality standards for development and energy performance.

This work will be reviewed and tested over time as development comes forward. Developers will be required to monitor and report on actual energy demand and carbon emissions for a period of five years after a building has been occupied.

OPDC recognises that carbon performance needs to be balanced with health and wellbeing outcomes for residents and other users of the development. It understands the importance of considering daylight, overheating and carbon together in the design of new buildings.

It may be challenging to simultaneously deliver these policy ambitions in tall buildings and dense developments and therefore developers may need to make trade-offs between the different objectives when designing buildings.

This study looks at how best to address these challenges.

2.2 Aims

The aims of this project are to:

- Assess whether it is technically feasible to meet the GLA's new energy efficiency targets in tall buildings
- Understand the cost implications of doing so
- Understand how best to balance carbon, daylight and overheating targets.

2.3 Scope

The scope of work included:

- Testing Draft New London Plan energy efficiency policy to see if targets are achievable in the tall buildings planned for Old Oak and Park Royal
- Carrying out energy, overheating and daylight modelling in residential, retail and office accommodation
- Understanding how design can optimise daylight, overheating and carbon objectives
- Identifying potential design responses
- Performing life cycle costing of energy efficiency measures to understand cost impact of setting a range of policy requirements
- Considering impact of energy efficiency targets on OPDC's zero carbon ambitions
- Identifying non-technical challenges to delivering solutions for energy efficiency, daylight and overheating, including market maturity for delivering advanced energy efficiency levels.

2.4 Methodology

The study methodology is summarised below in Figure 2—1. Qualitative and quantitative data sources have been used to generate inputs to a parametric modelling exercise testing over 86,000 permutations and combinations of building measures that can affect carbon, daylight and overheating performance. Looking at the data, we can see what matters most in the design of new buildings to deliver the desired outcomes. Guidance has been produced on how to approach design to optimise and balance energy, daylight and overheating in a range of different situations.

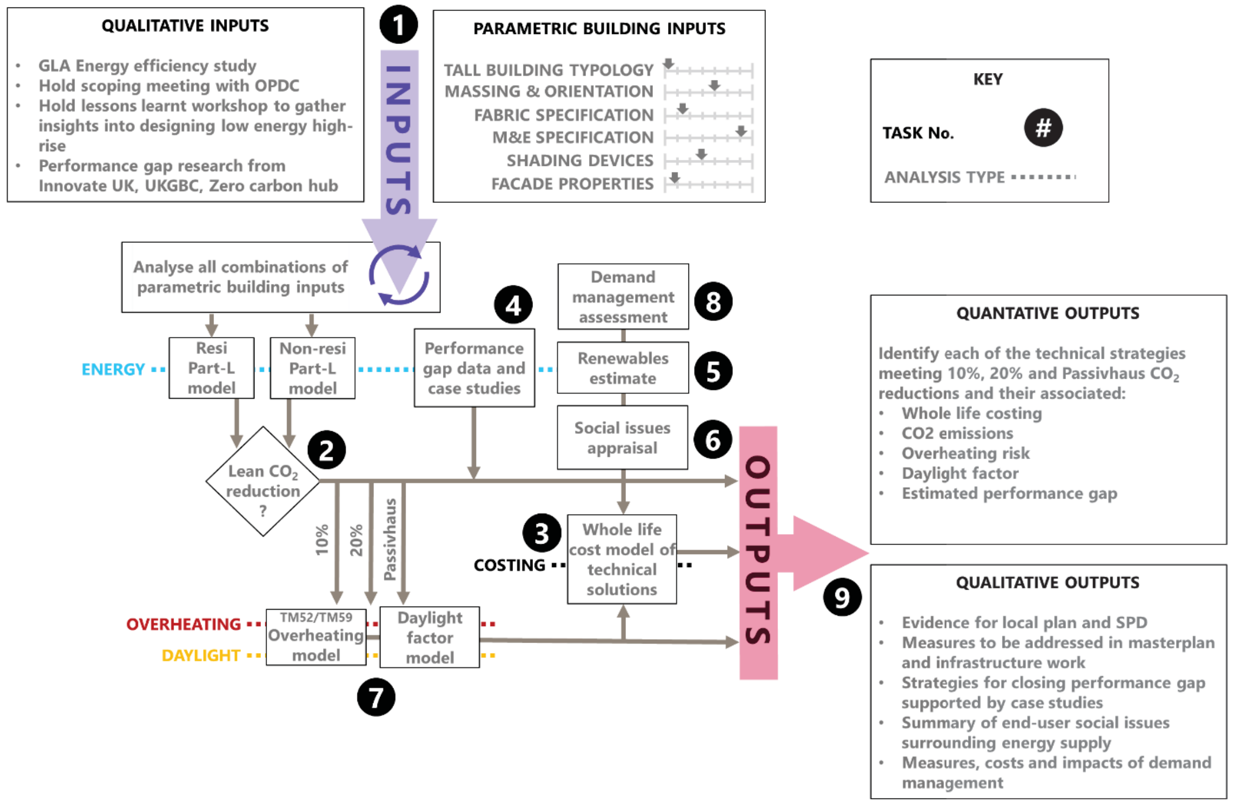


Figure 2—1 Study process diagram

2.5 Outputs of the study

The study outputs are as follows:

- Policy recommendations for tall building energy efficiency, daylighting and overheating to be included in the OPDC Second Revised Draft Local Plan 2018
- Guidance on submission requirements and explanation of the key modelling insights to be included within a Supplementary Planning Document (SPD)
- Evidence base analysis

3 Policy context

3.1 Draft New London Plan

The GLA has introduced new energy efficiency targets within the Draft New London Plan, published for consultation in December 2017. These were introduced, alongside an update on other requirements to provide daylight and minimise risk overheating. These are ambitious in order to set a level of stretch for developers whilst recognising that there will be a learning rate for the industry, reflected in the choice of words within the policy. The policies have been outlined in this section for reference.

Energy and carbon

Policy S12 Minimising greenhouse gas emissions
B Major development should include a detailed energy strategy to demonstrate how the zero-carbon target will be met within the framework of the energy hierarchy and will be expected to monitor and report on energy performance.

C In meeting the zero-carbon target a minimum on-site reduction of at least 35 per cent beyond Building Regulations[2] *is expected. <u>Residential development should aim to achieve 10 per cent, and non-residential development should aim to achieve 15 per cent through energy efficiency.</u>*

Daylighting

Policy D4 Housing quality and standards
E Residential development should maximise the provision of dual aspect dwellings and normally avoid the provision of single aspect dwellings. A single aspect dwelling should only be provided where it is considered a more appropriate design solution to meet the requirements of Policy D1 London's form and characteristics than a dual aspect dwelling and it can be demonstrated that it will have adequate passive ventilation, daylight and privacy, and avoid overheating.

F The design of development should provide sufficient daylight and sunlight to new housing that is appropriate for its context, whilst avoiding overheating, minimising overshadowing and maximising the usability of outside amenity space.

Overheating

Policy S14 Managing heat risk
Major development proposals should demonstrate through an energy strategy how they will reduce the potential for overheating and reliance on air conditioning systems in accordance with the following cooling hierarchy:

1) *minimise internal heat generation through energy efficient design*
2) *reduce the amount of heat entering a building through orientation, shading, albedo, fenestration, insulation and the provision of green roofs and walls*
3) *manage the heat within the building through exposed internal thermal mass and high ceilings*
4) *provide passive ventilation*
5) *provide mechanical ventilation*
6) *provide active cooling systems.*

Draft New London plan policy strategy

Policy S12 is being introduced in response to anticipated changes to the Standard Assessment Procedure (SAP) which has been adopted by Government as the UK methodology for calculating the energy performance of dwellings. The changes are explained below.

The GLA has chosen to use SAP as the method for developers to calculate the expected energy demands and carbon emissions in residential planning applications and therefore these changes will have a significant impact on the approach taken by developers in both residential and mix-use schemes. Policy 5.2 of the GLA's current London Plan (2016) requires a 35% improvement on-site on a fixed Baseline Target Emission Rate (TER) using individual gas boilers of 89.5% efficiency. The remaining CO_2 emissions are to be offset to comply with Zero Carbon Homes policy. In 2017, the GLA commissioned a series of studies to understand the implications of the potential changes to SAP on developments in London. They concluded that there would be a significant reduction on the reported carbon benefit of CHP and district heating and therefore many developments will struggle to meet the 35% on-site carbon reduction target.

In response, GLA examined the potential for introducing a new energy efficiency target to be incorporated within the Draft New London Plan. The aim was to mitigate the loss of benefit from gas CHP and secure additional carbon reductions whilst developers transition away from gas CHP to lower carbon heat sources such as waste heat or heat pumps powered by a decarbonised electricity grid.

The evidence base concluded that it was technically feasible to introduce energy efficiency targets for residential and non-residential development and a series of levels were considered. Commentary was provided on the feasibility of meeting the targets with a range of different building types. It was found that some buildings will find it more straightforward than others to meet the new targets. The cost implications were fed into a viability assessment for the whole Draft New London Plan. This study only considered Office and Retail typologies for Non-residential as they make up the majority of the use in the masterplan. For further detailed energy and carbon modelling of further typologies see AECOM's GLA energy efficiency target – development case studies, Nov 2017 developed for the evidence base for the New London Plan which outlines energy outcomes for masonry houses and apartment blocks, as well as Office, Hotel and School uses.

3.2 Changes to SAP and Building Regulations Part L

The Standard Assessment Procedure (SAP) has been adopted by the government as the UK methodology for calculating the energy performance of dwellings. SAP compliant software produces a Dwelling CO_2 Emission Rate (DER) based on the architecture and systems for a dwelling. This metric is used for the purposes of compliance with building regulations, Approved Document Part L (Part L). The DER is equal to the annual CO_2 emissions per unit floor area for space heating, water heating, ventilation and lighting, less the emissions saved by energy generation technologies, expressed in kg/m^2/year.

Part L 2013 uses the actual dwelling/building and creates a notional dwelling (for residential) and building (for non-residential) to compare the actual space against. This building matches the geometry for the actual space and uses fixed performance efficiencies. The energy and carbon performance of the notional building then provides the Target Emission Rate (TER).

---

[2] Building Regulations 2013. If these are updated, the policy threshold will be reviewed

Part L enforces the SAP results and sets criterion targets. The SAP methodology and Part L are therefore separate and can be updated independently of each other. Part L has historically been updated every few years by Department for Communities and Local Government (DCLG), with versions released in 1995, 2002, 2006, 2010 and 2013. An update was due in 2016, however this was cancelled by DCLG. SAP methodology updates preceded these Part L updates, the first version of which was published in 1995, with further updates in 1998, 2001, 2005, 2009 and 2012. The Department for Business, Energy & Industrial Strategy (BEIS) (formally DECC) proposed amendments to the latest version of SAP (referred to as SAP 2016 Consultation from this point on) which closed on 27th January 2017. The consultation proposed changes to the SAP approach which, if enacted, would form part of the latest Building Regulations Approved Document Part L to respond to the SAP change. For simplicity within this report, this change has been referred to as Part L 2019.

The consultation responses are being reviewed at the time of writing and an official response is expected later in 2018. If changes are adopted it is expected that they may come into force during 2018 or 2019 but no official comment has been provided by BEIS, DCLG or BRE. There are two significant proposed changes that will significantly reduce the benefit of gas CHP and heat networks which have been the lynchpin of low carbon strategies for major mixed-use developments in London. They are:

- fuel prices, CO_2 emissions and primary energy factors have been updated
- the default distribution loss factors (DLF) associated with communal heating networks have been revised

3.3 OPDC Local Plan

OPDC is in the process of updating and consulting on its emerging Local Plan. It wants to understand how feasible it is to achieve the policy targets set out in the Draft New London Plan and what the likely cost to developers would be in the OPDC area. As a Mayoral body seeking to lead by example, it wants to understand how far it can reasonably push developers. The output of the study can be used to inform updated policy and SPD guidance for planners and developers.

4 Challenges OPDC faces in meeting the Draft New London Plan policies

4.1 The need for tall buildings

Old Oak will consist of at least 24,000 new homes and non-residential development. This will comprise of a mix of house types and tenures, including affordable homes that cater for residents at all stages of life. To build and deliver this number of new homes in the 65 hectare site density is a challenge. OPDC is envisaging a very dense development with many mid and high-rise developments. Dense residential development inevitably requires tall towers blocks, of which the Old Oak Common development will have range. These buildings are typically expected to take the form of a block comprising a tall element with a shoulder and/or podium at lower levels. This will mean that many tall buildings will have two varying conditions across their facades: high exposure at the top of the towers and partially-shaded, low solar exposure in the shoulder elements, as these might typically be overshadowed by the tall building itself or adjacent blocks.

4.2 Environmental design challenges in tall buildings

There are a series of environmental design challenges in tall buildings and dense developments as summarised below:

4.2.1 Residential

1. High energy density – tall buildings tend to have a high energy density footprint. Residential units have high heating and hot water demands. To counter this, low carbon communal heating/cooling systems can be designed to decarbonise heat supply.

2. Heat loss from heat networks - poor internal heat pipe design and lagging, and poor performance of heat interface units can be a major issue contributing to overheating and poor system performance. Therefore, limiting flow and return temperatures with 4th generation communal heating or ambient heat networks can significantly reduce this challenge.

3. Limited roof space for solar renewables – due to Building Management Units (BMUs), lift overruns, and low ratio of roof space to height, and a range of competing uses such as green roofs and amenity space, roof space on tall towers is very limited compared to lower rise development.

4. A prevalence of deep floor plans and single aspects – this increases lighting and ventilation demands and impacts on health and wellbeing of occupants, who can be deprived of access to natural light.

5. Orientation - southern and western aspects in tall buildings are sometimes prone to overheating, whilst north-facing units have increased heating demands and may have limited access to good daylight and sunlight.

6. Floor to ceiling glazing – this can further contribute to overheating, especially in summer if windows are directly exposed to sunlight and contribute to poor energy performance. High glazing ratios and high reflecting materials can deliver more daylight to homes which can be beneficial on north and east aspects and in shaded areas.

7. Poor daylighting in low-level over-shaded areas – the bottom of towers or the adjacent shoulder elements of tower blocks can be shaded and have obstructed sky views. In these locations, gaining access to natural daylight in living and working spaces can be challenging, and impact on occupant health and wellbeing. Increasing glazing ratios, increase the visual light transmittance (VLT) of the glass and making units dual aspect can help mitigate poor daylighting. However, these could have an unintended consequence of increasing overheating risk due to increased solar gains.

4.2.2 Non-residential

1. Lighting design – this is a crucial contribution to the energy consumption of non-residential spaces. To drive carbon performance, it is essential that best-practice lighting design is specified during the design stage and implemented at fit-out stage.

2. The cooling and ventilation strategy – this is a key factor in the building's carbon performance, with natural ventilation allowing for greater % carbon savings against Part L baseline and reduced overall carbon emissions. However, natural ventilation is challenging in non-residential spaces, due to high overheating risk. South-facing, west-facing and unshaded locations are the most critical. Noise and pollution are other material factors in choosing an appropriate ventilation strategy.

3. Surroundings - where offices and retail units are partially shaded by surrounding buildings, allowing sufficient daylight in the spaces is critical. The design should therefore aim to maximise daylight; however, the measures aimed at improving daylight also cause increased solar gain exposure which leads to greater overheating risk and cooling loads.

4. Plan depth – achieving the right balance between daylight and overheating risk is particularly challenging in offices, as they are often characterised by deeper floorplates.

5 Approach adopted to test the technical feasibility and cost implications

5.1 Introduction

Having identified the challenges of meeting and balancing carbon, daylight and overheating, we have tested and modelled different ways in which a typical tall building could meet the Draft New London Plan standards.

5.2 Example development block

An example development block has been identified through conversations with AECOM who have developed a potential development typology for the OPDC area. This example development block is depicted in Figure 5—1. A range of different conditions have been identified related to location: tower, tower shoulder, adjacent shoulder, podium commercial. These terminologies may differ between documents.

Figure 5—1 Example section and layout showing block types represented

5.3 Parametric modelling

A series of key parameters were identified that are likely to have a significant impact on energy, overheating and daylight of tall buildings. These include balcony types, glazing ratios, orientation and a range of fabric and building services measures such as U-value, g-value, air-tightness, thermal bridging and ventilation type.

These were inputted into a parametric model to test performance of over 86,000 combinations of measures. The results were analysed in detail as shown in the appendices to this report.

Key insights were derived regarding the most principal factors to control through design. The following section is intended to guide developers and their design teams on key challenges and potential solutions that they should investigate on a project-specific basis.

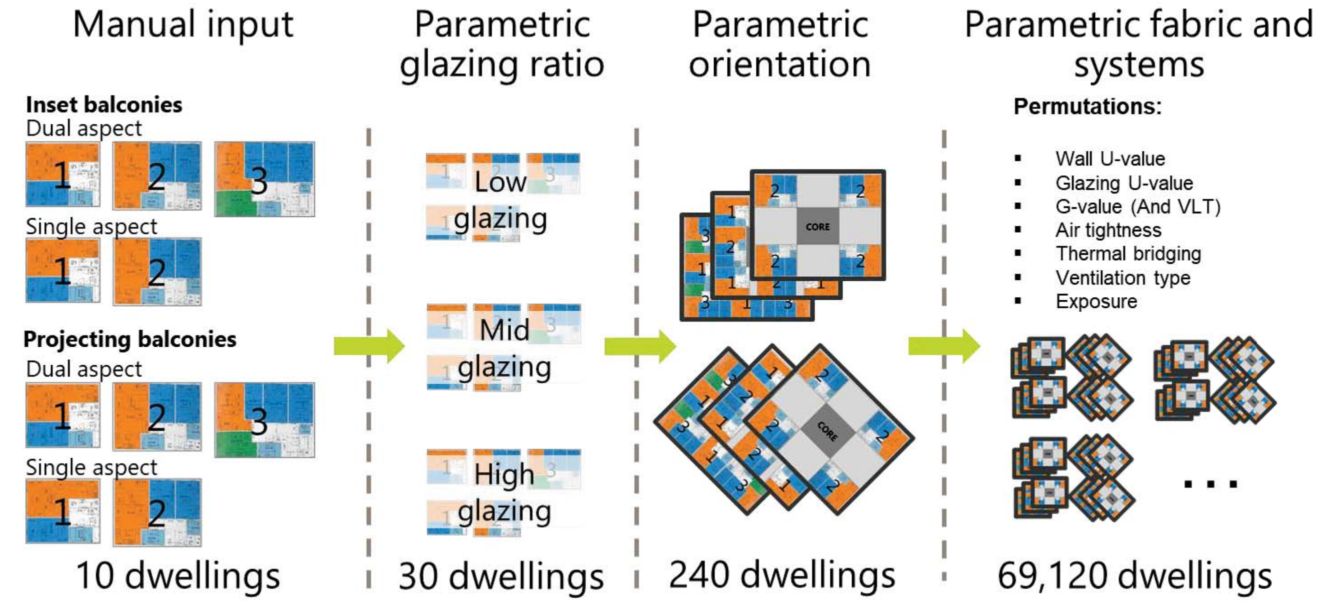


Figure 5—2 Residential energy modelling process

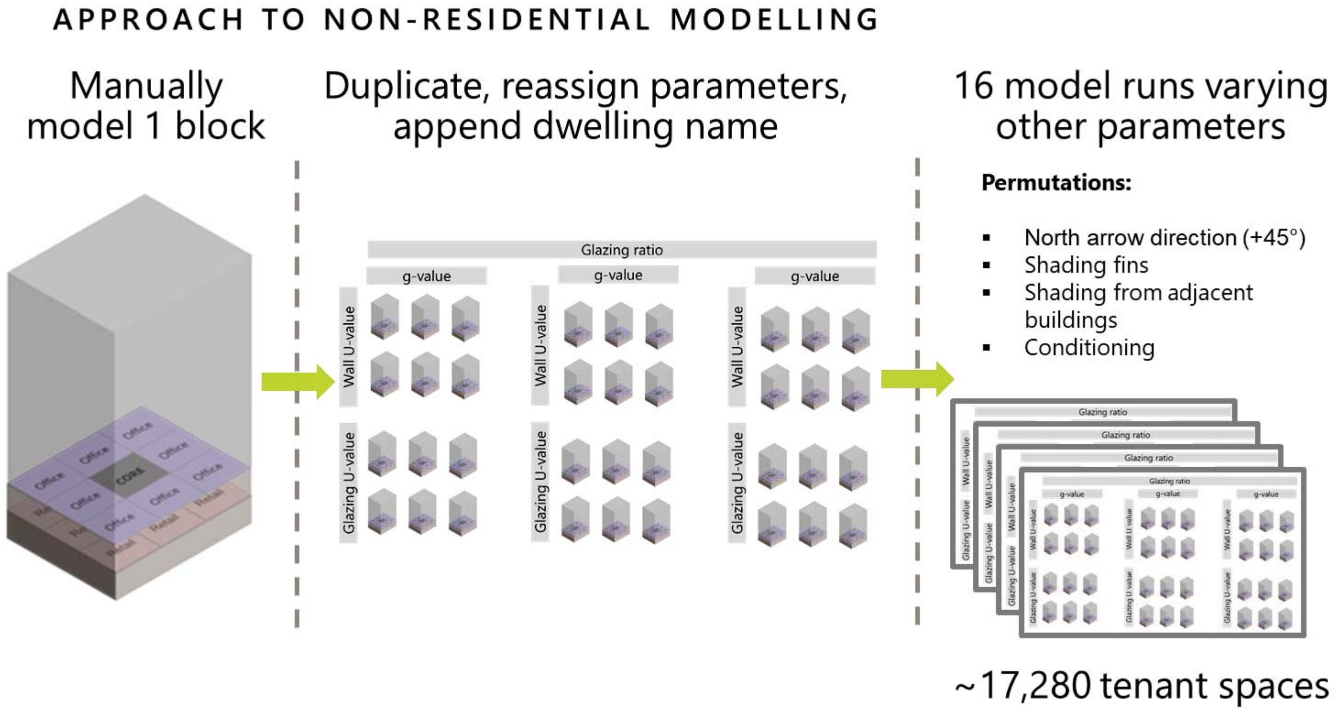


Figure 5—3 Non-residential energy modelling process

5.4 Cost analysis

Specifications of building elements were provided to Currie & Brown for costing. Individual components within each element were itemised and costed, then summed to give the overall cost. This approach was undertaken for each of the parameters tested in the energy modelling, so that both cost variability and cost differences from a 'typical London' baseline could be determined. This is explained further in the results section.

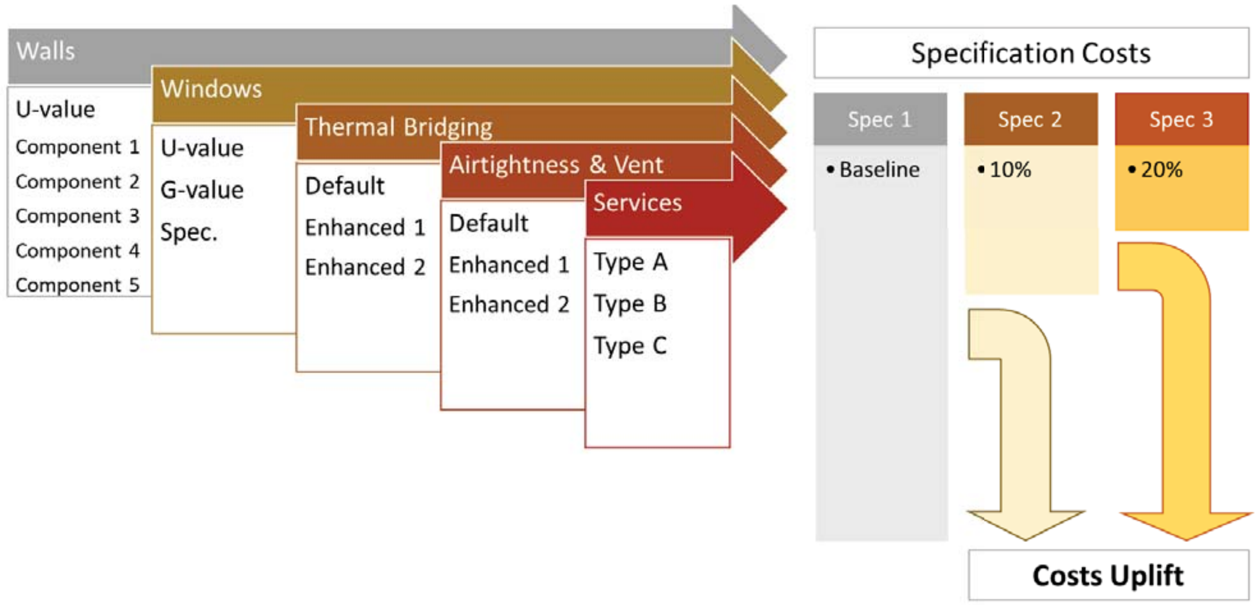


Figure 5—4 Elemental costing and uplift calculation process

5.5 Definition of shaded and exposed locations within the modelling

The analysis takes into consideration several massing options that could occur across the masterplan. One that is considered most significant is whether a unit/space is 'shaded' or 'exposed'. For the purposes of the study, these two conditions are referred to in these terms going forward.

Figure 5—5 outlines the definition of these two conditions along with the implications for daylighting and overheating.

'Shaded' conditions meaning a unit or dwelling has a building directly opposite and adjacent which is higher than the space's location. This could either be across a road, internal courtyard or a tower element, as per Figure 5—1, to the south of a development.

This arrangement partially blocks out the view of the sky, which reduces daylight. It also leads to partial shading from direct sun. However high solar angles from the summer sun, May to September, can penetrate between buildings and can cause overheating, even in 'shaded' locations. In effect, these are partially shaded and the amount of shading depends on the unit position, time of year and time of day.

The report outlines the impact on facade design requirements to meet daylighting in these locations, i.e. increasing glazing ratios, which can have an adverse impact on overheating. The study has examined the impact of solar heat gain to dwellings but not studied sunlight hours that may be required to meet other planning targets.

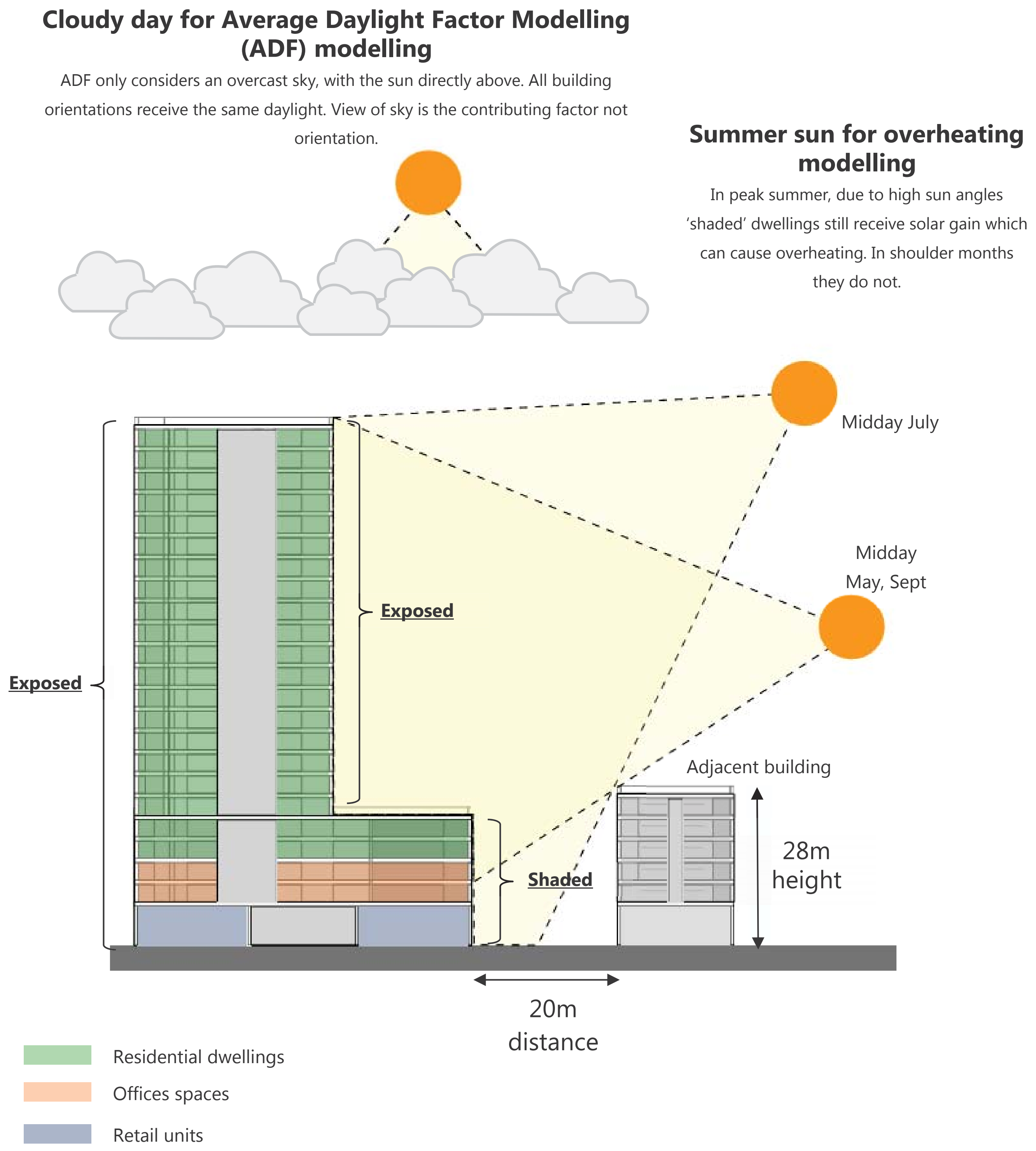


Figure 5—5 Definition of shaded and exposed locations with considerations relevant to daylighting and overheating modelling

6 Results

6.1 Overview

Our findings suggest that there is a range of design strategies that could be adopted in tall buildings to optimise development for environmental performance. We have divided our answers into two broad categories: residential and non-residential. However, we are aware that there are many types of non-residential development, and each type poses its own challenges. With our results necessarily high level, developers will need to commission detailed modelling for their specific projects.

6.2 Residential

6.2.1 Carbon

The analysis shows that it is technically feasible to achieve the GLA's 10% energy efficiency carbon reduction target proposed within the Draft New London Plan.

This could be achieved in a number of ways, typically through a combination of triple glazing, MVHR and an airtightness <3 and calculating thermal bridging rather than using default values.

The Median cost uplift against typical London practice is approximately £1000-1500/unit but this is highly dependent on the amount of glazing and there is substantial variability in overall costs depending on the architectural design. MVHR was found to be the most significant cost item per m^2 floor area.

Following conversations with leading architects, the commercial impact of increased wall thickness on building efficiency was deemed to be low in new build development (compared with a potentially large impact on the fixed area of an existing building) therefore hasn't been included in the calculations in this study.

Achieving greater than 10% energy efficiency is very challenging and there are very few examples of tall buildings that meeting Passivhaus levels in the UK.

6.2.2 Daylight

In exposed locations with good sky views (e.g. top of a tall building), it is possible to achieve good daylight (as measured by an Average Daylight Factor (ADF) >1.5%) with a variety of glazing ratios and g-values.

However, lower down the tower where overshadowing is an issue, the target can be challenging to meet, especially for single aspect units.

Potential design solutions include increasing glazing area, greater visible light transmittance, the use of projecting balconies rather than inset balconies and use of reflective surfaces on the outside of surrounding buildings. Dual aspect units perform best in these locations, not just because there may be more glass but because the daylight is more evenly distributed.

6.2.3 Overheating

Designing for future climate can be challenging and the risk of overheating presents a major risk in new developments over their lifetime. This can be addressed in whole or in part by design solutions to mitigate the risk by passive means, following the GLA's cooling hierarchy.

The response varies greatly depending on orientation; north and north-east facing elevations are at low risk of overheating; east, south-east and north-west elevations are at medium risk of overheating and south, south-west and west elevations are at high risk of overheating.

On low risk elevations there are many options available but in medium risk elevations the glazing ratio should be no greater than 50% of external wall area and ideally nearer 35%. An alternative limit is a glazing area no greater than 25% of the floor area. In risk elevations it can be extremely challenging to pass the overheating criteria, and bespoke project specific solutions will need to be identified. Options could include use of tilt and turn and high level openable windows to increase ventilation rates, use of carefully positioned thermal mass, window positioning with respect to balconies, use of external shutters and other movable shading features.

G-values for glazing will also need to vary depending on risk and whether a space is single or dual aspect. On dual aspect units it is best to focus glazing on one primary facade and limit glazing on the secondary facade to the maximum needed for daylight and ventilation.

In general it is most difficult to prevent overheating in three bedroom apartments where occupancy rates can be high which increases internal heat gain.

6.2.4 Optimising across all three

The analysis shows that there are design solutions that can balance the requirements of energy, overheating and daylight. Generally, energy solutions can be found that don't impact overheating and daylight.

In exposed locations at the top of a tall building, there is an abundance of daylight so the key challenge is designing to minimise overheating.

Lower down a tall building where the sky view is poorer but high sun can still cause overheating at the height of summer, greater effort needs to be placed on optimising daylight and overheating.

On south and west-facing elevations, where it can be most challenging to balance all three considerations, a potential design approach might therefore be:

- Triple glazing
- Mechanical Ventilation with Heat Recovery (MVHR) instead of Mechanical Extract Ventilation (MEV)
- Air tightness <3
- Thermal bridging calculated instead of using default values
- Glazing area <35%
- G value =0.3
- Single aspect one bed units potentially preferred in this context but needs consideration against wider policy objectives
- Introduction of further passive design measures such as thermal mass, external movable shading, optimised window design to maximise ventilation rates.

Further guidance on potential approach is shown in Table 6—2.

6.2.5 Cost implications

Figure 6—1 demonstrates the cost uplift required to increase improvement over TER. The most significant item is MVHR, as opposed to MEV, which is required to achieve greater than 10% improvement over TER. Beyond an improvement over TER of 10-15%, the rate of cost uplift diminishes. It also shows the substantial cost variability (as indicated by the wide 'whiskers' in the 'box and 'whisker graph') reflecting the wide range of potential design options.

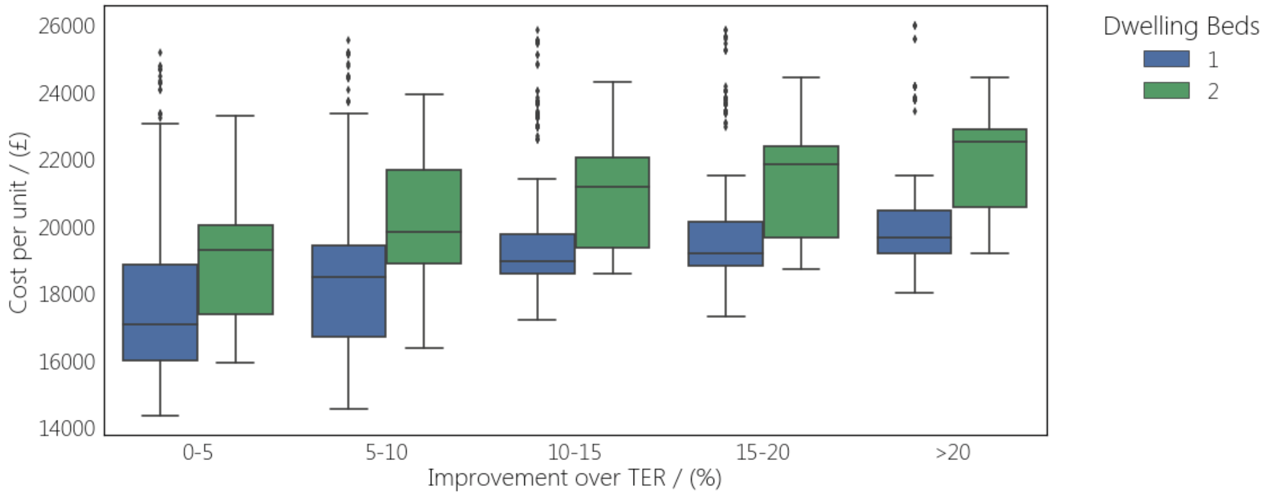


Figure 6—1 Distribution of cost per unit to achieve different bands of improvement over TER by number of beds in dwelling (for dwellings that pass overheating assessment and achieve ADF > 1.5 in living spaces)

The GLA's evidence base for the Draft New London Plan showed that typically London developments are achieving an improvement over TER in the range of 0-4.9%. Therefore, Table 6—1 shows the cost uplift compared with this baseline. OPDC will need to consider this within its own whole-plan viability testing of the emerging Local Plan.

Table 6—1 Median capital cost uplift (from London typical) per unit to achieve different bands of improvement over TER by number of beds in dwelling (for dwellings that pass overheating assessment and achieve ADF > 1.5 in living spaces)

Dwelling beds	Improvement over TER (%)				
	0-4.9%	5-9.9%	10-14.9%	15-19.9%	>20%
1 bed	(Baseline)	£462	£867	£1,250	£1,972
2 bed	(Baseline)	£836	£1,460	£1,673	£2,402

6.4 Residential design considerations

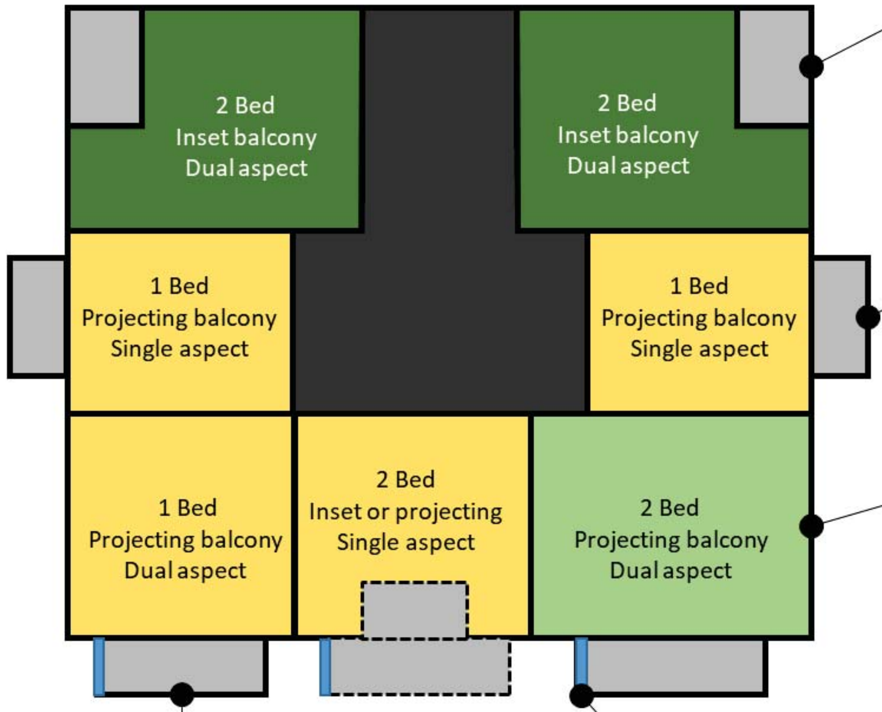
Table 6—2 outlines the design considerations, facade and systems specifications identified through the modelling as potentially required to balance all three environmental drivers in residential developments for shaded and unshaded locations. The corresponding cost impacts are also outlined for the requirements.

The design considerations are also visually represented in Figure 6—2 and Figure 6—3. To understand the fenestration strategies identified from the modelling see Figure 11—4 , which visually shows the corresponding glazing ratios (window/floor).

Table 6—2 Residential design responses to maximise daylighting whilst minimising overheating risk and carbon emissions

	Shaded	Unshaded	Cost impacts
Modelled design responses to meet minimum policy requirements	• Less than 35% glazing ratio (window/floor) to maximise daylight whilst reducing overheating risk	• Less than 25% glazing ratio (win/floor) to maximise daylight whilst reducing overheating risk • MVHR in all cases • Triple glazing or airtightness ≤3 • For default thermal bridging: ○ Airtightness ≤3 for Units facing S, SE, SW, W • For calculated bridging: ○ Airtightness ≤3 for Units facing S • Projecting balconies for units facing S, SW, W • Need to consider wind issues relating to projecting balconies at high level • Projecting balconies for glazing ratio (win/wall) ≥ 0.65 • Glazing ratio (win/wall) ≤ 0.5 for 2 bed units • Single aspect 1-beds (inset balcony) can meet all targets with 50% glazing ratio (win/wall) • Single aspect 1-beds (projecting balcony) can meet all targets with 65% glazing ratio (win/wall). Need to consider wider policies regarding single aspect units. • G-values of 0.3 in locations at risk of overheating • To mitigate overheating whilst maintaining daylight and energy performance, prioritise single aspect 1-bed units with projecting balconies on South and South-East facades	Reduced glazing ratios will reduce overall development costs as glazing is typically more expensive than opaque areas. Typical cost uplift of £1500 per unit for increasing glazing ratio by 15% relative to wall area MVHR will increase costs by £2,800 per unit. Careful siting of MVHR units can help to reduce ducting lengths and costs. Triple glazing will increase development cost with uplift levels dependent on glazed area (£53/m2 of glazing) Air tightness must be tightened to at least 3m^3/m^2/hr before MVHR is considered. Typical cost uplift of reducing airtightness from 5 to 3 m^3/m^2/hr £300 per unit.
Modelled design responses to support encouraged activities			Additional consultancy/managerial cost may be required, e.g. due to additional modelling (estimated in the order of £50-100k for a typical development) Additional capital costs required if delivering advanced energy targets as show in Table 6—1.
Key considerations	• In zones with overheating risk, maximise ventilation by increasing the free openable area of windows • Reduce glazed area in dual aspect units (which typically have fewer daylighting issues) to reduce overheating risk	• In zones with overheating risk, maximise ventilation by increasing the free openable area of windows • Reduce glazed area in dual aspect units (which typically have fewer daylighting issues) to reduce overheating risk	Reduced glazing ratios will reduce overall development costs as glazing is typically more expensive than opaque areas.
Further measures to review	• Consider external shutters/shades to mitigate overheating during times of extreme heat, whilst maintaining daylighting and energy performance	• Consider external shutters/shades to mitigate overheating during times of extreme heat, whilst maintaining daylighting and energy performance	External shutters will increase cost, not costed within this study, however applicants should balance this against the cost of additional glazing

CARDINAL ORIENTATION



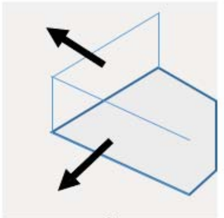
Inset balconies on the north aspect units are required to increase daylighting.

Projecting balcony required for single aspect 1 beds in cardinal orientations. Additional wall and glazing required with an inset balcony causes overheating risks, whilst negatively impacting daylighting.

Projecting balconies on the South are shown to be the most effective at reducing overheating risk. This is because they are effective at reducing high solar gains at midday.

Due to height and exposure, consider adding 'shielding' or high balustrades to allow for projecting balconies to reduce wind exposure without impacting daylight.

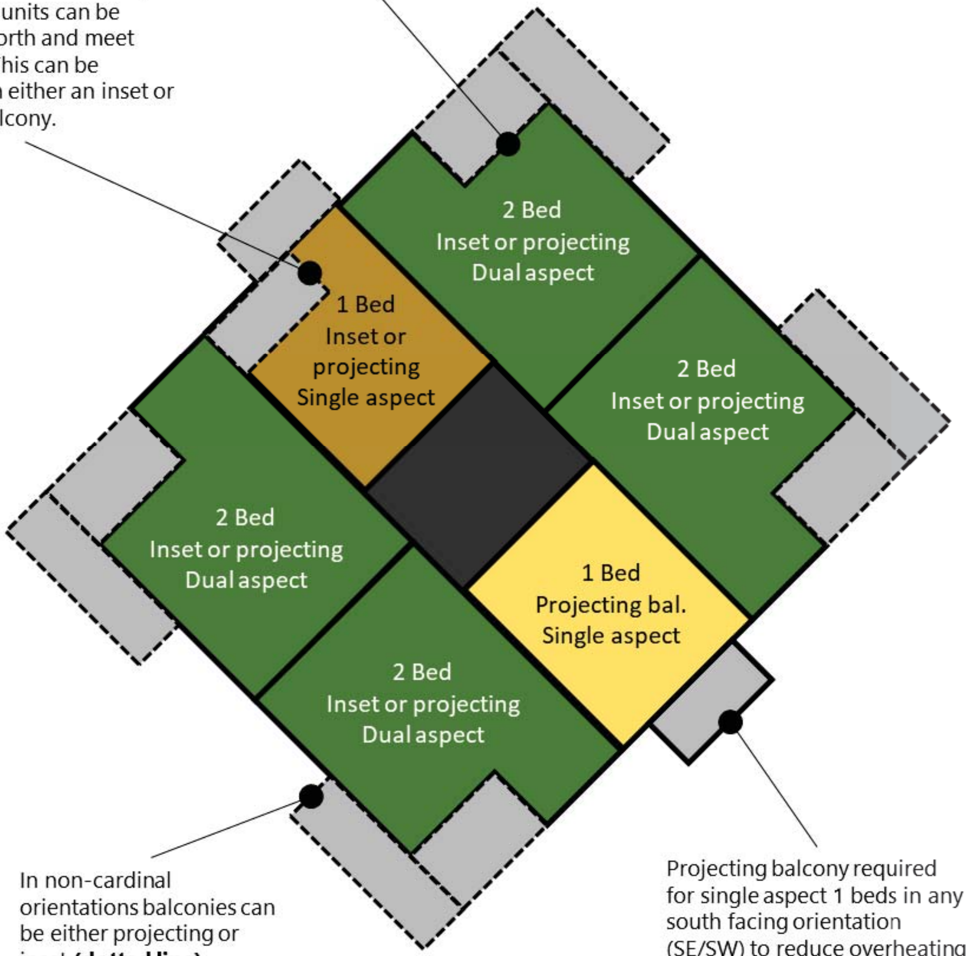
DUAL ASPECT UNITS



Dual aspect, particularly on southern apexes, mean that the facade area as a % to floor area is high. Typically modelling includes equal glazing on both aspects, one of which is unshaded as no balcony is present.

