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Old Oak Common Masterplan Environmental Modelling Framework

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expedition

Contents

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Executive Summary

The OPDC development is the UK's largest regeneration project, aiming to provide 25,000 new homes and 65,000 new jobs. The main objective of the development is to create high quality and resource efficient urban environments that enhance placemaking and wellbeing and reduce energy use. To achieve this, a high density urban environment is proposed, with densities that have not been achieved in the UK to date.

Expedition has been appointed by the Old Oak and Park Royal Development Corporation (OPDC) to develop an approach to appraise wellbeing and energy efficiency to support the development of the masterplan for the Old Oak Common site. This study focuses on how the built environment can influence health and wellbeing at the masterplanning stage, when defining the urban layout and building massing.

A framework has been developed based on a review of published research, design guides, modelling tools and consultation with experts. Environmental criteria that are quantifiable and influenced by building massing and the urban layout were chosen.

The framework sets out performance metrics, benchmark scales and an appraisal method for evaluating daylight within buildings, internal sunlight, outdoor sunlight, urban wind and energy efficiency. It differentiates between the masterplanning stage, when several building blocks need to be tested without detailed information being available, and the building design stage, when more detailed calculations are feasible.

This framework can be used as a tool to compare alternative designs, by providing an objective and systematic means to evaluate them. It should also be used in conjunction with other aspects of urban design such as design for amenity, quality of space and access to services to provide a holistic design approach.

The framework is applied to a sample of the masterplan, to illustrate how it can be used to influence design variables and explore the trade-offs between multiple objectives. Many of the proposed tools and methods form part of the Urban Modelling Interface being developed by the Massachusetts Institute of Technology. These innovative tools are being developed further, and it is recommended to closely follow their development.

To illustrate the workings of the proposed framework and modelling tool several alternative massing arrangements have been tested, using the Rhinoceros 3D modelling platform and its parametric module, Grasshopper. The results of the alternative massing configurations illustrate that daylighting is the environmental criterion that is most sensitive to massing changes and that daylight performance could be improved by making changes to the massing whilst maintaining target densities.

1. Introduction

Expedition has been appointed by the Old Oak and Park Royal Development Corporation (OPDC) to develop an approach to appraise wellbeing and energy efficiency, to support the development of the masterplan for the Old Oak Common site.

Creating high quality and resource efficient urban environments is now part of the sustainable development agenda for new urban developments around the world. Placemaking, wellbeing and energy use are strongly influenced by the urban layout and building massing.

The OPDC development is the UK's largest regeneration project, aiming to provide 25,000 new homes and 65,000 new jobs. The main objective of the development is to create high quality and resource efficient urban environments that enhance placemaking and wellbeing and reduce energy use. To achieve this, a high density urban environment is proposed, with densities that have not been achieved in the UK to date.

Based on a review of published research, design guides, different modelling tools and consultation with a number of experts in the field, an approach has been developed to measure performance against some aspects of wellbeing and energy efficiency. This approach includes:

- A framework defining the metrics to be used and the benchmark scale they should be appraised against, and
- A set of tools and methods, integrated within a 3D parametric modelling platform, to allow fast and interactive analysis of urban layout and massing proposals, to be used by the OPDC planning team.

This approach has been tested on part of the current masterplan proposal for the Old Oak Common site to identify potential issues associated with achieving a comfortable, healthy and energy efficient urban environment. To illustrate the workings of the proposed approach we have also tested a number of modifications to the building massing, as well as the effect of architectural decisions, for example, glazing ratios.

Section 2 of this report presents the proposed framework and analysis methods. Section 3 presents the analysis of the current masterplan and Section 4 discusses how a range of modifications to the building massing and design could improve performance. Section 5 concludes and offers recommendations for further work and next steps.

Figure 1 - Old Oak Common Masterplan

2. Analysis framework

2.1. Overview

Wellbeing in the urban environment covers many aspects and has been the subject of extensive research. A number of criteria have been identified to provide some measure of wellbeing to be considered alongside energy efficiency (Section 2.2.). This study focuses on quantifiable criteria that are influenced by building massing and the urban layout.