Design should look to minimise glazing on one of the facade orientations and maximise it on the other along with a balcony.

45° ROTATED ORIENTATION



In non-cardinal orientations, single aspect units can be located on North and meet daylighting. This can be achieved with either an inset or projecting balcony.

In non-cardinal orientations balconies can be either projecting or inset **(dotted line).**

Projecting balcony required for single aspect 1 beds in any south facing orientation (SE/SW) to reduce overheating risk.

FACADE AND SYSTEMS SPECIFICATION

With stated glazing ratios it minimise overheating risk, the following specifications will be required to meet 10% carbon reduction:

- MVHR in all units
- Calculated thermal bridging
- <$3m^3/m^2$ air tightness + double glazing

Or

- <$5m^3/m^2$ air tightness + triple glazing

EXTERNAL MOVEABLE SHADING

Moveable shading should be a key design consideration where overheating and daylighting cannot be balanced. i.e. A reduction in glazing ratio to reduce overheating risk that would result in poor daylighting.

This can be applied to balcony or window locations across the facade that allow for occupant control to limit solar gain. These are more effective than internal blinds as they limit solar gains before entering the unit, which is the most significant contributor to overheating.

Figure 6—2 Illustrative floors shows the facade and units conditions across cardinal and 45 degree orientation blocks, within a tall tower element

GLAZING RATIOS BY UNIT SIZE

Glazing ratios as a % of floor area is a more useful metric to understand performance compared to a % of external wall. This accounts for floor plan depth and unit size relative to facade area.

1 Beds: Set glazing area to be 25% of internal floor area, to minimise overheating and provide greatest flexibility in facade specification.

2 Beds: Glazing ratio more stringent due to increased number of people in living. Glazing ratio of 15 - 25% of internal floor area. >25% will cause overheating risk.

GLAZING RATIOS BY SOLAR EXPOSURE

Glazing ratio in shaded location:

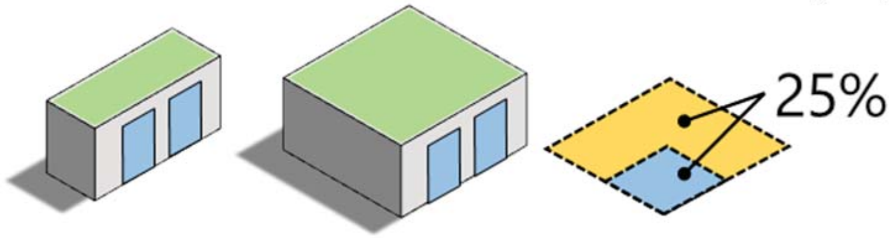
- 30% - 35% (single aspect units)
- 25% - 35% (dual aspect units)

A glazing ratio of above 25% of floor area is required to meet good daylighting. A glazing ratio of lower than 35% of internal floor area is required to reduce overheating risk.

Glazing ratio in exposed locations:

- 20% - 35% (single aspect units)
- 15% - 25% (dual aspect units)

Dual aspect units gain higher solar gains for longer periods of time, therefore glazing ratios should be reduced on these units to reduce overheating in exposed locations.



GLAZING LOCATIONS

Glazing location is a precise and detailed design consideration. Glazing is required across the elevation to maintain good daylight. However placing this in the best location to either maximise or minimise solar gains is required.

Dual aspect units show a higher overheating risk, especially in SW corners, due to increased exposure to solar gains across a long period of the day. This is as the sun moves around to early evening when occupancy increases and internal gains from cooking and equipment are present.

Differing location and facades should have differing fenestration strategies. It is suggested that to reduce overheating risk in an exposed dual aspect unit glazing on the secondary facade should be minimised. Meaning moving glazing to a location under the balcony; whilst maintaining cross ventilation.

However in shaded locations where daylighting is challenging, additional glazing could be added to increase daylight uniformity and ADF.

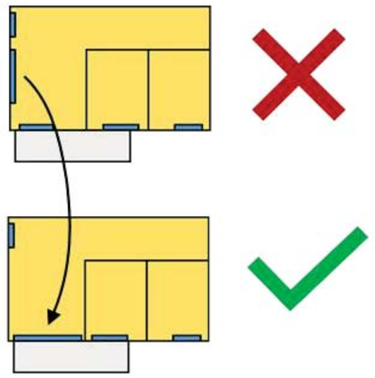


Figure 6—3 Design, specification and facade responses in residential

6.5 Non-residential

6.5.1 Carbon

The analysis shows that for the office and retail units tested it is technically feasible to meet the 15% energy efficiency carbon reduction target set out in the Draft New London Plan.

However, non-residential units can vary significantly in terms of their type of use, internal comfort requirements, and plan depths. Therefore, in other situations and with other use types, the target may be more challenging. The GLA evidence base for the Draft New London Plan indicated that the target is approximately in line with the performance required for BREEAM Outstanding, and therefore represents a stretch target for many developments.

Naturally ventilated offices and retail units tend to perform better than fully conditioned ones. This is mainly because reductions in lighting carbon emissions are more important in naturally ventilated spaces than in conditioned ones. In these situations, shifting from poor lighting (equivalent to notional specifications but without lighting controls) to best practice lighting design (with high efficacy and daylight/occupancy controls) can produce a 50% reduction in CO_2 emissions compared to a notional baseline.

In conditioned spaces, auxiliary and cooling consumption are the main contribution to carbon emissions alongside lighting. For this reason, measures to save carbon also reduce solar gains. Reducing the glazing g-value from 0.5 to 0.3 can produces on average a 3.2% carbon reduction. Other important design factors for reducing cooling demand include reduced glazing areas and high efficiency systems to reduce fan energy.

The analysis has shown that there is no strong correlation between capital costs and carbon reductions. This means that the measures required to improve carbon performance are not dependent on a higher capital investment and could be achieved without significant uplift costs.

6.5.2 Daylight

Where office and retail spaces are not overshadowed by adjacent buildings, it is possible to deliver minimum daylight levels (an average daylight factor of at least 2%) and, often, well daylight conditions (an average daylight factor of at least 5%).

Retail units tend to have higher average daylight factors compared to offices in this analysis as they have been assumed to have a shallower floorplate.

Obstruction from adjacent buildings has a considerable impact on daylight. In the analysis, only 14% of these spaces achieve an average daylight factor of 2% or above, and none of them achieves an average daylight factor of 5%.

Single aspect units are the most at risk of poor daylight, with none of the modelled spaces meeting the 2% daylight factor where overlooked. This suggest that dual aspect units are preferable in locations with a poor sky view.

6.5.3 Overheating

Only 5.7% of naturally ventilated spaces analysed achieved the overheating criteria for future climate conditions (2020-40). Orientation is critical. No south-facing units or dual aspect south and south-west facing units passed the test criteria whilst north and north-east orientations are generally the ones at lowest risk.

Other important design parameters included having sufficient openable window areas and introducing thermal mass, together with night-time cooling. Glazing specification and shading are also of vital importance.

In retail, operable windows could be considered to increase the ventilation rate. The results show that louvres do not provide sufficient ventilation rates to mitigate the risk of overheating, and all retail units with this configuration failed the overheating criteria. Further details of which options passed and failed the test are contained within the Appendices.

6.5.4 Optimising across all three factors

The analysis results show that almost none of the naturally ventilated spaces passed the criteria for all three factors, energy, daylight, and overheating. The only spaces that passed are north-facing, single-aspect units with a g-value of 0.3. Section 13.2 summarises which options passed and failed the criteria.

South-facing units are the most at risk of overheating and should therefore have a resultant g-value (factor of glazing ratio, shading, and glazing g-value) of 0.2 or lower.

This could be achieved in a number of ways, for example a 70% glazing ratio and g-value of 0.3, or with a 50% glazing ratio and g-value of 0.4. Shading elements could further reduce cooling loads and maximise carbon savings.

Best-practice lighting design is key to maximising carbon savings and doesn't have any negative impacts on overheating and daylight.

Measures aimed at increasing solar exposure have a positive effect on daylight, but a negative effect on overheating risk for naturally ventilated spaces or carbon savings for fully-conditioned spaces.

Balancing the three environmental drivers in semi-obstructed spaces is particularly challenging. As daylight is critical in these locations, measures should be taken to maximise the exposure. Retail units should be dual aspect with no/movable shading. In order to pass daylight criteria, offices need dual aspect, 70% glazing ratio and 70% Visual Light Transmittance (VLT). In these conditions, overheating risk was high and natural ventilation wasn't appropriate. Potential solutions include:

- Naturally ventilating the spaces, providing cooling in peak summer conditions only. This is however not feasible in S/SE/SW orientations.
- Fully condition the space and reduce glazing g-value (keeping a VLT of 70%) to 0.4 or lower and/or add movable shading. South-facing spaces should have a g-value of 0.3 or lower.

6.6 Cost implications

As demonstrated by the analysis, it can be challenging for developments in shaded conditions to achieve an average daylight factor of 2%, whilst limiting carbon emissions and overheating risk. It is therefore assumed that typical London developments can achieve an average daylight factor in the range of 1-1.9% and this is the baseline for determining cost uplifts.

In exposed offices, where the analysis hasn't shown any spaces in this range, we've assumed that the cost is equal to achieving ADF in the 2-2.9% range.

Figure 6—4 and Figure 6—5 (for office and retail respectively) confirm the trend observed for daylight and cost. The figures show the cost distribution by daylight factor level for all cases where a 15% carbon reduction is achieved and overheating criteria are met.

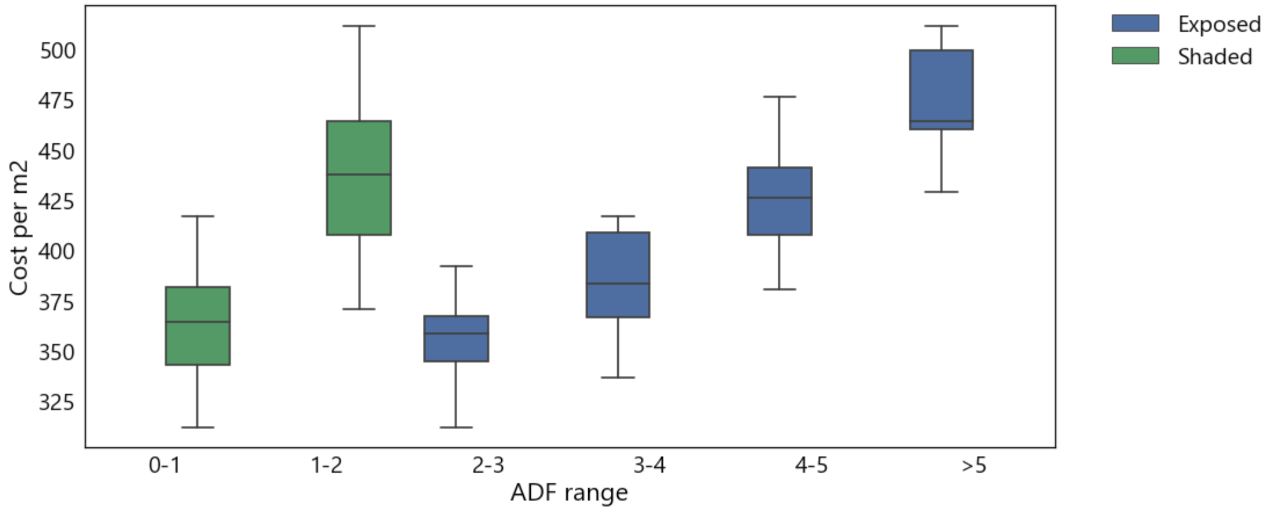


Figure 6—4 Distribution of cost to achieve different Average Daylight Factor ranges in office spaces

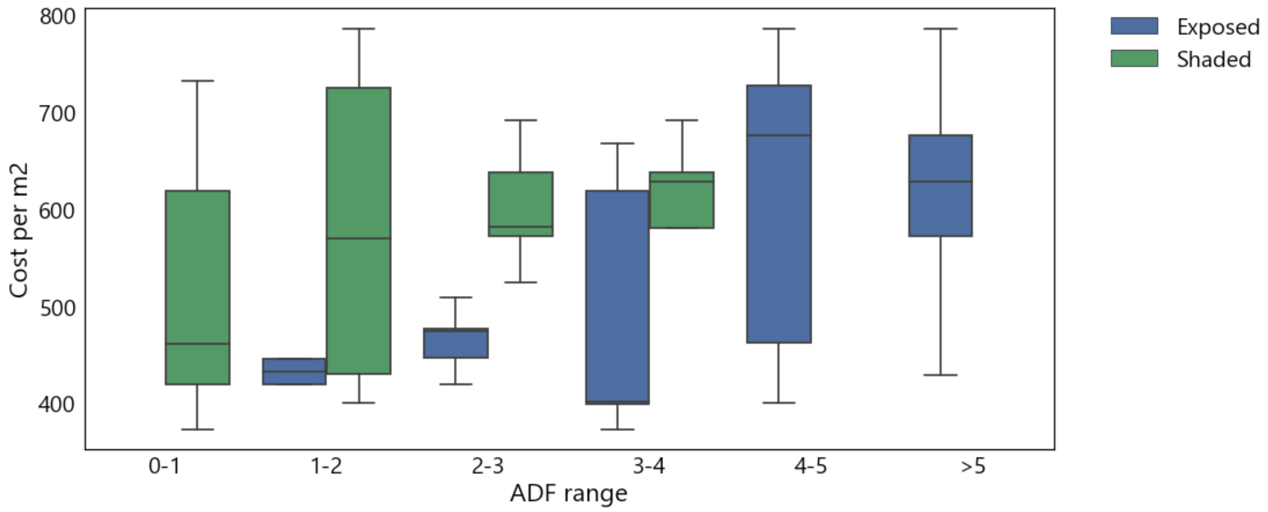


Figure 6—5 Distribution of cost to achieve different Average Daylight Factor ranges in retail spaces

Table 6—3 Median cost uplifts to achieve different Average Daylight Factor ranges by non-residential typology and shading conditions

Adjacent buildings	Typology	Median cost per m^2					
		ADF 0-0.9%	ADF 1-1.9%	ADF 2-2.9%	ADF 3-3.9%	ADF 4-4.9%	ADF >5%
Exposed	Office	NA	£0	£0	£25	£67	£106
	Retail	NA	£0	£42	-£31	£243	£195
Shaded	Office	-£74	£0	NA	NA	NA	NA
	Retail	-£108	£0	£12	£59	NA	NA

Based on these assumptions, the cost uplifts to achieve the different levels of daylight factor are summarised in Table 6—3 for the different typologies and shading conditions. The baseline cost region is highlighted in yellow.

Higher cost is generally required in shaded locations to achieve the same level of daylight, as measures such as dual aspect and higher glazing ratios are needed to improve daylight in this case.

Lower costs are shown in an exposed location to achieve daylighting performance as lower glazing ratios are required. Exposed retail units have a lower median cost in the 3-3.9% ADF range than in the 2-2.9% range. This is due to the fact that most of the spaces in the 2-2.9% ADF range can improve their daylight (and reducing cost) by removing shading canopies.

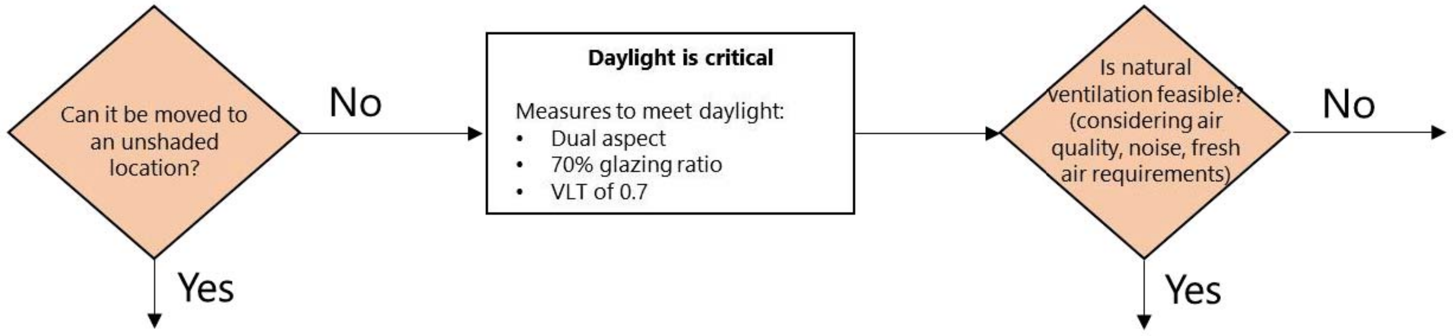
6.7 Non-residential design considerations

Table 6—4 outlines the design considerations, facade and systems speciation's that the modelling showed may be required to balance all three environmental drivers in Office and retail developments for shaded and unshaded locations. The corresponding cost impacts are also outlined for the requirements.

The design considerations and decisions flow diagrams are also visually represented in Figure 6—6 and Figure 6—7. To understand the fenestration strategies outlined as an outcome from the modelling see Figure 11—6, which visually shows the corresponding glazing ratios (window/wall).

Table 6—4 Non-residential design responses to maximise daylighting whilst minimising overheating risk and carbon emissions

	Shaded	Unshaded	Cost impacts
Modelled design responses to meet minimum requirements	• Efficacy of lighting exceeding Notional levels • Lighting controls including daylight dimming and occupancy sensing **Office:** • Dual aspect • Balance higher glazing ratios with lower g-values • High VLT of glass • Consider locating units away from south and south-west direction, to allow for natural/assisted ventilation whilst limiting overheating risk ○ In naturally ventilated spaces, use low g-values (0.3 or lower) ○ Use exposed soffits to increase thermal mass ○ Provide sufficient opening free area for ventilation **Retail:** • Mechanical cooling • Dual aspect • Avoid fixed shading elements, such as fins and overhangs	• Efficacy of lighting exceeding Notional levels • Lighting controls including daylight dimming and occupancy sensing **Office:** • Consider natural/assisted ventilation for single aspect north-facing units ○ Use low g-values (0.3 or lower) ○ Use exposed soffits to increase thermal mass ○ Provide sufficient free area for ventilation • When mechanically cooled: ○ Balance higher glazing ratios with lower g-values ○ Use g-values of 0.4 or lower in South-facing spaces **Retail:** • Mechanical cooling • Reduce solar gains, especially in South-facing units, through either low g-values, lower glazing ratios, shading or less stringent fabric U-values	Achieving the targets in unshaded conditions is considered to present no cost uplift (see section 6 for further details) The measures for offices in shaded conditions have a cost uplift of £102/m^2 compared to the baseline (represented by the unshaded conditions achieving 2% ADF). The main contribution to cost is given by the larger glazing areas due to shifting from single aspect to dual aspect units and using higher glazing ratios. Similarly, retail spaces in shaded conditions need to be dual aspect to maximise daylight and for this reason present a cost uplift of £107/m^2 over the considered baseline.
Modelled design responses to support encouraged activities	• LED lighting with best practice efficacy • Lighting controls including daylight dimming and occupancy sensing **Office:** • None of the cases modelled achieve all minimum requirements. Further measures should be to maximise daylight while limiting cooling loads **Retail:** • Mechanical cooling • Dual aspect • Avoid fixed shading elements, such as fins and overhangs • Reduce solar gains in south-facing locations through low g-values and low glazing ratios to reduce operational energy and provide future climate resilience where this doesn't compromise daylight.	(Same as minimum requirements because the limiting factor is overheating not daylight) • LED lighting with best practice efficacy • Lighting controls including daylight dimming and occupancy sensing **Office:** • Consider natural/assisted ventilation for single aspect North-facing units ○ Use exposed soffits to increase thermal mass ○ Provide sufficient free area for ventilation • When mechanically cooled: ○ Balance higher glazing ratios with lower g-values ○ Use g-values of 0.4 or lower in South-facing spaces **Retail:** • Mechanical cooling • Reduce solar gains, especially in South-facing units, through either low g-values, lower glazing ratios, shading or less stringent fabric U-values	The requirements don't impact the carbon, overheating and daylight targets and therefore do not necessarily lead to a capital cost uplift. However, additional consultancy/managerial cost may be required, e.g. due to additional modelling and Green Lease Agreements.
Key considerations	Lighting is the main driver to reduce carbon emissions. Daylight is critical in shaded locations, therefore measures are aimed at maximising sunlight exposure. This increases the risk of overheating, thus generally requiring cooling to achieve thermal comfort. The daylight target is harder to achieve in deeper floorplates (as in the case of offices) and therefore further measures need to be considered to allow for better daylight while limiting solar gains.	Lighting is the main driver to reduce carbon emissions. In unshaded locations, solar gains are critical and therefore measures should be taken to reduce the cooling load or allow for natural ventilation.	
Further measures to review	• Albedo of public realm and/or surrounding elements • Change plan depth and geometry of units • Move units to unshaded locations where possible • Use high-reflectance materials and paints • Use windows with high VLT and low g-value • Use movable shading elements to be used during summer months to reduce solar gains, while not compromising daylight for the remaining part of the year • Consider a mixed mode strategy using mechanical cooling only during summer months and natural ventilation during the remaining months • Consider internal cross-ventilation through atria or chimneys	• Consider a mixed mode strategy using mechanical cooling only during summer months and natural ventilation during the remaining months • Consider internal cross-ventilation through atria or chimneys	



Daylight is critical

Measures to meet daylight:
- Dual aspect
- 70% glazing ratio
- VLT of 0.7

SHADED OFFICE – COOLED

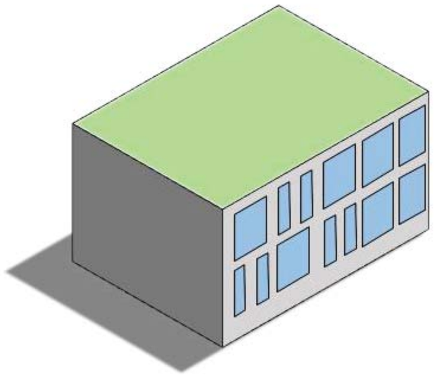
Daylight and carbon are critical

Maximising daylight leads to high solar exposure. Cooling loads need to be limited, in order to achieve 15% carbon savings. The following should be done to meet all criteria:

- Measures required to meet daylight
- Mechanical cooling
- G-value of 0.4 or lower and/or movable shading
- If South-facing, g-value of 0.3 or lower and/or movable shading

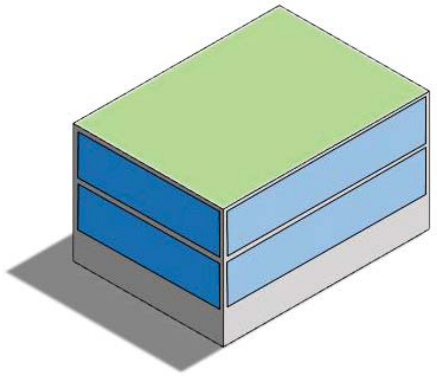
UNSHADED OFFICE

50% GLAZING RATIO



G-VALUE = 0.4

70% GLAZING RATIO

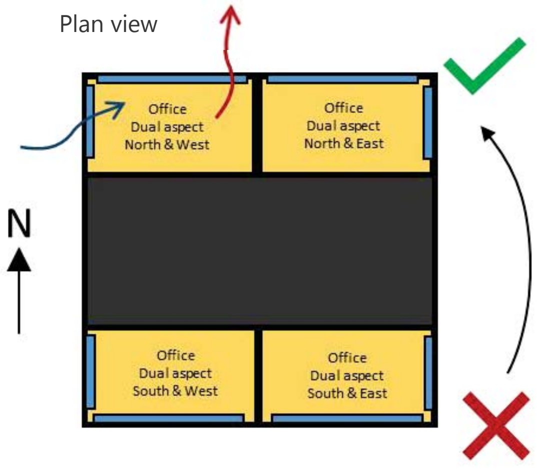


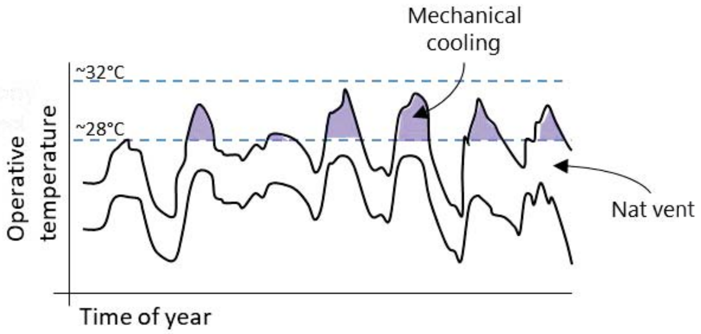
G-VALUE = 0.3

In unshaded locations modelling has shown that daylight is not critical. However overheating risk and cooling loads for Part L need to be controlled. The following should be done to meet all criteria, especially in South-facing spaces:

- G-value should be balanced with glazing ratio on single or dual aspects
- Resultant G-value of 0.2 (factor of glazing ratio, shading and G-value of glass)
- Occupant control of blinds
- Natural ventilation with comfort cooling only in peak summer conditions, or fully conditioned if overheating risk still present

SHADED OFFICE – NATURAL VENTILATION





Mechanical cooling only for peak overheating conditions, Naturally cooled for shoulder seasons

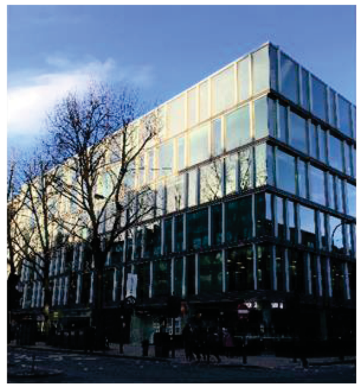
Daylight and overheating are critical

Natural ventilation allows achieving large carbon savings. However, the measures required to maximise daylight lead to high overheating risk. This can be mitigated through a mixed mode strategy, where cooling is only used in peak summer conditions. The strategy to meet all criteria is the following:

- Requirements to meet daylight
- Natural ventilation
- Comfort cooling only in peak summer conditions
- Avoid S/SE/SW orientations

EXAMPLE BUILDINGS

Lower glazing ratios and window recess or shading elements can be considered in unshaded locations to reduce overheating risk



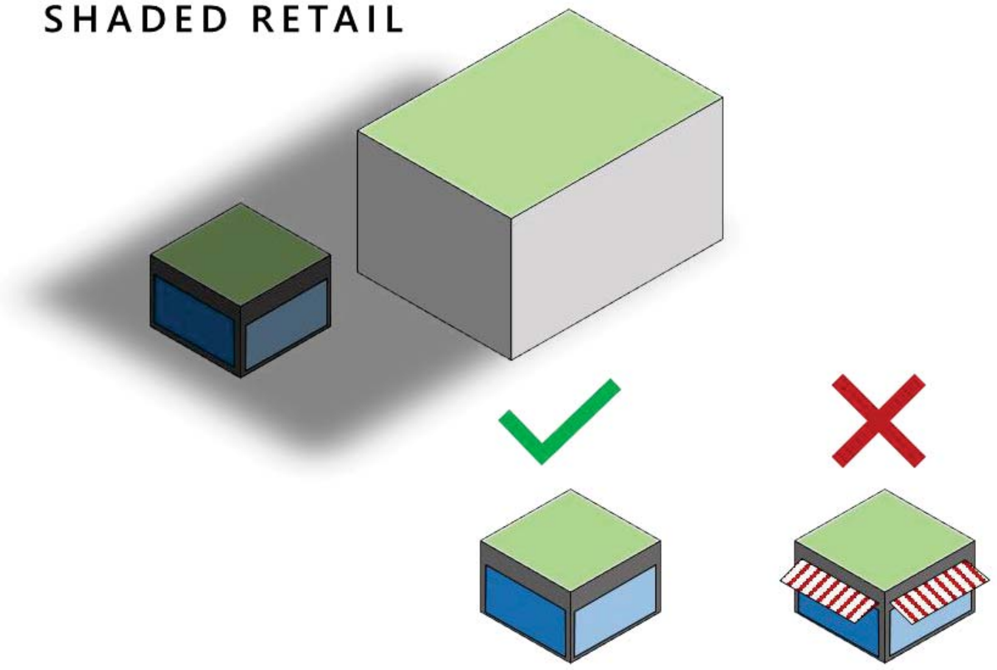
High glazing ratio used in shaded locations helps maximising daylight.

In unshaded locations high glazing ratios can be used but should be compensated with low g-values to reduce overheating risk

Different facade treatments can be applied. Lower floors are more shaded and benefit from higher glazing ratios to maximise daylight, while overheating risk in more exposed upper floors can be mitigated through reduced glazing ratios, lower g-values and shading elements.

Figure 6—6 Office decision flow diagram with appropriate massing, location and facade response to balance all three factors

SHADED RETAIL



To meet the minimum daylighting requirements in shaded retailed locations:

- Position retail units in dual aspect locations (increasing active frontage)
- Minimise horizontal shading and fins
- If shading is used ensure it is retractable

EXAMPLE BUILDINGS

Retail units can typically be single aspect so avoiding fixed shading devices is advised otherwise poor daylighting could be achieved.

Higher albedo flooring could be specified outside units to reflect further light into the unit.

Floor to ceiling heights could be increased with higher elements of fixed glazing could be added to project daylight into deep units.

Design out shading on certain orientations and allow for tenants to fit retractable shading devices them selves.

Figure 6—7 Retail facade responses for shaded locations to balance all three factors

6.8 Further cost considerations

6.8.1 Key sensitivities

a) Insulation

One of the main cost sensitivities is the type of insulation specified. Insulation materials with a greater thermal resistance (e.g. 0.021 λ-value) can have costs per m^2 many times higher than those with lesser thermal resistance (e.g. 0.033 λ-value). As a trade-off, you need to use less volume to achieve comparable U-values to build-ups using cheaper but less thermally efficient insulation materials. There are also consequential costs/benefits in relation to element thickness and floor area, for example.

b) Windows

Windows are a vitally important feature of any building, and care must be taken to optimise specification and design. There are many things to consider, all of which will have direct and indirect cost impacts, such as: size, number, specification (glazing and frame) and orientation.

Windows are more expensive than the opaque fabric, and are much less thermally efficient. They do, however, introduce daylight and passive solar gain (heat) into internal spaces, vital for health and wellbeing, but also reduce the need for artificial lighting and heat generation.

Clearly, there is a balance to be found between the cost and thermal performance negatives, and the daylighting and solar gain benefits. Spending time assessing the options and finding the optimum balance is recommended, as it will allow you to achieve the best value for money.

c) Facade complexity

The facade types modelled and costed in this research have been uniform and absent of architectural complexity. These types of facade are cost efficient as they avoid variation in specifications and design, which costs time and money.

By their nature, complex facades would have a larger number of specification variations and differing design details, all of which will add to the cost of designing and constructing such facades compared to simpler, standardised facades.

It is recognised that there is a balance to be struck between simplicity and overall design quality which will necessitate a focus at design stage on optimising the approach.

d) Standardisation

Where designs are simpler, standardisation of components is possible which allows for cost efficiencies to be taken advantage of, such as:

- **Purchasing leverage:** Being able to order larger quantities of standard components and materials offers increased purchasing power, where customers can benefit from economies-of-scale and arrange more frequent deliveries to support just-in-time processes.
- **Lowering material overhead:** Standard components and materials have much less material overhead, as they are more common, more readily available, and have more sources.
- **Spontaneous resupply possible:** Many costs can be reduced by arranging spontaneous resupply of components and materials, instead of more expensive forecast-based purchase orders and holding inventories.
- The desire to simultaneously capture cost advantages of standardisation without compromising design quality will need careful value engineering so that standardisation is targeted in the right places.

e) Prefabrication

High-rise buildings lend themselves to prefabrication and off-site construction, which offers the following benefits:

- **Faster on-site construction:** Provided the appropriate programming and just-in-time delivery systems are set up, modular construction can significantly reduce the overall completion schedule.
- **Quality:** As prefabricated components are constructed in controlled factory environments, precision and predictability of product is much more attainable compared to structures that are cut and built onsite.
- **Indoor construction:** The factory environment allows for construction independent of weather conditions, which increases efficiency and avoids damaged building materials.
- **Low waste:** Because each component is precision manufactured for exact fit according to the plans, manufacturers understand exactly what quantities are needed, and a project's material waste is reduced.

f) Mechanical ventilation with heat recovery (MVHR)

Increasing airtightness supports high levels of energy efficiency. As the level of airtightness increases, fresh air needs to be introduced into a building. Ideally, this would be by MVHR.

Where you site an MVHR unit can have a significant impact on costs. A significant cost, beyond the unit itself, is the cost of the ducting – both within the building, and the intake/extract ducting to and from the unit, and the outside. The location of the unit should be carefully planned, so that the optimum location is determined, which takes advantage of the minimum practicable duct lengths.

6.8.2 Market innovations and responses

a. Heating via MVHR

As buildings become more and more energy efficient, the space heating demand correspondingly falls. At the highest levels of energy efficiency, the heating demand is so small that a traditional heating system is not necessary. Indeed, this is the philosophy promoted by the Passivhaus standard, which dictates that heating and cooling is delivered via post-heating or post-cooling ventilation air within the MVHR system.

The heating is provided by either an electrical element or a wet heating coil within the ductwork, which heats fresh air as it is distributed by the system to individual rooms. Cooling is delivered by a chilled coil.

This arrangement allows for savings to be made by reducing plant size to that only needed for domestic hot water (DHW) and removing a traditional distribution system. It also lends itself to being linked-up to low/zero carbon (LZC) technologies, such as photovoltaics (PV) or heat pumps.

b. Heat pumps

Heat pump technology is fairly mature, and costs are not expected to fall dramatically, unless a major innovation is discovered. In the UK, however, there is a lack of qualified technicians who can install and maintain systems. Labour currently accounts for around 60% of the total installed cost. As this market matures and more installers are trained, costs should come down.

c. Thermal bridging and detailing

As buildings become more energy efficient, the proportion of heat lost through thermal bridges increases. As such, in the future more attention will be given in the future to reducing these losses, which will increase understanding and bring approaches to reducing thermal bridging much more into the mainstream, with the associate cost efficiencies of doing so.

With an increase in understanding, and as libraries of solutions are built up, less time will need to be taken to design-out thermal bridges and verify them through modelling. Designs that are currently specialist, and require specialist components to create will become the norm and allow suppliers to invest in economies-of-scale, and bring new products to the market.

d. Contractor and supply chain capability

Current contractor and supply chain unfamiliarity (at a mass level) with delivering higher levels of energy efficiency mean that premiums are put on fees charged to those projects that demand it. These premiums should come down as standards become the norm.

7 Conclusions

7.1 Carbon

The analysis shows that for the residential and non-residential units tested, it is technically feasible to meet the energy efficiency targets set out in the Draft New London Plan. However, energy use in non-domestic buildings can be highly variable and therefore some building types may find it more difficult to meet the targets.

Pushing beyond the target level is very challenging in residential development but in some situations, may be possible for non-residential units.

For residential developments, the capital cost uplift of meeting the target is comparable to that identified in the GLA evidence base, suggesting no material difference to the viability assessment carried out in support of the Draft New London Plan. OPDC will need to consider this within its own whole-plan viability testing of the emerging Local Plan

For non-residential office and retail units, the analysis found no direct correlation between capital costs and energy efficiency, again suggesting that the targets can be met through good design rather than increased expenditure. However, as noted above, the high variability of energy use in non-domestic building makes it difficult to draw general conclusions on the cost implications for all use-types.

7.2 Daylight

The analysis has shown that for the indicative development type examined, good daylight can be provided to exposed residential and non-residential units.

However, lower down the building where sky views may be partially limited, daylight levels are much harder to achieve, particularly for non-residential units. In these spaces there will be a cost uplift to achieve good daylight.

7.3 Overheating

Overheating was found to be a significant challenge. In residential development, the problem is acute in south and west facing units and dual aspect units with long hours of solar exposure. A range of measure have been identified to potentially mitigate the risk but these will need to be examined on a case-by-case basis through detailed modelling.

In non-residential development, there is significant risk of overheating to naturally ventilated buildings under future climate conditions. The GLA's cooling hierarchy should be followed to maximise the opportunities for passive cooling before applying mechanical cooling.

7.4 Optimising environmental design

The study has examined the technical and cost sensitivity of a wide range of measures that affect carbon, daylight and overheating performance. The focus of the study is on these three issues alone but in practice there will be a need to consider a wider range of policy factors including air quality, noise, housing policy etc.

Design approaches have been described for optimising performance across the three focus areas, depending on orientation and location of units that may affect the degree of shading from surrounding buildings and access to daylight.

On south and west-facing elevations where it can be most challenging to balance all three conditions, the design of residential units will need to carefully optimise a range of design measures. These may include triple glazing, MVHR, air tightness, thermal bridging, glazing area, g-value and the location of different unit types as well as opportunities to push beyond those explicitly modelled in this study such as thermal mass and movable shading.

The analysis show that almost none of the naturally ventilated non-residential options simultaneously passed the criteria for carbon, daylight and overheating. This suggest that a conscious trade-off between performance targets may be required, or alternative solutions deployed such as mixed mode systems, mechanical ventilation or comfort cooling.

8 Further energy considerations

8.1 Meeting carbon reduction targets with Future Carbon factors

The impact of future changes to the electricity grid will have a considerable impact on the carbon saving potential of differing heating systems. Carbon reductions from gas CHP will reduce while those from efficient electric heat pumps (either individual or communal) will increase.

Analysis has been undertaken to assess the potential for the meeting the GLA's 35% on-site carbon reduction target through a combination of energy efficiency and different low carbon heating systems.

It was found that the overall 35% residential carbon reduction target could be met in two ways:

- 10% energy efficiency + low carbon heat from communal or air source heat pumps
- 15% energy efficiency + direct electric heating space heating, communal domestic hot water and solar PV on shoulder level blocks
    - However cost to occupant should be a further key consideration

Further details including lifecycle carbon abatement costs are contained in Appendix D - Meeting carbon reduction targets with Future Carbon factors.

8.2 Closing the performance gap

The performance gap is the difference between expected (or as designed) performance modelling and the in-use performance that experienced in reality. The compliance gap is the difference between the regulated compliance modelling undertaken for this study and in use performance.

Numerous building performance evaluations have shown that buildings use significantly more energy in-use than predicted by their designers; 2.6 times more in the case of dwellings, and 3.6 times for non-domestic buildings. Buildings that prioritise passive energy measures have a smaller performance gap than those relying more on mechanical solutions or active energy efficiency measures, i.e. MVHR and boiler improvements. It is therefore important to consider the impact of proposed energy efficiency measures on the potential for in-use performance as well as their impact on the Part L compliance model.

It is possible to bridge the gap between the compliance model and the in-use performance through following extended calculation methods such as those described in CIBSE TM54. Whilst this may close the 'compliance gap' it still does not address the full 'performance gap' between predictions and reality, as there are limitations to all predictive calculations undertaken at the design stages of a project. The UKGBC task group report – Delivering Building Performance identifies five key success factors in delivering building performance, covering aspiration, control, design for performance, feedback and knowledge.

Glazing U-value, air tightness, and MVHR are key factors with a significant impact on the gas demand of dwellings and could be impacted by quality of workmanship and value engineering. These need to be carefully controlled through design, procurement, construction and operation.

For office and retail, the energy consumption of fully-conditioned units is heavily influenced by the demand for cooling therefore assumptions about shading from adjacent buildings could have a big impact. For naturally ventilated units, glazing U-value was a significant factor; which could be impacted by quality of workmanship and value engineering. Overall, the energy consumption of non-residential buildings is highly dependent on internal activities, occupancy patterns and effective controls.

Further details including sensitivity analysis of a wide range of parameters are contained in Appendix E - What is the potential performance gap and how to minimise it.

8.3 Demand management technologies

Buildings can provide significant Demand Side Management (DSM) capabilities given the nature of their thermal and electrical demand. This is particularly useful in dense urban areas, where the electricity grid may be under greater strain in the future. Demand management programmes typically involve very large demand centres, co-ordinated by National Grid.

The opportunity is to harness both electrical and thermal demand side response (DSR) innovations and use these to reduce peak load capacity of plant with associated reductions in capex and opex. The challenge is capturing the full value through emerging new energy markets that are susceptible to change. Transposing this approach to residential can be challenging. Without a significant number of homes or single commercial tenants, demands cannot be aggregated and shifted to balance the grid, reduce carbon or reduce cost.

DSR can be facilitated with the use of energy storage within a system. Heating can be easily stored using hot water, in dwelling cylinders or communal thermal storage. Electricity can be stored using power batteries, electric vehicles and within hot water for the use of heating. Storing hot water is standard practice however the UK domestic/small commercial-scale battery market is still in infancy.

Systems should look to include either one or both within a building systems in order to maximise the DSR opportunities that may arise post construction. SMART metering and control with the combined functions of an adapted communal heating or district heating systems could allow for the Old Oak Common Masterplan to reduce network utilities demand peaks, increase utilisation of low carbon heat sources and reduce cost of electric heat pump operation.

Further details including technologies for consideration and the value that can be added are contained in Appendix F - Impact and consideration of demand management technologies.

8.4 Social impact

The design of a home and its surrounds are a key contributor to the health and wellbeing of the people who live and work there. This includes factors such as daylight, temperature, air quality, internal layout and a wide range of neighbourhood factors such as natural environment, amenities and public transport.

Developers should carefully consider social issues and end user needs associated with low-energy specifications (and the design as a whole). Specifically, research makes reference to "committed client and owners", "manageable complexity" and "handover" as key success factors. As we investigate how low and zero carbon technologies could provide heating in developments, it is important to consider potential cost for occupants and therefore their impact on affordability.

Communal CHP or communal ASHPs present a heat cost to consumers that is only slightly greater than for communal boilers. However, the cost can be considerably lower if revenues from the CHP electricity sales or from incentives, such as the Renewable Heat Incentive (RHI) for ASHPs, are passed on to consumers. Individual ASHPs show nearly zero net fuel costs. When RHI benefits are passed on to the consumer cost, the cost of heat associated with individual ASHPs is nearly zero. However, this only lasts for seven years for residential dwellings under current government policy and without it, the cost of heat of individual heat pumps reaches levels comparable to communal boilers.

Direct electric systems show the highest cost to consumers per kWh. This is due to the lower relative efficiency and use of a high cost fuel. If used in combination with passive measures, the increase in the overall fuel bill cost could be limited through a reduction in heating demand. Whilst appropriate design should aim at delivering low-energy comfortable buildings, the in-use performance will be highly dependent on the operation and maintenance of the buildings. For this reason, it is important that the design is simple, robust and low-maintenance and that the expected mode of operation is well communicated to its users.

These issues are explored further in Appendix G - Social assessment.

9 Policy and guidance recommendations

9.1 Residential

9.1.1 Minimum requirements

In order to reduce carbon emissions, development proposals should:

i). Comply with the London Plan energy policies in force at the time
ii). Achieve at least 10% carbon reduction through energy efficiency where possible

In order to deliver good daylight, development proposals should:

iii). Achieve average daylight factor of 1.5% in living spaces where windows of residential units have an unobstructed sky view

In order to minimise overheating risk, development proposals should:

iv). Demonstrate that the design complies with CIBSE TM59, based on 2020 DSY weather files.
v). Demonstrate how the GLA cooling hierarchy has been followed to reduce and mitigate overheating risk

In order to optimise environmental design, applicants should:

vi). Demonstrate through modelling how the proposed designs aim to balance consideration of carbon, daylight and overheating.

9.1.2 Encouraged activities

In order to reduce carbon emissions, applicants are encouraged to:

i). Undertake in-use energy performance modelling at design stage to identify the potential performance gap and identify ways to reduce it.
ii). Aim to exceed the London Plan energy requirements and achieve carbon reductions greater than 10%, through best-practice energy efficiency measures

In order to deliver good daylight, applicants are encouraged to:

iii). Maximise daylighting in shaded locations, aiming to achieve an average daylight factor of 1.5% in living spaces whilst mitigating overheating
iv). Use climate-based daylight simulation, aiming to maximise Useful Daylight Illuminance

In order to minimise overheating risk, applicants are encouraged to:

v). Develop an adaptation strategy for future compliance with CIBSE TM59 or CIBSE Guide A criteria (if mechanically cooled), using 2050 weather files
vi). Aim to show that the present-day design complies with CIBSE TM59 criteria (if naturally ventilated) or CIBSE Guide A criteria (if mechanically cooled), based on 2050 DSY weather files

9.2 Non-residential

9.2.1 Minimum requirements

In order to reduce carbon emissions, development proposals should:

i). Comply with the London Plan energy policies in force at the time
ii). Achieve at least 15% carbon reduction through energy efficiency where possible
iii). Carry out operational energy performance modelling at design stage, to identify the potential performance gap and identify ways to reduce it.

In order to deliver good daylight, development proposals should:

iv). Demonstrate how the design has sought to optimise daylight depending on the types of use the building is designed for.

In order to minimise overheating risk, development proposals should:

v). Demonstrate that the design complies with CIBSE TM52 criteria (if naturally ventilated) or CIBSE Guide A criteria (if mechanically cooled), based on 2020 DSY weather files
vi). Demonstrate how the GLA cooling hierarchy has been followed to reduce and mitigate overheating risk

In order to optimise environmental design, applicants should:

vii). Demonstrate through modelling how the proposed designs aim to balance consideration of carbon, daylight and overheating

9.3 Encouraged activities

In order to reduce carbon emissions, applicants are encouraged to:

i). Put in place green lease agreements or equivalent in shell and core spaces, to ensure the recommended design is adopted by tenants
ii). Aim to exceed the London Plan requirements and achieve carbon reductions of at least 20%, through best-practice energy efficiency measures

In order to deliver good daylight, applicants are encouraged to:

iii). Achieve an average daylight factor of 2% in all occupied spaces where technically feasible
iv). Use climate-based daylight simulation, aiming to maximise Useful Daylight Illuminance

In order to minimise overheating risk, applicants are encouraged to:

v). Develop an adaptation strategy for future compliance with CIBSE TM52 or CIBSE Guide A criteria (if mechanically cooled), using 2050 weather files
vi). Aim to show that the present-day design complies with CIBSE TM52 criteria (if naturally ventilated) or CIBSE Guide A criteria (if mechanically cooled), based on 2050 DSY weather files

10 SPD Checklist

10.1 Potential SPD checklist

Below is a suggested checklist of quantifiable and simple tangible considerations for applicants and designers to report upon to allow for ease of consideration by Planning Officers. This is not considered exhaustive and can be added to if further elements are considered.

Included within Energy and/or Sustainability Statement submitted for planning?	Yes/No or Value
Overheating	
Has the application of natural ventilation for commercial spaces be reviewed?	Y/N
If so has natural ventilation been applied? (Spaces types or unit types)	Y/N
Has dynamic overheating modelling been undertaken with the use of 2020 London Heathrow weather files?	Y/N
Has further overheating analysis been undertaken using 2050 London Heathrow weather files?	Y/N
Do the commercial units shows an overheating risk in line with CIBSE TM52 or CIBSE Guide A for conditioned spaces?	Y/N
Energy	
Has Performance or Predictive energy modelling been undertaken?	Y/N
For non-residential what is the average Lumens/circuit Watt of display lighting specified?	lumens/W
For non-residential what is the average Lumens/circuit Watt of ambient lighting specified?	lumens/W
For residential what is the average Lumens/circuit Watt of fixed lighting specified?	lumens/W
For residential has MVHR been considered?	Y/N
For residential what proportion of units will be air-tightness tested?	X%
For residential what is the average glazing ratio, as a proportion of external wall?	X%
Daylighting	
Have overheating and daylighting results been combined for the proposed development?	Y/N
Has average daylight factor within Residential units modelled?	X%
Has average daylight factor within Non-residential units modelled?	X%
Has any other daylight modelling approaches been used other than ADF?	Y/N

11 Appendix A - Study Process

11.1 Energy and carbon approach

The Greater London Authority's (GLA) London Plan energy hierarchy, outlined in Policy 5.2 Minimising carbon dioxide emissions, requires new building development to follow the energy hierarchy when proposing site energy strategies to achieve carbon reductions:

1. Be lean: use less energy and manage demand during construction and operation.
2. Be clean: exploit local energy resources (such as secondary heat) and supply energy efficiently and cleanly. Development in Heat Network Priority Areas should follow the heating hierarchy in Policy SI3 Energy infrastructure.
3. Be green: generate, store and use renewable energy on-site.

The energy and CO_2 modelling undertaken for the energy efficiency elements in section 12.1 is based upon the Be lean section of the hierarchy outlined above. Lean includes measures within the dwelling or unit that focus on energy efficiency. This covers both passive (facade measure) and active (mechanical ventilation/lighting/heating delivery). The savings discussed within the section on energy efficiency cover all elements of Lean Savings over the TER (Notional dwelling).

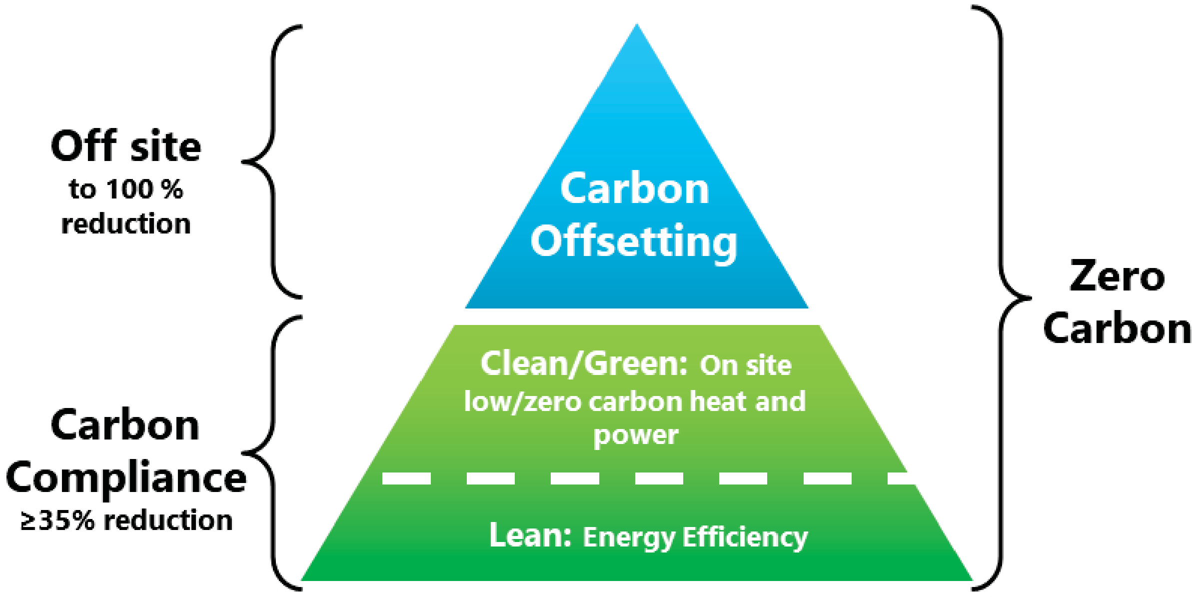


Figure 11—1 GLA's regulated zero carbon process

11.1.1 Building Regulations approved document Part L Notional Building/Dwelling

Building Regulations approved document Part L 2013 has been used to analyse the energy and carbon compliance of both residential and non-residential modelling. This is because the current carbon performance of the London plan is judged against this until future variations are released. Therefore current compliance software is also only available under Part L 2013. Future carbon scenarios have been post-processed based on demand figures and carbon intensities outlined in Section 14 Appendix D - Meeting carbon reduction targets with Future Carbon factors.

11.1.2 Notional Building/Dwelling

Part L 2013 uses the actual dwelling/building and creates a notional dwelling (for residential) and building (for non-residential) to compare the actual space against. This building matches the geometry for the actual space and uses fixed performance efficiencies. The actual spaces has an associated energy demand and carbon emissions per m^2 called the Dwelling Emission Rate (DER) or Building Emission Rate (BER). The energy and carbon performance of the notional building then provides the Target Emission Rate (TER).

In non-residential buildings the notional systems will match the actual systems. This means that a naturally ventilated building will have a naturally ventilated baseline, therefore changing the parameters of which each building type is compared against.

For this reason naturally ventilated and cooled results and fully conditioned non-residential results have been split where possible to show the improvements over the varying TER.

11.2 Overheating approach

Overheating modelling has been undertaken using the same IES 2017 software model as used for the energy analysis and a specific one for the residential typologies. Overheating analysis has only been run for both variables and development types that are not mechanically cooled (Conditioned). Mechanically cooled non-residential buildings are assumed to comply with CIBSE Guide A criteria, based on operational control, set points and cooling capacity. Therefore, overheating analysis for this typology has not been carried out.

CIBSE TM52 has been used as an assessment criteria for overheating. The application of the CIBSE TM59 guidance has been applied to the Residential units. Future weather files have been used in both analysis sets. In line with CIBSE TM49 guidance, residential units have been tested against 2020 DSY1 weather file (based on year 1989). Non-residential spaces have been tested against worst case 2020 weather file, corresponding to DSY 2 (based on year 2003).

Where is natural venation technically feasible?

According to CIBSE AM10 rules of thumb (see Figure 11—2), if only single-sided ventilation is possible, the room width should be less than 2 times the height, in order for fresh air to be adequately mixed within the space. If cross flow ventilation is possible, then the room width should be less than 5 times the height. For this reason, among the non-residential spaces considered in the analysis, single-sides spaces were considered to be too deep for natural ventilation and fans for assisted ventilation were considered. This is summarised in Table 11—1.

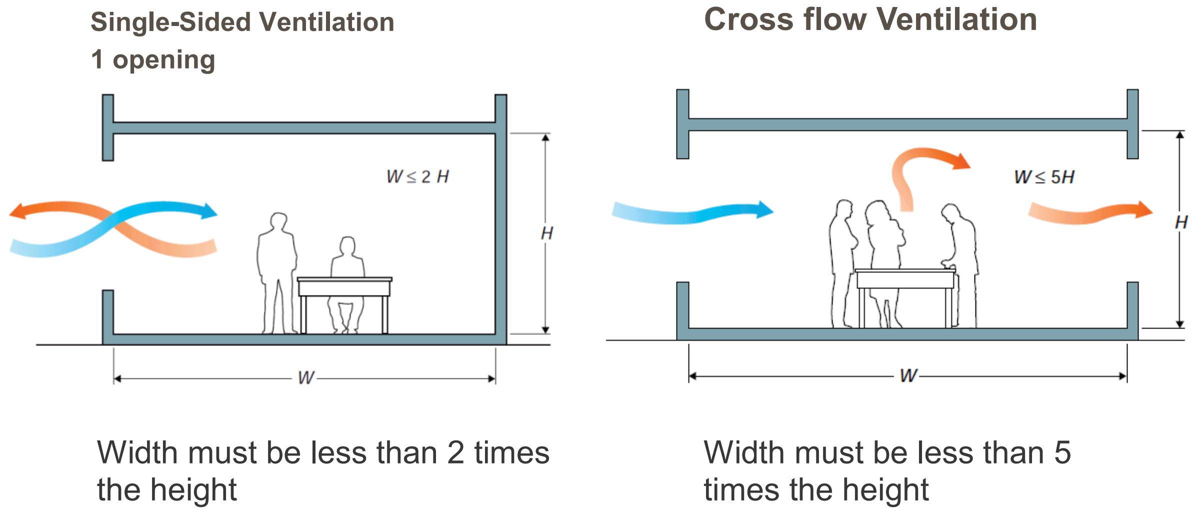


Figure 11—2 CIBSE AM10 rules of thumb for natural ventilation

Table 11—1 Technical feasibility considered for natural ventilation and free cooling in commercial spaces

	Natural ventilation (no cooling or auxiliary ventilation systems)	Assisted ventilation (no cooling but with MVHR for ventilation)	Conditioned (Fully cooled and ventilated)
Single aspect	×	✓	✓
Dual aspect	✓	✓	✓

Offices are considered to have openable windows, with the opening area corresponding to 40% of the total glazed areas. The openable windows are considered to be top-hung with a 30° opening angle.

Retail units don't typically have operable windows; louvres are therefore considered in these cases to provide natural ventilation. The louvre is assumed to be located on top of the windows, extending along the whole length of the facade. A 0.5m louvre height has been considered, in line with the rule of thumb that opening area be at least 5% of floor area (from Building Regulations Part F).

Worst case lighting has been assumed in the overheating calculations. A lighting efficacy of 60lm/W has therefore been considered for both office and retail spaces and no daylight or occupancy controls have been applied. Display lighting efficacy has been set to 25lm/W.

11.3 Daylighting approach

Daylighting quality is typically demonstrated at planning through an assessment of the average daylight factor. Daylight factor is defined as the ratio of the illuminance on the indoors working plane to the illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky, see Figure 11—9.

The working plane is defined at a height of 0.85m for residential and 0.7m for non-residential. Daylight factor in both residential and non-residential spaces has been evaluated through Grasshopper/Honeybee software tools.

According to the BS 8206 Code of practice for daylighting, in order for rooms to have a predominantly day-lit appearance, they should have an average daylight factor of at least 2%. If the average daylight factor within the space is between 2% and 5%, supplementary electric lighting is usually needed. If the average daylight factor exceeds 5%, then electric lighting is not normally needed during the daytime.

For dwellings, in particular, the BRE 209 and Home Quality Mark guidance document recommends the following standards as a minimum:

- Minimum for kitchens, ADF = 2%
- Minimum for living rooms, ADF = 1.5%
- Minimum for bedrooms, ADF = 1%

The London Mayor's SPG on housing (Mar 2016) states that daylighting should be optimized, however quantitative standards on daylight and sunlight should not be applied rigidly, without carefully considering the location and context and standards experienced in broadly comparable housing typologies in London, as per the GLA's and London First's Guiding Light: Unlocking London's residential density report, May 2017.

11.4 Modelling Process

The energy, overheating and daylighting modelling processes, tasks 1, 2, 3, and 7 in Figure 2—1 have been developed to cover the majority of typical architectural permutations of dwelling and non-residential scenarios that could arise on the OOCPR masterplan. Typical dwellings and commercial spaces have been modelled based upon standard units and principles developed by MaccreanorLavington, Masterplan Architect, and input from other architects.

Residential Units

Single and dual aspect units have been modelled for 1 bed and 2 bed units and dual aspect only for 3 bed units, see Figure 11—3. Inset and projecting balcony scenarios have been considered as two separate typologies, as internal layouts vary due to this change. Varying glazing ratios have been applied to all units, based on % of external wall area. All units have been modelled in all orientations as well as with a 45 degree variation to allow for SW, SE, NE and NW units scenarios. All permutations of fabric and systems have been tested against each architectural scenario and typology; providing a full suite of sensitivity analysis.

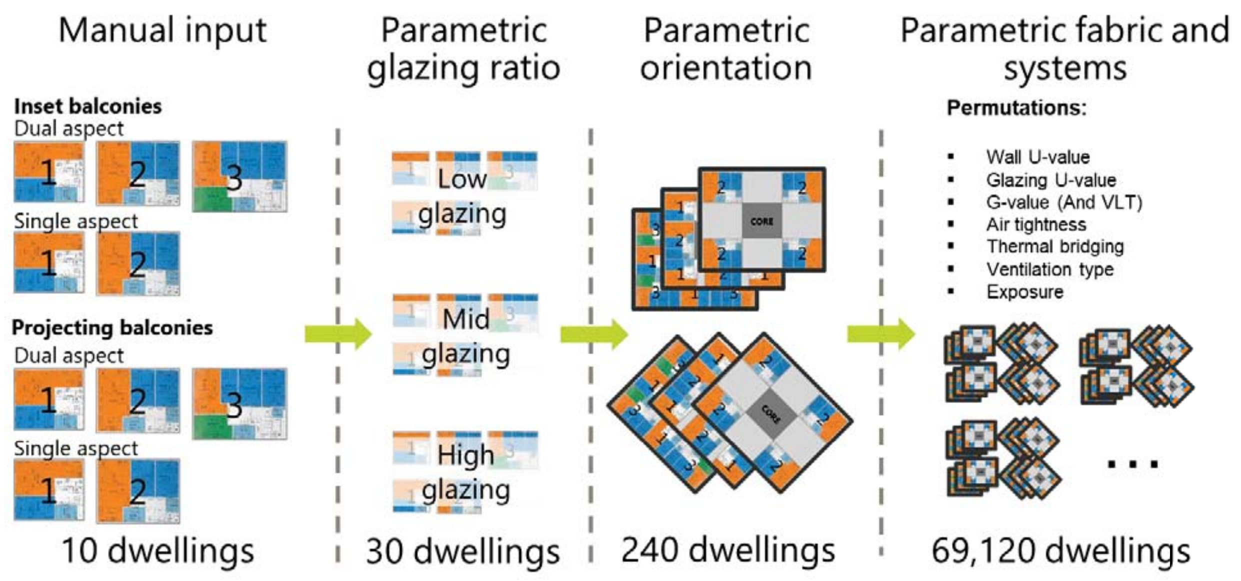


Figure 11—3 Residential energy modelling process

To understand the implications of glazing ratios on fenestration design, Figure 11—4 shows a visual matrix of each dwelling type by single and dual aspects with the increments of glazing ratios (window/wall) modelled. The 50% and 60% glazing ratio models include full height glazing across all glazing, as this is a key architectural consideration with London vernacular. However to reduce the glazing ratio to 35% overall, sill heights of 1100mm have been added to windows that are not considered sliding doors for balcony access.

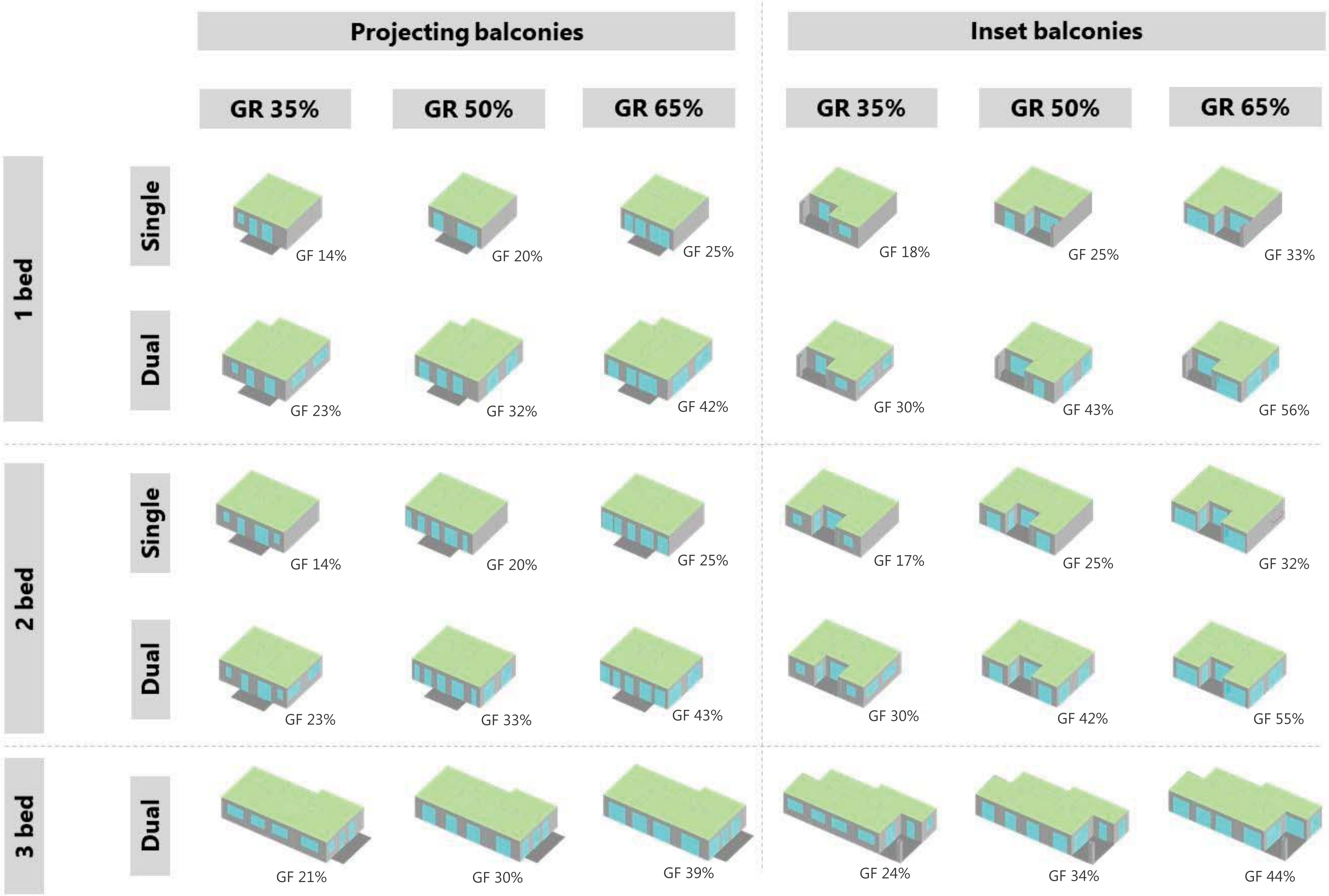


Figure 11—4 glazing layout in residential typologies analysed, each one also shows the Glazing ratio as a proportion of floor area (GF) for cross referencing with modelling outcomes

Commercial Spaces

It is expected, that the development in the OPDC area will consist of typical mixed-use blocks . Office and retail elements will form the majority of the non-residential typologies and therefore these have been modelled as a priority. The commercial spaces will typically form the ground and podium level up to 4-5 floors on many/ the typical block used. Based on example typical units, the analysed spaces were assumed to be 12m x 25m for offices and 10m x 10m for retail. The results are therefore representative of relatively small commercial spaces, rather than large open office configurations.

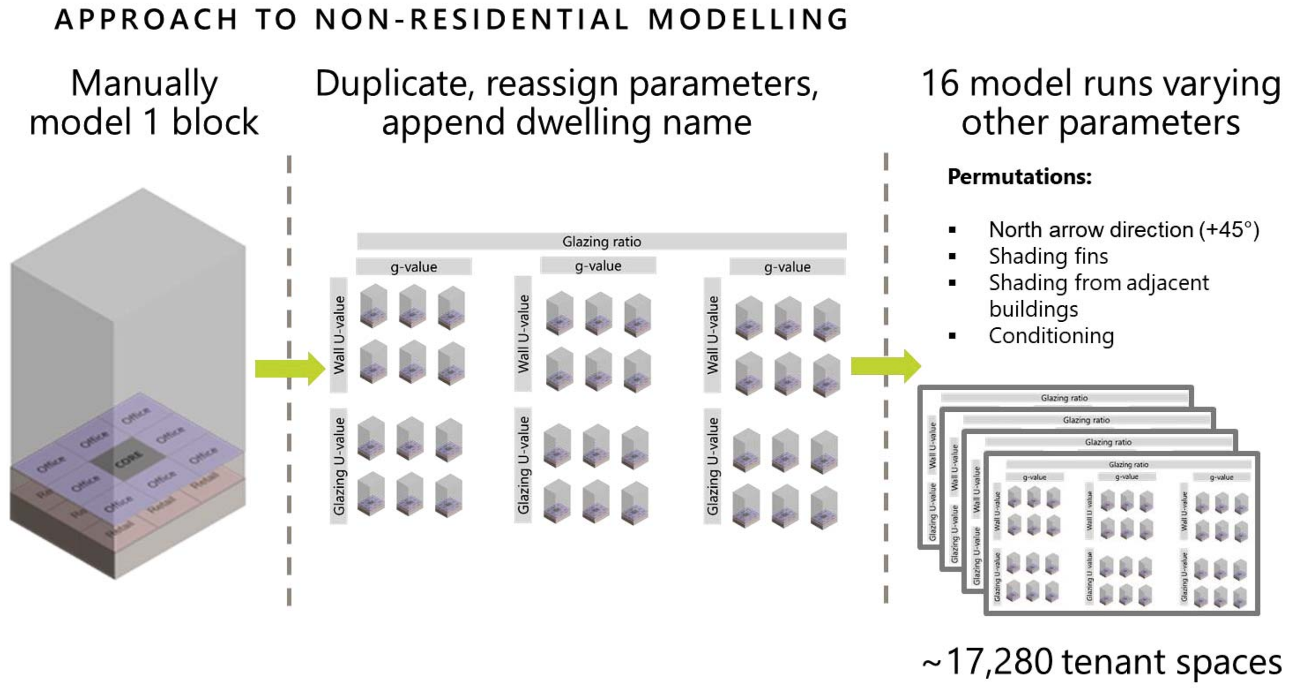


Figure 11—5 Non-residential energy modelling process

Figure 11—6 and Figure 11—7 outline the interruption of glazing ratios and shading devices across the office and retail elements. Retail element are considered the ground floors and include full width glazing and horizontal shading devices. However offices are considered low level but above ground floor. They have been modelled with vary the width of glazing by glazing ratio and include vertical shading fins.

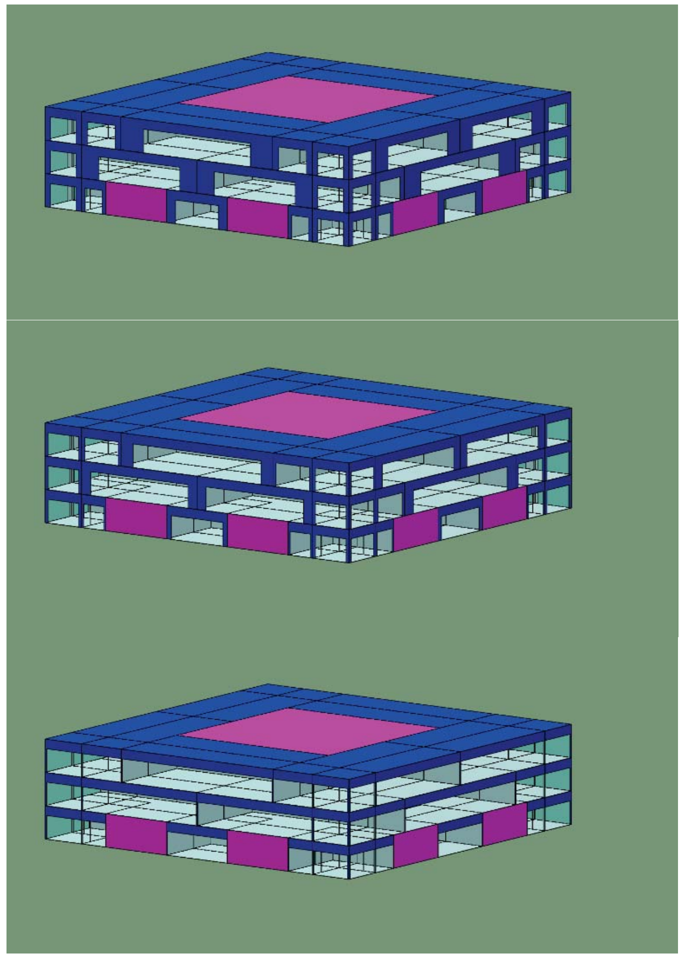


Figure 11—6 Non-residential modelled glazing ratios: 50% (top), 60% (middle), 70% (bottom)

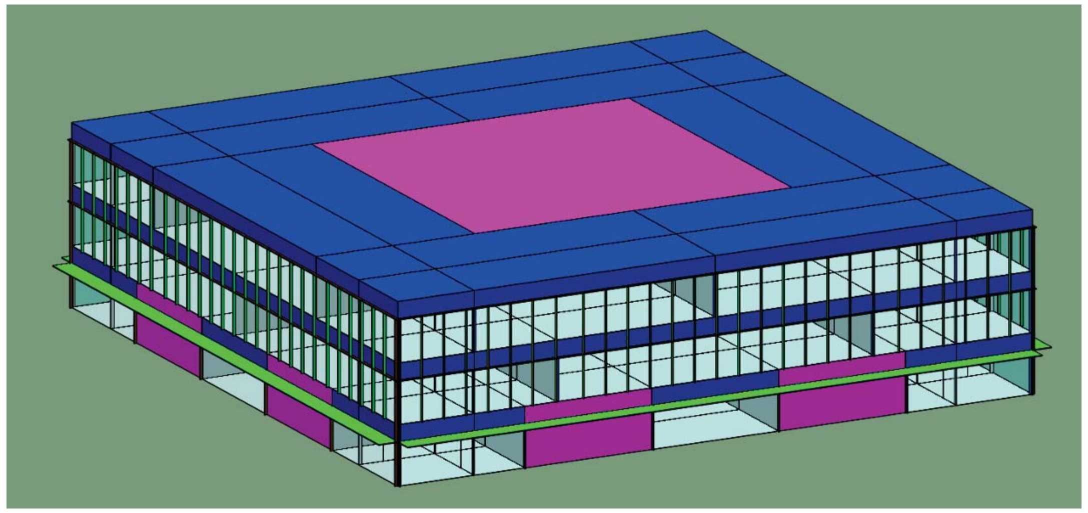


Figure 11—7 Non-residential shading elements

11.4.1 Example development plot

An example development block has been chosen to represent a single development plot that could be brought forward within the OPDC area. Typical development will review all permutations that could occur, to ensure the modelling outcomes can be applied to any development situation.

Unit numbers (approximately 500) and areas have been based on this example plot. Specific floor arrangements, unit types and locations are not considered. The example plot includes several non-residential use types, including retail, office, Cinema and cafes/restaurants. For the purposes of this study, the total non-residential floor space ~4,000 m^2, has been assumed to be offices or retail.

As per the modelling procedure, all permutations of orientations, unit types, balcony types and glazing ratios have been modelled parametrically. This then makes the analysis findings in section 12.1 applicable to development in the OPDC area.

Unit numbers and commercial floor areas are outlined as follows. These have been used to develop the following:

- Total capital costs of development (within cost scoping)
- Peak plant sizing and costing of communal or individual heating and cooling systems
- Renewable energy potential onsite
- Lean block averaging
- Total development cost of Lean, Clean and Green measures
- Cost of Zero Carbon

Table 11—2 Example plot unit numbers by element used 'typical development' analysis

Block	Element type	Floors in element	units per floor	No. blocks in plot	units by element	Total Units
1	Tower	24	7	1	168	144
	Tower Shoulder	5	12	1	60	60
2 - 6	Adjacent shoulder	10	6	5	60	300
Total units		29			288	504

Table 11—3 Example plot unit sizes and orientations used 'typical development' analysis

Dwelling Aspect	1 Bed total	2 Bed total	3 Bed total	Total units	% by aspect
Single aspect	103	68	0	171	34%
Dual Aspect	79	116	139	334	66%
Total units	182	183	139	504	-
% by size	36%	36%	28%	-	-

Table 11—4 Commercial sizes and orientations used 'typical development' analysis – total non-residential areas used for benchmarking

Commercial unit Aspect	Office		Retail	
	Tenant Spaces	Area (m^2)	Tenant Spaces	Area (m^2)
Single aspect	4	1225	16	1560
Dual Aspect	4	1213	4	380
Total units	8	2438	20	1940
% of total area		56%		44%

Figure 11—8 Example plot section and layout showing block types represented

11.5 Definition of shaded and exposed locations within the modelling

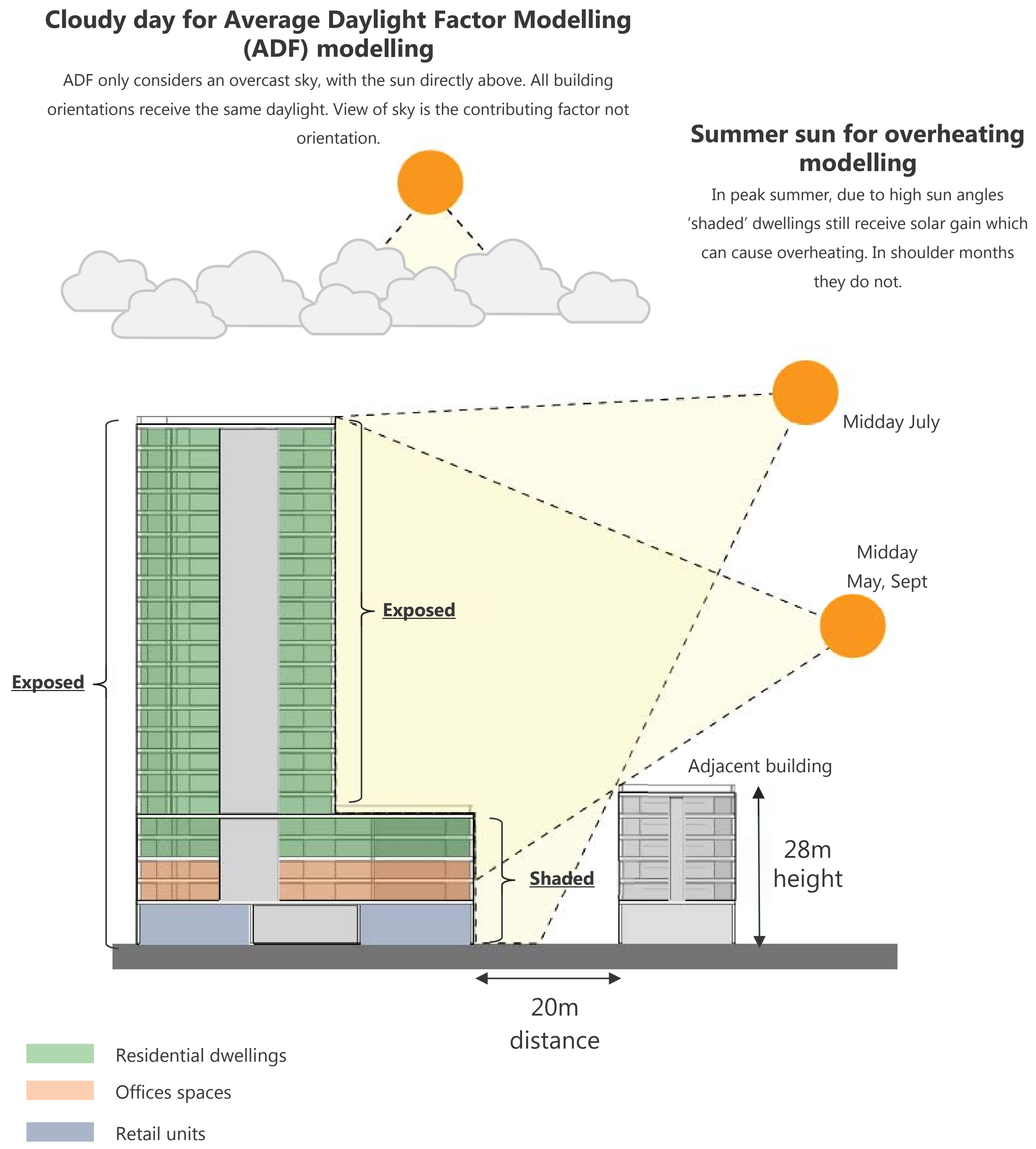
The analysis takes into consideration several massing considerations that could across the masterplan. One that is considered most significant is whether a unit/space is ‘shaded’ or ‘exposed’. For the purposes of the study, these two conditions are referred to in these terms going forward.

Figure 11—9 outlines the definition of these two conditions along with the implications for daylighting and overheating.

‘Shaded’ conditions meaning a unit or dwelling has a building directly opposite and adjacent which is higher than the space’s location. This could either be across a road, internal courtyard or a tower element, as per Figure 10—8, to the south of a development.

This arrangement partially blocks out the view of the sky, which reduces daylight. It also leads to partial shading from direct sun. However high solar angles from the summer sun, May to September, can penetrate between buildings and can cause overheating, even in ‘shaded’ locations. In effect, these are partially shaded and the amount of shading depends on the unit position, time of year and time of day.

The report outlines the impact on facade design requirements to meet daylighting in these locations, i.e. increasing glazing ratios, which can have an adverse impact on overheating. The study has examined the impact of solar heat gain to dwellings but not studied sunlight hours that may be required to meet other planning targets.



Cloudy day for Average Daylight Factor Modelling (ADF) modelling

ADF only considers an overcast sky, with the sun directly above. All building orientations receive the same daylight. View of sky is the contributing factor not orientation.

Summer sun for overheating modelling

In peak summer, due to high sun angles ‘shaded’ dwellings still receive solar gain which can cause overheating. In shoulder months they do not.

Figure 11—9 Definition of shaded and exposed locations with considerations relevant to daylighting and overheating modelling

12 Appendix B – Costing approach

12.1 Capital costs

Capital costs are based on a building with a concrete frame with solid floors and flat roofing. External walls would comprise a masonry inner leaf, insulation and brickwork cladding. Some of the assumptions made in the cost modelling are as follows:

Inclusions and exclusions
• The costs used are supply and install rates. • Consequential impacts on other parts of the building accounted for, for example; the impact of element thickness on building weight and foundations, etc.) • Costs do not include an allowance for preliminaries, design fees, builders work in connection, overheads and profits, contingency and VAT
Development / project / client factors
• The costs are based on a single project basis (i.e. do not assume any level of cost reduction for scale of project) • Costs are based on a London rates • No specific site factors (restricted access, height, unsociable working hours, congested location, etc.) have been taken in to account in the pricing
Age
• The costs presented are current (March 2018).

Further cost breakdowns can be found in Appendix K - Costing variables.

12.1.1 Sources of information

Reference capital costs for this study have been based on the internal cost database of Currie & Brown's QS specialists. These costs are 2018 representative and have been developed and updated with real-world cost information from live projects they are providing cost support on. These rates were cross-checked with peers and cross-referenced with third-party databases. These comparisons show that the presented costs are consistent with the cost ranges identified.

12.1.2 Wall build ups and insulation type implications

There are numerous construction build-ups which can be used for the thermal envelope, depending on a wide range of design and structural considerations. Within this research, the variable of interest was the U-value. While all construction elements have a thermal resistance, to a greater or lesser degree, the main factor which contributes to the overall U-value is the type and thickness of insulation material. As such, it was the insulation thickness which was varied between different specifications, giving rise to cost variations between U-values, whilst other elements remained constant.

Mineral wool has been chosen as the insulation material, given the current market trend towards that product.

12.1.3 Polyisocyanurate (PIR) vs mineral wool

This research has been conducted within a construction climate where the effects of the Grenfell tower block fire are still being felt. At the time of writing, the market has swung strongly away from polyisocyanurate (PIR) insulations (the type installed on the Grenfell tower) and heavily towards mineral wool.

Mineral wool is currently viewed as preferable due to its more inert properties compared to PIR products, despite its thermal performance not being as good. The reduced thermal performance is acceptable given the current uncertainty surrounding the appropriate application of PIR.

It is expected that the PIR market may recover in time, as developments in the technology address the concerns the market currently has. How long this will take, until it is deemed a suitable application for high rise, is currently unknown.

Therefore, given the current state of the market, and the unknown length of the downturn, mineral wool insulation has been used as the insulation of choice in this study.

In the future, if/when PIR (or other high-performing, thinner, insulation products) become the norm again on high-rise developments, then thinner wall build-ups compared to mineral wool will be possible.

Although higher performing (thinner) insulation products are typically more expensive, they facilitate the construction of thinner walls, which have a number of knock-on benefits, such as requiring reduced foundations and smaller components such as wall ties, lintels, cavity closers and the like. This offsets the additional cost of the higher specification insulation.

There is also the consideration of the impact on net lettable area (NLA). If a development is being constructed on a constrained site, the increased wall thicknesses would have a negative impact on NIA, which means a reduction in the sale value of completed units.

The Old Oak Common and Park Royal sites do not have these constraints (they are expansive sites), so it is expected that net lettable area will not be negatively affected as the response would be to build outwards – i.e. have a larger footprint for the same floor area.

12.2 Life Cycle Costing

12.2.1 Fabric

The primary focus of this work is in testing the variables associated with different fabric measures, rather than services or Low and Zero Carbon (LZC) technologies, in order to achieve higher standards of energy performance. Fabric elements are typically designed and specified to meet the expected lifespan of the building. As such, there is little impact (within the scope of this study) on Life Cycle Costs of fabric elements, beyond the associated reduction in energy consumption due to higher levels of performance.

A variation in LCC would only occur if a change in thermal performance necessitated a different building system to be utilised. For the purposes of this study, we have assumed that the heating system remains consistent, communal gas boiler, and that the thermal performance (i.e. the level of insulation) is the variable. This is as it aligns with the current GLA guidance for preparation of energy statements.

12.2.2 Services

The area where lifecycle costs are most relevant is in the design and specification of building services. These typically have an expected lifespan far less than the building lifespan and, as such, will be replaced several times over the lifetime of a facility. During their lifespan they require continual operational maintenance and repair, to a greater or lesser degree. They also directly affect energy consumption and utility costs based on the technology and fuel source.

Given these variables it is important to assess the lifecycle costs of different services options to determine the most economically advantageous for a particular scheme. The LCC analyses is conducted in accordance with the principles prescribed within *ISO 15686:5 Buildings & constructed assets – Service life planning – Part 5: Life cycle costing*, taking in to account the following cost areas:

- Construction costs: These are typically obtained from the QS cost plan. These are construction costs only, and typically excluded costs associated with O&M Manuals, Security & Logistics, Notices, Consumables, ICT, VAT, insurances, rents, rates, inflation, currency risk and contingency.

- Maintenance costs (Hard FM): These include cyclical replacement of building components at the end of their serviceable life. Maintenance costs also include reactive maintenance activities anticipated during the study period of the LCC.
- Operational costs (Utilities costs)
- End of life: These can be considered, but are typically beyond the period of analysis assessed in most LCC’s.

13 Appendix C - Analysis findings

This section outlines the three different modelling analysis types of both non-residential and residential typologies. The final section outlines the requirements for balancing of the three and proportion of the modelling undertaken that achieves all three KPIs.

13.1 Impact of design measures on energy performance

13.1.1 Lean modelling performance overview

Figure 13—1 is a cumulative distribution graph showing the distribution of carbon savings (compared to Notional) for all the space types analysed. The solutions that don't pass Part L are excluded from this representation, as these would not be implemented in reality. By selecting a CO_2 reduction target (% improvement on TER) on the horizontal axis and finding the point at which each of the lines cross this CO_2 reduction target, the percentage of models which exceed this target can be identified. CO_2 reduction targets which have a small fraction of models passing mean that only a small set of parameter combinations modelled will meet this target. CO_2 reduction targets which have a greater proportion of models passing mean that a broader set of parameter combinations can meet this target, i.e. designs can be more flexible.

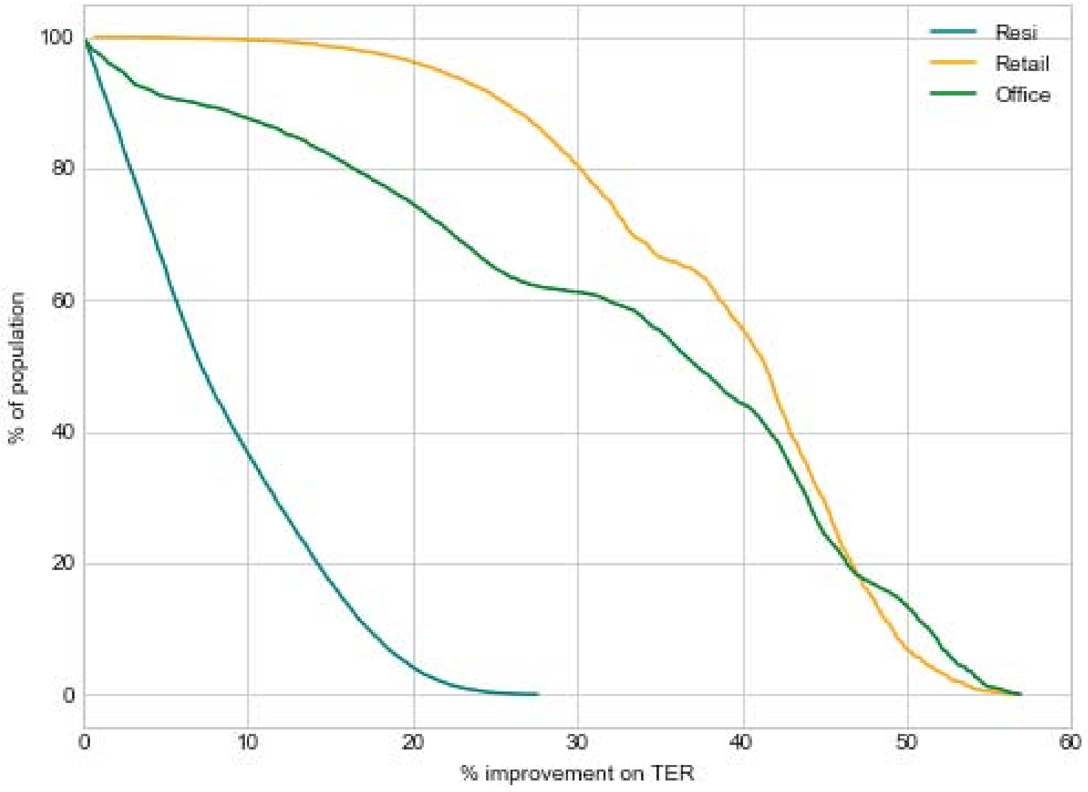


Figure 13—1 Cumulative distribution of carbon savings over Notional for residential and non-residential spaces analysed

It can be observed that approximately 37% of the residential models show carbon reductions above 10%. Higher carbon savings are observed for non-residential spaces, with 98% of retail and 82% of office spaces achieving at least 15% carbon reduction.

13.1.2 Residential Lean Analysis

The carbon improvement over the TER for all the spaces modelled is shown in Figure 13—2. The vertical axis represents the probability density, meaning that the sum of bar heights multiplied by bar widths equals 1 (or 100% of the population shown). The area of histogram between each of the segments represents the proportion of the results modelled which have TER improvements in each of these ranges. This shows that the maximum percentage improvement over TER is 27%. Of all the design specifications tested, 57% pass Part L (i.e. are right of the >0% line).

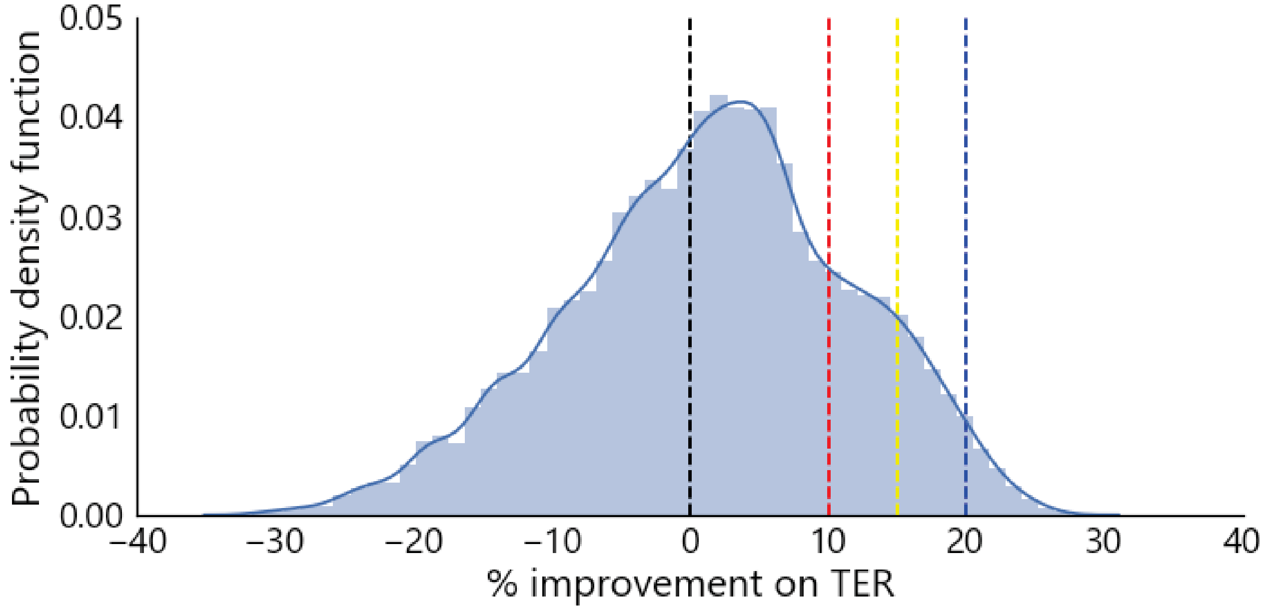


Figure 13—2 Distribution of carbon improvement over TER over the whole residential dataset (coloured bands denote the segments of the dataset above each of the thresholds in Table 13—1)

1.1.1.2 Residential Energy demands

Table 13—1 shows the energy demand breakdown corresponding to each CO_2 reduction band. It can be observed that a reduction in annual space heating demand is primarily responsible for the improvements in lean CO_2 savings. The increase in auxiliary demand with CO_2 savings shows that a switch from MEV to MVHR (which requires increased fan energy) is contributing to this reduction in space heating demand. It also shows that units with a larger floor area typically have the greatest CO_2 savings per m^2.