For each performance criterion, a number of different metrics and benchmark scales are used in industry. Based on a review of published research, design guides and consultation with experts in the field, a performance metric, benchmark scale and appraisal method has been proposed for each criterion (Section 2.3 to 2.7).

A synthesis is included in Section 2.8, which could feed into the development of a local policy for the area.

2.2. Wellbeing and energy efficiency criteria

The UK Green Building Council proposes that “health and wellbeing include social, psychological and physical factors” and notes that “health and wellbeing is influenced by a complex combination of genetics, behaviour and environmental factors” [1] (Figure 2). In this study, we focus on how the built environment can influence health and wellbeing at the masterplanning stage, when defining the urban layout and building massing. We have also focused on aspects that can be practically quantified at masterplanning stage and for which research has been carried out to define a benchmark scale defining what is “good”.

We propose to consider the following performance criteria:

1. Daylight within buildings: Natural light makes us aware of the passage of time; we are naturally in tune with external light levels and characteristics which regulate our circadian cycle. Research at the University of Oxford [2] links mental illness to abnormal circadian rhythms. Several studies have linked daylight to productivity in offices and reduced patient recovery time in hospitals [3,4].
2. Internal sunlight**:** Direct sunlight within buildings is generally welcome in buildings, for similar reasons to daylight. The sun provides light and warmth and is seen to have a therapeutic health giving effect [5]. However, sunlight access within buildings need to be balanced against the effect of excess solar gains on energy use and thermal comfort (point 5 below) and, at building design stage, with glare in non-residential buildings.
3. Outdoor sunlight: Direct sunlight in the spaces between buildings is equally important to support outdoor activities, children’s play, encourage plant growth, dry out the ground reducing moss and slime, and generally improve the appearance of the public realm [5].
4. Urban wind**:** High velocity winds in urban corridors or downdraughts generated by high rise buildings can significantly affect pedestrian comfort. On the other hand, wind helps flush pollutants from densely trafficked urban canyons and also helps mitigate the urban heat island effect.
5. Energy efficiency**:** The orientation and massing of a building, as well as some early decisions on glazing ratios has a significant impact on its energy use and/or thermal comfort. The following relationships need to be considered:
    - The design tension between achieving good levels of sunlight in buildings and controlling summer solar gains and their effect on cooling energy use and/or thermal comfort.
    - The beneficial effect of winter solar gains to help reduce space heating energy use.
    - The design tension between increasing glazing ratios or reducing the compactness of buildings to increase daylight distribution on the one hand and envelope heat losses and increased space energy use on the other hand.

The control of solar gains and heat losses can be addressed largely with an effective shading, glazing and building insulation strategy at building design stage. However, it is necessary to understand the potential consequences of the design decisions made at masterplanning stage to maximise daylight and sunlight penetration on energy use.

Other factors such as noise, air quality and the urban heat island effect are also significantly influenced by the urban layout and building massing. However, these factors are challenging to quantify and have not been considered as part of this study.

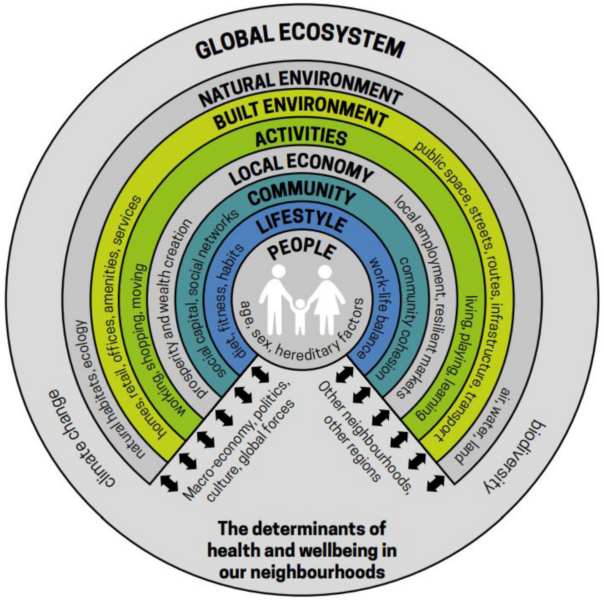


Figure 2 - Determinants of health and wellbeing (source: UKGBC [1])

Access to decent green spaces, local markets, public squares and proximity to leisure and fitness facilities are also key aspects that need to be considered when developing the Old Oak Common masterplan. These aspects may be grouped under the umbrella term “amenity”. They are difficult to quantify and have not been considered in this study. However, a recent study by London First and Gordon Ingram Associates (GIA), yet to be published, highlights the importance of considering amenity alongside environmental factors. The study notes that some of the densest parts of London, where access to daylight is relatively limited but amenity is high, are some of the most desirable parts of the city to live in.