Table 13—1 Average residential energy demand breakdown by carbon improvement

% Lean CO_2 reduction over notional building	Annual space heating demand (kWh/m^2)	Annual domestic Hot Water demand (kWh/m^2)	Annual auxiliary demand (kWh/m^2)	Annual lighting demand (kWh/m^2)	Average unit floor area (m^2)
<0% (failing Part L)	21.7	30.4	1.0	4.5	67.3
0-10%	13.5	30.9	1.2	4.5	65.7
10-15%	7.4	31.3	1.7	4.5	64.4
15-20%	5.2	30.7	1.7	4.5	66.2
>20%	4.1	29.3	1.8	4.4	70.4

13.1.3 Residential Analysis outcomes

The following histograms show the distribution of percentage improvement on TER (percentage reduction on CO_2 savings compared with the notional building). The effect of a design variable on the distribution of results is shown in each plot, demonstrating the improvement which a particular measure can have in reducing CO_2 emissions.

The choice between MEV and MVHR systems is the most significant factor influencing residential CO_2 reductions against the notional building, this is shown in Figure 13—3. Only a negligible set of design parameters with MEV achieve greater than 10% reduction on CO_2 emissions against the notional building.

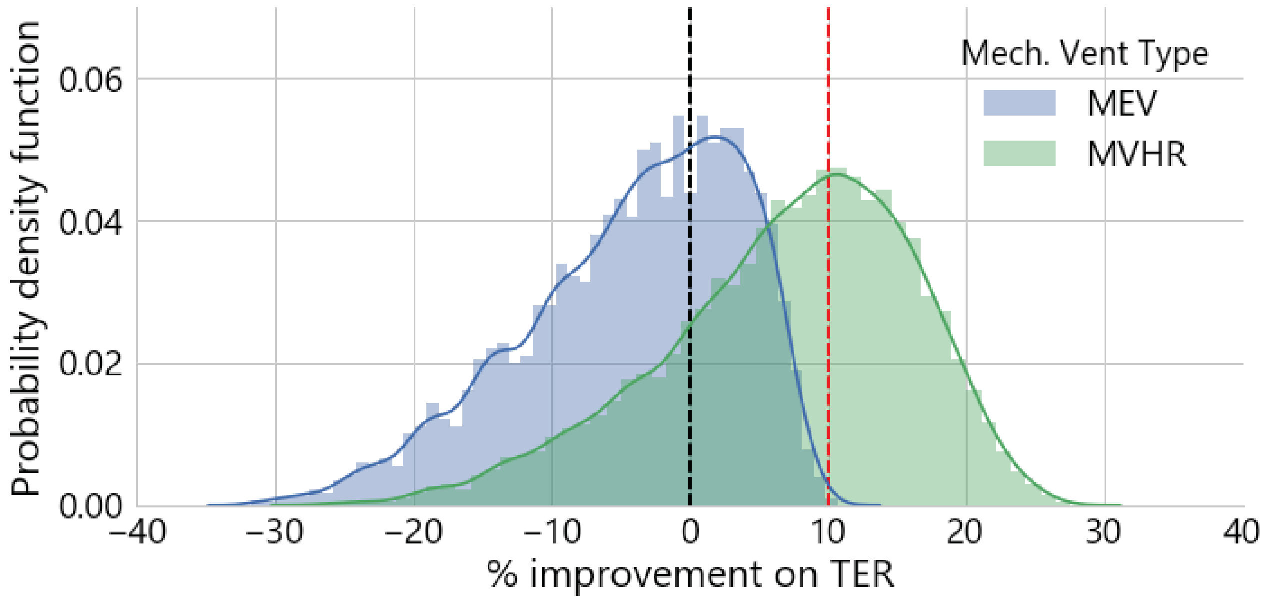


Figure 13—3 Effect of MEV vs MVHR on residential carbon emissions

Glazing U-value (or the choice between double and triple glazing) is significant factor, this is shown in Figure 13—4, in the high glazing ratio set of dwellings it is more significant in reducing CO_2 emissions than MVHR.

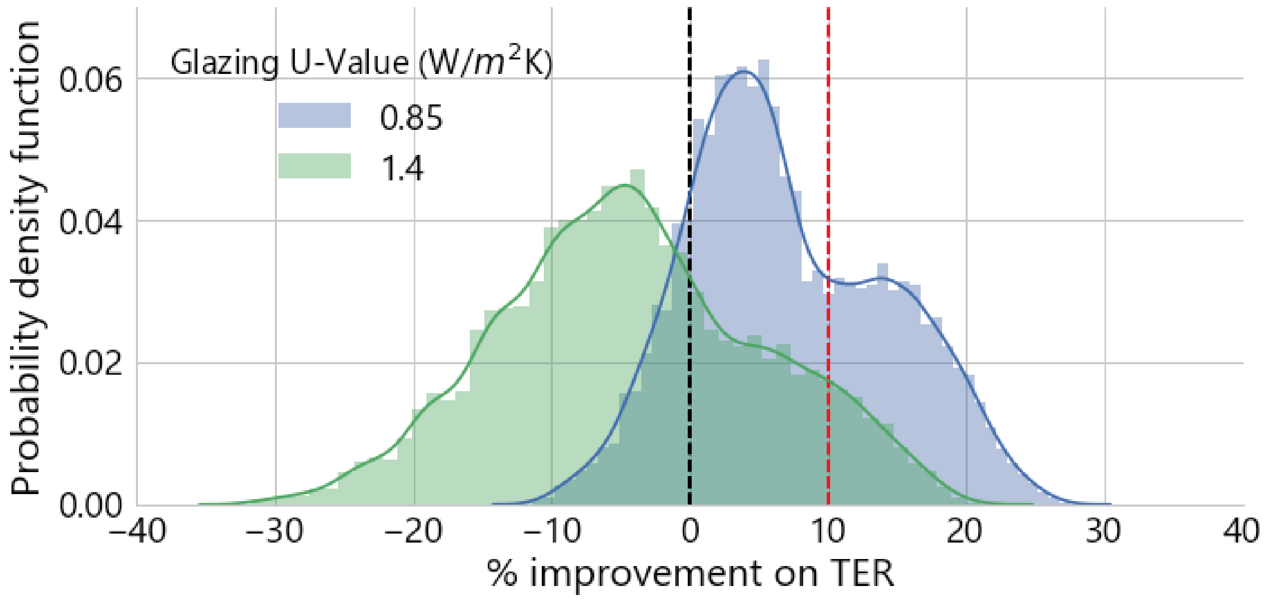


Figure 13—4 Effect of going from double to triple glazing (full frame U-value 1.4 to 0.85) on residential carbon emissions

Figure 13—5 shows that on average, a single aspect dwelling has a 5.5% reduction in CO_2 emissions in comparison with a dual aspect dwelling.

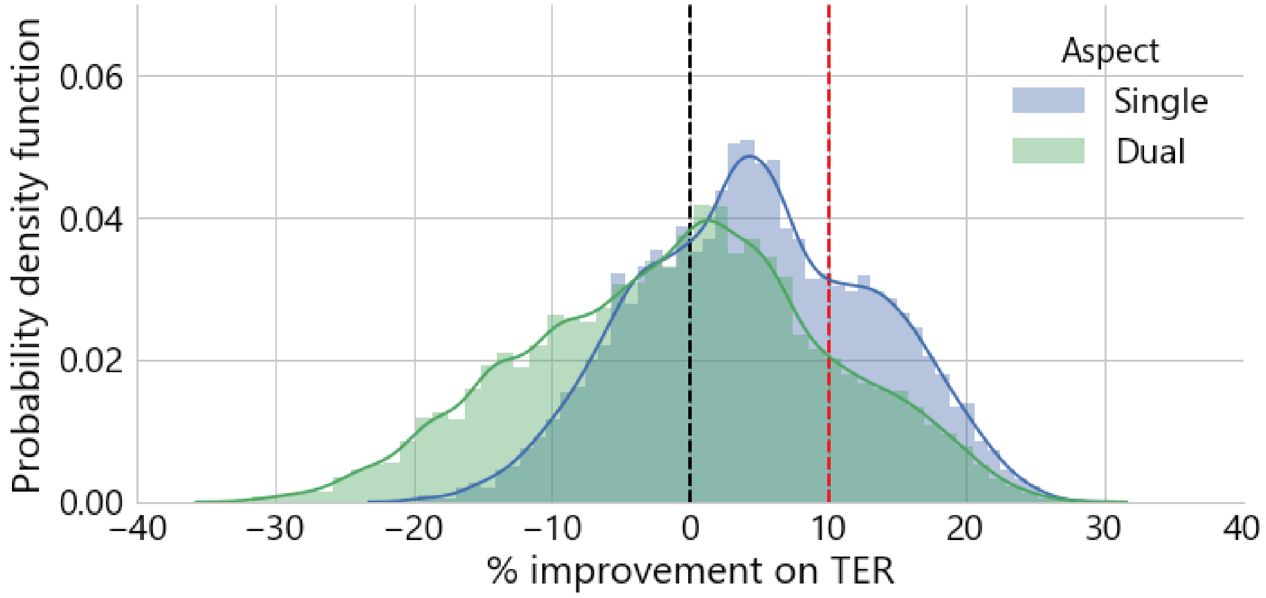


Figure 13—5 Difference in residential carbon emissions between single and dual aspect units

In the design process, default values can be assumed for thermal bridging, or the conductivity of each individual thermal bridge can be calculated. Going from default to calculated thermal bridging results in an average reduction in CO_2 emissions of 3.7% as shown in Figure 13—6.

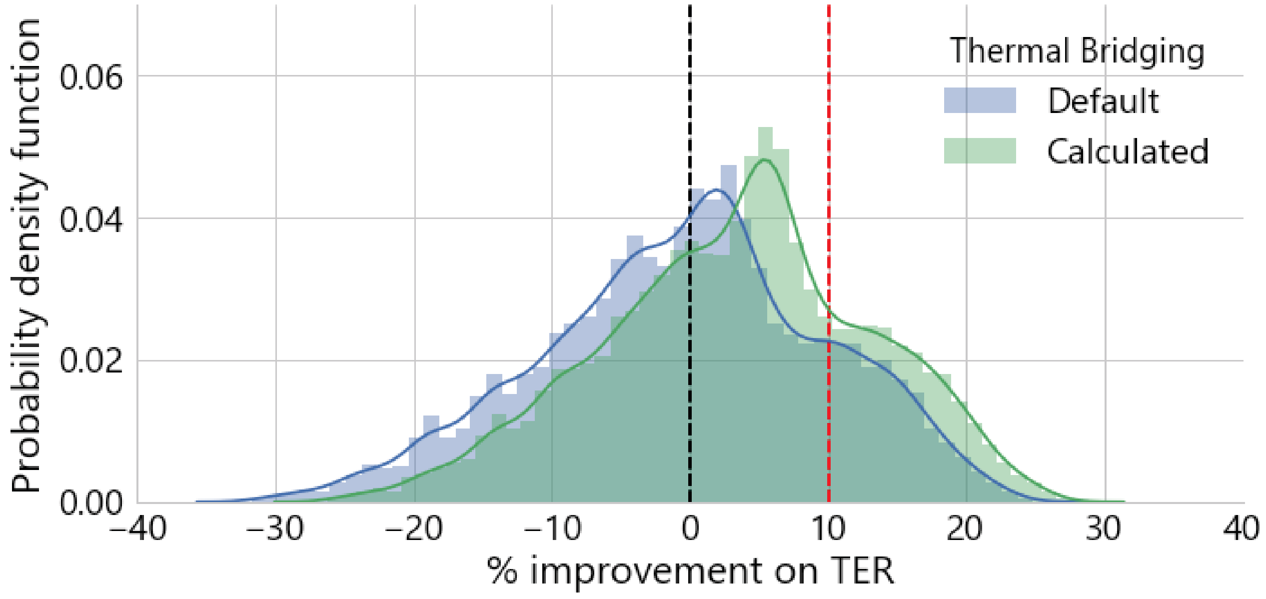


Figure 13—6 Difference in residential carbon emissions between Default thermal bridging and calculated thermal bridging

Airtightness is a significant factor, resulting in a 6% reduction in CO_2 emissions against the notional building on average, this is shown in Figure 13—7.

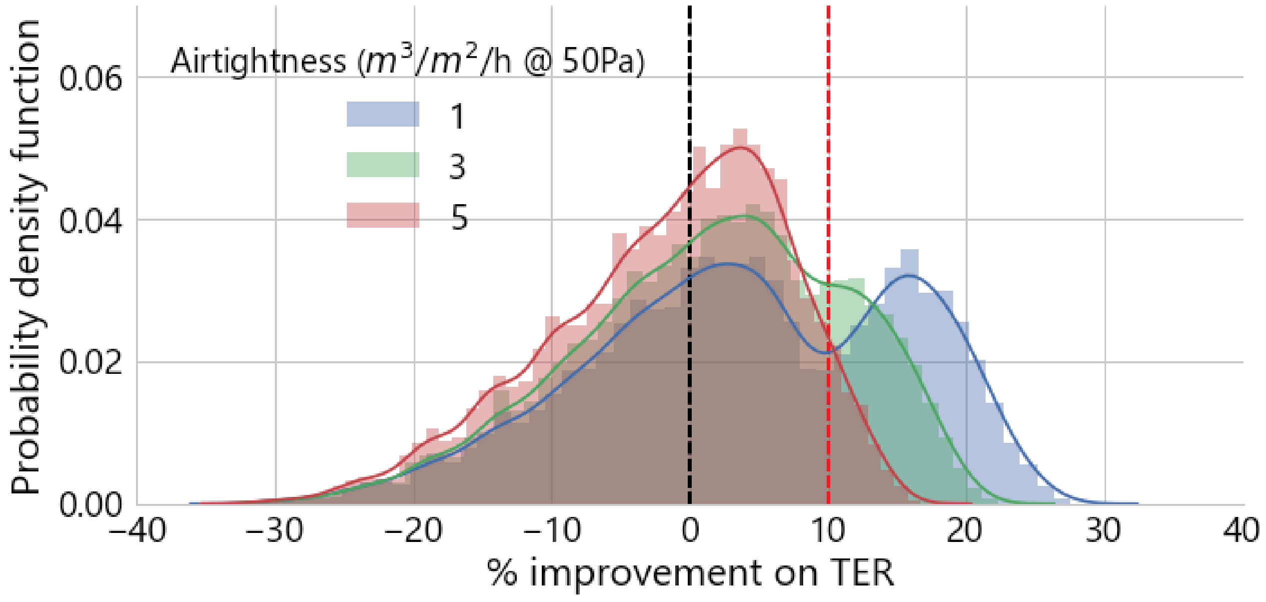


Figure 13—7 Difference in residential carbon emissions between units with airtightness of 5 and 1 (m3/m2/h at 50Pa)

13.1.4 Costing implications

Figure 13—8 shows the cost variation for each dwelling parameter costed for this analysis. Each coloured box represents the distribution of the cost of each parameter analysed. The spread of each coloured box represents the middle 50% of the dataset (i.e. the majority of costs lie within this range), the line in the middle of each box represents the median cost and the tails represent cost extremes. Large boxes represent cost items for which value varies significantly across the dataset (i.e. wall U-value, Glazing U-value and ventilation system). Items which appear high on the vertical axis (i.e. heating plant) represent a large proportion of the total dwelling cost; in the case of heating plant, there is no variation as this parameter was not varied as part of this analysis.

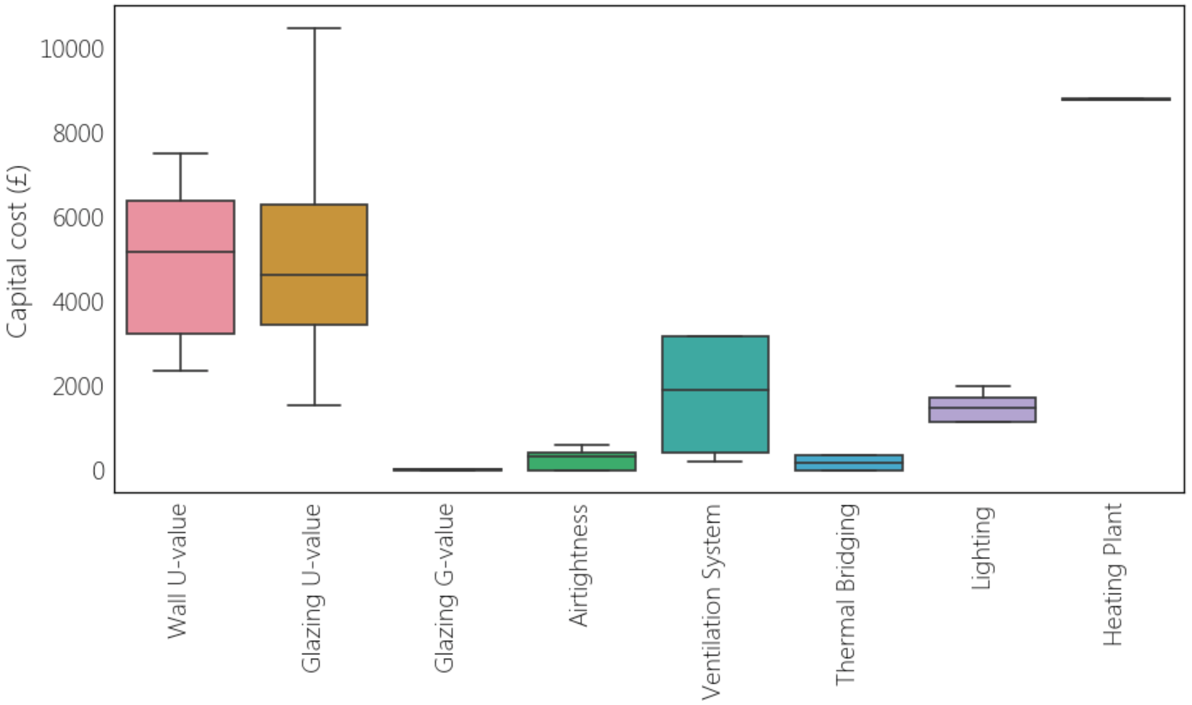


Figure 13—8 Cost ranges of fabric and system parameters analysed (per residential unit)

It can be seen that improving wall U-value (from 0.18 W/m2 to 0.12 W/m2), reducing glazing U-value (going from double to triple glazing) result in significant cost swings; this is because these parameters are a factor of wall area and glazing ratio which vary significantly between 1 and 3 bed units. Changing ventilation system from MEV to MVHR results in a significant cost uplift, but is highly effective at reducing emissions. The cost of airtightness testing is comparatively low, however, it may result in programme delays. Thermal bridging cost is comparatively low, calculating thermal bridging can bring significant CO_2 reduction at a low cost if it is considered early in the design process.

13.1.5 Residential technical and developer considerations

Figure 13—9 shows that of the units which meet Part-L requirements, the following improvement thresholds have been met across the ranges of variables tested:

- 36.6% of passing dwellings modelled achieve a 10% improvement on TER
- 17.1% of passing dwellings modelled achieve a 15% improvement on TER
- 4.1% of passing dwellings modelled achieve a 20% improvement on TER

This means that only a narrow subset of options modelled can achieve a 20% target. With the highest performing fabric and systems parameters modelled, some dwellings can only meet a 20% target for certain orientations. Limiting designers to this extent is likely to be prohibitive and would severely restrict architecture. A 10% improvement on TER is deemed to give design flexibility (a large set of fabric, architectural, and systems combinations can be used to meet the target) whilst pushing CO_2 reduction targets from the Part L pass mark.

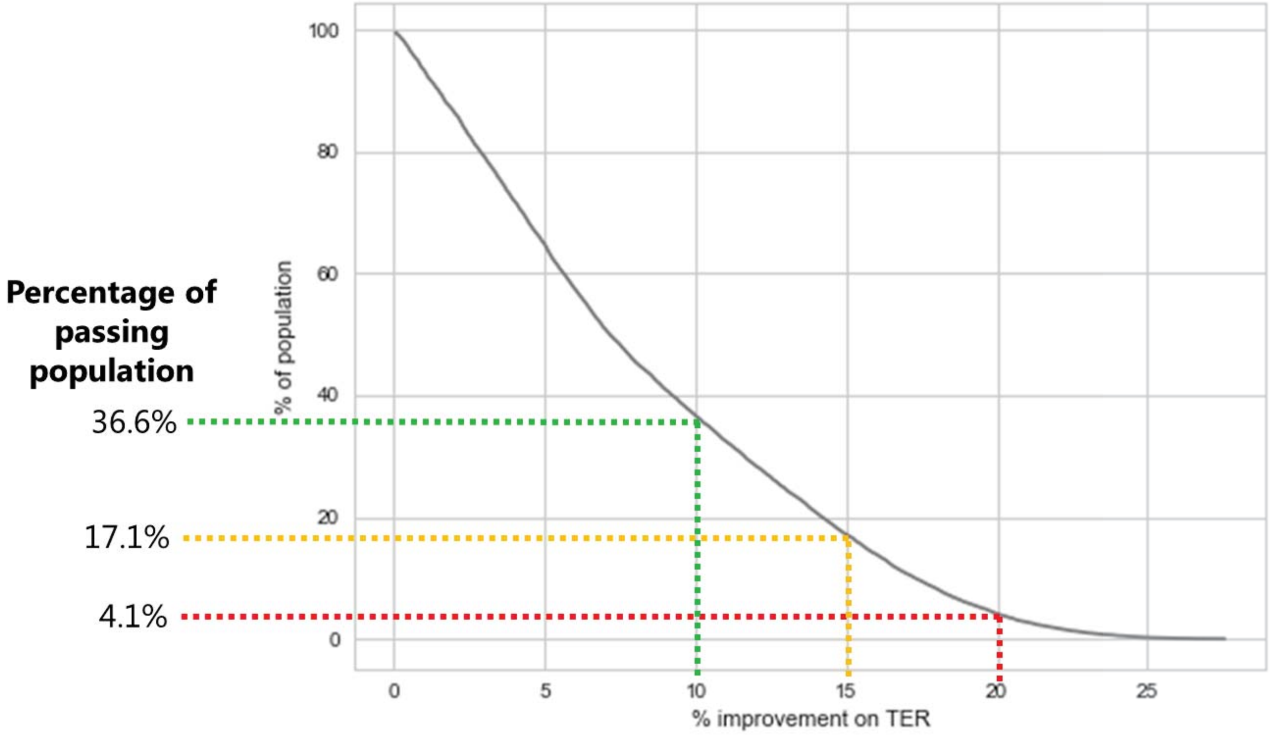


Figure 13—9 Cumulative frequency diagram showing the percentage of passing units achieving 10, 15 and 20% TER reduction threshold

Residential technical buildability considerations

Table 13—2 shows the expected combinations of design solutions required to meet the TER reduction thresholds shown in Figure 13—9.

Table 13—2 Technical and buildability considerations for meeting TER reduction targets

Policy Target	Technical considerations	Developer buildability considerations
0-9.9% lean reduction	• Triple glazing in majority of units • MVHR in 50% of cases	• Airtightness testing for 10% of units (half day per unit)
10-14.9% lean reduction	• 36.6% of passing units modelled achieved >10% lean reduction • Triple glazing in majority of units • MVHR in all units • Airtightness <3	• Airtightness testing for all units (half day per unit)
15-20% lean reduction	• 17.1% of passing units modelled achieved >15% lean reduction • Triple glazing in all units • MVHR in all units • Airtightness <1 • 550mm thick walls	• Airtightness testing for all units (1 day per unit) • Prefabrication key to density
Passivhaus certification	• 4.1% of passing units modelled achieved >20% lean reduction • Triple glazing • 550mm thick walls • MVHR • Airtightness < 1 • Glazing ratio 35% (window/wall)	• Passivhaus certified – only 2 major contractors • Prefabrication key to density • Post-occupancy performance requirements

13.1.6 Non-Residential Lean Analysis

The carbon improvement over the TER for all the spaces modelled is shown in Figure 13—10. The two peaks observed correspond to poor and best-practice lighting design cases, showing that lighting energy consumption has a great impact on overall carbon emissions. Both office and retail spaces can hardly pass Part L when poor lighting is specified. Poor lighting is here defined as a luminaire efficacy of 60lumen/W (equivalent to Notional) and no photoelectric or occupancy controls. Large carbon reductions can be achieved when good lighting design is implemented, in some cases exceeding 40%. This is further explanation regarding the impacts of lighting specifically see Figure 13—11. The models simulated have results spanning between -60% to +60% improvement on TER; these extremes represent the best and worst combinations of fabric, architectural and systems parameters in the parametric study.

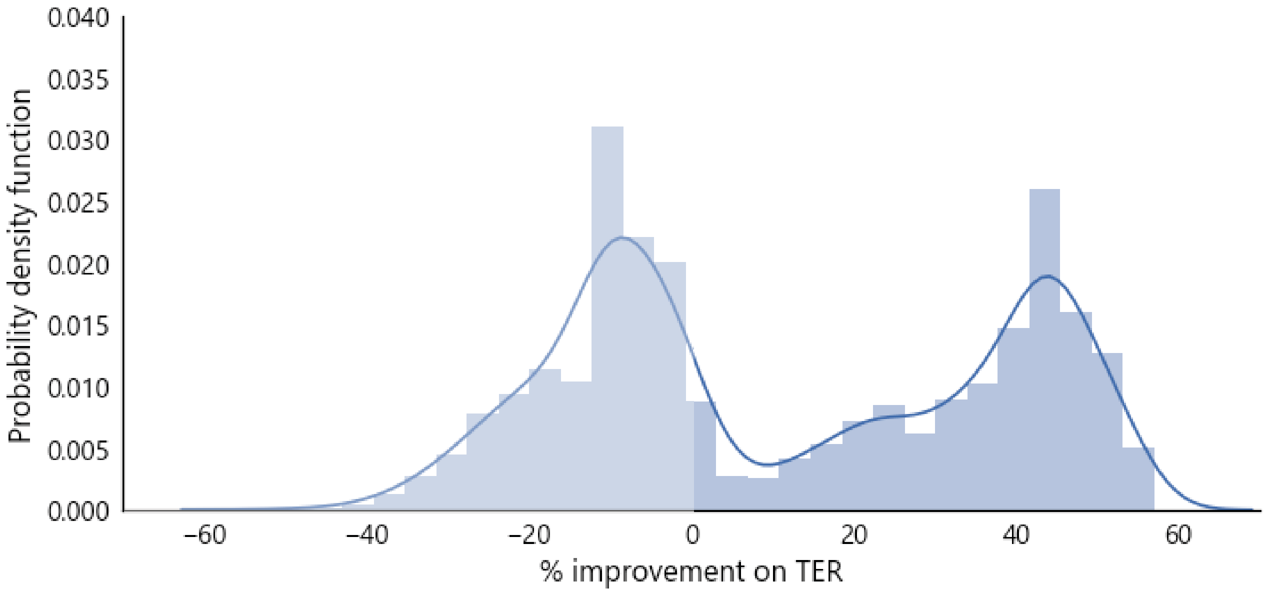


Figure 13—10 Distribution of carbon improvement over TER over the whole non-residential dataset

13.1.7 Non-Residential Energy demands

Table 13—3 shows the energy demand breakdown corresponding to each carbon improvement band. As energy demands can be very different depending on the cooling system used, these have been split in fully conditioned, mixed mode and naturally ventilated cases. It can be observed that mixed mode and naturally ventilated spaces present only carbon improvement in the low and very high end of the spectrum. This is due to the shift in carbon savings produced by moving from a poorly efficient lighting system to a best-practice one. The same shift occurs in fully conditioned spaces, however with lower overall carbon savings.

Table 13—3 Non-residential energy demand breakdown by carbon improvement

Average development at % Lean reduction	Space heating demand (kWh/m²)	Domestic Hot Water demand (kWh/m²)	Auxiliary demand (kWh/m²)	Cooling Demand (kWh/m²)	Lighting demand (kWh/m²)	Unregulated demand (kWh/m²)	Total Primary Energy consumption (kWh/m²)
Fully conditioned							
<0%% (failing Part L)	2.8	2.4	19.5	54.5	41.1	33.5	153.8
0-10%	3.1	2.8	21.8	51.7	10.1	40.8	130.3
10-15%	3.8	2.8	19.8	43	10.9	40.1	120.4
15-20%	3.9	2.7	18.9	38.6	12.2	38.6	114.9
20-30%	4.5	2.4	18.8	34.9	17.1	32.8	110.5
>30%	5.4	1.7	18.8	30.8	28.1	20.3	105.1
Mixed mode							
<0%% (failing Part L)	4.4	2.4	4.9	0	41.6	33.3	86.6
0-10%	2.1	2.9	4.6	0	25.4	42.2	77.2
10-15%	NA	NA	NA	NA	NA	NA	NA
15-20%	NA	NA	NA	NA	NA	NA	NA
20-30%	14.8	2.9	4.6	0	9.1	42.2	73.6
>30%	7.2	2.4	4.9	0	16.7	33.3	64.5
Naturally ventilated/cooled							
<0%% (failing Part L)	4.9	2.3	1.1	0	44	32	84.3
0-10%	1.5	2.9	1.1	0	25.9	42.2	73.6
10-15%	NA	NA	NA	NA	NA	NA	NA
15-20%	NA	NA	NA	NA	NA	NA	NA
20-30%	NA	NA	NA	NA	NA	NA	NA
>30%	7.3	2.4	1.1	0	16.6	33.4	60.8

13.1.8 Non-Residential Analysis outcomes

The analysis has shown that there are a number of key drivers of carbon performance in non-residential spaces. Although the absolute carbon emissions of office and retail spaces can be different, the drivers and trends observed are applicable to both typologies.

Key drivers and considerations drawn from the analysis results are the following:

1. Lighting is the main contribution to carbon emissions. Shifting from poor lighting (equivalent to notional specifications but without lighting controls) to best practice lighting design (with high efficacy and daylight/occupancy controls) produces a 50% reduction in CO_2 emissions compared to notional.
2. Naturally ventilated offices and retail units tend to perform better than fully conditioned ones. This is mainly due to the fact that reductions in lighting carbon emissions are more important in naturally ventilated spaces than in conditioned ones (as there are no cooling and little auxiliary carbon emissions).

In naturally ventilated spaces;

3. When the building is naturally ventilated, heating is the second most important contribution to carbon emissions after lighting. Therefore, improving fabric (triple glazing, low wall U-value) and using higher g-values have a positive impact on carbon savings.
4. Naturally ventilated spaces with best practice lighting achieve carbon reductions above 30% with a range of orientations, shading conditions or fabric used. If poor lighting is in place, instead, the spaces will have difficulty complying with Building Regs Part L; in order to pass Part L (and therefore achieve positive carbon reductions) in this case, high-performance fabric (triple glazing and low wall U-value) are required, as well as glazing g-values of at least 0.4.

In conditioned spaces:

1. In conditioned spaces, auxiliary and cooling consumption are the main contribution to carbon emissions together with lighting. For this reason, measures to reduce carbon savings are those that reduce solar gains inside the space (conversely to the naturally ventilated case). These include lower g-values, lower glazing ratios and installing shading.
2. Fully conditioned spaces don't achieve any carbon savings over notional if poor lighting is specified. Poor lighting design has a negative impact on both lighting energy and cooling demand, therefore increasing considerably the carbon emissions.
3. In conditioned spaces, it is important that solar gains are reduced in dual aspect spaces. Even when best practice lighting is specified, if the spaces are unshaded by surrounding buildings, low g-value or shading elements have to be considered in order to achieve a carbon reduction of 20% below notional. This is particularly true in South-facing spaces, where unshaded buildings won't achieve 15% reductions unless low g-value (<0.4) or shading elements are considered.

Lighting is the biggest contribution to carbon emissions in non-residential developments. In the spaces modelled, lighting represents on average 70%-80% of total carbon emissions in naturally ventilated offices and retail, respectively; the contribution drops to 23%-41% in fully conditioned offices and retail space, while still being the most important single source of carbon.

Lighting specification and design therefore appears to be the main driver to reduce carbon emissions. The distribution of the evaluated carbon improvement over Notional for the two lighting specifications analysed is shown in Figure 13—11. This shows that introducing photoelectric and occupancy controls, as well as best-practice luminaire efficacy, can increase carbon savings by 50% (median). In addition, it can be observed that poor lighting design (no controls, low efficacy) prevents in most cases from passing Building Regulations Part L requirements. It should be noted that carbon performance impacts not only carbon emissions directly link with lighting energy consumption, but also cooling demand and in turn auxiliary consumption.

Only two iterations of lighting specification have been included with the scope of this analysis. A further study is recommended to review lighting design in non-residential typologies and their impacts on energy performance, as this is seen to be one of the most significant factors in carbon reduction.

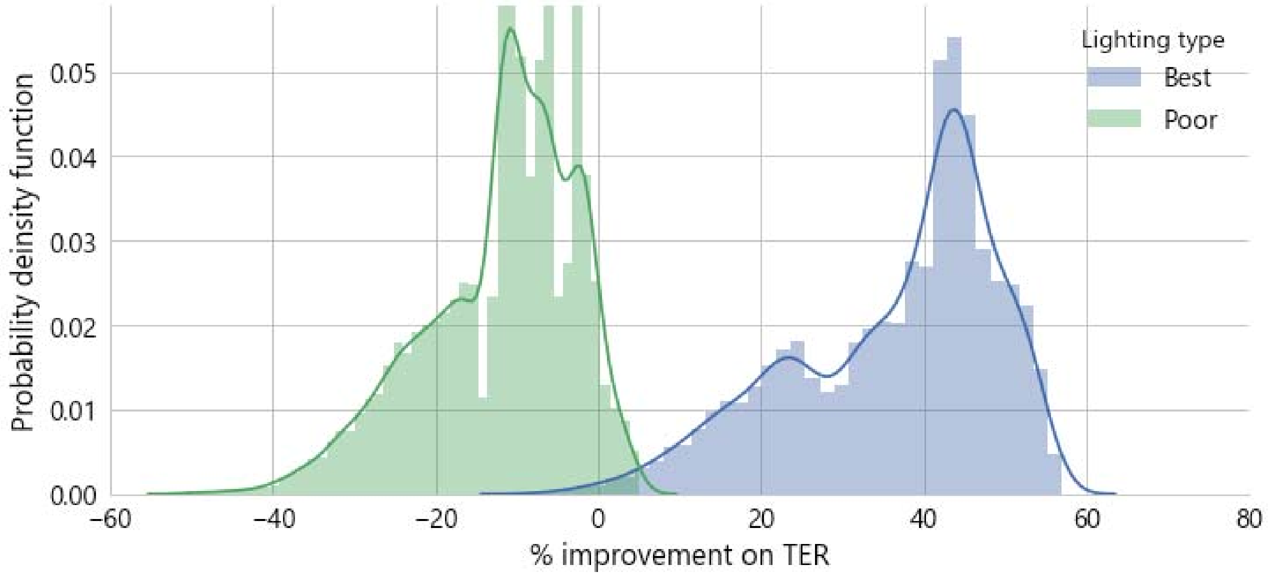


Figure 13—11 - Effect of lighting on non-residential carbon emissions

Modelling has shown that spaces where cooling is provided through natural or fan-assisted ventilation perform better than fully conditioned ones. This is due to the implementation of best-practice lighting, the carbon savings deriving from them become more significant in naturally ventilated spaces.

In fully conditioned spaces, auxiliary and cooling make up for significant portions of the total carbon emissions and their performance tends to be equivalent to or worse than notional. As shown in Figure 13—12, natural ventilation can increase carbon savings by 23% (median) compared to fully conditioned systems, while assisted ventilation can increase them by 20%. In addition, natural ventilation can have a great impact in reducing absolute carbon emissions, as cooling emissions are avoided and auxiliary emissions greatly reduced.

A further study is recommended to review the potential for natural venation in differing non-residential typologies and their impacts on energy performance, as this is seen to be the a significant factor in carbon and energy reduction.

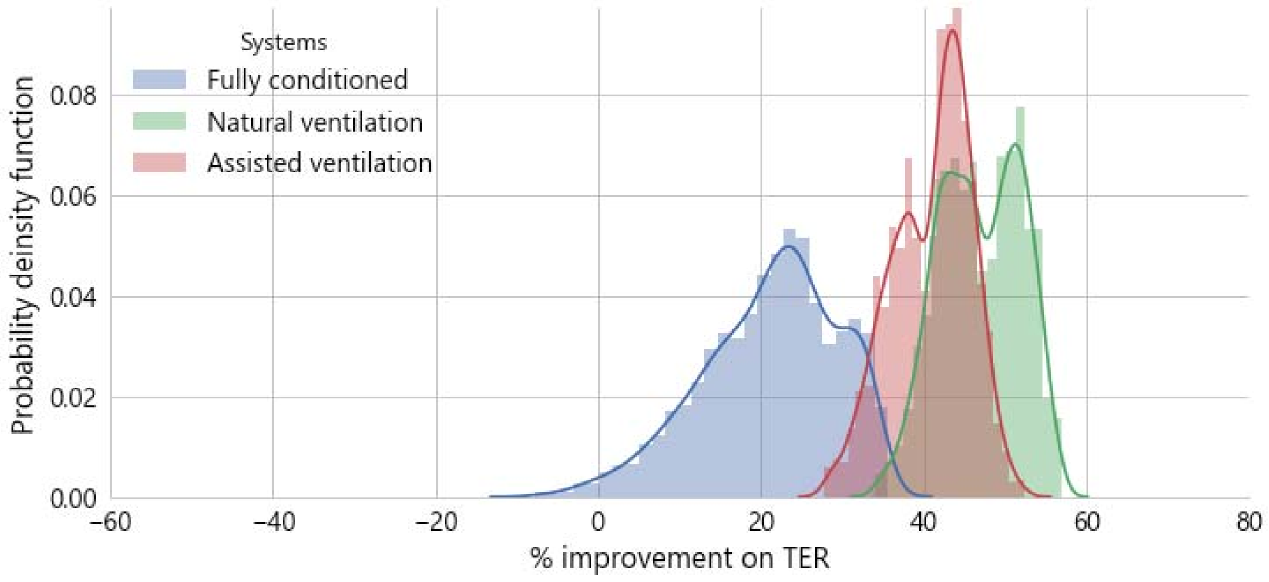


Figure 13—12 - Comparison between system types in non-residential carbon emissions (for best-practice lighting case)

Fabric can have different impacts on carbon depending on the system used. In naturally ventilated spaces, heating is, although small, the second most important contribution to carbon after lighting. For this reason, carbon emissions can be reduced through lower window and wall U-values, see Figure 13—13, and higher g-values. It should be mentioned, however, that increasing g-value has a small positive impact on carbon but can have a very negative effect on overheating risk; this will be further discussed in section 13.4.

For fully conditioned systems, cooling is a key driver to carbon performance. Reducing glazing g-value from 0.5 to 0.3 can increase carbon savings by 3.2% (median), see Figure 13—14.

Other parameters, such as glazing ratio, aspect and shading have shown limited effect on carbon emissions.

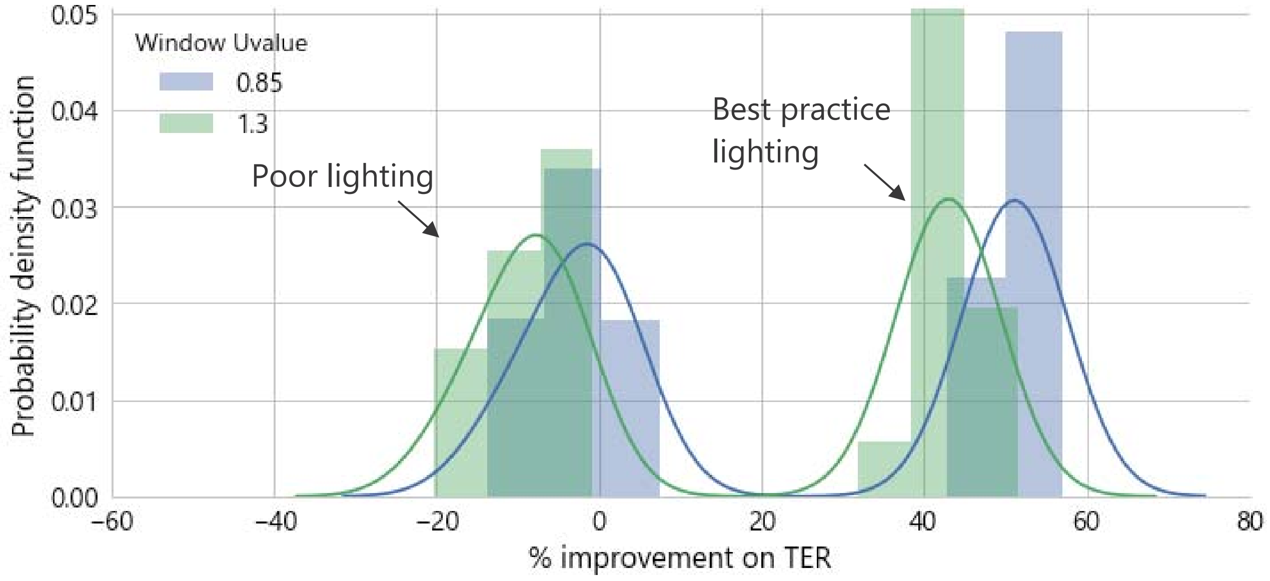


Figure 13—13 – Effect of Window U-value on naturally ventilated spaces

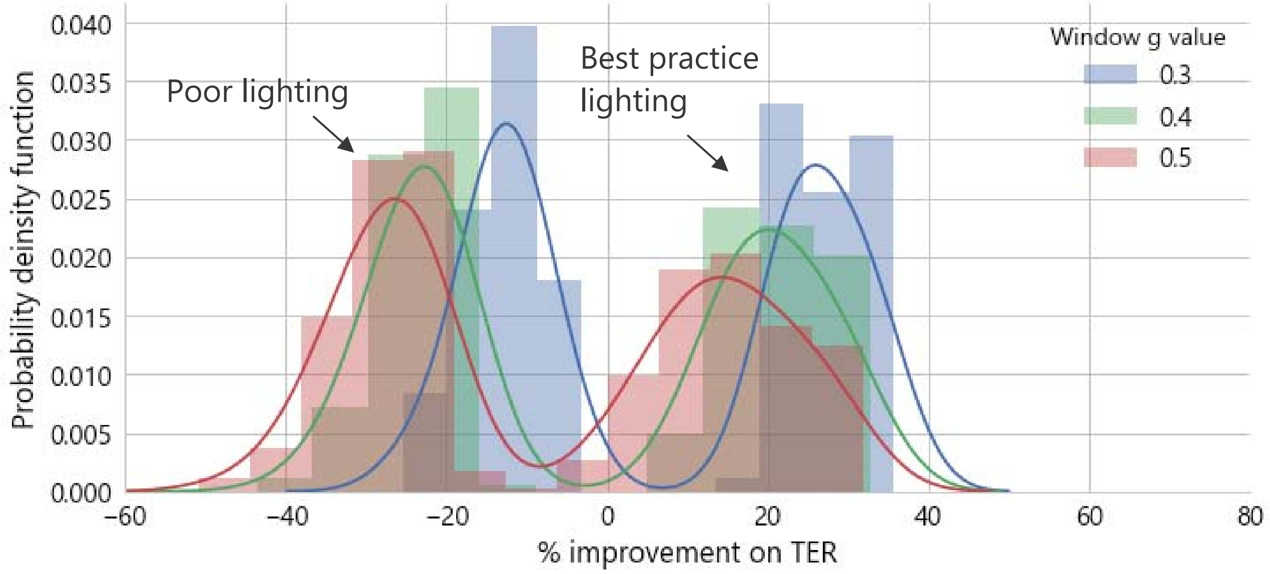


Figure 13—14 – Effect of window g value on fully conditioned spaces

13.1.9 Costing implications

The cost ranges of each parameter analysed can be seen in Figure 13—15.

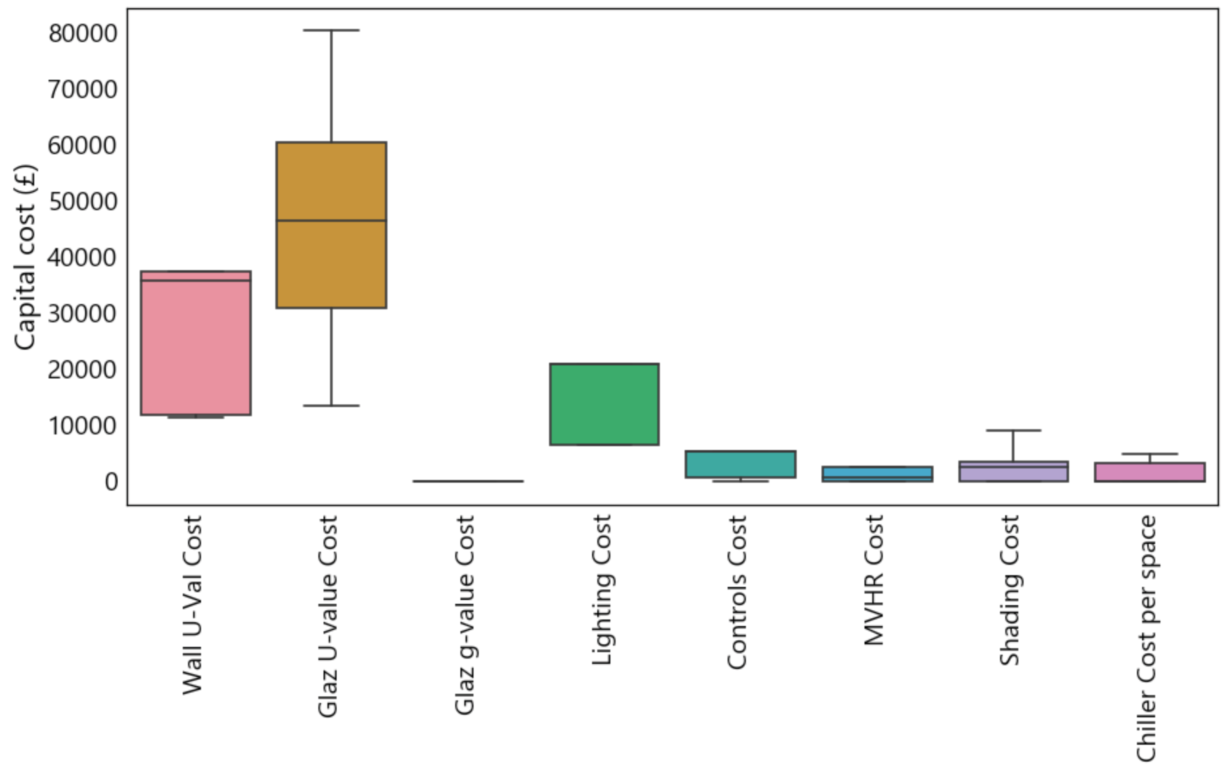


Figure 13—15 Cost ranges of fabric and system parameters analysed for office and retail

The costs associated with improving the lighting specifications from poor to best-practice design have been evaluated as the sum of costs to improve lighting efficacy and cost of introducing lighting controls. The increase in cost from poor to best-practice lighting are summarised in Table 13—4. In offices, where both photoelectric dimming and occupancy sensors are assumed to be installed, the cost of installing lighting controls dominate. Lower controls cost are expected in retail, where occupancy sensors are generally less applicable. Large variations in the glazing and wall U-value costs can be seen; the areas of wall and glazing vary greatly between single and dual aspect units, as well as between glazing ratios, which explains the high variability in these costs.

Table 13—4 Cost uplift from poor to best-practice lighting in non-residential

Typology	Controls Cost (£/m^2)	Lighting Cost (£/m^2)	Total lighting cost (£/m^2)
Office	17.4	12.0	29.4
Retail	8.8	11.0	19.8

Natural ventilation presents cost savings compared to conditioning the space, as no chiller or ventilation systems will be installed. Cooling is assumed to be emitted through fan coil units; however as fan coil units might be installed regardless for heating purposes their cost is not considered. Total cost savings amount to £25/m^2 for office and £43/m^2 for retail.

13.1.10 Non-residential technical and developer considerations

Policy Target	Technical considerations	Developer buildability considerations
10% lean reduction	• 92% of passing units modelled achieved>10% lean reduction • Good practice LED lighting	• Not particularly difficult to achieve this in non-residential • •
15% lean reduction	• 88% of passing units modelled achieved>15% lean reduction • Best practice LED lighting • Low g-value or shading elements when mechanically cooled and in unshaded locations	• In line with BREEAM Outstanding • Green Lease Agreements most likely required
20% lean reduction	• 83% of passing units modelled achieved>20% lean reduction • Best practice LED lighting and display lighting • Natural ventilation (free running) could be considered to increase savings	• Air quality issues – is natural ventilation appropriate for certain locations? • Close to railways, major roads may cause undue air quality issues internally and should be reviewed.
PassivHaus certification	• Triple glazing • 550mm thick walls • MVHR • Airtightness < 1 • Glazing ratio ~35%	• Post-occupancy performance requirements • Fabric could result in lower carbon performance overall as the space is cooling driven

Carbon savings in excess of 10% could easily be achieved in the considered non-residential spaces, as long as good-practice lighting design is used, with high efficacy LED lighting and some lighting controls implemented.

As the requirement increases to 15%, it is important to ensure that best-practice lighting is specified. If the spaces are delivered as shell and core units, this might entail that Green Lease Agreements are required to make sure that the specified level lighting efficiency is implemented by the tenants. In addition, in mechanically cooled spaces attention should be given to reduce cooling loads, especially in south-facing exposed locations, through low g-values or shading elements.

Carbon savings of the order of 20% are feasible in most cases modelled. In order to increase carbon savings, natural ventilation might be considered. This should be reviewed on a case-by-case basis, considering issues with overheating, air quality and acoustics.

13.2 Impact of design measures on overheating risk

13.2.1 Residential Analysis outcomes

The analysis has shown that mitigating overheating is a challenge, particularly on the south-west, west and south-facing aspects. Permutations of three residential typologies were modelled in single and dual aspect locations with inset and projecting balconies, g-value, solar exposure and orientation. Of all the permutations modelled, 18.7% pass the criteria set out in the CIBSE TM59 overheating methodology.

The concentric circles, centred on the origin in Figure 13—16 correspond to the percentage of units modelled which pass the specified overheating criteria in a particular orientation (laid out in compass-fashion). The three colours, in this instance, correspond to the percentage of occupied hours exceeding the maximum comfortable temperature (TM52 criterion 1). The larger the resulting area of the polygon, the greater number of models pass using this parameter/variable.

CIBSE TM59 overheating methodology defines overheating as exceeding 3% (green in Figure 13—16) for TM52 criterion 1 (and <1% night-time hours above 26 °C in bedrooms). The modelling undertaken to inform this study involved a parametric study, varying parameters which have an influence on overheating (such as g-value and orientation) in order to determine their significance. Whilst this approach provides a valuable starting point for positioning and orienting dwellings, it is thought that overheating could be mitigated further through a typical detailed-design process. Figure 13—16 shows the percentages of living spaces which achieve Criterion 1 scores of less than 4% and 5% in order to suggest what proportion of designs may potentially be able to pass TM59 if the design were developed in detail, for example through introducing greater openable area, exposed thermal mass and additional external shading.

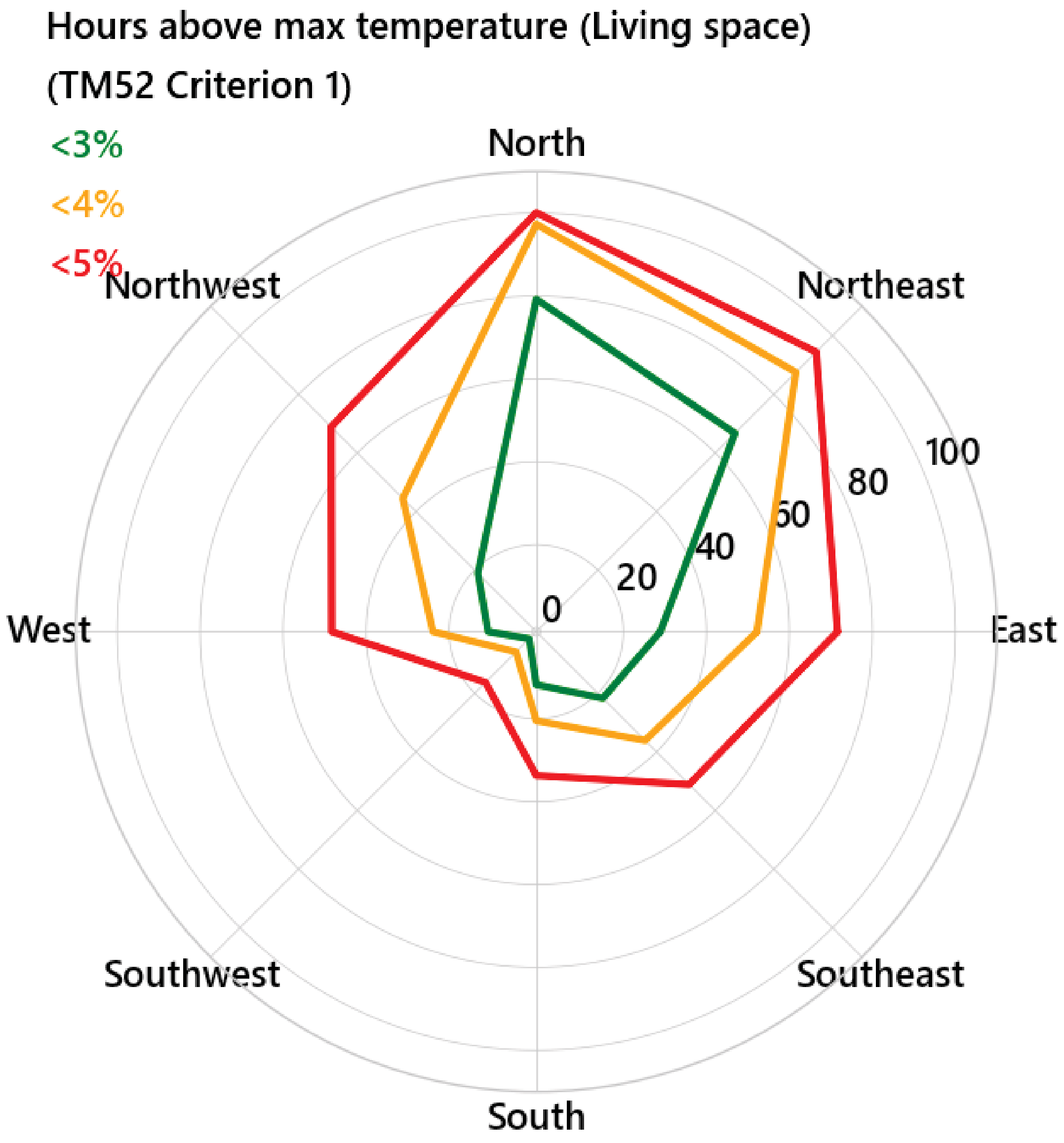


Figure 13—16 Percentage of spaces in each TM52 Criterion 1 range by orientation – residential living spaces

The impact of various design measures on the proportion of units passing the 3% TM52 Criterion 1 threshold can be seen in Figure 13—17, Figure 13—18 and Figure 13—19. The following key considerations have been derived from the analysis shown:

- Orientation is critical: few South-Westerly, Westerly, and Southerly units passed TM59 criteria; North and North-East orientations are generally the ones at lowest risk
- Glazing ratio and g-value are highly significant factors which influence overheating risk, as a general rule glazed area should be less than 25% of unit floor area. Higher glazing ratios and g-values can be used on Northerly facades with low solar exposure. Typically g-values of 0.3-0.4 and glazing ratios equivalent to 35%-50% of wall area are most effective at mitigating overheating.
- Having sufficient openable area for free cooling is key to reduce overheating risk, a sufficient proportion of window area be openable (40% was assumed in this analysis). Allowing windows to be securely opened at night enables occupants to cool their dwelling before the start of each day, helping to maintain comfortable temperatures later in the day.

- The key drivers to mitigate overheating risk are the positioning of high-risk dwellings in locations of low solar exposure; 3-bed units (with increased occupancy gains) and dual aspect units (increased solar gains over a prolonged period) should be avoided on southerly aspects. South-west facing glazing should be avoided where possible, consider limiting glazing to a single faced or locating stair cores on this aspect.

The impact of inset/projecting balconies and shaded/exposed locations was found to be less significant than other factors. In general, projecting balconies perform better than inset balconies. This because dwellings with inset balconies have a greater facade area, and glazing for this analysis was defined as either 35%, 50% or 65% of facade area; the resulting increase in glazed area for an inset balcony is more detrimental for overheating than the additional shading afforded by insetting the balcony. In exposed locations, there is a reduction in solar gain, reducing overheating risk; however, the corresponding reduction in access to daylight may result in designers specifying larger areas of glazing – increasing overheating risk overall.

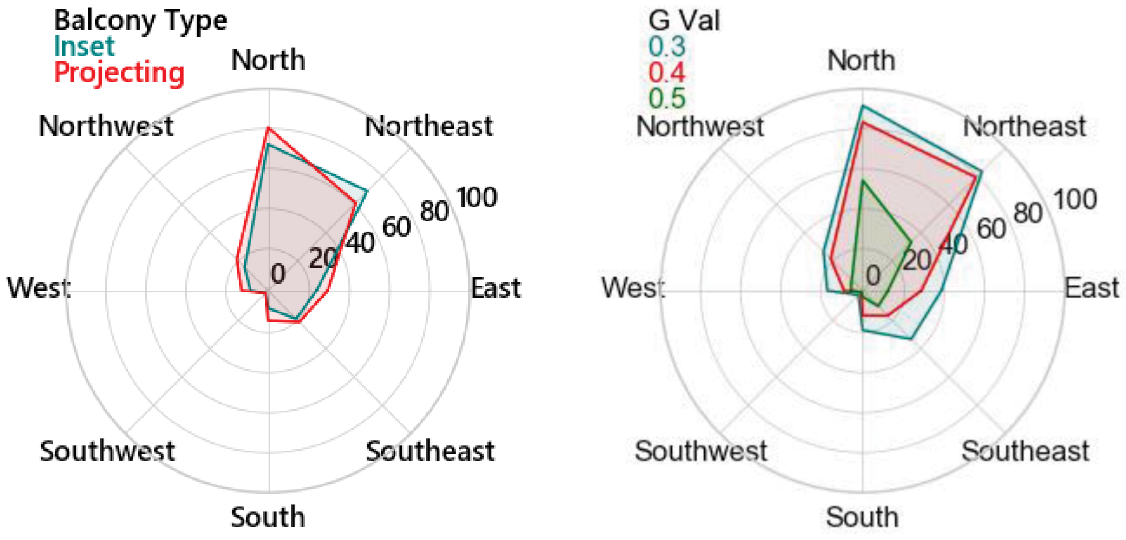


Figure 13—17 Percentage of residential living spaces passing overheating criteria by orientation and balcony type (left), G-value (right)

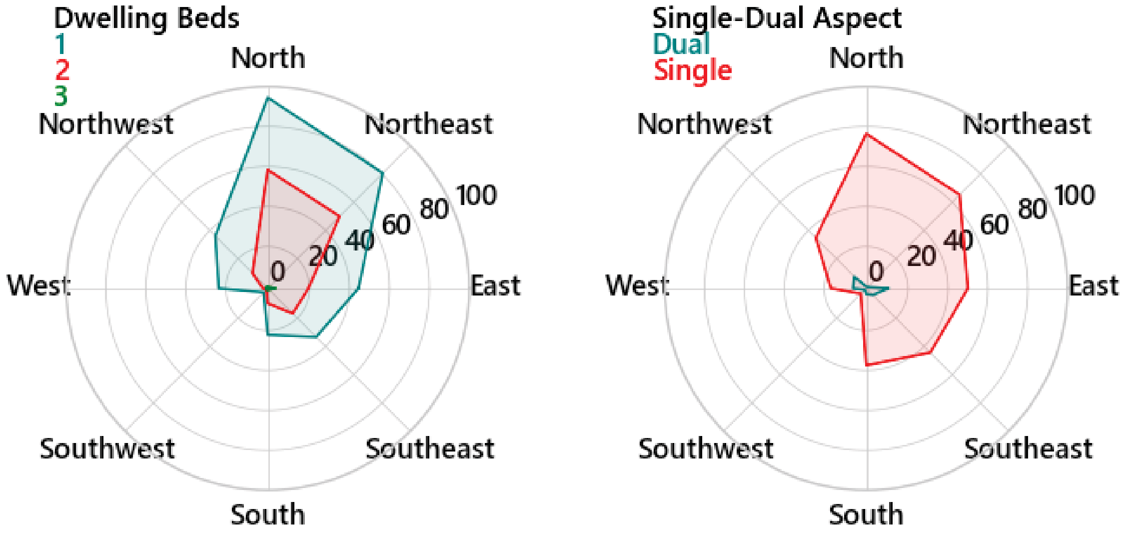


Figure 13—18 Percentage of residential living spaces passing overheating criteria by orientation and dwelling beds (left), aspect (right)

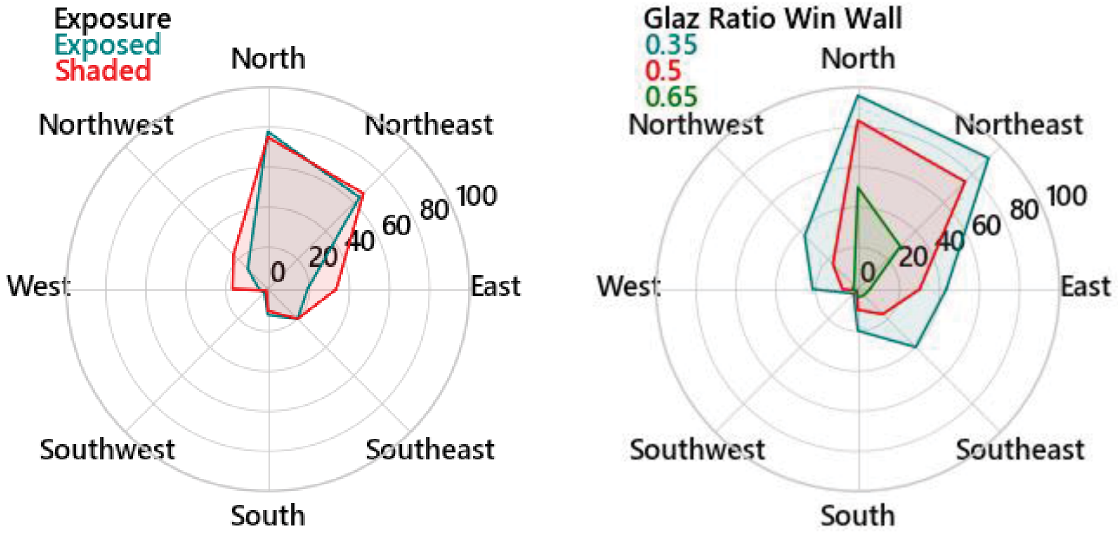


Figure 13—19 Percentage of residential living spaces passing overheating criteria by orientation and exposure (left), glazing ratio (right)

Table 13—5 shows the overheating criteria pass rate with varying parameters values.

Table 13—5 Percentage of residential spaces modelled passing TM59 overheating criteria by parameter

Variable				
Glazing g-value	Variable value	0.3	0.4	0.5
	# units passing	27.3%	19.8%	9.0%
Exposure	Variable value	Exposed	-	Shaded
	# units passing	16.7%	-	20.7%
Balcony type	Variable value	Inset	-	Projecting
	# units passing	16.9%	-	20.4%
Glazing ratio	Variable value	35%	50%	65%
	# units passing	31.5%	18.5%	6.0%
Aspect	Variable value	Single	-	Dual
	# units passing	3.8%	-	41.0%
Dwelling size (No. beds)	Variable value	1	2	3
	# units passing	32.6%	13.9%	0.3%

Figure 13—20 shows the risk of overheating for dwelling types of varying glazing ratio (window/floor). It demonstrates that 1 bed units cannot meet the 3% TM52 criterion 3 target with glazing ratios of greater than 35% (as a percentage of floor area). 2 bed units cannot meet the target with glazing ratios greater than 25%.

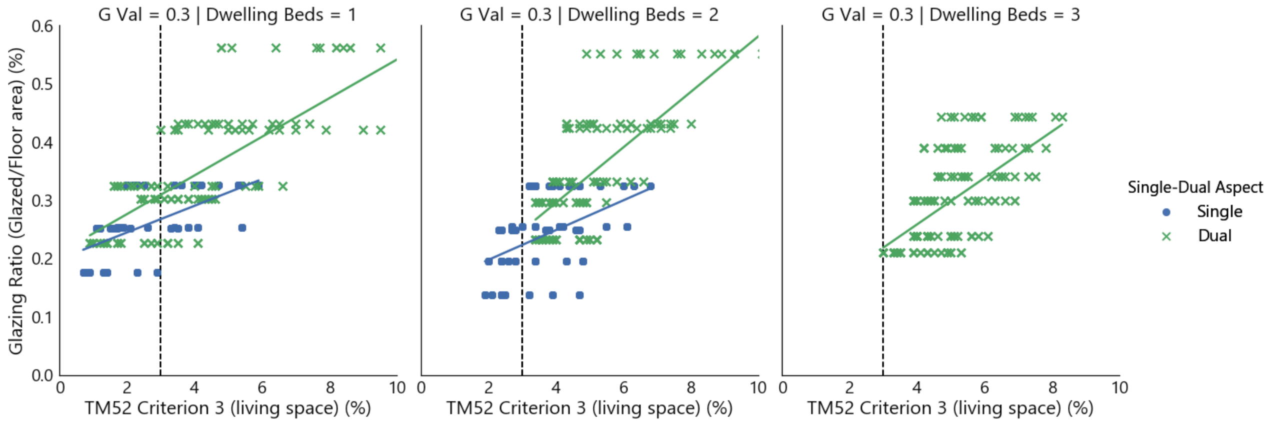


Figure 13—20 Overheating (TM52 criterion 1) Vs. glazing ratio as a proportion of floor area - for single and dual aspect dwellings (1-3 bed) Dataset shown is for lowest g-value (0.3)

Modelling of 3 bed, and 2 bed dual aspect units shows that a negligible number can pass overheating analysis, Figure 13—20 shows that none of these have a glazing ratio of less than 25% as a percentage of floor area. Trends suggest that glazing ratios less than 25% of floor area would be needed to mitigate overheating. Further modelling of lower glazing ratios is required to understand how to mitigate overheating in these residential typologies.

13.2.2 Residential costing implications

Reducing glazing ratio, reducing glazing g-value and changing orientation are the most significant factors for reducing overheating. These measures are all low capital cost, or result in a capital cost saving. Reducing overheating risk is not likely to increase capital cost, but may result in design limitations in terms of glazed area and block layout.

An additional measure to effectively cut out solar gain, which has not been considered in this study, would be the use of movable external shuttering or shading; this would introduce some capital cost uplift. Exposed thermal mass with night time ventilation may also provide passive cooling without incurring net additional cost. This has not been modelled in this study but could be considered by design teams.

13.2.3 Non-Residential Analysis outcomes

The analysis has shown that overheating risk is a critical issue for naturally ventilated non-residential spaces. Only 5.7% of the naturally ventilated spaces analysed passed the TM52 criteria (8.7% for offices, none for retail).

The following key considerations have been derived from the analysis results:

- Thermal mass, in combination with some night cooling, is required to reduce the indoor temperature and allow spaces to be naturally ventilated. Exposed soffits should be considered in the spaces in order to increase the thermal mass.
- Having sufficient openable area for free cooling is key to reduce overheating risk. Where operable windows are present (most common case in office spaces) a sufficient portion of these should be openable (40% was assumed in this analysis).
- In retail, operable windows could be considered to increase the ventilation rate. However, as these are less common, louvres have been assumed to provide natural ventilation for this analysis. The results show that louvres do not provide sufficient ventilation rates to mitigate the risk of overheating and all retail units with this configuration failed the TM52 criteria.
- The key drivers to mitigate overheating risk are overshading from surrounding buildings and glazing g-values
- Orientation is critical: no South-facing units or dual aspect South and South-West facing units within the analysis passed TM52 criteria; North and North-East orientations are generally the ones at lowest risk

Figure 13—21 shows how the percentage of spaces passing overheating criteria varies depending on orientation and other parameters. Office spaces only are shown in the graphs, as no retail spaces in the analysis pass overheating criteria. Firstly, it can be observed that greater percentages of spaces pass overheating criteria in North-facing locations as they have significantly lower levels of solar gains. No spaces whose primary orientation is South pass TM52 criteria.

Where spaces are not overshaded by surrounding buildings, overheating risk is particularly high. Of the spaces analysed in these conditions, natural ventilation is deemed to be feasible only in North-facing units. Similarly, glazing g-value is a key driver for overheating risk: if a g-value of 0.5 is used, only North-facing units can be naturally ventilated; even with a g-value of 0.4 the percentage of rooms passing overheating criteria is low and limited to Northern orientations.

Glazing ratio and aspect can also impact overheating risk. It can be observed that as the glazing ratios are reduced, more spaces analysed can be naturally ventilated without failing TM52 criteria. In addition, dual aspect units present significantly higher risk of overheating, as the risk brought by higher solar gains exceed the benefit of a larger openable area.

Table 13—6 also shows the overheating criteria pass rate with varying parameters values. In addition to the effect of adjacent buildings and g-values, as discussed above, it can be noticed that higher U-values (e.g. double glazing rather than triple glazing) have a small positive effect on reducing overheating risk.

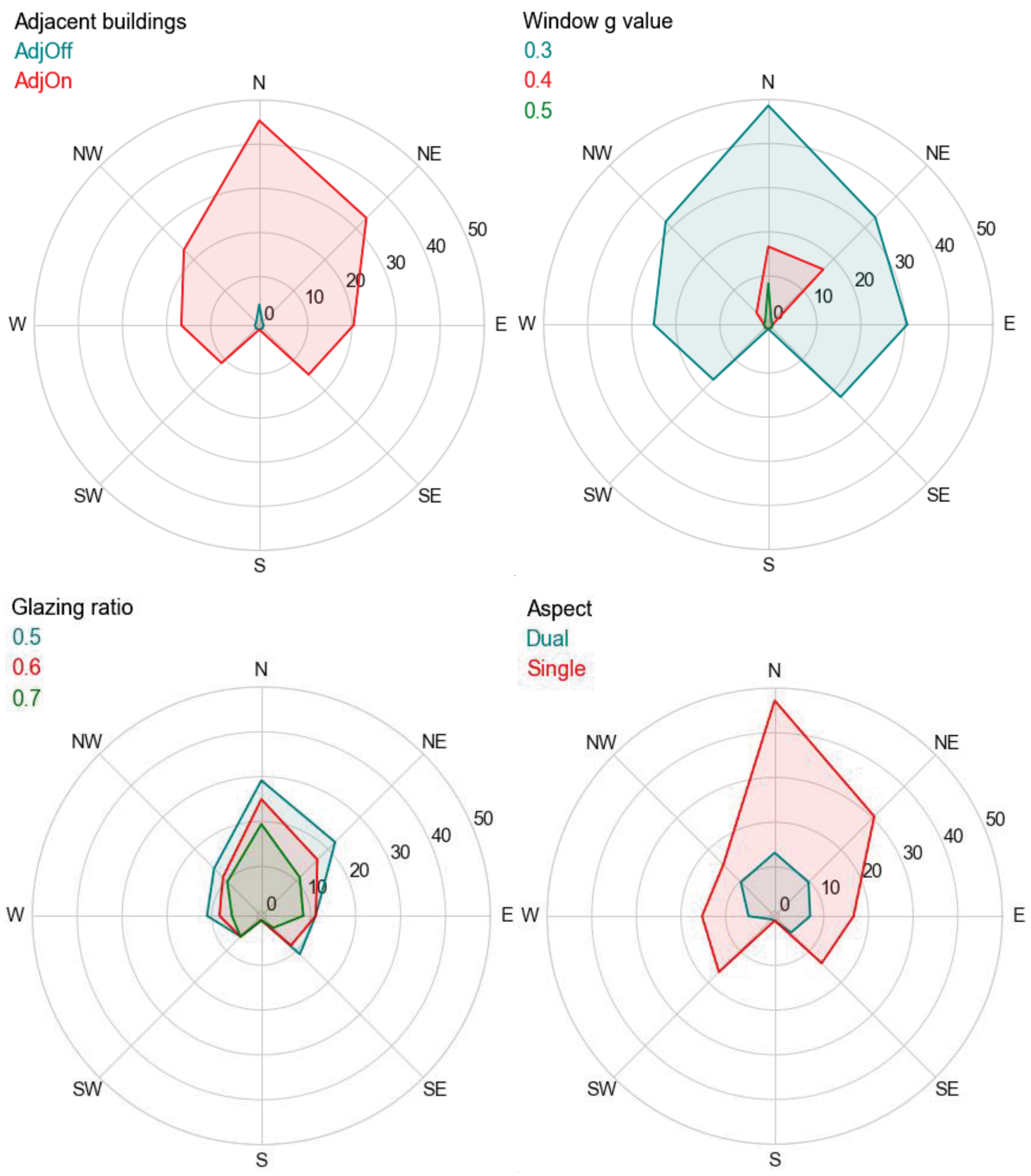


Figure 13—21 Percentage of naturally ventilated office spaces passing overheating criteria by orientation

Table 13—6 Percentage of non-residential spaces modelled passing overheating criteria by parameter

Variable				
Window U-value	Variable value	1.3	-	0.85
	# units passing	7%	-	4.6%
Shading	Variable value	Off	-	On
	# units passing	5.5%	-	5.9%
Adjacent buildings	Variable value	Off	-	On
	# units passing	0.2%	-	10.8%
Glazing ratio	Variable value	70%	60%	50%
	# units passing	4.2%	5.6%	7.2%
Window g value	Variable value	0.5	0.4	0.3
	# units passing	0.7%	2.5%	15.6%

It should be noted that a significant portion of the spaces analysed fails TM52 Criterion 1 by a relatively small amount of hours. Where the percentage of occupied hours exceeding the maximum comfortable temperature is between 3% and 4%, further measures (beyond the ones modelled for this study) could be put in place to successfully naturally ventilate the spaces. These medium risk spaces are shown in orange in Figure 13—22 and Figure 13—23; these graphs show the percentage of spaces in various TM52 Criterion 1 ranges, for office and retail respectively.

Approximately 9% of the naturally ventilated offices analysed pass TM52 Criterion 1 and therefore exceed the maximum comfortable temperature for up to 3% of occupied hours. An additional 13% of spaces has temperatures that exceed the maximum comfortable temperature between 3% and 4% of occupied hours and could be potentially naturally ventilated if further measures were taken to reduce overheating risk.

For retail, none of the spaces modelled passes the overheating criteria. However, it can be observed that a number of spaces are at medium risk, with up to 4% of occupied hours presenting temperatures above the maximum comfortable temperature. Specifically, 7% of the naturally ventilated retail spaces present a medium risk, based on TM52 criterion; most of these spaces face North or East directions, while none face South.

Measures that could be taken to reduce the overheating risk in these spaces include further reducing glazing g-value below 0.3, increasing openable area, taking advantage of cross-ventilation in single-aspect units, increasing the depth of shading fins and canopies. In addition, a mixed mode strategy could be implemented, where the spaces are naturally ventilated throughout the year and only make use of comfort cooling in peak summer conditions.

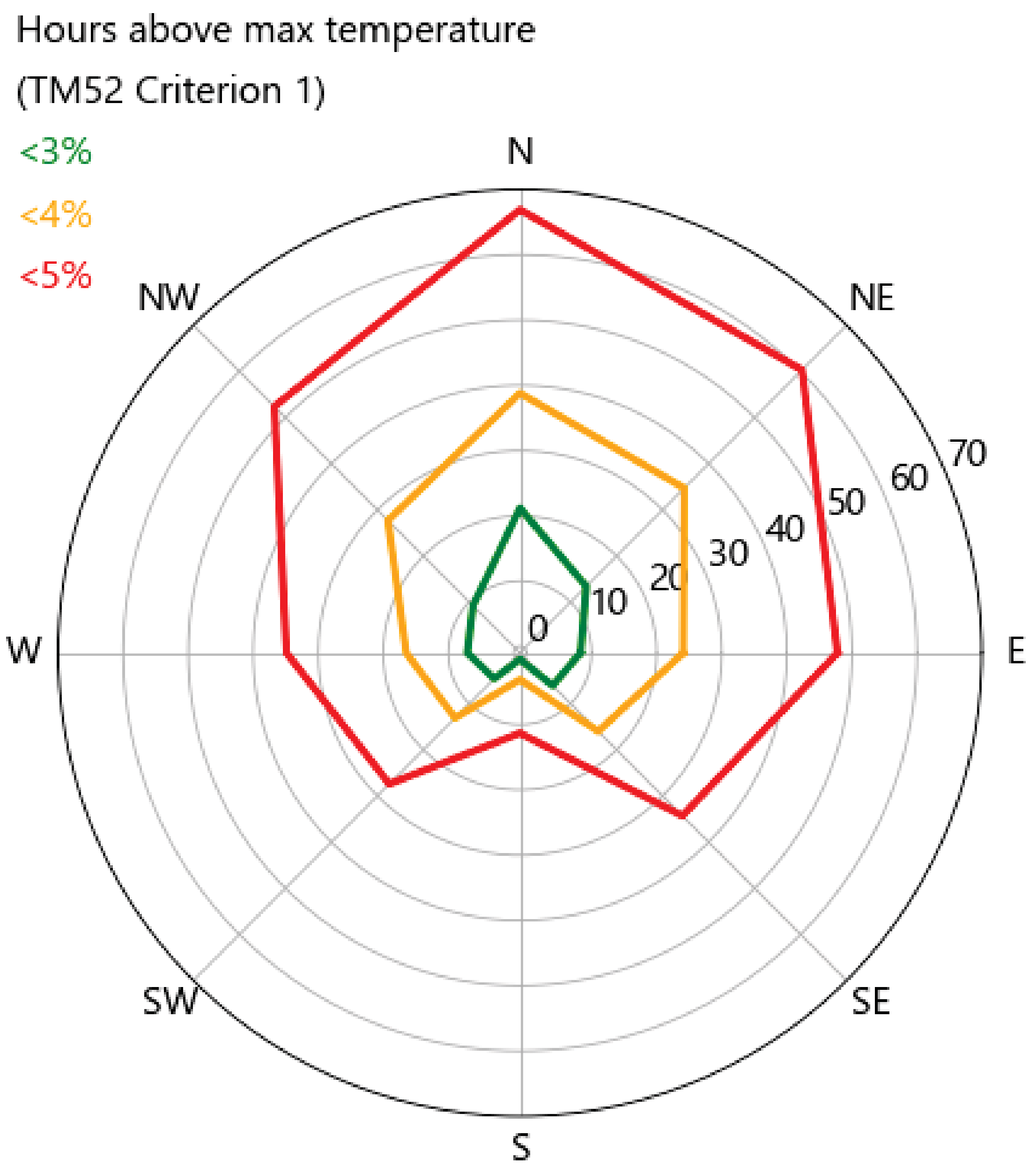


Figure 13—22 Percentage of spaces in each TM52 Criterion 1 range by orientation - Office

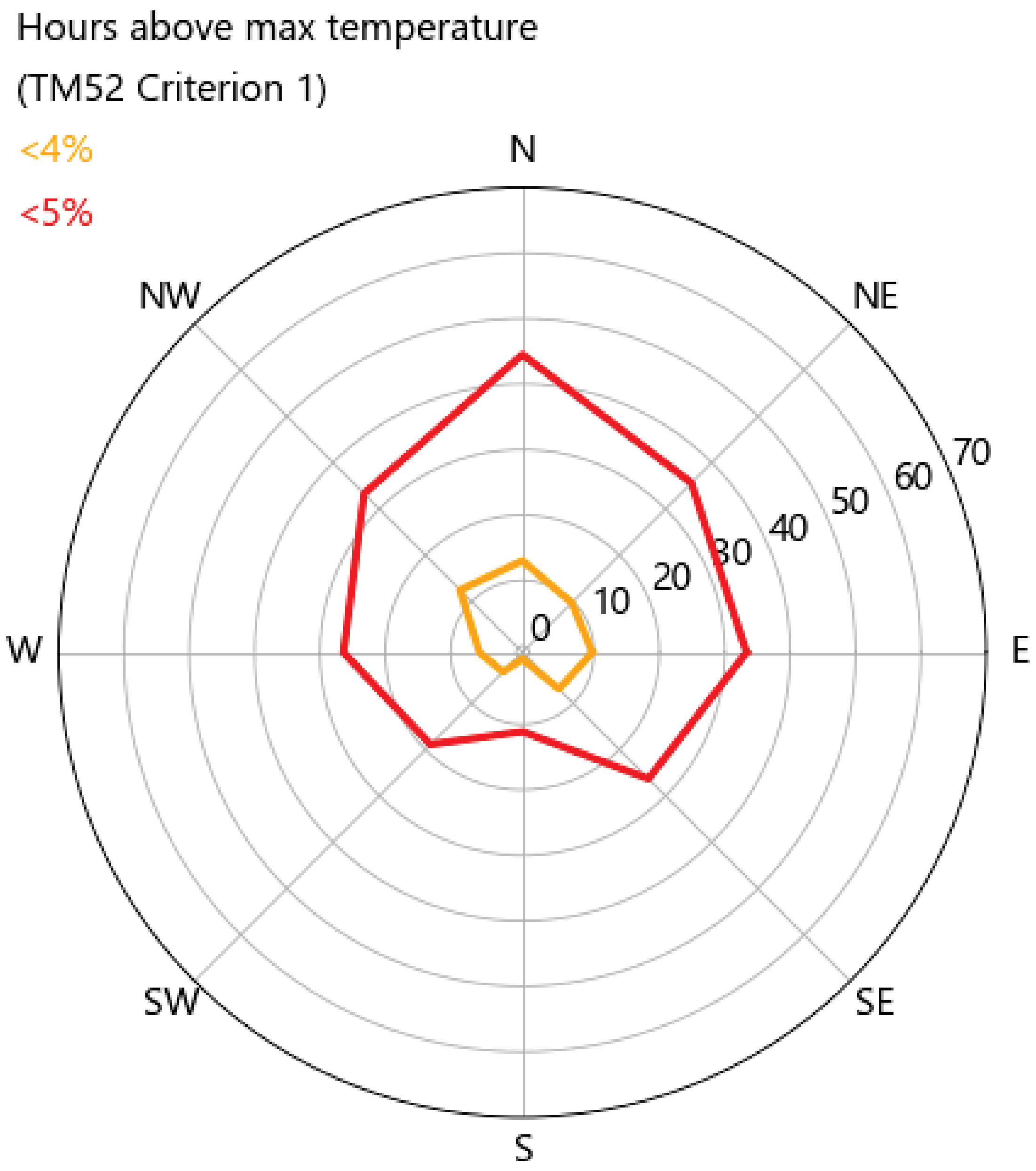


Figure 13—23 Percentage of spaces in each TM52 Criterion 1 range by orientation - Retail

13.2.4 Non-Residential Costing implications

Reducing glazing g-value is a key driver to mitigate overheating risk. As shown in Figure 13—15, reducing g-value does not present a cost uplift and can be therefore achieved with no additional capital investment. Other measures, such as reducing glazing ratio, increasing fabric U-values and shifting from dual to single aspect have a positive impact on cost, i.e. they produce capital cost savings.

However, limiting the overheating risk in naturally ventilated spaces presents some design challenges, related to the need for shading from surrounding buildings and orientation constraints. When these cannot be addressed through design and overheating risk cannot be mitigated, comfort cooling will be needed (at least in peak summer conditions) to guarantee occupants thermal comfort. Additional costs in this case include fans and chiller and, as discussed in section 13.1.9, amount to £25/m^2 for office and £43/m^2 for retail.

13.3 Impact of design measures on daylighting

13.3.1 Residential analysis outcomes

Figure 13—24 shows the distribution of average daylight factor for the living spaces of dwellings analysed (excluding those that don't pass Part L). 75% of living spaces achieve the BRE target (ADF >= 1.5%). Single aspect units in shaded locations suffer daylighting challenges.

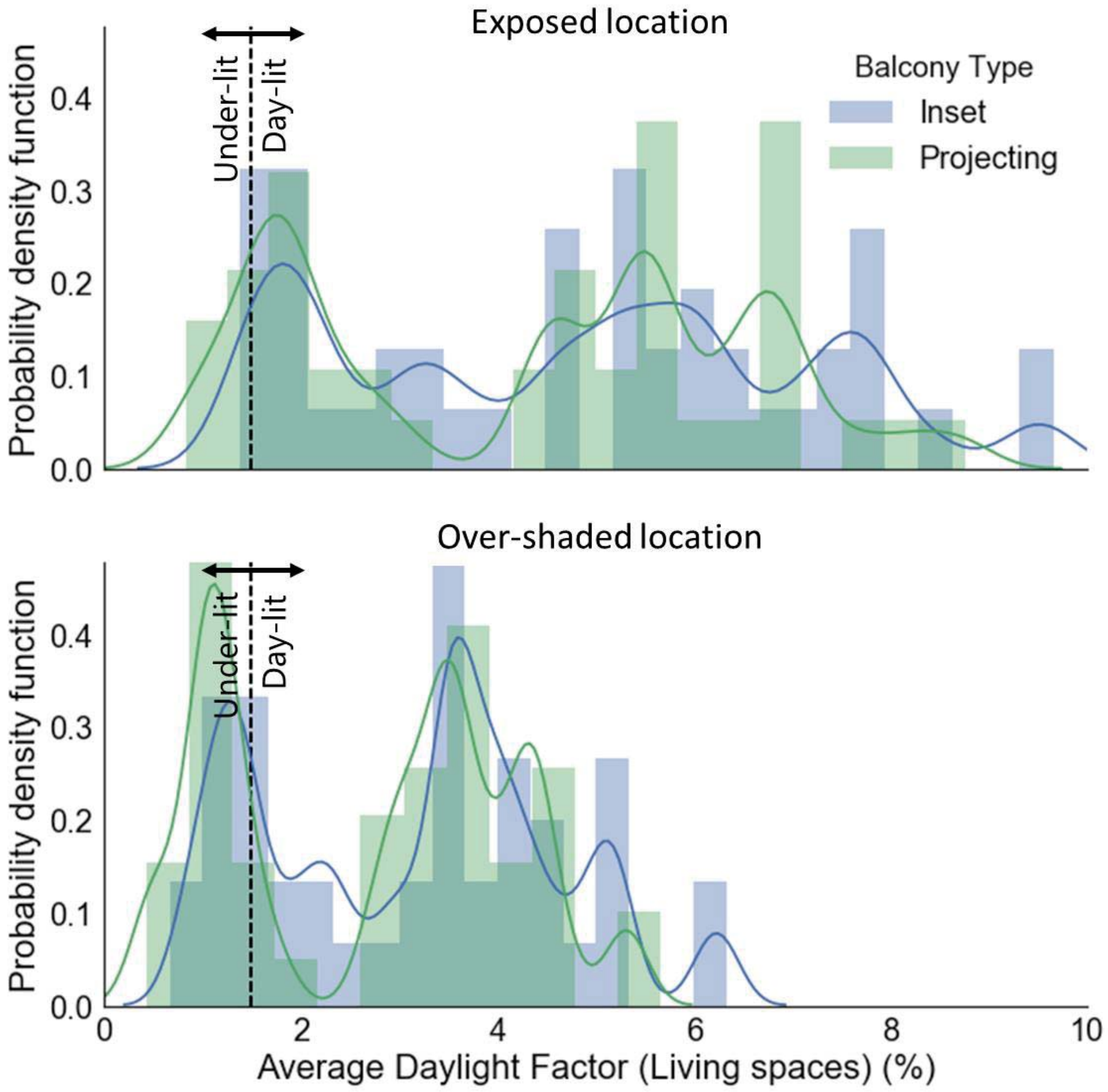


Figure 13—24 Distribution of average daylight factor over the whole residential dataset

Daylighting is primarily influenced by glazing ratio, whether a dwelling is single or dual aspect, and its position relative to neighbouring blocks (whether it is exposed or shaded). Figure 13—25 shows that average daylight factor is positively correlated with glazing ratio. For a given glazing ratio (window area as a proportion of floor area) dual aspect dwellings achieve consistently higher average daylight factors (additional 1-2% ADF). Dwellings in exposed locations require lower glazing ratios to meet the same glazing targets as in shaded locations.

Increasing visual light transmittance from 60% to 70% also results in an average daylight factor increase of 0.75%. The inset balconies modelled in this study typically achieve improved ADF compared with projecting balconies, because inset balconies are associated with larger areas of glazing in relation to floor area.

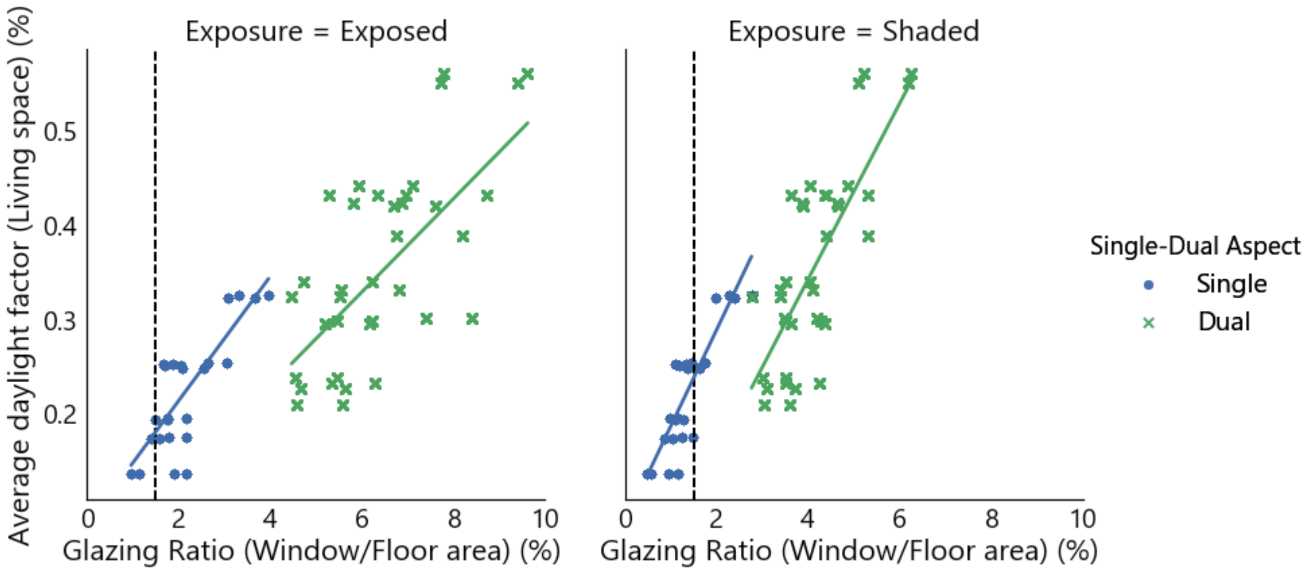


Figure 13—25 Average daylight factor (living spaces) Vs. glazing ratio as a proportion of floor area - for single and dual aspect dwellings

13.3.2 Residential costing implications

Dual aspect units are to be preferred over single aspect in order to maximise daylight. Dual aspect units present an increase in capital cost, determined by the increase in glazed area. The most significant contribution to cost is therefore represented by the glazing cost: this is an average of £6,000 greater for dual aspect residential units. Similarly, increasing the glazing ratio from 35% to 65% of the external wall area results in an average cost increase of £3,000 per unit.

Designing a residential unit in a location with strong over-shading from surrounding buildings indirectly generates an increase in cost, as higher glazing areas will be needed to achieve sufficient daylight penetration.

13.3.3 Non-residential Analysis outcomes

As outlined in section 11.3, spaces are considered to have a predominantly daylit appearance if their average daylight factor exceeds 2%. If the average daylight factor is above 5%, the spaces generally don't require any electric lighting during the daytime.

Figure 13—26 shows the distribution of average daylight factor for the spaces analysed (excluding those that don't pass Part L). This shows that 56% of the spaces achieve an average daylight factor of at least 2% and 19% achieve an average daylight factor of at least 5%. Retail units tend to have higher average daylight factors compared to offices, as they have been assumed to have a shallower floorplate in this analysis.

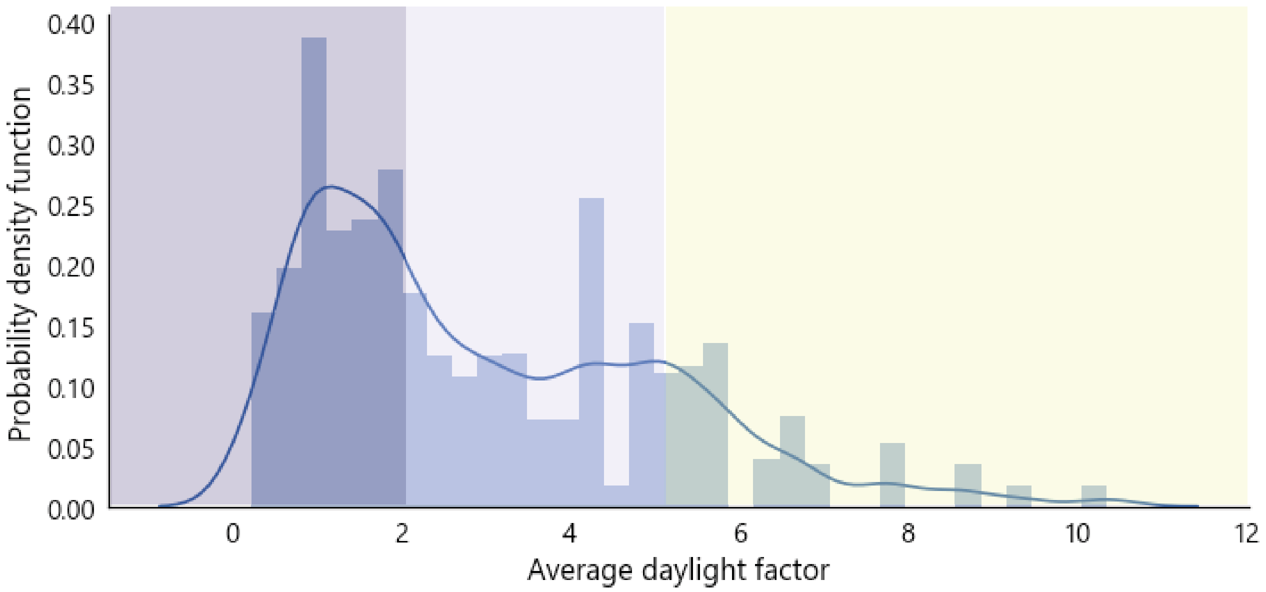


Figure 13—26 Distribution of average daylight factor over the whole non-residential dataset

Shading from adjacent buildings has a considerable impact on daylight. As shown in Figure 13—27, only 14% of shaded spaces achieve an average daylight factor of 2% or above, and none of them achieves an average daylight factor of 5%. Conversely, 98% of spaces in unshaded locations achieve an average daylight factor of at least 2%.

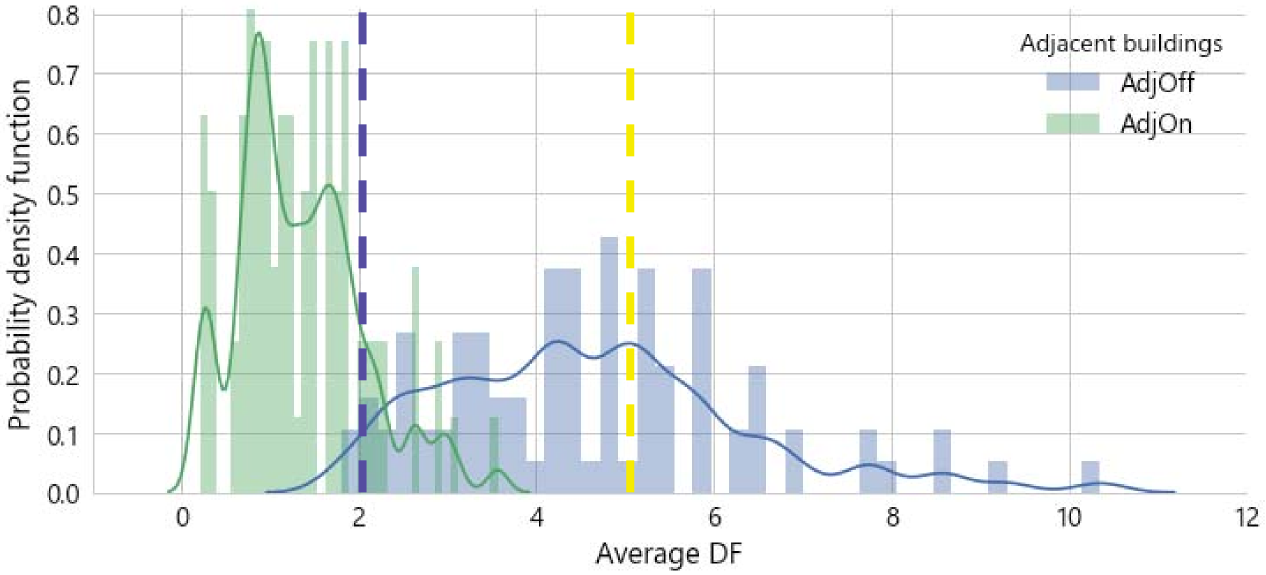


Figure 13—27 Impact of adjacent buildings on average daylight factor

Aspect is also an important factor determining the availability of daylight within a space. Single aspect units are the most at risk. In particular, only dual aspect units achieve a 2% average daylight factor in shaded conditions.

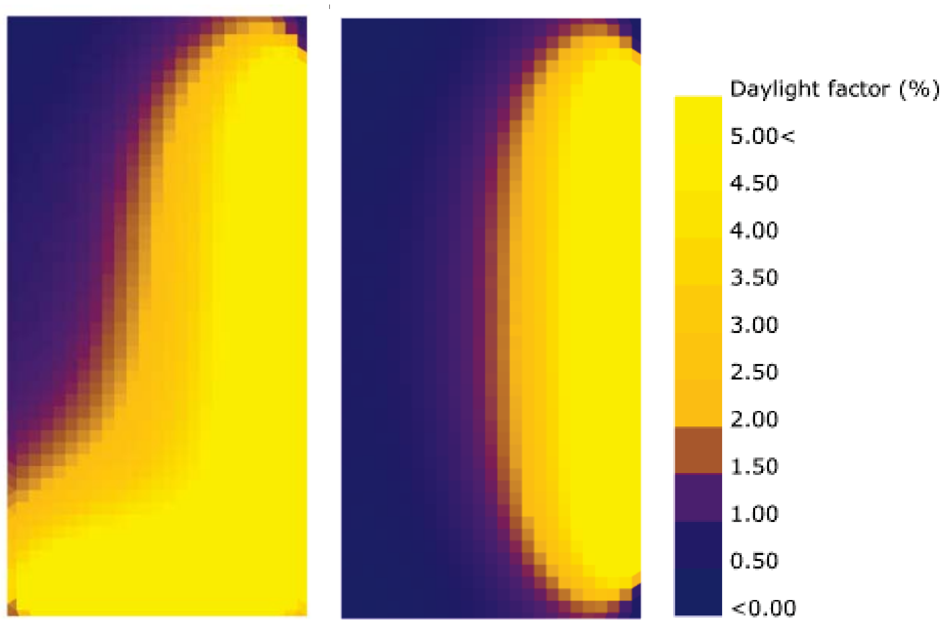


Figure 13—28 Daylight factor comparison between dual and single aspect spaces (Office, unshaded conditions, 60% glazing ratio, no shading fins, VLT 0.6)

Further measures to increase daylight factor include increasing the glazing ratio, removing any shading elements and increasing the glass Visual Light Transmittance (VLT).

Costing implications

As discussed in the section above, dual aspect units are to be preferred over single aspect in order to maximise daylight. Dual aspect units present an increase in capital cost, determined by the increase in glazed area. The most significant contribution to cost is therefore represented by the glazing cost: this is £72/m^2 higher in dual aspect offices and £184/m^2 higher in dual aspect retail than it is for the corresponding single aspect spaces.

Similarly, increasing the glazing ratio from 50% to 70% of the external wall area produces an average cost increase of £62/m^2 for office and £85/m^2 for retail spaces. Conversely, avoiding shading elements can save capital investment, in the order of £11/m^2 for office and £70/m^2 for retail.

It should also be noted that designing a commercial space in a location with strong overshading from surrounding buildings indirectly generates an increase in cost, as higher glazing areas will be needed to achieve sufficient daylight penetration.

13.4 How to balance all three environmental drivers

13.4.1 Residential

The graph in section 13.4.2 summarise the impact that the considered measures have on carbon, overheating risk, daylight and capital cost, as resulting from the analysis.

Daylighting and overheating mitigation

Overheating and daylighting targets drive designs in opposing directions; the larger glazing ratios and higher transmittance glass required to improve daylighting result in increased solar gain and greater overheating risk. Careful balancing can be achieved through positioning of lower risk units on exposed facades and reducing glazed area and g-values in high solar-gain locations.

The challenge is increased at lower levels where dwellings are over-shaded by neighbouring blocks. Higher glazing ratios are required to meet daylighting targets in over-shaded locations as shown in Figure 13—25. Dwellings on southerly facades in these locations still receive unobstructed solar gains during peak summer when the altitude of the sun is highest. Perhaps counter intuitively, overheating risk is greatest for dwellings in partly over-shaded locations because of the additional glazed area required to meet daylighting targets.

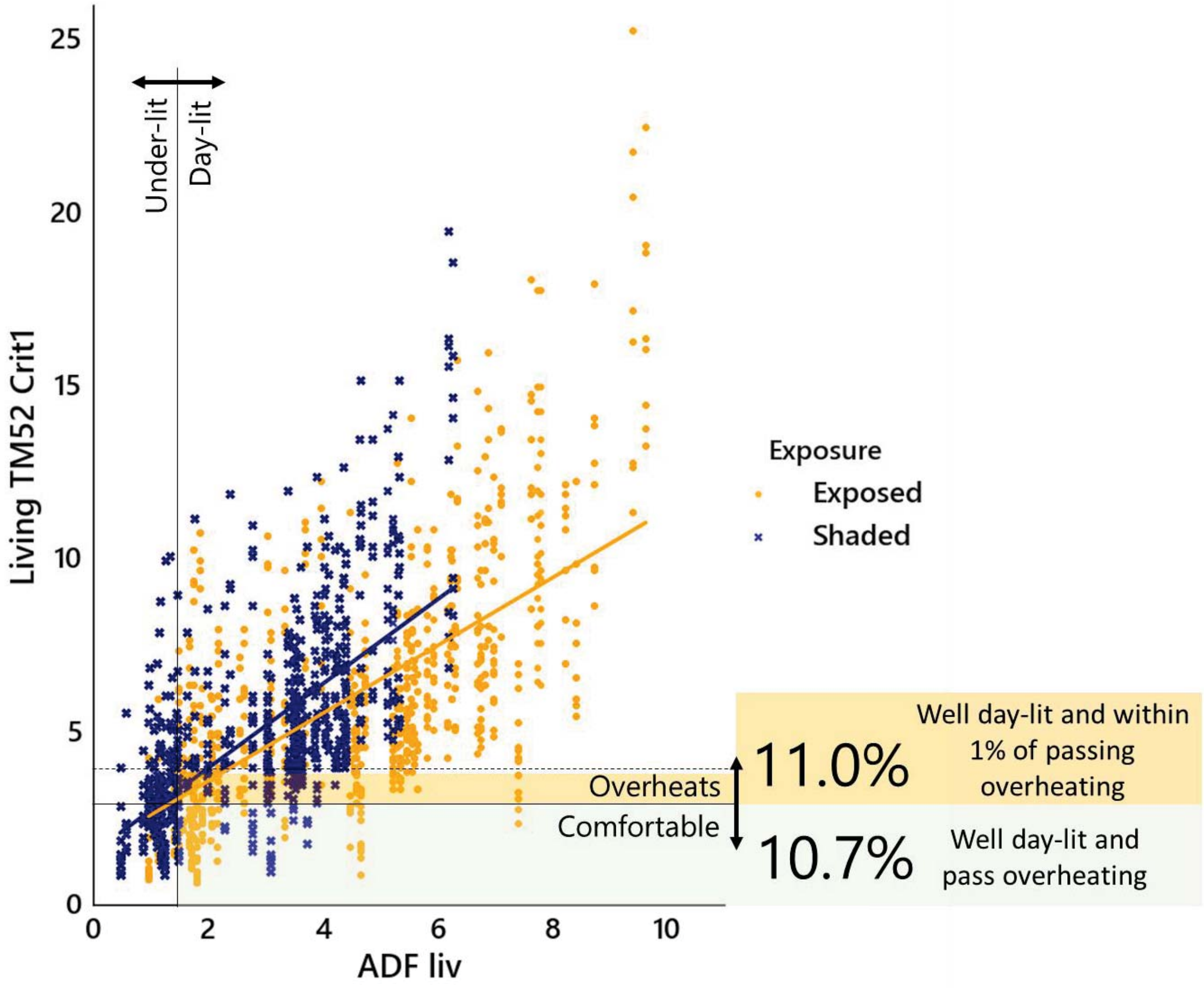


Figure 13—29 Balancing overheating and daylight for living spaces in shaded and unshaded locations (sample shown achieves 10% or greater uplift over TER)

Figure 13—29 demonstrates the challenge of balancing overheating and daylighting whilst achieving 10% reduction over TER, metrics are shown for living spaces which are indicative of whole-dwelling performance. It can be seen that 10.7% of units modelled meet daylighting, energy and overheating targets. An additional 11% of units are within 1% of the TM52 Criterion 1 score required to pass the overheating check; it is thought that through the course of a detailed design process, the design of units in this band may be refined, by increasing vent area for instance, such that they can pass the TM59 overheating requirements.

Figure 13—30 shows that orientation is a key determinant in whether all three environmental drivers can be balanced (primarily driven by overheating challenges on southerly and westerly aspects). On the Southwest aspect, less than 1% of dwellings modelled meet all three environmental criteria. Conversely, on the North and Northeast aspects, the pass rates are 15% and 11% respectively.

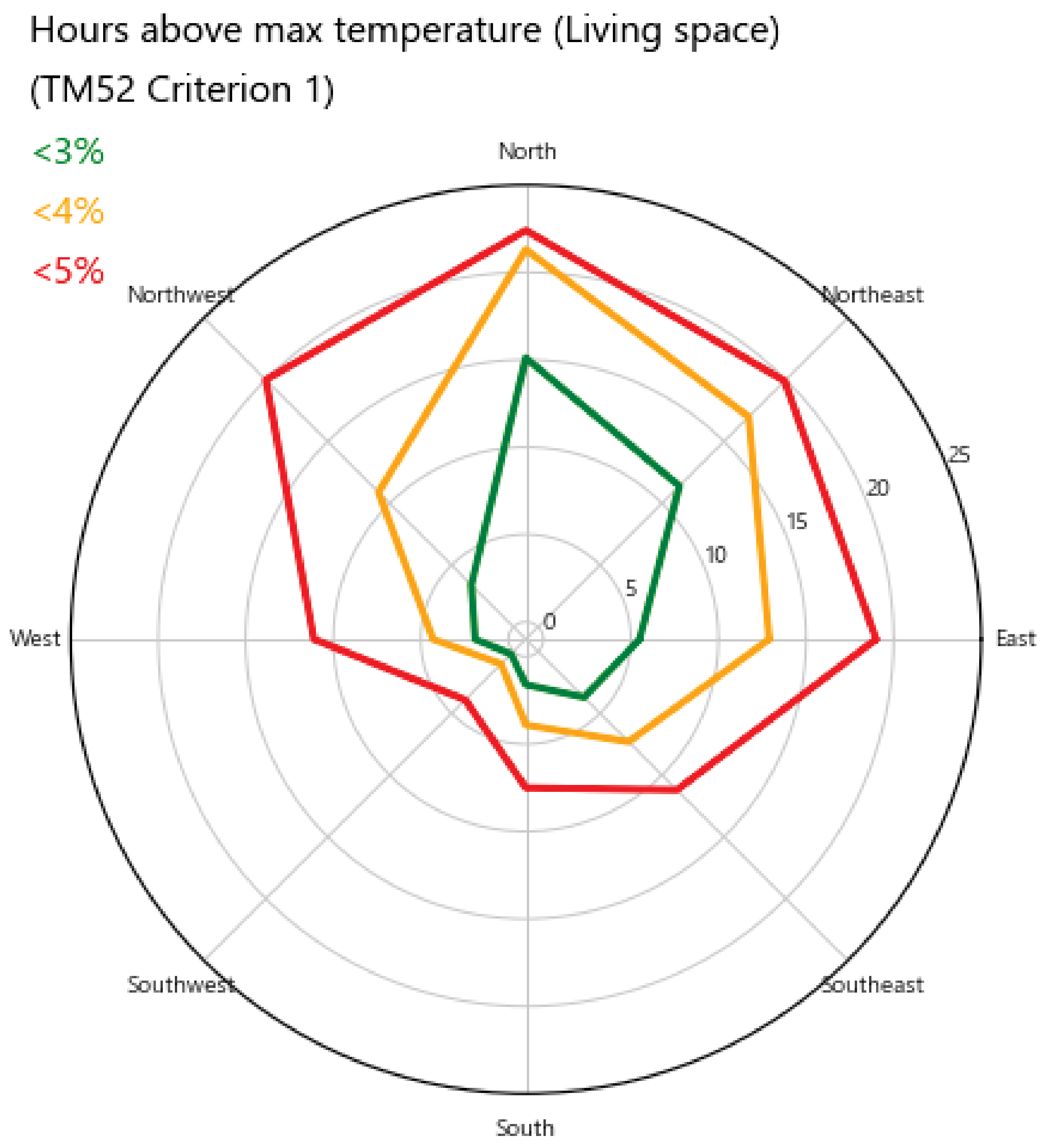


Figure 13—30 Percentage of dwellings modelled passing daylight targets and achieving > 10% improvement over TER for varying bands of TM52 Criterion 1 (as a proportion of dwellings which pass Part-L)

CO_2 Emissions reduction

The key drivers which improve CO_2 reduction generally have negligible impact on daylighting and overheating (these are the installation of MHVR, triple glazing, improved airtightness and calculated thermal bridging). Consequently, it is less challenging to balance CO_2 reduction targets than overheating and daylighting. The main exception to this rule is where large areas of glazing are required to optimise daylight in shaded locations, which will have a detrimental effect on carbon performance. The most impactful measures can be seen in Figure 13—31.

Calculating thermal bridging and improving airtightness have the lowest cost uplifts; however, airtightness testing may require construction programme extensions. MVHR and triple glazing result in significant cost uplifts, averaging £2770 and £1080 respectively; however, the majority of these costs would be required in order to meet building regulations Part L. Increases in glazing ratio in order to improve daylighting performance result in reductions in CO_2 savings;

However, these can be offset through the measures discussed above. The maximum glazing ratio will be primarily limited by overheating mitigation, rather than energy performance.

13.4.2 Residential low carbon design responses

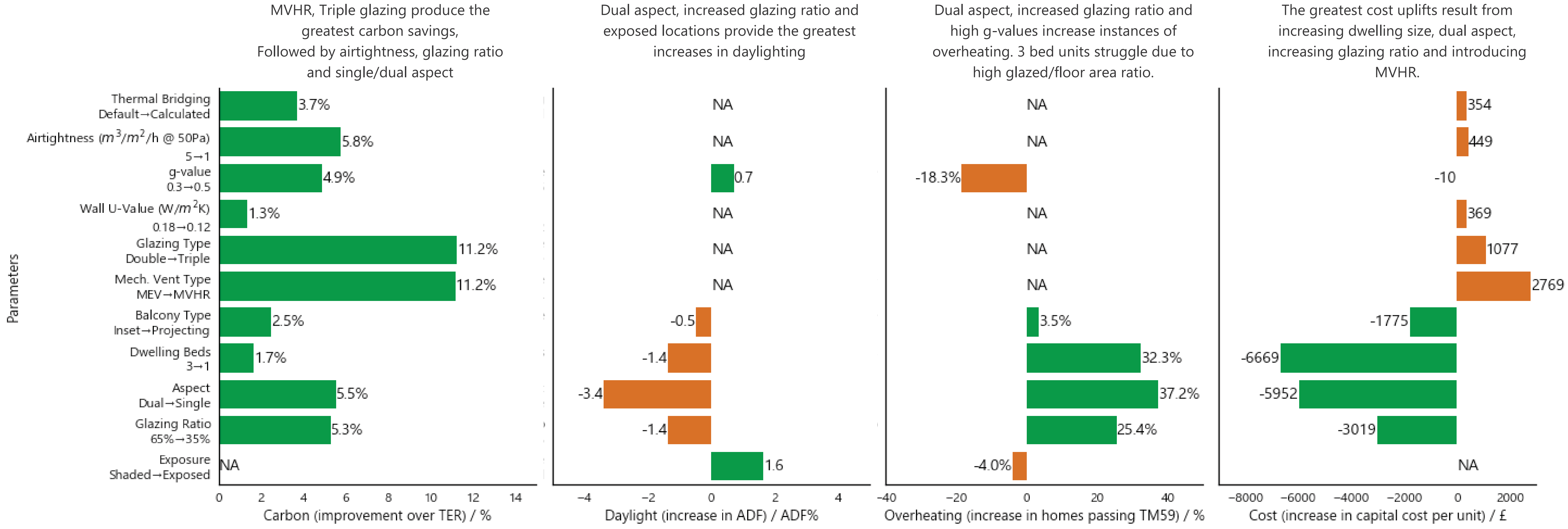


Figure 13—31 Impact of design measures on Carbon, overheating, daylight and cost for residential units

13.4.3 Cost baseline and uplift

Figure 13—33 demonstrates that a cost uplift is required to increase improvement over TER from 0%-15%, this is primarily due to the increased cost of MVHR, as opposed to MEV, which is required to achieve greater than 10% improvement over TER. Above the 10-15% cost uplift band, the rate of cost uplift diminishes.

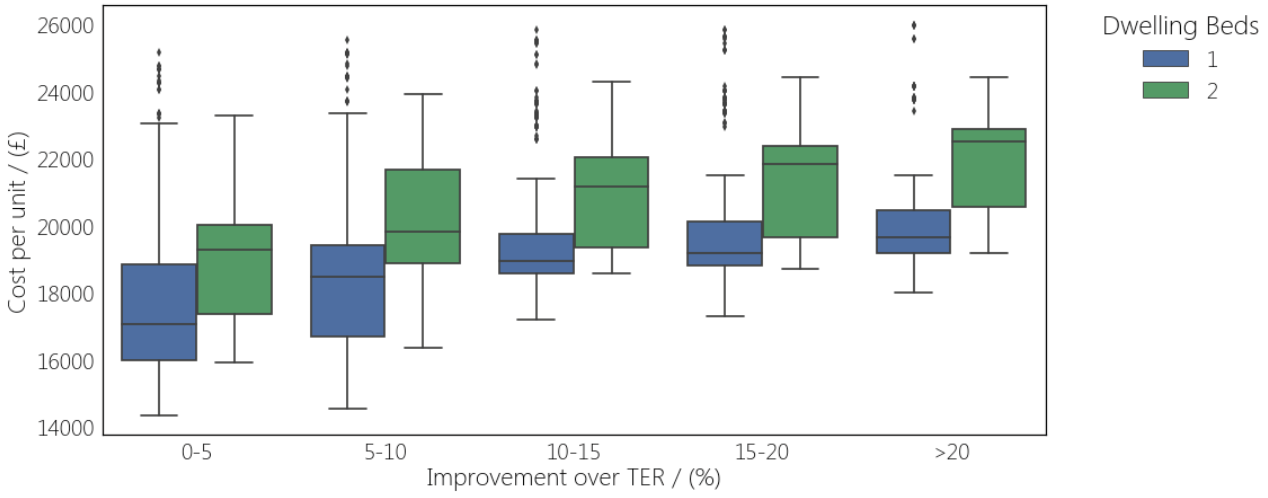


Figure 13—32 Distribution of cost per unit to achieve different bands of improvement over TER by number of beds in dwelling (for dwellings that pass overheating assessment and achieve ADF > 1.5 in living spaces)

Table 13—7 Median capital cost per unit to achieve different bands of improvement over TER by number of beds in dwelling (for dwellings that pass overheating assessment and achieve ADF > 1.5 in living spaces)

Dwelling beds	Improvement over TER (%)				
	0-4.9%	5-9.9%	10-14.9%	15-19.9%	>20%
1 bed	£ 18,643	£ 19,105	£ 19,510	£ 19,893	£ 20,615
2 bed	£ 19,552	£ 20,388	£ 21,012	£ 21,225	£ 21,954

Table 13—8 Median capital cost uplift (from London typical) per unit to achieve different bands of improvement over TER by number of beds in dwelling (for dwellings that pass overheating assessment and achieve ADF > 1.5 in living spaces)

Dwelling beds	Improvement over TER (%)				
	0-4.9%	5-9.9%	10-14.9%	15-19.9%	>20%
1 bed	(Baseline)	£462	£867	£1,250	£1,972
2 bed	(Baseline)	£836	£1,460	£1,673	£2,402

If these figures were to include those units failing overheating, as compromised performance, the costs would increase. This is because many of the units that have higher glazing ratios will overheat. These units have glazing ratios of 50-65% (as a proportion of wall area); these large areas of glazing would result in a significant cost uplift.

The analysis suggests that achieving good energy performance whilst balancing overheating and daylighting does not need to come at a significant cost uplift. Maintaining glazing ratios equivalent to 20-35% of floor area can balance overheating and daylighting whilst keeping glazing costs comparatively low. Energy performance of greater than 10% improvement on TER can be achieved through a combination of MVHR and airtightness testing to <3m3/m2/h or triple glazing; these measures typically result in a cost uplift of £870-£1460 compared with London typical (0-5%), for 1 and 2 bed units respectively. London typical was calculated to be 3.7% for residential in the GLA energy efficiency study, based upon the typical historical performance of planning applications received between 2015 and 2017. The costs associated with achieving 10-15% are in line with those identified in the GLA energy efficiency study.

13.4.4 Commercial

The graphs below summarise the impact that the considered measures have on carbon, overheating risk, daylight and capital cost, as resulting from the analysis. Naturally ventilated spaces and fully conditioned spaces have a different energy breakdown and therefore their carbon savings are influenced differently by the considered measures. For this reason, the impacts on naturally ventilated and fully conditioned spaces are here shown separately.

Lighting

The main driver in maximising carbon savings, for both naturally ventilated and fully conditioned spaces, is improving the lighting design. Best-practice lighting increases carbon savings by 48% on average compared to poor lighting. The effect of improving lighting design on overheating has not been evaluated; however, it is expected that this will have a positive effect, increasing the percentage of comfortable spaces, as internal gains are reduced. There is also a synergy with daylight: as more daylight is let into the space, there is less need for electric lighting which can be dimmed or turned off during the day, therefore increasing in turn carbon savings. Thus, good lighting design is key to maximising carbon savings and doesn't have any negative impacts on overheating and daylight. The cost associated with it is of the order of £26/m^2. However, most of this cost is already required just to meet Building Regulations Part L, as good lighting is generally required to meet the Target Emission Rating. In fact, high-efficacy LED lighting, as well as installing lighting controls, are considered to be current standard practice.

Improving fabric

Improving fabric thermal insulation (lower wall and window U-values) generates small carbon savings in naturally ventilated spaces by reducing their heating load. This, however, has an additional cost and is detrimental for overheating risk.

Sun exposure – Overheating vs Daylight trade-off

It can be observed that measures that are aimed at increasing solar exposure have a positive effect on daylight but a negative effect on overheating risk for naturally ventilated spaces or carbon savings for fully conditioned spaces. These measures include increasing VLT (and with it, generally, g-value), reducing shading from on-building shading elements and from surrounding buildings, increasing glazing ratio and maximising dual aspect units. Due to this trade-off, it might prove challenging in some spaces to balance all three environmental drivers, as shown graphically in Figure 13—33 and Figure 13—34 for naturally ventilated and fully conditioned spaces, respectively.

In naturally ventilated spaces (Figure 13—33), only 0.14% of spaces analysed achieve 15% carbon savings, 2% ADF and pass TM52 overheating criteria.

- Exposed spaces, while easily achieving average daylight factor levels in excess of 2%, present excessive solar gains and therefore overheat unless they are North-facing, single-aspect units and a low glazing g-value (0.3 or below) is used. Comfort cooling is recommended for exposed spaces in different orientations.

- The shaded spaces could not concurrently achieve the three targets with the measures analysed. Daylight is critical in these locations and it proves challenging to maximise it without incurring in excessive solar gains. It should be noticed, however, that spaces where the temperature exceeds the maximum comfortable level (TM52 criterion 1) by up to 4% could be still naturally ventilated whilst using comfort cooling only in peak summer conditions.

In fully conditioned spaces (Figure 13—34), measures aimed at improving daylight are detrimental for cooling loads and in turn carbon emissions.

- In exposed spaces, daylight is not critical and an average daylight factor of 2% is achieved by most spaces; in these conditions, efforts should therefore be directed to maximise carbon savings by reducing solar exposure. South-facing units are the most at risk and should therefore have a resultant g-value (factor of glazing ratio, shading and glazing g-value) of 0.2 or lower: this could be achieved for example, with a 70% glazing ratio and g-value of 0.3, or with a 50% glazing ratio and g-value of 0.4. Shading elements could further help reduce cooling loads and maximise carbon savings.
- Conversely, in locations over-shaded by surrounding buildings daylight is the limiting factor. As concerns retail units, the analysis has shown that dual aspect and shading canopies are needed to achieve the targets. On the other hand, no office units in the study could achieve 2% ADF and 15% carbon savings in these conditions, as they are characterised by a deeper floorplate. Additional measures that haven't been studied in the analysis could be considered to reduce cooling loads whilst maximising daylight; these may include moveable shading and glazing characterised by low g-value but high VLT.

In terms of cost, the main driver is represented by glazing area. Measures to maximise daylight, such as dual aspect and increasing glazing ratio therefore may have a significant impact on capital cost.

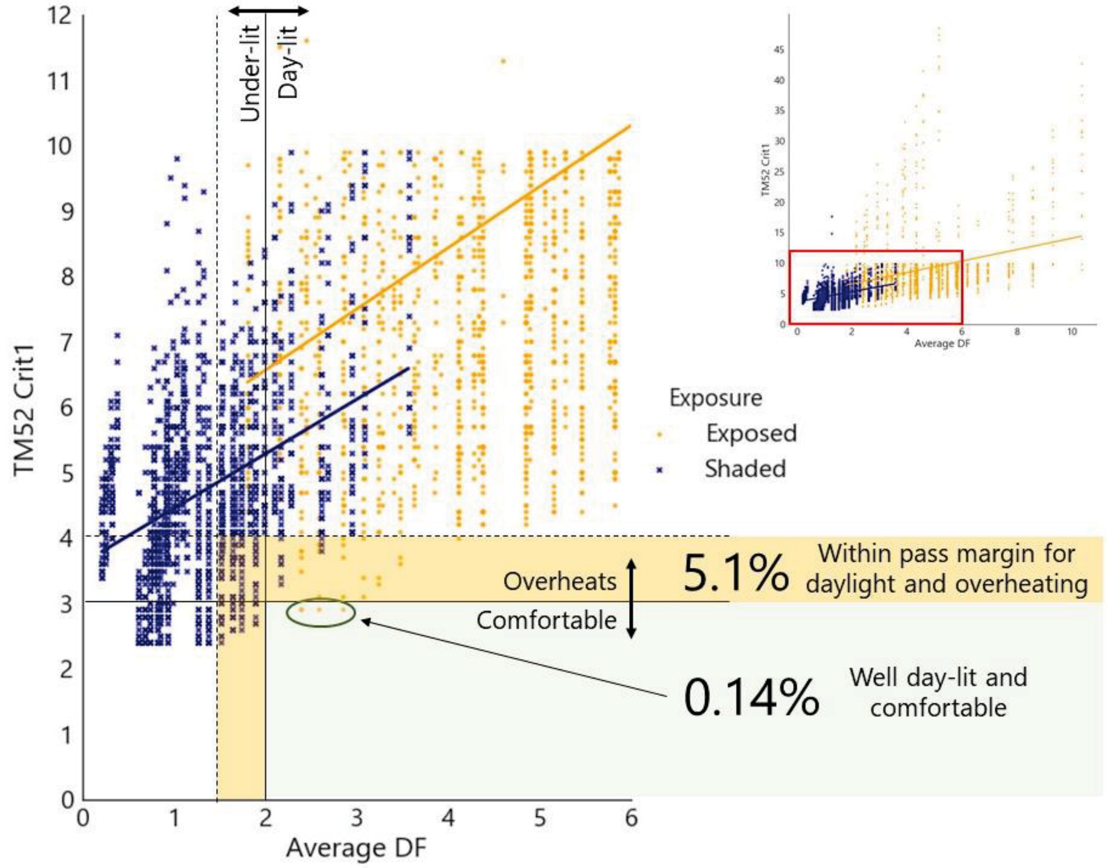


Figure 13—33 Balancing overheating and daylight for naturally ventilated non-residential spaces in shaded and unshaded locations (sample shown achieves 15% or greater uplift over TER)

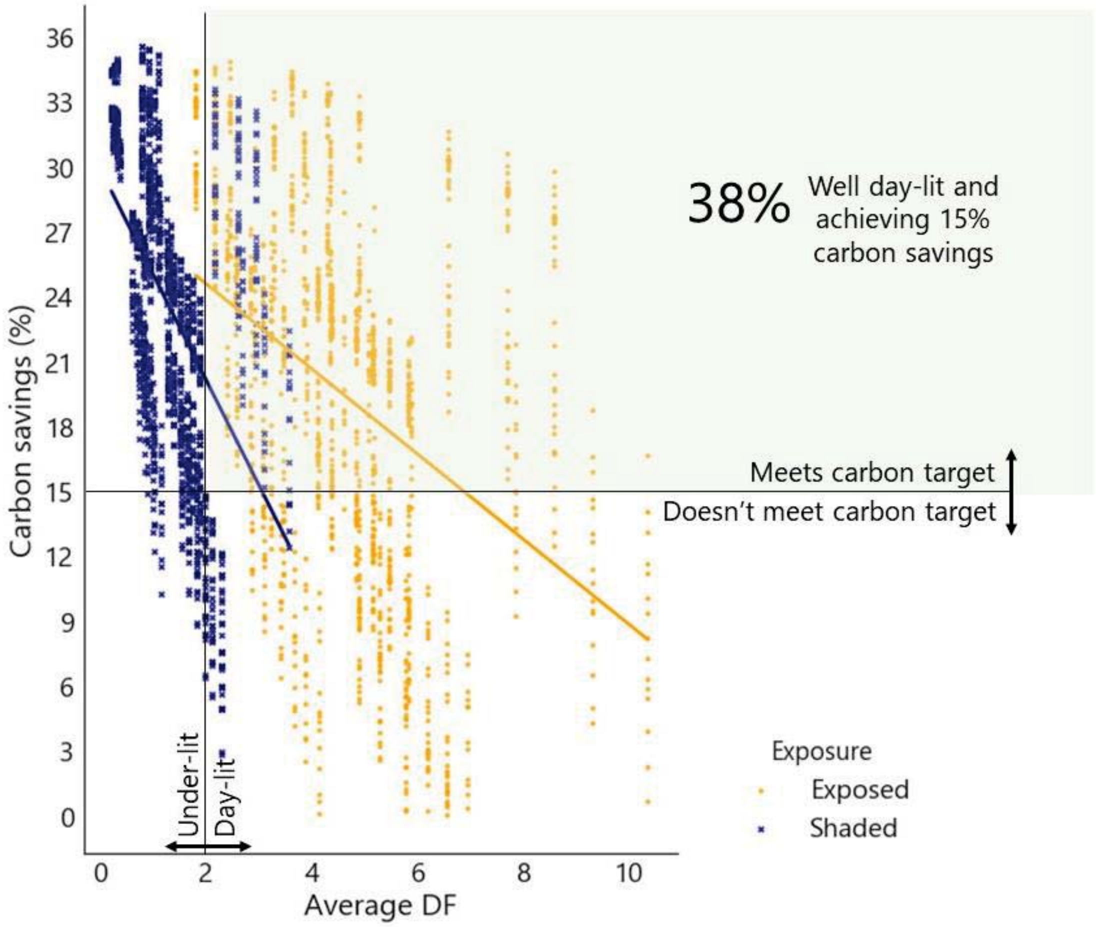
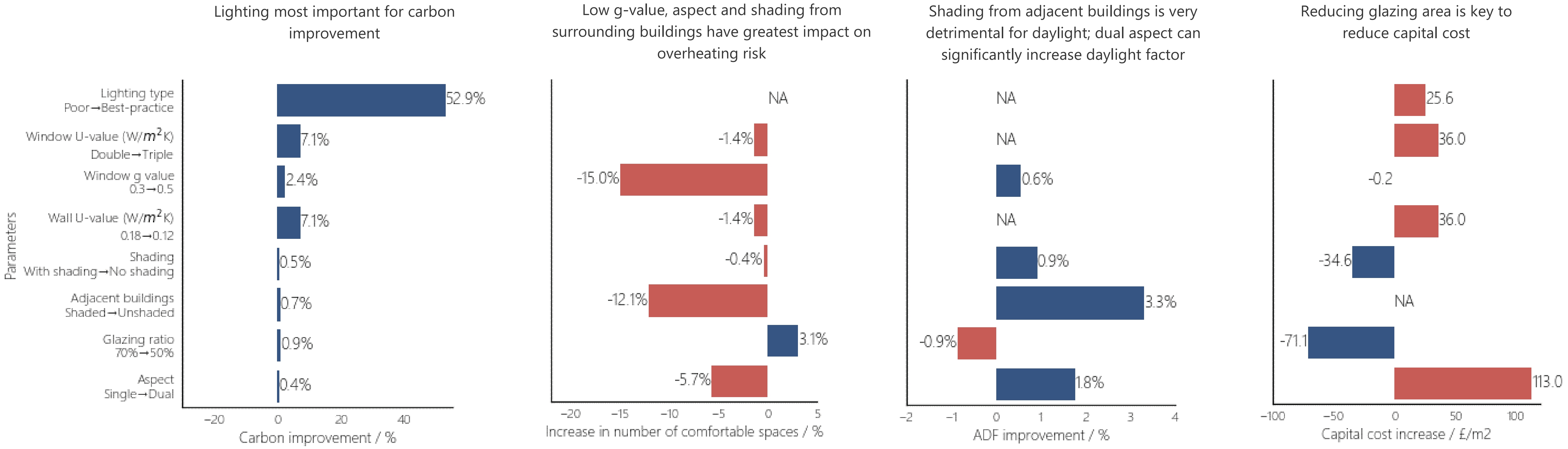


Figure 13—34 Balancing carbon savings and daylight for fully conditioned non-residential spaces in shaded and unshaded locations

System

Using natural ventilation as a cooling method instead of mechanical cooling can provide an increase in carbon savings in the order of 20%. In addition, this would also generate a cost savings, by avoiding the cost of a cooling and ventilation system (£32/m^2 on average). Natural ventilation feasibility, however, should be reviewed based on the location in terms of overheating risk, as well as air quality and acoustic issues.

Low carbon design responses naturally ventilated



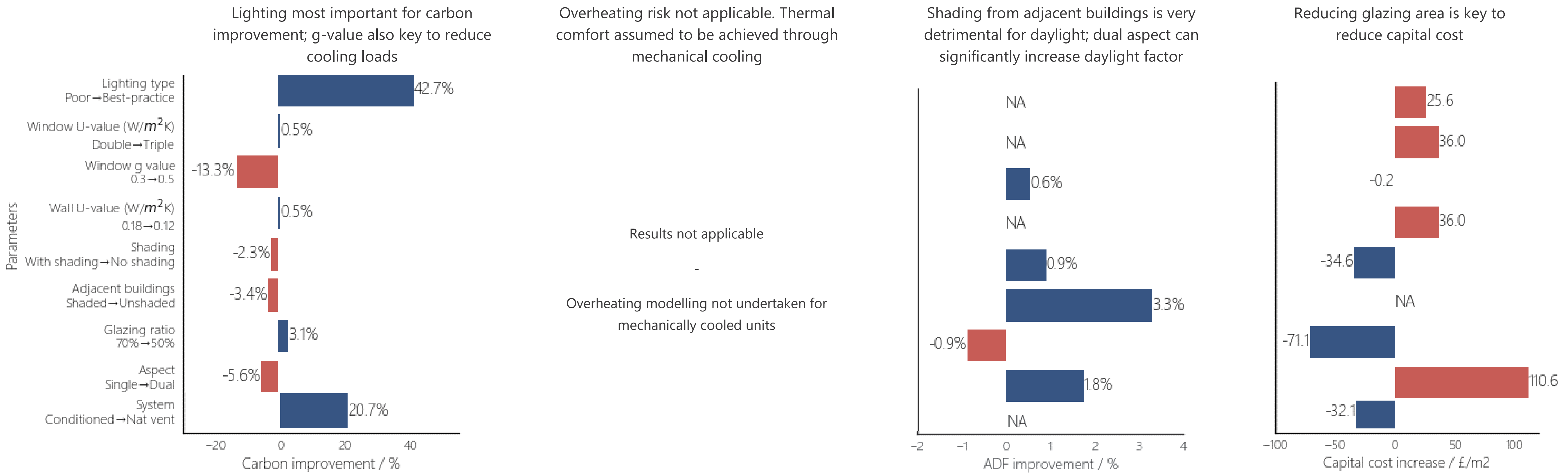
Lighting most important for carbon improvement

Low g-value, aspect and shading from surrounding buildings have greatest impact on overheating risk

Shading from adjacent buildings is very detrimental for daylight; dual aspect can significantly increase daylight factor

Reducing glazing area is key to reduce capital cost

Low carbon design responses fully conditioned



Lighting most important for carbon improvement; g-value also key to reduce cooling loads

Overheating risk not applicable. Thermal comfort assumed to be achieved through mechanical cooling

Shading from adjacent buildings is very detrimental for daylight; dual aspect can significantly increase daylight factor

Reducing glazing area is key to reduce capital cost

Results not applicable

-

Overheating modelling not undertaken for mechanically cooled units

13.4.5 Cost baseline and uplift

Carbon savings and overheating don't correlate well with cost, meaning that a better energy and overheating performance is not driven by an increase in capital cost investment (Figure 13—35 and Figure 13—36).

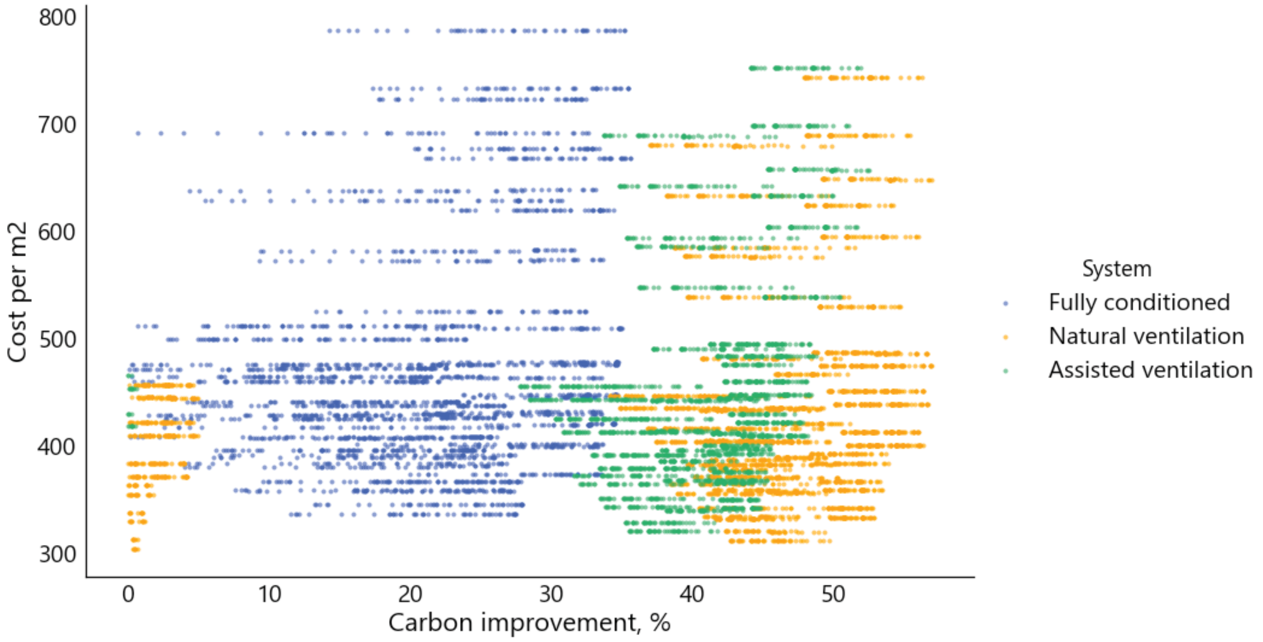


Figure 13—35 Non-residential cost vs. carbon savings by system type

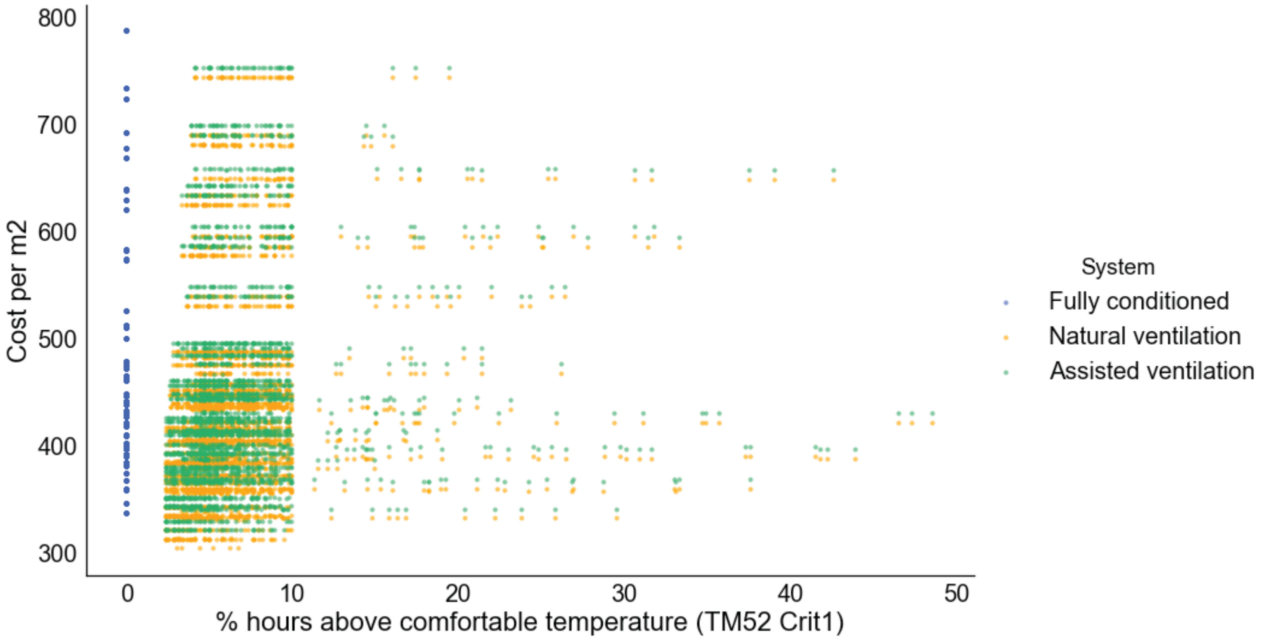


Figure 13—36 Non-residential cost vs. overheating Criterion 1 by system type

However, cost has a strong correlation with daylight, as observed in Figure 13—37. In order to improve daylight, a higher capital investment is required. This is due to the fact that the main drivers for daylight are aspect and glazing ratios, which are key drivers for cost uplift. This can be observed in Figure 13—38 and Figure 13—39, where, especially for aspect, a proportional increase in both daylight factor and cost can be observed.

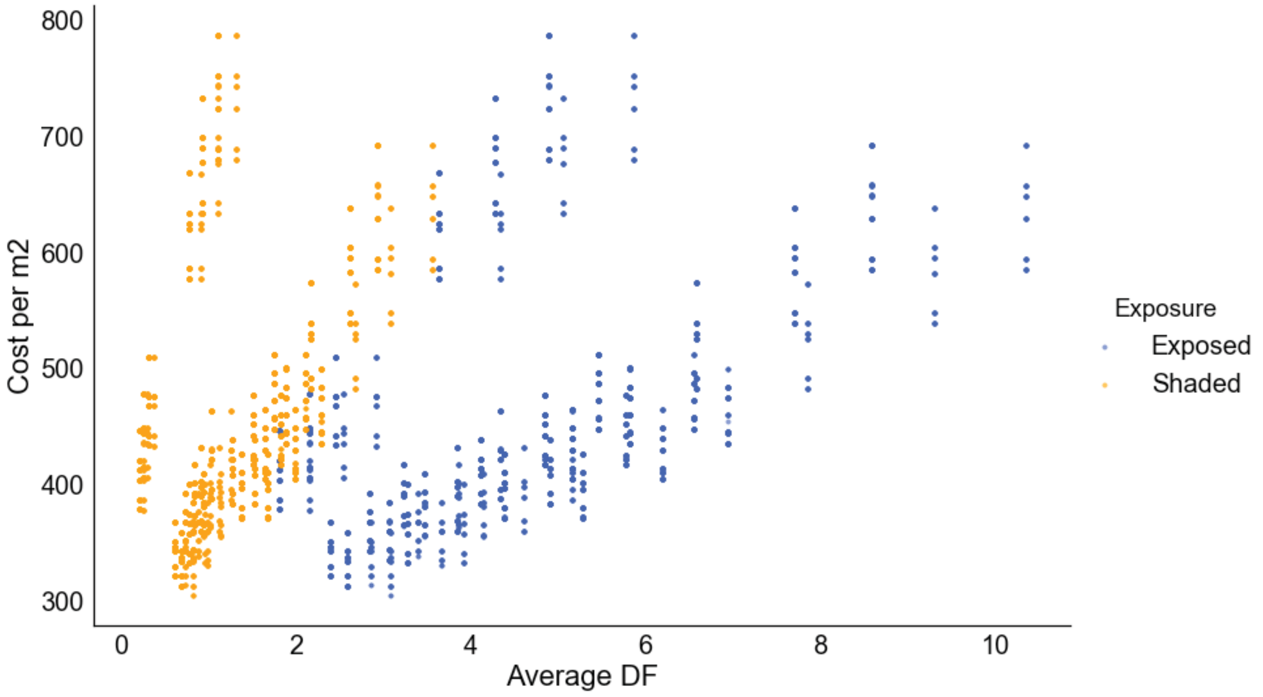


Figure 13—37 Non-residential cost vs. average daylight factor by system type

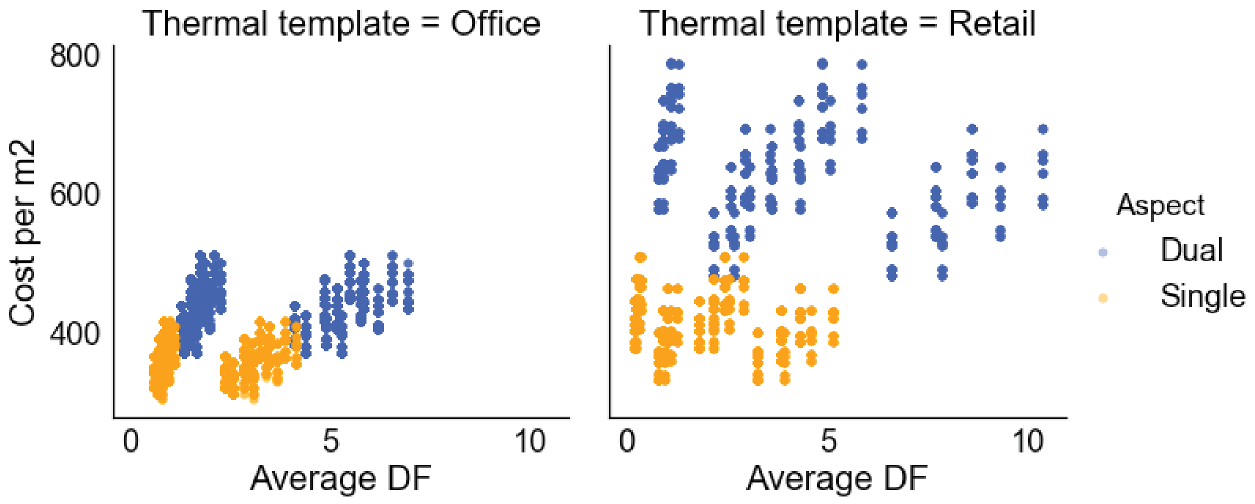


Figure 13—38 Effect of aspect on daylight factor and cost for office and retail spaces

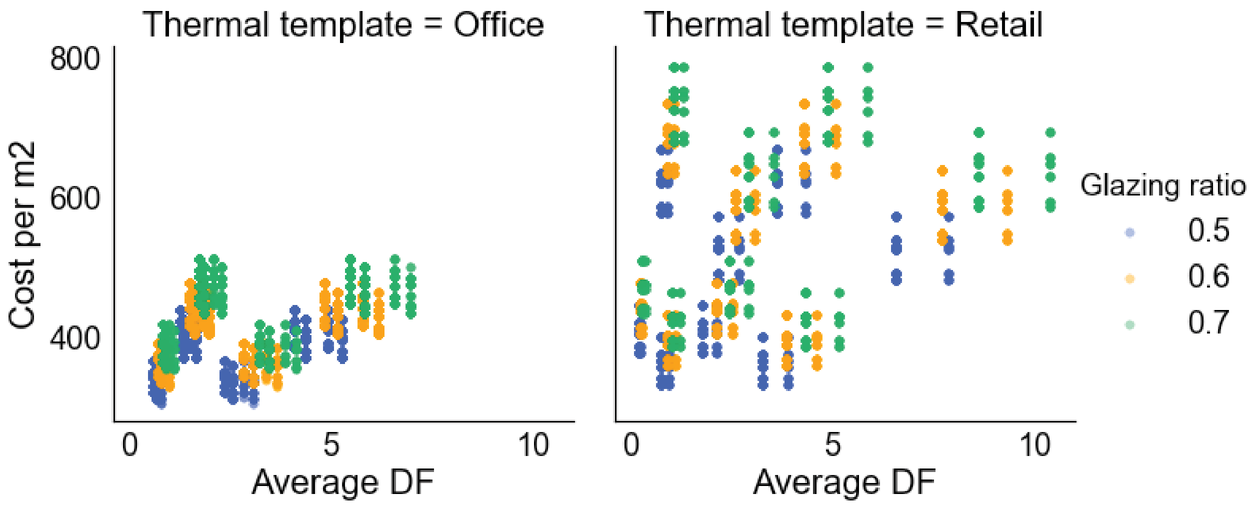


Figure 13—39 Effect of glazing ratio on daylight factor and cost for office and retail spaces

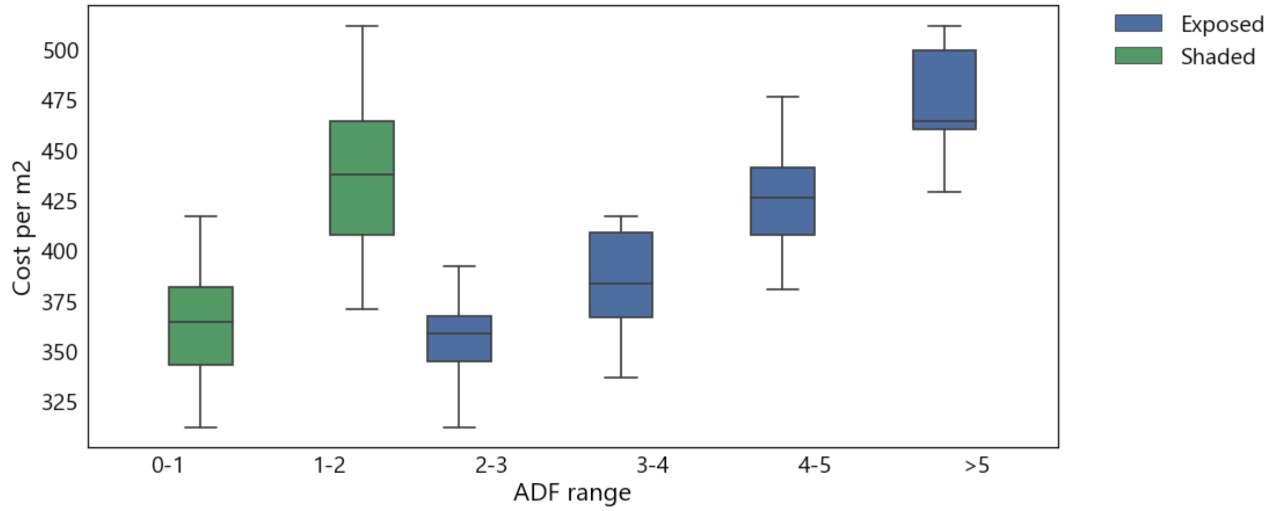


Figure 13—40 Distribution of cost to achieve different Average Daylight Factor ranges in office spaces

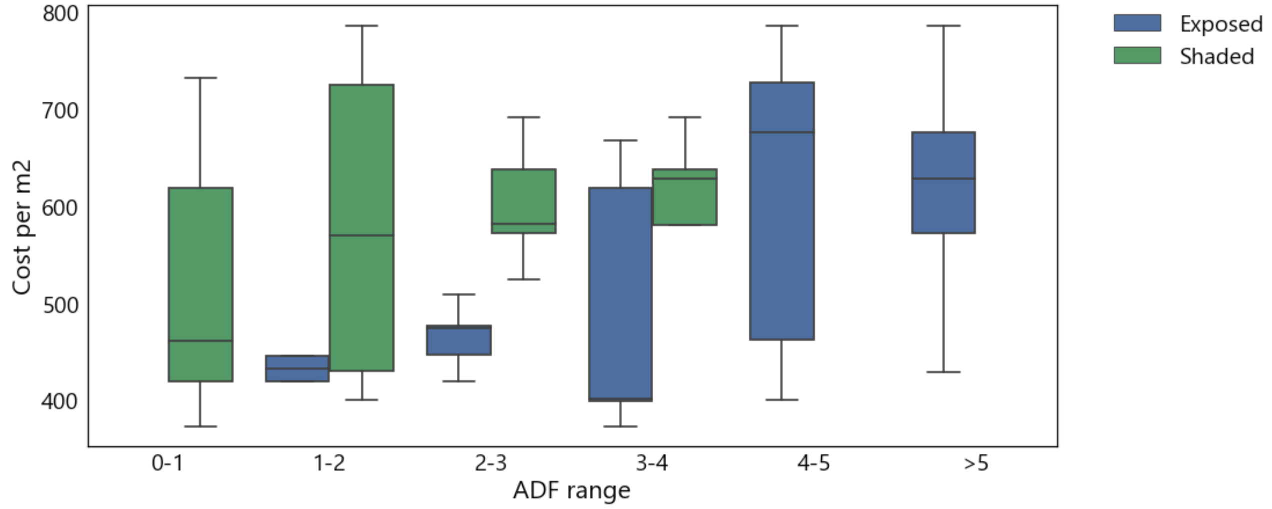


Figure 13—41 Distribution of cost to achieve different Average Daylight Factor ranges in retail spaces

Table 13—9 Median cost to achieve different Average Daylight Factor ranges by non-residential typology and shading conditions

Adjacent buildings	Typology	Median cost per m^2					
		ADF 0-0.9%	ADF 1-1.9%	ADF 2-2.9%	ADF 3-3.9%	ADF 4-4.9%	ADF >5%
Exposed	Office	NA	NA	£359	£384	£426	£465
	Retail	NA	£433	£476	£402	£677	£629
Shaded	Office	£365	£438	NA	NA	NA	NA
	Retail	£462	£570	£582	£629	NA	NA

Figure 13—40 and Figure 13—41 (for office and retail respectively) confirm the trend observed for daylight and cost. The figures show the cost distribution by daylight factor level for all cases where a 15% carbon reduction is achieved and overheating criteria are met. Table 13—9 also shows the estimated median cost to achieve increasing levels of daylight factor in different shading conditions for office and retail spaces. The following observations can be made:

- Higher cost is generally required in shaded locations to achieve the same level of daylight, as measures such as dual aspect and higher glazing ratios are needed to improve daylight in this case.
- A larger range of costs is observed in retail: as the units modelled are less deep, the same daylight factor level can be achieved with a wider range of measures, with varying levels of cost. In particular, in offices a stronger divider is observed between single and dual aspect spaces (which is the main cost driver): for example, in the exposed case, ADF levels up to 4% are achieved by single-aspect spaces only, while ADF levels above 4% are achieved by dual-aspect spaces only. Conversely, in retail single-aspect spaces can achieve ADF levels in excess of 5%.
- Exposed retail units have a lower median cost in the 3-3.9% ADF range than in the 2-2.9% range. This is due to the fact that most of the spaces in the 2-2.9% ADF range can improve their daylight (and reducing cost) by removing shading canopies.

As demonstrated by the analysis, it can be challenging for developments in shaded conditions to achieve an average daylight factor of 2%, whilst limiting carbon emissions and overheating risk. It is therefore assumed that typical London developments can achieve an average daylight factor in the range of 1-1.9% and for this reason this has been considered as the baseline to determine cost uplifts. In exposed offices, where the analysis hasn't shown any spaces in this range, it has been assumed that the cost is equal to achieving ADF in the 2-2.9% range. Based on these assumptions, the cost uplifts to achieve the different levels of daylight factor are summarised in Table 13—10 for the different typologies and shading conditions. The baseline is here highlighted in yellow.

Table 13—10 Median cost uplifts to achieve different Average Daylight Factor ranges by non-residential typology and shading conditions

Adjacent buildings	Typology	Median cost per m^2					
		ADF 0-0.9%	ADF 1-1.9%	ADF 2-2.9%	ADF 3-3.9%	ADF 4-4.9%	ADF >5%
Exposed	Office	NA	£0	£0	£25	£67	£106
	Retail	NA	£0	£42	-£31	£243	£195
Shaded	Office	-£74	£0	NA	NA	NA	NA
	Retail	-£108	£0	£12	£59	NA	NA

14 Appendix D - Meeting carbon reduction targets with Future Carbon factors

14.1 Impact of future carbon factors

The scope of this study is to analyse carbon emissions in line with a future carbon scenario. The GLA London plan will assume that the 2019 Carbon factors as projected by the BRE will be used when it comes into force.

The BRE produced a Consultation Paper: CONSP:07 CO_2 and primary energy factors for SAP 2016 Version 1.0 30/06/16 with the SAP 2016 consultation release that described the development of CO_2 and primary energy factors for SAP 2016, as well as future carbon factors outlined Table 14—1.

Table 14—1 BRE future carbon factors

Part L version /years	2013 -2016	2017 - 2018	2019 -2021	2022 – 2024	2025 -2027
Information Source	**SAP 2012**	**BRE SAP 2016 Consultation**	**Projected (assumed for future carbon analysis)**	**Projected**	**Projected**
Unit	$kgCO_2/kWh$				
Natural Gas	**0.216**	**0.208**			
Grid Electricity	**0.519**	0.398	**0.302**	0.229	0.183

The paper outlined how the projected system average electricity emission factors for current and future periods (coinciding with anticipated revisions of Part L of the Building Regulations). This provided an indication of the likely trajectory, but the emission factor for future years may be different. These are outlined below and have been used for future SAP years within this study

The Marginal grid emission factors, as outlined by the LLDC consultation response, were not used and the following justification was provided by the BRE:

"System average values reflect the primary energy and emissions associated with grid supply electricity in the UK and are appropriate for measuring and reporting energy and carbon impacts. In contrast marginal emission factors are appropriate for measuring the effect of changes in demand compared to a normal or baseline situation."

As the BRE have used the system average carbon emissions figures, this study will also follow this approach. These align with the Updated energy and emissions projections 2014: projections of greenhouse gas emissions and energy demand 2014 to 2030, October 2014, DECC.

14.2 Impact of Low and Zero Carbon heating technologies

The impact of future changes to the electricity grid will have a considerable impact on the carbon saving potential of differing heating systems. As found in The Future Role of the London Plan in the Delivery of Area-Wide District Heating – final report, Buro Happold, Jun 2017, that from 2019 certain technologies will not show carbon reductions using proposed BRE Part L carbon factors, for instance gas fired CHP. However efficient electric heat pumps, either individual or communal, show carbon reductions into the future.

As a result the expected performance district/communal heating as well as the low or zero carbon heating source is a key considered in the creation of the energy efficiency policy, as well as a having significant infrastructure impacts across the whole of the masterplan.

For the purposes of this study the same systems as analysed in The Future Role of the London Plan in the Delivery of Area-Wide District Heating – final report, Buro Happold, Jun 2017 report have been analysed. Carbon intensities of heat and communal heat losses as outlined in the report as well as outlined in Figure 14—1.

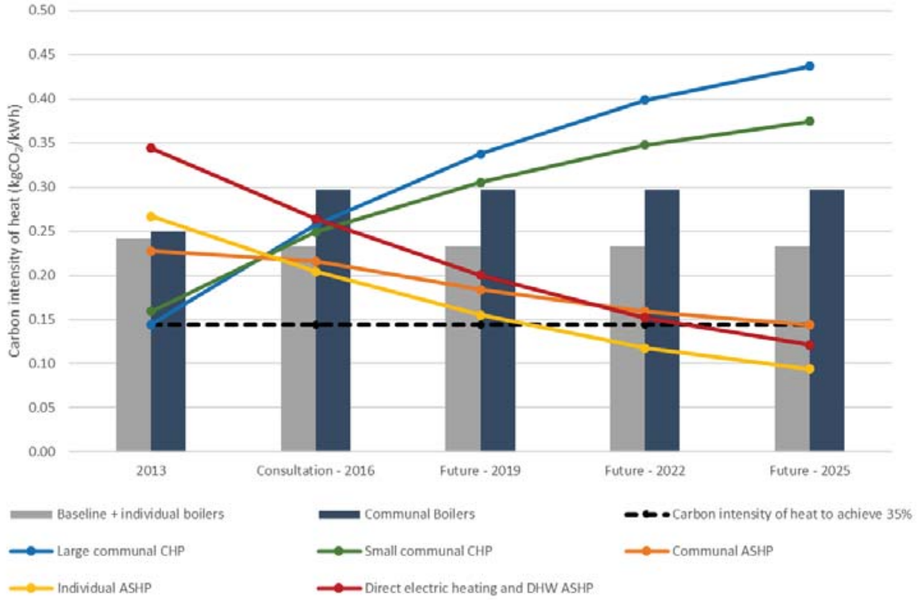


Figure 14—1 expected carbon intensities of heat for each systems types analysed, from the GLA The Future Role of the London Plan in the Delivery of Area-Wide District Heating study

The systems considered as follows:

1. Communal Gas boiler – 91% and 95% efficiency
2. Communal gas fired Combined heat and power (CHP) Engine with gas boiler backup
3. Individual Air Source Heat Pump (ASHP) per dwelling
4. Communal ASHP with gas boiler backup
5. Hybrid systems
    5.1 Space heating by direct electric underfloor mats; and
    5.2 Domestic Hot Water (DHW) by communal ASHP (system 4).
6. Direct electric
    6.1 space heating by direct electric underfloor mats; and
    6.2 Communal ASHP for (DHW)

The impact that these system variations will have on the DER/BER has been calculated using both Part L 2013 and 2019 averaged carbon factors. This has been post-processed for typical developments and the impacts on the resulting on-site carbon compliance outlined in Figure 14—3.

14.3 On-site Renewables

Solar PV is the only on-site renewable considered within this section. Other renewable and low zero carbon systems have been considered within section. The systems in that section are associated to the production of heat on a plot or District heat network level.

Solar PV array design and energy production benchmarking

The roof layout of the example plot has been reviewed and potential PV arrays sized based on the areas available. Consideration for roof top smoke extract vents, BMUs, lift overruns and any plant has been taken into consideration. As a result 40% of the lower shoulder roofs is allocated for PV.

Solar array design has been considered as to be combined with green roofs for SUDs, to align with the OPDC Integrated Water Management Strategy, 2017. This increases spacing between panels therefore panels will take 60% of the area per array, as outlined in Table 14—2.

Table 14—2 PV array assumed systems variables and expected outputs

Array variable	**Input**
Roof area available for array	40%
PV to Roof array (allow for spacing to minimise self-shading)	60%
Solar PV angle	30 deg
Solar Panel kWp (per panel)	0.325 Wp
Inverter Efficiency	95%
Panel efficiency	16.7%
Solar collector effectiveness	80%
Assumed irradiance on Panel (kWh/m^2.yr)	1000
Array system specifics	**Output**
Assumed roof area available	2880 m2
Assumed area available for PV arrays	1150 m2
PV area	690 m2
PV Panel install capacity	116 kWp
Electricity output from arrays	87,758 kWh
Assumed carbon savings (Part L 2013) (Tonnes)	45.5
Assumed carbon savings (Part L 2019) (Tonnes)	26.5

Table 14—2 shows that the output of the Solar PV is ~90 MWh/yr however the carbon reductions available from this array would be expected to nearly half with the change in grid carbon factors.

Figure 14—2 shows the assumed extent of the roof top arrays that would be considered feasible on a development of this type and massing. Arrays are only considered feasible on the only on lower shoulder blocks. It is considered that tower element across the masterplan would not have the available roof space to accommodate PV, due to maintenance and BMU access required on tall towers. BMUs are expected to be required for both prefabricated facade installation/construction, on-going maintenance as well as window cleaning.

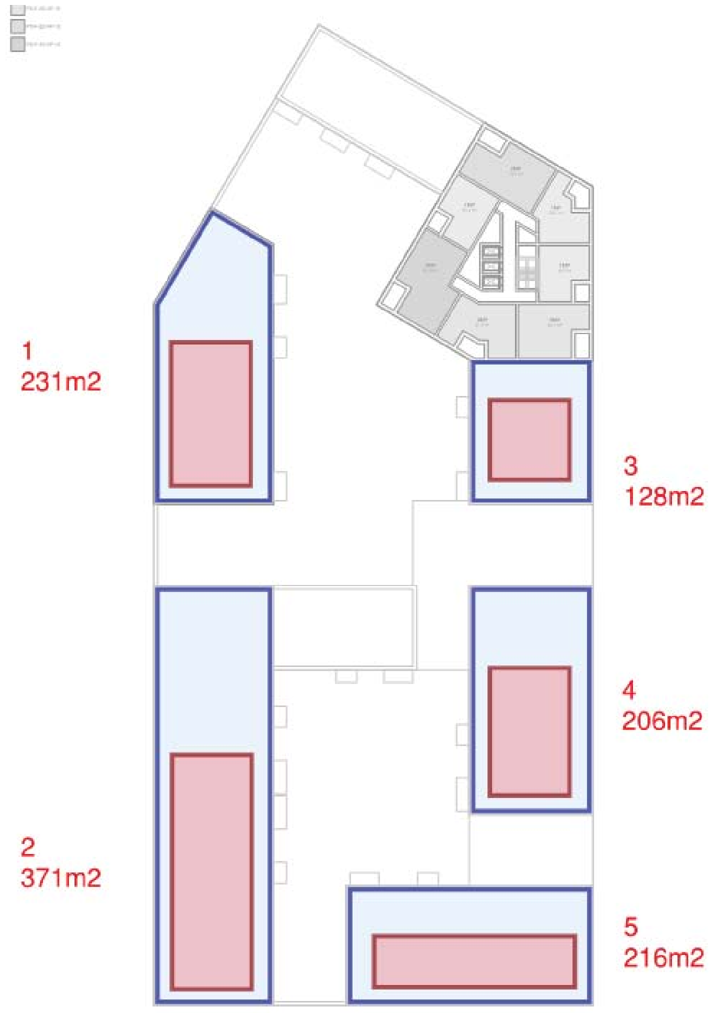


Figure 14—2 Assumed roof areas available for Solar PV

14.4 Systems cost drivers

Table 14—3 summarises the capital and lifecycle costs of the different building services costs assessed for the residential development areas.

The use of resistive electric heating (option 7) is substantially less expensive in capital terms compared to those options using a hydronic heating space system. These capital savings would need to be set against the substantially higher energy costs associated with these systems (for a given level of energy efficiency). Option 8 combines ASHP for DHW and resistive heating which in part offsets the impact on energy costs through the higher efficiency of the heat pump, however this solution is more expensive in both capital and lifecycle terms than the alternative of individual ASHP's in each unit (Option 6) and this solution would also deliver lower running costs because of its greater efficiency for space heating in comparison to option 8.

After resistive electric heating, Option 6 individual ASHP units is the least expensive in both capital and lifecycle cost terms. Installation of individual ASHP units would require additional space to be found both within and outside each unit to contain the heat pump and cylinder.

Communal systems (Options 1-4 and 8) are generally more expensive than the alternative of an individual system (accepting that individual gas boilers would not be possible in these buildings), this is in part because of the need for a heat interface unit (HIU) in each apartment. HIU's are relatively expensive to install and they more than offset any reduced cost associated with large centralised plant. CHP systems are the most expensive in both capital and operating costs, they require a similar set of services to the gas boiler solution but with the addition of the CHP engine which increased the capex and replacement costs. CHP maintenance is also more expensive than the other technologies considered as they require more a substantial servicing regime.

It is important to remember that these options are not 'comparable' systems in compliance terms (i.e. they are do not all deliver similar performance relative to Part L 2013 and so would need to be paired with a energy efficiency and renewable energy package to determine the overall performance level.

Table 14—3 Capital cost and discounted replacement, O&M costs by systems type and normalised per dwelling rate

No.	Servicing option/ energy system	Total Cost Capital (£)	Discounted Replacement Cost (£)	Discounted O&M Cost (£)	Total Discounted Life Cycle Cost (£)	Total Life cycle cost per dwelling (£/Dwelling)
1	**Centralised boiler (91%) for space heating and DHW**	£4,949,000	£1,208,000	£495,000	£6,652,000	£13,300
2	**Centralised boiler (95%) for space heating and DHW**	£4,974,000	£1,222,000	£495,000	£6,691,000	£13,400
3	**Communal CHP with gas boiler backup**	£5,234,000	£1,194,000	£993,000	£7,421,000	£14,800
4	**Communal ASHP with gas boiler backup**	£5,225,000	£1,286,000	£537,000	£7,048,000	£14,100
6	**Individual ASHP**	£3,952,000	£1,129,000	£596,000	£5,677,000	£11,400
7	**Direct electric space heating and DHW**	£2,559,000	£629,000	£553,000	£3,741,000	£7,500
8	**Hybrid System:** **DHW - Centralised ASHP with boiler backup** **Space heating - Direct electric**	£4,719,000	£1,165,000	£729,000	£6,612,000	£13,200
9	**Solar PV Array**	£124,000	£62,000	£19,000	£205,000	£400

Excluding CHP, the O&M costs of dwelling level services are similar (slightly higher) than those for centralised systems, however this distinction overlooks the distribution of these costs between the building manager and occupier / landlord. For options 6 and 7 there is relatively little ongoing maintenance that would fall to the building manger while in other scenarios their obligations are more substantial and would be reflected in service charges. O&M costs associated with the CHP option are higher than for the others considered because, the CHP unit represents an additional maintenance burden and will require more frequent servicing than either gas or ASHP alternatives.

14.5 How do Lean reductions impact system applications and carbon reductions in future carbon?

Analysis has been undertaken to assess the impact of the new Lean energy efficiency target on 'Clean' or 'Green' low and zero carbon heating technologies, as well as the extent to which Solar PV systems can also contribute to zero carbon. Analysis has been run on a residential development wide basis, as outlined in the typical development as per section 11.4.1.

Systems analysis in Figure 14—3 compares the carbon emissions to the use of a Gas fire CHP engine with gas boilers using Building Regulations Part L 2013 in each case. This is because it is the only technology to show the 35% carbon reduction required under the current London plan.

Analysis conclusions

- Gas fired CHP shows increased carbon emissions under Part L in 2019.
- Moving from SAP 2012 to the proposed SAP 2016 Consultation update communal heating distribution factors, 1.05 to 1.3, shows a fail with lean measures alone. It is recommended that individual boilers are used in modelling to show lean performance. Without this, a 10% lean improvement under 2013 will not show any savings under future Part L iterations.
- With a 10% lean improvement under Part L 2013 Communal and individual Air Source Heat pumps meet 35% on site.
- If fabric is pushed to 15% improvement a hybrid system could be employed by developers and the 35% onsite could be met. This means direct electric heating and a form of communal domestic hot water. Solar PV would still be required in this case, therefore meaning shoulder level blocks, as per the typical development would be required. Therefore a challenge in standalone tower blocks.

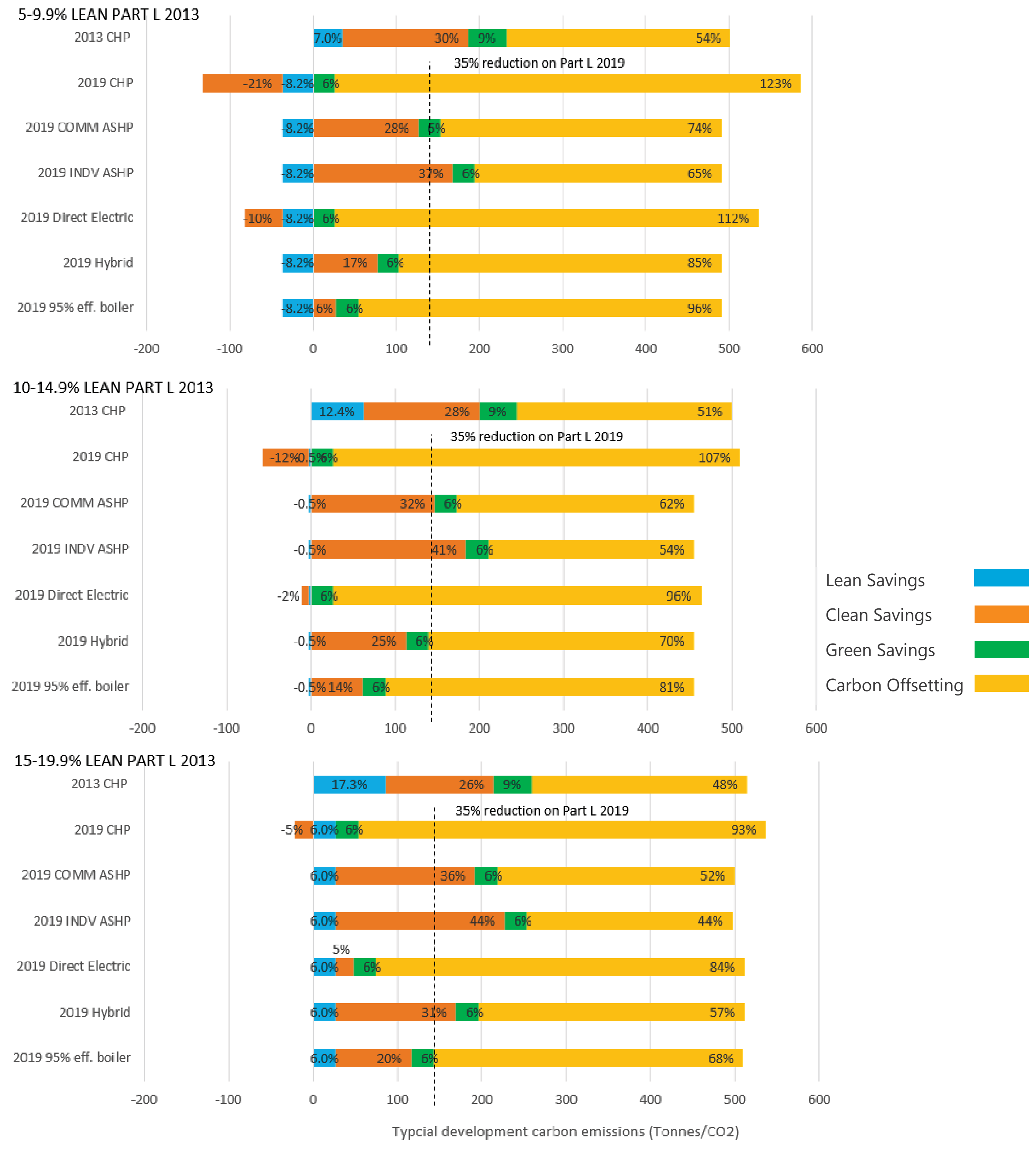


Figure 14—3 Development regulated carbon emissions utilising varying low and zero carbon technologies for three of Lean carbon reductions

14.6 Cost effectiveness of measures to Zero Carbon

Total lifecycle cost for each considered scenarios, including cost of lean measures, heating system and PV system, are shown in Table 14—4. This also shows the onsite carbon savings (including lean, clean and green measures) and the corresponding abatement costs (cost per unit of carbon saved per dwelling). The abatement costs are also shown in Figure 14—4.

Table 14—4 Total lifecycle cost, onsite carbon savings and cost per carbon of each scenario

5-9.9% Lean Part L 2013	**2019 91% boiler**	**2019 95% boiler**	**2019 CHP**	**2019 COMM ASHP**	**2019 INV ASHP**	**2019 Direct Elec**	**2019 Hybrid**
Lifecycle cost (£)	£15,177,257	£15,183,672	£16,050,947	£15,277,952	£13,832,483	£12,278,907	£14,930,970
CO$_2$ savings (tCO$_2$)	-10,773	7,330	-68,934	153,286	194,657	-17,801	103,831
£/tCO$_2$/unit	N/A	N/A	N/A	£197	£141	N/A	N/A
10-14.9% Lean Part L 2013	**2019 91% boiler**	**2019 95% boiler**	**2019 CHP**	**2019 COMM ASHP**	**2019 INV ASHP**	**2019 Direct Elec**	**2019 Hybrid**
Lifecycle cost (£)	£15,562,053	£15,571,466	£16,426,112	£15,689,914	£14,251,296	£12,662,539	£15,314,630
CO$_2$ savings (tCO$_2$)	24,447	40,884	-28,364	173,413	210,978	18,065	139,682
£/tCO$_2$/unit	£1473	£789	N/A	£180	£134	£2031	£217
15-20% Lean Part L 2013	**2019 91% boiler**	**2019 95% boiler**	**2019 CHP**	**2019 COMM ASHP**	**2019 INV ASHP**	**2019 Direct Elec**	**2019 Hybrid**
Lifecycle cost (£)	£15,600,063	£15,611,638	£16,457,176	£15,747,519	£14,313,843	£12,699,711	£15,351,730
CO$_2$ savings (tCO$_2$)	53,582	68,818	4,630	191,662	226,482	47,667	169,323
£/tCO$_2$/unit	£589	£455	N/A	£162	£125	£542	£180

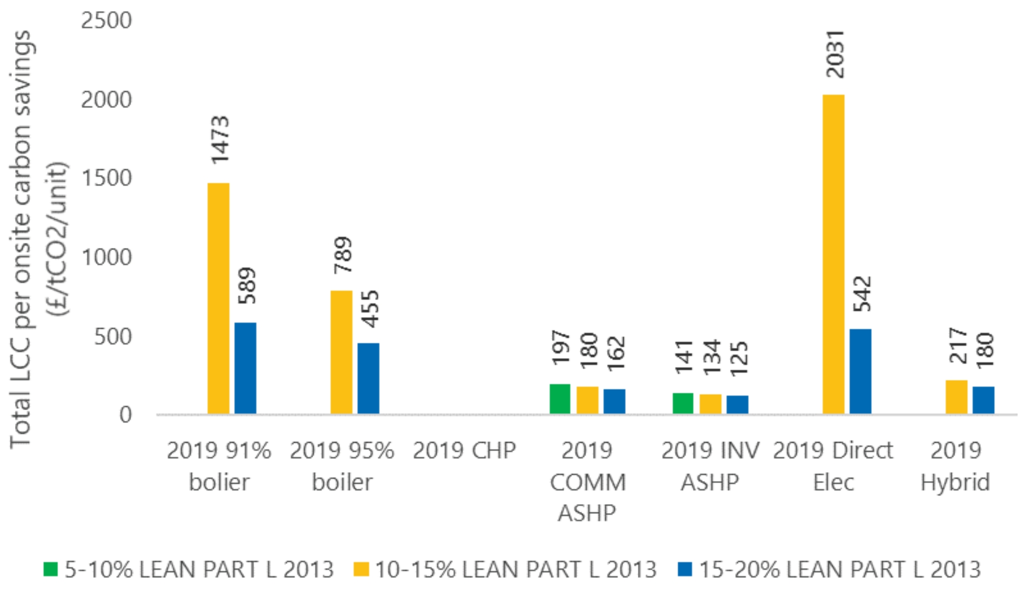


Figure 14—4 Cost per unit of carbon saved per dwelling in each heating system scenario

It can be observed that when lean measures achieve carbon savings (compared to Notional) in the range of 5-10% in 2013, only ASHPs, either communal or individual, would achieve positive carbon savings in 2019 (abatement costs are not shown where no carbon savings are achieved). Their cost is lower or comparable to communal boiler systems and therefore they present relatively low abatement costs.

In developments pushing lean savings to 10-15% in 2013, all heating systems except CHP achieve positive carbon savings in 2019. Direct electric systems present the highest abatement cost, due to the limited carbon savings produced (despite their low lifecycle cost). Hybrid systems have comparable abatement cost to communal ASHP, as the reduced emissions are compensated by a lower lifecycle cost.

As lean emissions increase further and reach the 15-20% range in 2013, the abatement costs in 2019 reduce considerably for all technologies as the overall emissions saved onsite increase.

It should be noted that CHP systems are characterised by negative savings even in the 15-20% lean savings range.

15 Appendix E - What is the potential performance gap and how to minimise it

15.1 Overview

The performance gap is the difference between expected (or as designed) performance modelling and the in use performance that experienced in reality. The compliance gap is the difference between the regulated compliance modelling undertaken for this study and the in use performance. [3]

Numerous building performance evaluations [3, 4, 5] have shown that buildings use significantly more energy in-use than predicted by their designers; 2.6 times more in the case of dwellings, and 3.6 times for non-domestic buildings. The same research showed that buildings that prioritise passive energy measures have a smaller performance gap than those relying more on mechanical solutions or active energy efficiency measures, i.e. MVHR and boiler improvements. It is therefore important to consider the impact of proposed energy efficiency measures on the potential for in-use performance as well as their impact on the Part L compliance model.

It is possible to bridge the gap between the compliance model and the in-use performance through following extended calculation methods such as those described in CIBSE TM54. Whilst this may close the 'compliance gap', as illustrated in Figure 15—1, it still does not address the full 'performance gap' between predictions and reality, as there are limitations to all predictive calculations undertaken at the design stages of a project.

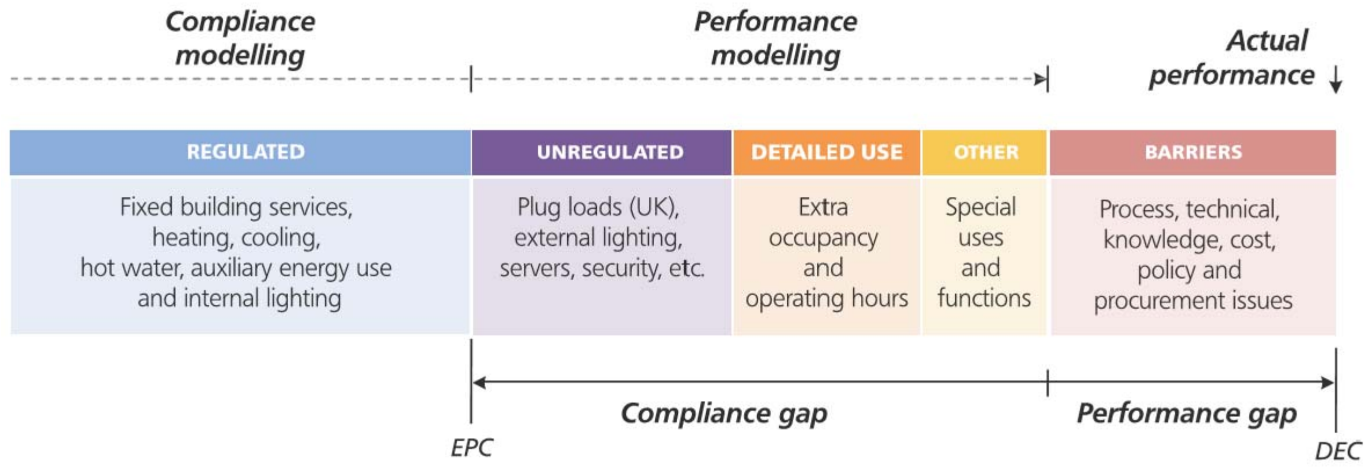


Figure 15—1 Performance gap and compliance gap [4]

15.2 Key success factors

The UKGBC task group report – *Delivering Building Performance* identifies five key success factors in delivering building performance; these are outlined below:

UKGBC key success factors for delivering building performance [4]

1. **ASPIRATION** : Setting a simple target – at the very least for energy (kWh/m2) – helps to create a common language and shared aspirations across the delivery process.[6]
2. **CONTROL** : Collaborative contracting, with performance guaranteed and control maintained throughout the delivery process helps to ensure predictable outcomes.
3. DESIGN FOR **PERFORMANCE** : Performance improves when aspirations are not limited to compliance or, in other words, "going for the ceiling, not the floor".
4. **FEEDBACK** : Reciprocal links and a commitment to monitor and feedback, particularly during the handover process, is vital. So, too is giving time for well documented building commissioning. 'Links must be made between operational facilities management (FM) and the design team, and between FM and building occupiers.
5. **KNOWLEDGE** : Improved knowledge, across the whole value chain, supports good outcomes. This is enabled by participating openly in lesson-sharing activities.

15.3 Considerations within industry to achieve success factors

There were several common themes in the literature reviewed, surrounding the causes of the performance gap and methods for reduction. These are identified in the following sections:

General observations

- "There was no single, simple recipe for a successful building with low energy use and carbon emissions" [6]
- "Building performance is far broader than just energy and carbon. We know, for example, that how a building operates impacts human health and wellbeing, and productivity of building users." [4]
- "Building performance describes how well a building functions against your needs. Most visibly for the occupier this would include being secure, waterproof, accessible, and providing space for the number of people and the processes that an organisation needs for its operations. Less visible elements include energy efficiency, occupier health, workplace productivity, carbon emissions and resilience of the building when in use. " [4]
- "Most new buildings come without any prediction or assurance as to the less visible performance elements. Occupiers are expected to take financial risk in terms of energy costs and the staff productivity drops that occur with heat, lighting and indoor air quality problems. So the financial benefit resulting from moderately efficient, comfortable buildings is substantial as staff are usually the biggest organisational asset, and operating expense. Other benefits include carbon reductions and brand enhancement. " [4]
- "Too often, buildings do not match the original aspirations of designers. This leads to higher-than-expected energy use and missions. There are many reasons for this, including building energy modelling difficulties during design; specification changes before and during construction; rushed or incomplete commissioning; and unanticipated occupant behaviour. " [6]

---

[3] C. v. Dronkelaar, "A Review of the energy Performance Gap and its Underlying Causes in Non-Domestic Buildings," 2017.

[4] UKGBC Task Group, "Delivering Building Performance," 2016

[5] Zero Carbon Hub, "Closing The Gap Between Design And As-Built Performance," 2014.

[6] Innovate UK, "Building Performance Evaluation Programme: Findings from non-domestic projects," 2016.

Passive solutions

- Of the buildings surveyed, “many with natural ventilation achieved low-carbon emissions, whereas buildings with poor control of space and water heating and/or lighting often had high emissions” [7]
- “To reduce energy use, use natural ventilation and/or mixed mode (with natural ventilation and supplementary mechanical ventilation for specific areas or at specific times of the year)” [7]

Technological solutions

- Most projects studied had problems with some new technologies, including solar water heaters, heat-recovery ventilation, automatic blinds, and heating controls. In most cases, these undermined carbon performance. Part of this is inevitable during early adoption of new technologies, as installers are inexperienced using unfamiliar systems. " [7]
- “Building Management Systems (BMSs) are another big challenge. Many buildings had systems their occupants could not use. Sometimes, they conflicted with other system controls, leading to confusion and wasteful energy use” [7]
- “Controls are a problem. There is a tendency to make controls for mechanical and electrical services too complicated. This alienates occupants and can mean the building defaults to high energy use” [7]
- “Allow extra time in the programme for innovative systems. Installation often takes longer than expected, and full commissioning before handover is essential” [7]
- “Do not rely on a BMS giving the control needed over building services – building operators may need specialist help for this, which can be expensive.” [7]
- “Put simplicity first – especially when it comes to controls” [7]

Airtightness

- "Homes built to Passive House standards achieved the best airtightness and insulation values, which means they had the lowest heat loss and best thermal performance." [7]
- "Most new homes do not achieve the heat-loss figures and airtightness figures submitted to Building Control in planning applications" [7]
- "Remember that airtightness often deteriorates over time – sometimes by more than a third. So the tested airtightness on day 1 is unlikely to endure for the home’s lifetime" [7]
- "Wet construction typically achieves better airtightness than dry lining with plasterboard" [7]
- "To reduce margin for error, architects should show the air barrier clearly on drawings, ideally in a different colour, and monitor this carefully during site work" [7]
- "The average airtightness test result was 6.1 m^3/m^2h, which is significantly better than the Building Regulations’ minimum requirement for air permeability. Surprisingly, there is hardly any link between airtightness and carbon performance." [7]
- “Ensure all operatives understand the importance of airtightness, and how to avoid puncturing an air barrier” [7]

Operation

- "Handover is a critical opportunity to explain to residents how to operate their homes in different seasons – and outline any maintenance they might need. Prepare clear instructions, and leave a simple summary for householders to refer to afterwards" [7]
- "Teething problems in the first year often push up CO_2 emissions – sometimes considerably. Without performance evaluation and some intervention, such problems may never be spotted and fixed. " [7]

Compliance gap

- "There is scarcely any link between the SAP estimate of CO_2 emissions for space and water heating, lighting and ventilation, and the actual total emissions." [7]
- "EPCs are not reliable predictors of actual energy use, little correlation between EPCs and DECs" [7]

15.4 Significance of factors modelled

The UKGBC key success factors for delivering building performance identified that knowledge of how to install and operate building elements is crucial to reducing the performance gap. Additionally, the literature review highlighted that overestimation of performance of building elements (i.e. building fabric U-value, airtightness or MEV) were key causes of performance gap; this overestimation could result from poor installation, value engineering or degradation over time. Figure 15—2, and Figure 15—3 show the relative impact of the parameters varied in this study, weighted by their impact on the overall energy demand of the building. Measures which are have been identified as significant predictors of energy consumption in the compliance modelling undertaken in this study have been cross referenced with the findings of the literature review in order to identify areas which should be scrutinised throughout the course of the design process in order to minimise the performance gap.

Figure 15—2 shows that in the residential analysis, glazing U-value and airtightness both have a significant impact on the gas demand of a dwelling. These factors could both be impacted by quality of workmanship and value engineering. Mechanical ventilation type has a significant impact on the energy consumption of a dwelling. If an MVHR unit is specified, which is then value engineered for a less performant model, or does not work/is not operated as anticipated, there may be a large impact on energy consumption.

---

[7] Innovate UK, “Building Performance Evaluation Programme: Findings from domestic projects,” 2016.

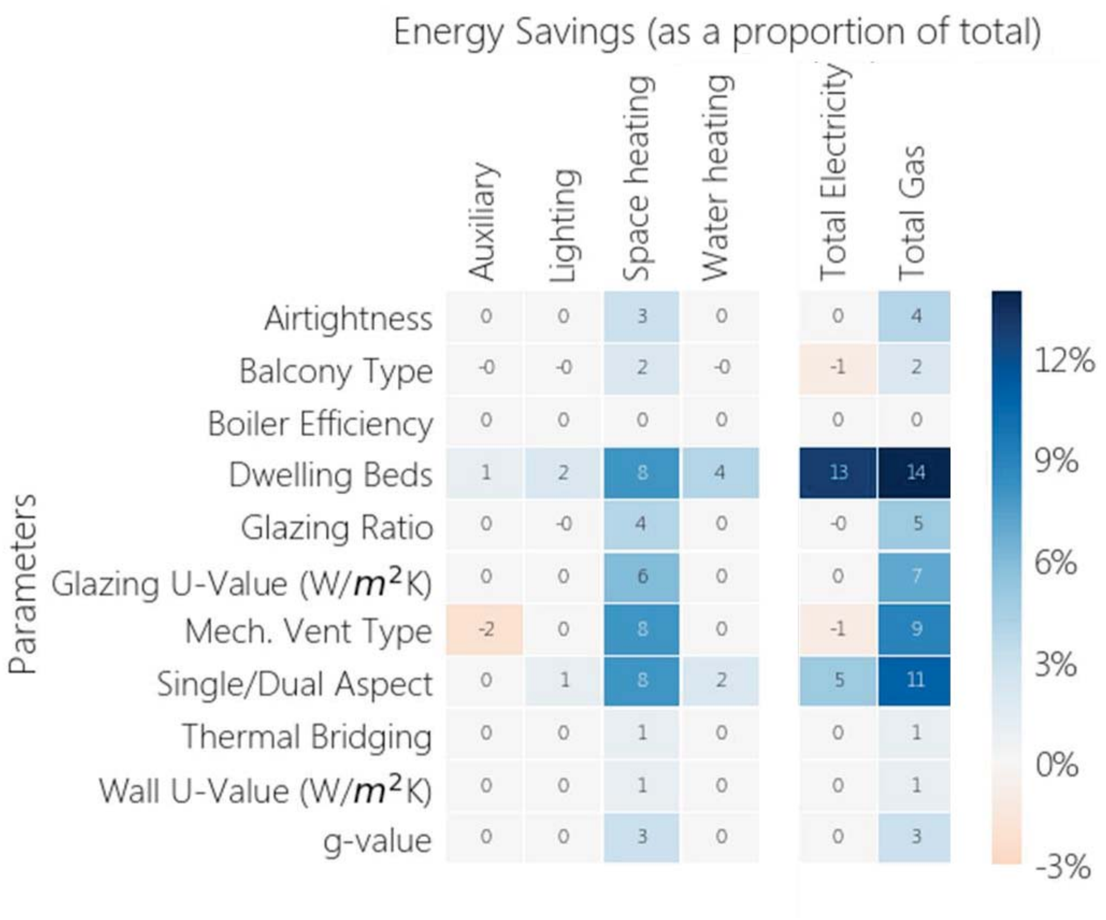


Figure 15—2 Relative impact of design measures on energy consumption for residential units

Figure 15—3 shows the key factors for the office and retail analysis. The energy consumption of the fully conditioned units modelled was heavily influenced by the demand for cooling. If adjacent buildings are assumed in the energy modelling which are either demolished or never built, the cooling demand will be significantly greater than anticipated. For assisted and naturally ventilated units, glazing U-value was a significant factor; this could both be impacted by quality of workmanship and value engineering.

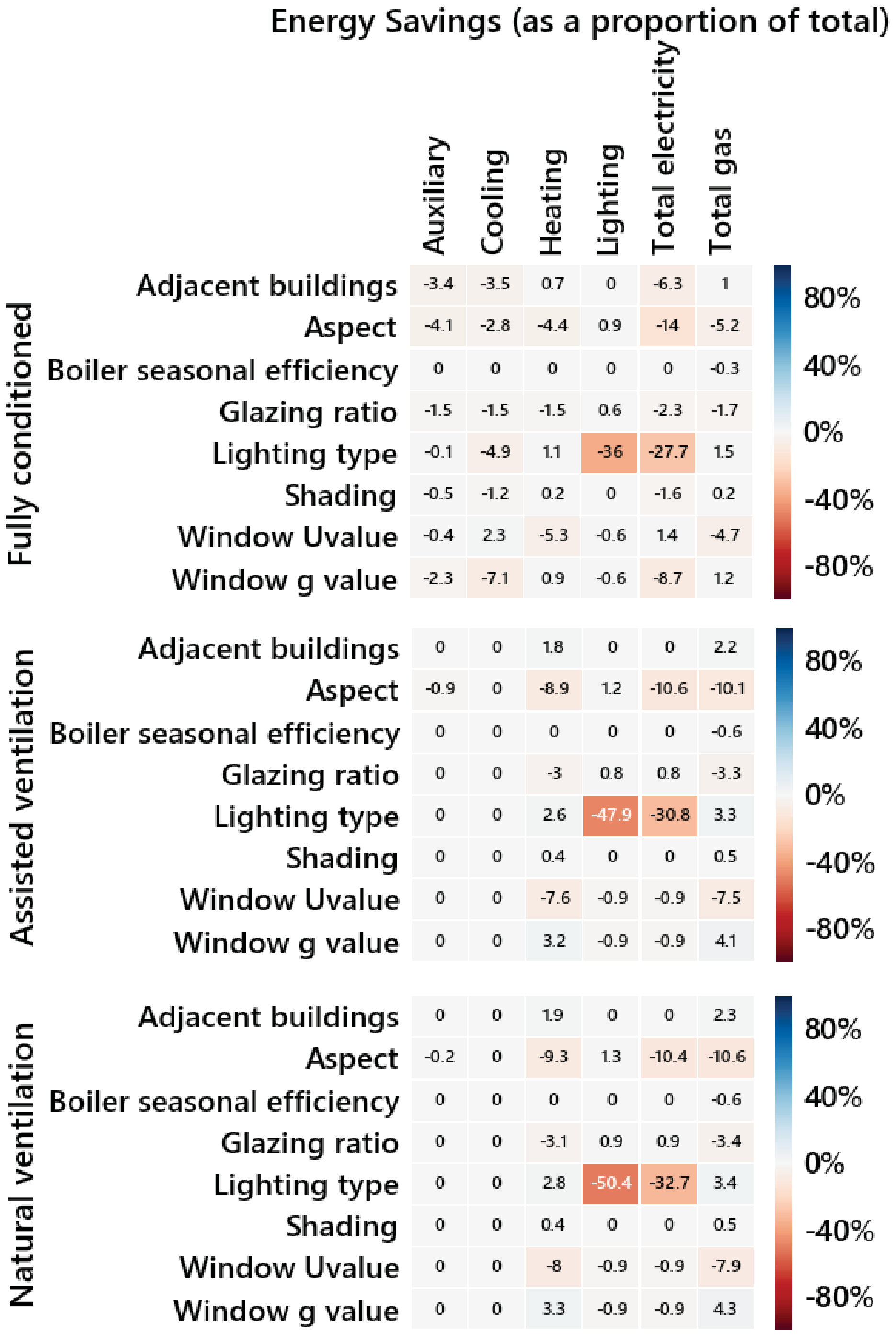


Figure 15—3 Relative impact of design measures on energy consumption for Retail/Office

16 Appendix F - Impact and consideration of demand management technologies

Buildings can provide significant Demand Side Management (DSM) capabilities given the nature of their thermal and electrical demand. This is particularly useful in dense urban areas, where the electricity grid may be under greater strain in the future. Demand management programs typically involve very large demand centres, co-ordinated by National Grid. The opportunity is to harness both electrical and thermal demand response innovations (such as Open Energi's Living Grid or Passivesystems) and use these to reduce peak load capacity of plant with associated reductions in capex and opex. The challenge is capturing the full value through emerging new energy markets that are susceptible to change.

16.1 UK Market and maturity

The DSM market within the UK non-domestic sectors are well established for certain operators and building owners, i.e. supermarkets, heavy industry and utilities providers. However, the overall market is small within the scale of the UK power market. The contribution of demand side flexibility in GB electricity markets is currently small and mainly in balancing.

The technical limits, scope expected for the UK market an ambition of power distributors is large. National Grid estimates that increasing flexibility (interconnection, storage and DSR) could deliver up to £2bn of consumer value per year by 2030. National Grid has set an aspiration for 30–50% of balancing capability from demand side sources by 2020. The Association for Decentralised Energy estimates potential for demand side response of 9.8 GW by 2020. [8]

16.2 Demand Side Response

Demand side response (DSR) is where levels of electricity demand are changed (increased, reduced or shifted) at a particular moment in time in response to an external signal (such as a change in price, or a message). Customers can decide whether to react to these signals or override them. National Grid uses the wider term demand side flexibility to include five categories of flexible response:

1. DSR by flexible load shifting (e.g. heating/cooling systems, business operations and appliances)
2. DSR by onsite generation
3. DSR by onsite energy storage
4. Distributed generation – for export
5. Distributed energy storage – for export. [9]

Demand side flexibility is the ability to change electricity output or demand in reaction to an external signal. The use of demand side flexibility tools such as demand side response, storage and distributed generation will be particularly important in the shift to a lower carbon future. Business customers can benefit financially by offering demand side flexibility services to market actors.

However transposing this approach to residential can be challenging, as without a significant number of homes or single commercial tenants, demands cannot be aggregated and shifted to balance the grid, reduce carbon or reduce cost.

16.3 DSM and DSR in Residential developments

However transposing this approach to residential can be challenging. Without a significant number of homes or single commercial tenants, demands cannot be aggregated and shifted to balance the grid, reduce carbon or reduce cost.

DSR can only really be facilitate with the use of energy storage within a system. Heating can be easily stored using hot water, in dwelling cylinders or communal thermal storage. Electricity can be stored using power batteries, electric vehicles and within hot water for the use of heating. Storing hot water is standard practice however the UK domestic/small commercial scale battery market is still in infancy.

Systems should look to include either one or both within a building systems in order to maximise the DSR opportunities that may arise post construction.

16.3.1 Technologies for consideration

A few technologies will allow for residential developments to balance on a dwelling by dwelling basis or on a site wide basis; these include but not limited to:

- Electric storage heaters – taking advantage of night time economy 7 markets for reduced cost of electricity;
- Solar PV with Electric Vehicles (EVs) – could be used in combination to charge or store electricity that would previously be taken from the grid for use in landlord areas or for powering vehicles;
- Washing machines and dishwashers – shifting the time of use of hot water using appliances to use electricity at time of low carbon or cheapest; and
- Metering and control – integrating SMART occupant control and demands into a communal heating system to allow for smoothing of aggregated demand profiles.

SMART metering and control with the combined functions of an adapted communal heating or district heating systems could allow for the Old Oak Common Masterplan to reduce network utilities demand peaks, increase utilisation of low carbon heat sources and reduce cost of electric heat pump operation.

16.4 DSR integrated communal heating systems

In the 4th generation DH, strengthening the link between the electricity grid and the heat networks will allow for further integration of intermittent renewable energy sources (RES) whilst securing grid stabilisation (voltage and frequency in the electricity supply). In that context heat pumps will play a crucial role in RES integration. The first attempts in achieving this were tried in Scandinavia on the Nordpool market, whereby a small CHP and electric boiler were operating on the spot market (day ahead), the regulating power market (real-time) and the automatic primary reserve market.

Intelligent control of the heating and peak shaving result in flattening the total energy use and a better balance is achieved between summer and winter. In this way the total energy use being relatively constant could be delivered by RES at lower cost. These monitoring and control capabilities enable anticipating heat demand on a day-ahead basis, therefore providing network operators with the opportunity to identify availability periods for participating in flexible reserve power and/or fast frequency response services.

---

[8] Association for Decentralised Energy (July 2016) Flexibility on demand: Giving customers control to secure our electricity system

[9] Online, powerresponsive.com/wp-content/uploads/2017/01/Power-Responsive-Annual-Report-2016-FINAL.pdf, accessed 02/05/18

Figure 16—1 illustrates how PassivSystems' intelligent controls could integrate in a 4th generation DH context, through using buildings' ability to absorb or forgo heat (buy or sell electricity) without compromising occupants thermal comfort.

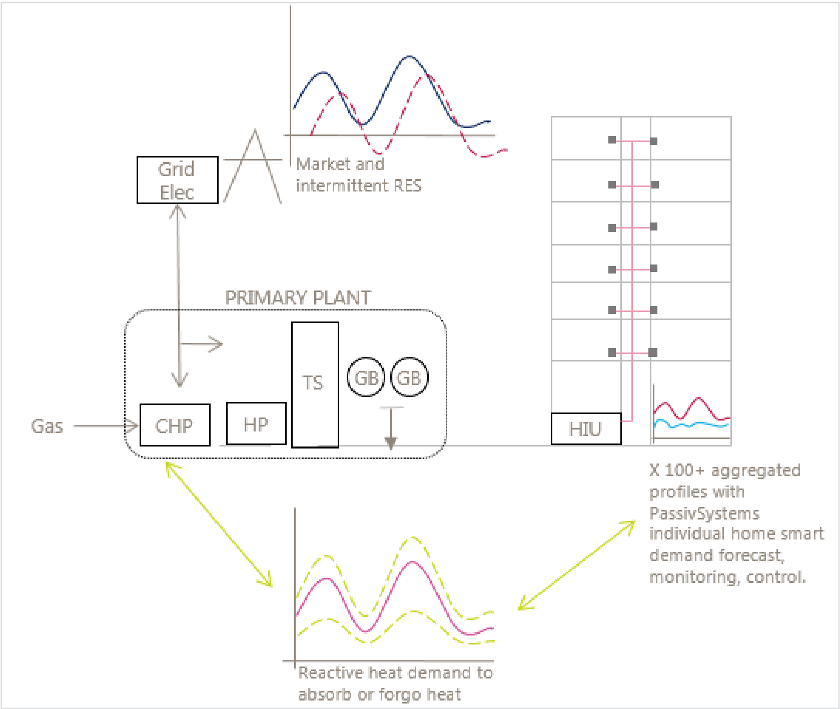
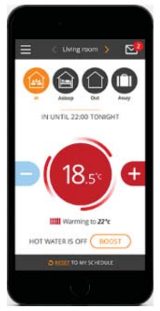


Figure 16—1 Context sketch of how PassivSystems controls could integrate in a 4th generation DH

16.4.1 How does the occupant contribute?

- Occupant control based on desired temperature and assets are managed to maintain desired temperatures for all in the most efficiency manner.
- Using PassivLiving HEAT smart controls, consumers are able to set their heating schedule on an app10.
- PassivSystems can then anticipate future demand spikes and flatten the profile by altering the heat demand without undue impact on consumers11. The aggregation of this across a network allows for whole network optimisation.



16.4.2 Value added from DSR in communal heating

The value that can be added across the whole energy market can be realised. Figure 16—2 outlines the value to be gained by the end user, building operator, distribution provider and energy centre operator.

16.4.3 Value added from DSR in communal heating

The value that can be added across the whole energy market can be realised. Figure 16—2 outlines the value to be gained by the end user, building operator, distribution provider and energy centre operator.

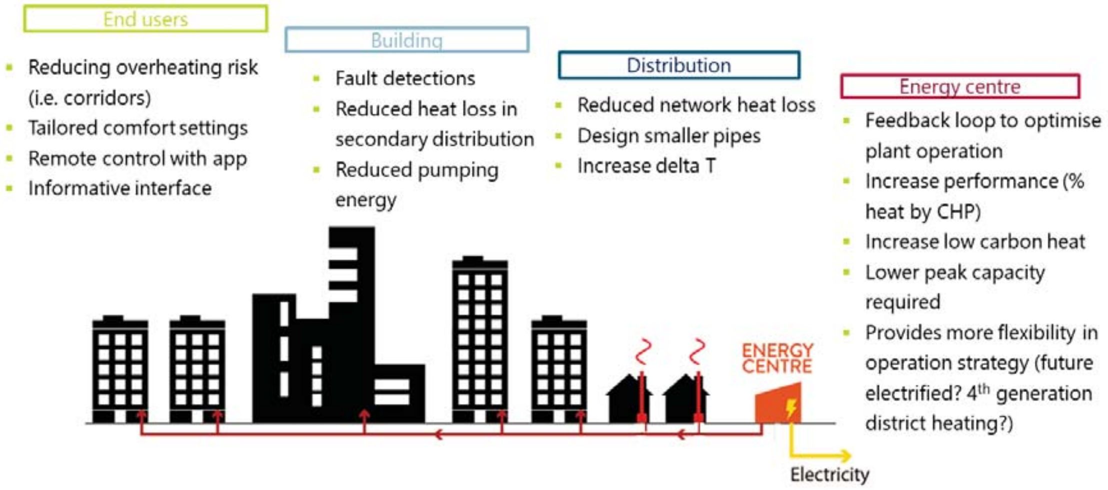


Figure 16—2 Potential value of demand responses systems within district heat networks and communal heating across the energy market

---

[10] PassivLiving HEAT app; https://itunes.apple.com/gb/app/passivliving/id948742898?mt=8

[11] PassivSystems previously demonstrated the PassivLiving HEAT technology that enables to proactively control heat demand profiles, tested successfully on 28 individual homes in the DECC funded notice project,.

17 Appendix G - Social assessment

17.1 Health and wellbeing

The design of a home and its community is a key contributor to the health and wellbeing of the people who live and work there. This includes factors such as daylight, temperature, air quality, internal layout and a wide range of neighbourhood factors such as natural environment, amenities and public transport[12]. This section focuses on why and how developments should provide good daylighting levels, whilst not negatively impacting overheating risk as well as the requirements to achieve a low carbon development for the long term.

17.1.1 Daylight

The availability of light and, in particular, of natural light can have considerable impacts on the physical and mental wellbeing of people living or working in buildings.

The lighting design should ensure sufficient levels of light to provide good visual acuity for the different tasks carried out in the space, to avoid eyestrain and headaches. This can be achieved with a combination of electric and natural light. Maximising daylight, however, has a number of advantages in terms of health and wellbeing.

In addition to facilitation vision, in fact, light influences the human body in non-visual ways. Humans and animals have internal clocks that synchronise physiological functions on roughly a 24-hour cycle called the circadian rhythm. Eyes contain sensors that detect the blueness of light, and send signals to the brain to trigger the secretion of hormones, which regulate multiple physiological processes, including those relating to alertness, digestion and sleep. Exposure to daylight throughout the day, therefore, helps regulate circadian rhythms and keep a physiological sleep pattern. On the other hand, abnormal circadian rhythms are associated to both physical and mental health illness, as sleep deprivation is linked to higher risk of issues such as diabetes, obesity, depression, heart attack, hypertension and stroke.

Sunlight and daylight also contribute to the general wellbeing of people, as they improve the appearance of their home or workplace. Daylight has excellent colour quality, which improves visual appeal and ensures accurate rendering of illuminated objects.

The provision of large glazing areas not only allows for better daylight but also provides views out. Access to views out is important for people's mental wellbeing, contributing to a feeling of social interaction and engagement. In addition, exposure to views of nature has been linked to faster healing and recovery times, boosting positive feeling and impacting people's mood.

Although exposure to natural light is to be sought for its health and wellbeing benefits, it should be considered that excessive sunlight can cause glare and unwanted visual contrast; in addition, increasing exposure to daylight through design can often lead to overheating issues, which affects thermal comfort and wellbeing.

17.1.2 Thermal comfort

People's ability to continue normal function relies on their bodies maintaining a temperature of around 37°C. Well insulated, warm homes can drastically reduce winter mortality and illness: the incidence of heart attacks, strokes, and other respiratory diseases is directly increased by excess cold. By prioritising measures on building fabric, homes can be kept warm whilst minimising energy consumption and carbon emissions. In addition, low carbon heating systems can be installed to provide winter space heating.

On the other hand, the risk of overheating in summer months has been increasingly an issue in recent years. Exposure to warm conditions in excess of approximately 25°C is associated to increased health risks, with thermal stresses affecting the performance of our body, productivity, and mood.[13] As the climate warms, with the increased frequency, length and peaks of summer heat waves in inner-city London specifically,[14] overheating will become a greater issue and maintaining thermal comfort in summer will become more challenging.

Passive design should be prioritised to mitigate the risk of overheating and allow cooling homes through natural ventilation and operable windows. When using natural ventilation in buildings, additional considerations should be taken to ensure air quality and acoustic issues are addressed. This includes locating the buildings and orientating openings away from main sources of air and noise pollution, considering landscaping and internal courtyards.

Overheating can be addressed through active means, such as providing mechanical cooling. However, passive-first design approaches are generally best for providing a healthy internal environment for occupants that also helps London achieve its zero carbon ambitions.

17.2 In-use performance and cost of low-energy buildings

Crucial issues to be considered by developers, and one identified in the Innovate UK research as key to the success of low-energy developments, are the social issues and end user needs associated with low-energy specifications. Specifically, research makes reference to "committed client and owners", "manageable complexity" and "handover" as key success factors.

Understanding the impacts of energy efficiency measures chosen by developers will be key to assuring in-use performance. This section discusses the key social issues, in relation to the specifications examined in the research, to provide an additional layer for appraising the viability of the different systems.

The opportunity is to tailor systems to meet different user types; the challenges come from the delivering loose-fit, long life buildings that are comfortable, flexible and adaptable through time and ensuring that the drive for electric heating systems doesn't increase overall energy bills or create affordability risks under a future with time based energy pricing.

17.2.1 Impact on likely cost to occupants/tenants

As low and zero carbon technologies are investigated to provide heating in developments, it is important to consider the cost that these have for occupants and therefore the impact on affordability. The study 'The Future Role of the London Plan in the Delivery of Area-Wide District Heating – final report', Buro Happold, Jun 2017, estimated the average cost of heat to consumers of different technologies, including communal boilers, communal CHP, individual and communal Air Source Heat Pump, direct electric and hybrid ASHP + direct electric systems.

---

[12] UKGBC, Healthy Housebuilding, Briefing note – April 2018

[13] UK GBC Health and Wellbeing in Homes report, July 2016

[14] CIBSE TM49: Design Summer Years for London, May 2014

Communal CHP or communal ASHPs present a cost of heat to consumers that is only slightly higher compared to the communal boilers case. However, the cost can be considerably lower if revenues from the CHP electricity sales or from incentives, such as the Renewable Heat Incentive for ASHPs, are passed on to the consumers.

Individual ASHPs, show nearly zero net fuel costs when RHI benefits are passed on to the consumer cost, the cost of heat associated with individual ASHPs is nearly zero. However, this only lasts for 7 years for residential dwellings under current government policy and without it the cost of heat of individual heat pumps reaches levels comparable to communal boilers.

Direct electric systems show the highest cost to consumers per kWh. This is due to the lower relative efficiency and use of a high cost fuel. If used in combination with passive measures, the increase in the overall fuel bill cost could be limited through a reduction in heating demand.

17.2.2 Challenges and opportunities of technology and applications

Whilst appropriate design should aim at delivering low-energy comfortable buildings, the in-use performance will be highly dependent on the operation and maintenance of the buildings. For this reason, it is important that the design is simple, robust and low-maintenance and that the expected mode of operation is well communicated to its users.

Home User Guides are a useful tool in residential developments to explain and advise on expected system operation. Common operating issues include occupants turning off MVHR units, or not using them correctly, because of noise, perceived energy cost of lack of understanding. Instructions should include how to use the units, how and when to replace filters, how to set into summer bypass mode. This would allow for a better usage of the system and consequent reduction in the energy performance gap. Similar issues can arise for overheating, and the Home User Guide should include instructions on when to open windows based on outside temperatures, to avoid letting warmer air in the rooms.

In non-residential systems, similar communication should be provided on how to operate and maintain the systems, including lighting controls and movable shading systems.

18 Appendix H - Modelling variables

This section outlines the variables modelled to create the permutations outlined. All ranges of variables are modelled against each other variable. Certain variables are not considered with overheating and daylighting analysis as they are considered not to impact the results, this is indicated with a Y or N.

18.1.1 Parametric analysis variable ranges and analysis included within

18.1.2 Residential

Factor	First value	Middle value	Last value	No. levels	Varied in energy analysis?	Varied in daylighting analysis?	Varied in overheating analysis?
Wall U-value	0.18	-	0.12	2	Y	N	N
Glazing U-value	Double glazed (1.4)	-	Triple glazed (0.85)	2	Y	N	N
G-value (And corresponding VLT)	0.5	0.4	0.3	3	Y	Y	Y
Air tightness	1	3	5	3	Y	N	Y
Glazing ratio (window/wall)	65%	50%	35%	3	Y	Y	Y
Thermal bridging	Default	-	Calculated	2	Y	N	N
Ventilation type	MEV	-	MVHR	2	Y	N	N
Total number of simulations:					**432**	**18**	**18**
Geometry variations	**First value**	**Middle value**	**Last value**	**No. levels**	**Varied in energy analysis?**	**Varied in daylighting analysis?**	**Varied in overheating analysis?**
Floor level (assume low floor is shaded by adjacent building)	Low	-	High	2	N	Y	Y
Orientation	Cardinal	-	45° Rotated	2	Y	N	Y
Number of units	N/A	-	N/A	30	Y	N	N
Number of rooms	N/A	-	N/A	120	N	Y	Y
Total geometries per simulation:					**60**	**240**	**480**
Total number of results entries:					**17,280**	**4,320**	**8,640**

18.1.3 Non-Residential

Factor	First value	Middle value	Last value	No. levels	Varied in energy analysis?	Varied in daylighting analysis?	Varied in overheating analysis?
Wall U-value	0.18	-	0.12	2	Y	N	Y
Glazing U-value	Double glazed (1.3)	-	Triple glazed (0.85)	2	Y	N	Y
G-value (And corresponding VLT)	0.5	0.4	0.3	3	Y	Y	Y
Glazing ratio (window/wall)	70%	60%	40%	3	Y	Y	Y
Conditioning	Cooling and MVHR	Mixed Mode	Naturally cooled	3	Y	N	Y
Shading fins (office) Horizontal Shade (Retail)	No	-	Yes	2	Y	Y	Y
Ventilation type	MVHR	-	Naturally ventilated	2	Y	N	Y (see Table 11—1)
Total number of simulations:					**216**	**12**	**36**
Geometry variations	**First value**	**Middle value**	**Last value**	**No. levels**	**Varied in energy analysis?**	**Varied in daylighting analysis?**	**Varied in overheating analysis?**
Orientation	Cardinal	-	45° Rotated	2	Y	N	Y
Shading from adjacent buildings	No	-	Yes	2	Y	Y	Y
Usage type	Office	-	Retail	2	Y	Y	Y
Zones per floorplate	N/A	-	N/A	8 (Retail) / 12 (Office)	Y	Y	Y
Total geometries per simulation:					**80**	**8**	**80**
Total number of results entries:					**17,280**	**96**	**2880**

19 Appendix I – Application of Passivhaus certification in Tall buildings

Passivhaus is currently considered the industry-recognised best practice for building energy and environmental design performance. However, the use of this certification method is not particularly mature around the world let alone in the UK in tall buildings. For this reason, it has been investigated and the opportunities and challenges of applying this standard to tall buildings by the OPDC are outlined below.

19.1.1 Market size

According to the International Passive House Association (iPHA), there are over 60,000 residential and non-residential units in existence worldwide designed to Passivhaus standards, and over 14,000 certified according to strict Passive House Institute certification criteria. The definitive criteria for the certification of Passive House components and Passive Houses are set by the Passive House Institute under the direction of Dr. Wolfgang Feist.[15]

However, the approach and certification is uncommon in tall buildings due to aspect constraints, cost uplifts and wall thickness at height. Furthermore, soundings from a sample of leading architects considered that UK contractors and suppliers are currently not set up to mass produce high density Passivhaus buildings.

19.1.2 Project precedent in UK and abroad

There are a handful of examples of tall buildings that have been built and certified to Passivhaus levels across the world. A few examples are outlined in Figure 19—1, only one of which (NYC Cornell University student residential) is complete.

- NYC Cornell Tech Campus – student Resi
- 26 Storeys
- Worlds tallest completed Passivhaus

- Agar Grove – Camden Council
- 500 dwellings
- Largest Passivhaus development in UK

- Vancouver towers – 450 dwellings, 149 retail units
- 48 and 43 storeys
- Not complete but will be worlds tallest

Figure 19—1 Global Passivhaus tall buildings examples

19.1.3 Challenges and opportunities of Passivhaus in tall buildings

Key challenges and opportunities of achieving Passivhaus standards in tall buildings include:

- Balancing heating demands – each dwelling must achieve a low space heating demand <15 kWh/m^2 per year and achieving this in north-facing units will be challenging. Conversely, minimising cooling demands on southerly aspects will also be challenging.
- Single facing aspect units – single aspect units have limited capability for integrated environmental design, using solar gains to balance heating demands through the seasons and year.
- High density, high cost of air tightness testing and triple glazing – due to the high density, the capital cost uplift for all facade element specifications, testing rigour and expertise would be high.
- In-use performance monitoring – performance through Passivhaus certification is assured, reducing and minimising the performance gap of homes and non-residential buildings.

Due to the number of challenges and limited number of case studies available of tall buildings applying the Passivhaus standard, it is not expected that the OPDC will apply this as a required standard or code for developers in tall buildings at this time. However, progress in this area should be kept under review to inform future policy.

---

[15] Online. Available: https://passivehouse-international.org/index.php?page_id=65, accessed 18/05/18

20 Appendix J - Industry engagement throughout study

Old Oak Masterplanning team – AECOM/Maccreanor Lavington - 23rd Feb

- Typical dwelling and commercial space layouts and locations
- Spacing of blocks across masterplan, including courtyard and roads
- Design principles of units and blocks, spaces types and glazing designs

Passivhaus and energy performance specialist Architects – Hawkins Brown and Feilden Clegg Bradley Studios – 5th March

- Extremes of performance and design acceptability – glazing ratios and positions
    - What Passivhaus pushes and 'bad' design (glass box)
- Insulation requirements and typical wall build ups- post Grenfell Tower
- Availability of UK major contractors that could build to high density Passivhaus

OPDC Planning officer workshop – 16th March

A workshop undertaken with the OPDC planning teams to gain input on analysis findings at the time as well to understand the level of guidance that would be useful for inclusion in the SPG.

Based on the outcomes of the workshop, a balance of all differing styles would be useful for the varying guidance elements in the following conclusions:

- When outlining the architectural drivers graphics may be good to show what has been modelled and why they perform differently
- Narrative provides a list of requires to be targeted for building designers/engineers – allowing flexibility for innovative on plot solutions
- Checklist for very quantifiable elements – such as;
    - provide these proscribed energy demands, or
    - Are energy demands lower than X?, or
    - has dynamic simulation for overheating be undertaken with 2020 and 2050 weather files (Yes/No)?
- As such the results and guidance conclusions look to follow this, as found in the following sections of this report.

21 Appendix K - Costing variables

21.1 Cost information – costs by package

21.1.1 Facade and Lean measures

Fabric Element	Specification	Unit	Itemised elements	Total Cost (£/m^2)	Comments
External Wall	0.18	W/m^2.K	100 mm outer layer brickwork	**£118.43**	
			50 mm cavity		
			160 mm mineral wool insulation (0.032 W/mK)		
			100 mm lightweight concrete block,		
			15 mm plaster (dense)		
			Cavity Closers		
			Cavity Trays		
			Lintols		
	0.15	W/m^2.K	100 mm outer layer brickwork	**£121.40**	
			50 mm cavity		
			190 mm mineral wool insulation (0.032 W/mK)		
			100 mm lightweight concrete block,		
			15 mm plaster (dense)		
			Cavity Closers		
			Cavity Trays		
			Lintols		
	0.12	W/m^2.K	100 mm outer layer brickwork	**£127.51**	
			50 mm cavity		
			250 mm mineral wool insulation (0.032 W/mK)		
			100 mm lightweight concrete block,		
			15 mm plaster (dense)		
			Cavity Closers		
			Cavity Trays		
			Lintols		
Windows	1.4	W/m^2.K	Double glazed 20 mm gap, Argon filled PVC frames	**£221.24**	
	1.2	W/m^2.K	Double glazed 20 mm gap, Argon filled PVC frames	**£221.24**	
	0.85	W/m^2.K	Triple glazed Argon filled PVC frames	**£274.34**	
	0.5	g-value		**£0.00**	
	0.4	g-value		**£0.25**	per m2 of glazing
	0.3	g-value		**£0.50**	per m2 of glazing
Air Tightness	5	m^3/m^2/hour	Air Tightness Testing	**£0.00**	
	3	m^3/m^2/hour	Air Tightness Testing + additional skills and care	**£4.73**	per m2
	1	m^3/m^2/hour	Air Tightness Testing + extra additional skills and care	**£6.76**	per m2
Thermal Bridging Y-value	0.15	W/m.K		**£0.00**	Per Apartment
	0.08	W/m.K	Thermal Bridge modelling	**£210.75**	Per Apartment
			Additional materials, higher spec., care in construction.		
	0.01	W/m.K	Thermal Bridge modelling	**£353.75**	Per Apartment
			Additional materials, higher spec., care in construction.		

Ventilation Element/Component	Specification	Itemised elements	Total Cost (£/unit)	Comments
Natural Ventilation	MEV	Intermittent extract fans (kitchen and bathrooms)	**£213.00**	
Mechanical Ventilation	cMEV Unit	Supply and install	**£1,993.81**	
		Ducting, boxing etc. to apartments		
MVHR	MVHR Unit	Supply and install	**£3,153.10**	
		Ducting and pipework to apartments		
		Sundries		
Services Element/Component	**Specification**	**Itemised elements**	**Total Cost (£/unit)**	**Comments**
Lighting	100% Low Energy Lighting	Wiring	**£1,500.00**	per apartment
		Lamps, luminaires and switches		
		Total Calculated Cost	**£22.60**	per m2

21.1.2 Communal heating systems and renewables, Clean and Green

Services – centralised 91% boiler

Inclusions	Exclusions
• 91% efficiency Boiler • Flue to roof • Gas to boiler • Gas to block • Buffer tank • Pumps, expansion vessel, pressurisation unit, pipework • Central BMS / Controls • Heat Interface Unit per flat • Flat controls • Distribution System; pipework to each flat, and pipework within apartments. • Low temperature underfloor heating	• Testing and commissioning • BWIC & Firestopping • M&E Preliminaries • VAT

Services – centralised 95% boiler

Inclusions	Exclusions
• 95% efficiency Boiler • Flue to roof • Gas to boiler • Gas to block • Buffer tank • Pumps, expansion vessel, pressurisation unit, pipework • Central BMS / Controls • Heat Interface Unit per flat • Flat controls • Distribution System; pipework to each flat, and pipework within apartments. • Low temperature underfloor heating	• Testing and commissioning • BWIC & Firestopping • M&E Preliminaries • VAT

Services – Communal CHP with gas boiler backup

Inclusions	Exclusions
• CHP Engines - incl installation • Gas to block • Boiler back up • Gas to boiler • Flue to roof • Buffer tank • Pumps, expansion vessel, pressurisation unit, pipework • Central BMS / controls • Heat Interface Unit per flat • Flat controls • Distribution System; pipework to each flat, and pipework within apartments. • Low temperature underfloor heating	• Testing and commissioning • BWIC & Firestopping • M&E Preliminaries • VAT

Services – Communal ASHP with gas boiler backup

Inclusions	Exclusions
• Transformer uplift to provide additional capacity • Large scale ASHP • Boiler back up • Gas to boiler • Flue to roof • Buffer tank • Pumps, expansion vessel, pressurisation unit, pipework • Central BMS / controls • Heat Interface Unit per flat • Flat controls • Distribution System; pipework to each flat, and pipework within apartments. • Low temperature underfloor heating	• Testing and commissioning • BWIC & Firestopping • M&E Preliminaries • VAT

Services – Individual ASHP

Inclusions	Exclusions
• Transformer uplift to provide additional capacity • Electrical distribution to each flat • Heat pump • Low temperature underfloor heating • Hot water cylinder of 250 litres • Flat controls • Sundries	• Testing and commissioning • BWIC & Firestopping • M&E Preliminaries • VAT

Services – Direct electric space heating and DHW

Inclusions	Exclusions
• Transformer uplift to provide additional capacity • Electrical distribution to each flat • Calorifier for DHW • Electric heaters to apartments - say 1 electric heater per room per apt & electric towel rail to the bathroom - say for 2 bed apt with living room and hall and 1 bathroom • Flat controls • Sundries	• Testing and commissioning • BWIC & Firestopping • M&E Preliminaries • VAT

Services – Hybrid System

DHW - Centralised ASHP with boiler backup SH - Direct electric

Inclusions	Exclusions
• Transformer uplift to provide additional capacity • Boiler back up • Gas to boiler • Flue to roof • Buffer tank • Pumps, expansion vessel, pressurisation unit, pipework • Central BMS / controls • Large scale ASHP • Flat controls • Distribution System; pipework to each flat, and pipework within apartments. Electric heaters to apartments - say 1 electric heater per room per apt & electric towel rail to the bathroom - say for 2 bed apt with living room and hall and 1 bathroom	• Testing and commissioning • BWIC & Firestopping • M&E Preliminaries VAT

22 Appendix L - Specifications to balance all factors by orientation and unit type

22.1 Residential – Specifications

Range of specifications which meet 10% reduction on TER, pass CIBSE TM59 overheating criteria and achieve ≥ 1.5% ADF in living spaces:

Exposed locations

Orientation A	DA_I_1B	DA_I_2B	DA_I_3B	DA_P_1B	DA_P_2B	DA_P_3B	SA_I_1B	SA_I_2B	SA_P_1B	SA_P_2B
East	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [1 3] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35]	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.5]	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5]
North	NA	NA	NA	NA	NA	NA	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [5 3 1] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5 0.65]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [5 3 1] G Val: [0.5 0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [5 3 1] G Val: [0.5 0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.5 0.65]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [5 3 1] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5 0.65]
Northeast	NA	NA	NA	NA	NA	NA	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5 0.65]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [5 3 1] G Val: [0.5 0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [5 3 1] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.65]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [5 3 1] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR’] Glaz Ratio Win Wall: [0.35 0.5]
Northwest	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5]	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5]	Failing	Failing	Failing

				G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35 0.5]			G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35 0.5]			
South	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [1 3] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35]	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35 0.5]	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [1 3] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.65]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35 0.5]
Southeast	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35]	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35 0.5]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.5 0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35 0.5]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.65]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35 0.5]
Southwest	Failing	Failing	Failing	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: ['MVHR'] Glaz Ratio Win Wall: [0.35]	Failing	Failing	Failing
West	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3]	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4]	Failing	Failing	Failing

				Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35]			Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35]			

Over-shaded locations

Orientation A	DA_I_1B	DA_I_2B	DA_I_3B	DA_P_1B	DA_P_2B	DA_P_3B	SA_I_1B	SA_I_2B	SA_P_1B	SA_P_2B
East	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35]	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1] G Val: [0.3] Wall U Val: [0.12 0.18] Glaz U Val: [0.85] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.65]	Failing	Failing	Failing
North	NA	NA	NA	NA	NA	NA	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.65]	Failing	Failing	Failing
Northeast	NA	NA	NA	NA	NA	NA	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.65]	Failing	Failing	Failing

Northwest	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Failing	Failing	Failing	Failing	Failing	Failing
South	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [1 3] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Failing	Failing	Failing	Failing	Failing	Failing
Southeast	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Failing	Failing	Failing	Failing	Failing	Failing
Southwest	Failing	Failing	Failing	Failing	Failing	Failing	Failing	Failing	Failing	Failing
West	Failing	Failing	Failing	Th Bridging Calc: ['Default' 'Calculated'] Airtightness: [3 1 5] G Val: [0.3 0.4 0.5] Wall U Val: [0.12 0.18] Glaz U Val: [0.85 1.4] Mech Vent Type: [‘MVHR’] Glaz Ratio Win Wall: [0.35 0.5]	Failing	Failing	Failing	Failing	Failing	Failing

22.2 Non-residential – Specifications

Range of specifications that meet 15% reduction on TER, pass overheating and achieve >= 2% ADF.

Shaded case:

Primary orientation	Office Dual	Office Single	Retail Dual	Retail Single
E	Failing	Failing	NA	Failing
N	Failing	Failing	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff'] System: ['FCU/MVHR']	Failing
NE	Failing	Failing	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff'] System: ['FCU/MVHR']	Failing
NW	Failing	Failing	NA	Failing
S	Failing	Failing	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff'] System: ['FCU/MVHR']	Failing
SE	Failing	Failing	NA	Failing
SW	Failing	Failing	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff'] System: ['FCU/MVHR']	Failing
W	Failing	Failing	NA	Failing

Unshaded case:

Primary orientation	Office Dual	Office Single	Retail Dual	Retail Single
E	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	NA	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']
N	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR' 'Nat vent' 'Mixed mode']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']
NE	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']
NW	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	NA	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']
S	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']
SE	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn']	NA	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn']

	System: ['FCU/MVHR']	System: ['FCU/MVHR']		System: ['FCU/MVHR']
SW	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']
W	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']	NA	Glazing ratio: [0.5 0.6 0.7] Window g value: [0.3 0.4 0.5] Window Uvalue: [0.85 1.3] Shading: ['ShdOff' 'ShdOn'] System: ['FCU/MVHR']

Jon Gregg
Buro Happold Limited
17 Newman Street
London
W1T 1PD
UK

T: +44 (0)207 927 9700
F: +44 (0)870 787 4145
Email: jon.gregg@burohappold.com