2.3. Daylight within buildings

Daylight in buildings is a vital environmental factor which can influence occupant health, wellbeing and productivity. Daylight has been considered an important aspect of the built environment for centuries, with the UK's Right to Light legislation dating back to the 19th Century [6] and probably earlier. A relatively large number of performance metrics have been developed throughout time and are in use in the industry.

Currently, the most common metric in use at masterplanning stage is the Vertical Sky Component (VSC). This is the ratio of illuminance on a vertical plane (window) to the illuminance on an unobstructed horizontal plane under a CIE (Commission Internationale de l'Eclairage) Overcast Sky (Figure 3). This method is favoured by planners and designers to evaluate masterplans as it is relatively fast and only requires the building massing as modelling inputs. BRE guidelines recommended that, for conventional window design, a minimum VSC of 27% is achieved to ensure adequate daylighting, and a minimum VSC of 15% for larger glazing ratios [5]. A shortcoming of the VSC metric is that it does not consider the annual variation in exterior illuminance due to the sun's position and cloud cover. Additionally and importantly, it does not consider the effects of glazing ratios, floor to ceiling height and internal layout on internal daylight distribution.

The most common metric used at the building design stage is the Daylight Factor (DF). This is the ratio of illuminance at a point within the building to the illuminance on an unobstructed horizontal plane under a CIE Overcast Sky (Figure 4). The DF does take into consideration the façade characteristics, floor to ceiling height and interior finishes but does not consider the annual variation in exterior illuminance due to the sun's position and cloud cover. Current best practice follows guidance from BS8206 [7], which recommends an Average Daylight Factor (ADF) of at least 2% to achieve a 'daylit appearance'. The limitation of ADF is that taking the average of the DFs across a floorplate doesn't ensure spatial uniformity of daylight. For example, very high DFs near glazing can hide poor DFs in other areas. This shortcoming can skew designers to use unnecessarily large glazing configurations.

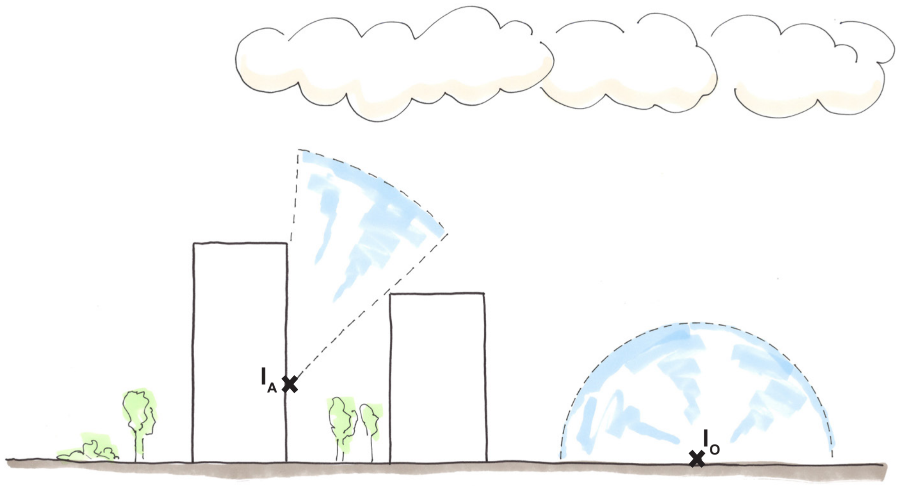


Figure 3 - Vertical Sky Component (VSC)

$VSC_A = I_A / I_O$

Where,
- I_A is the illuminance at the point (A) of interest on a vertical façade
- I_O is the illuminance on an unobstructed horizontal plane
- Both under CIE Overcast Sky condition

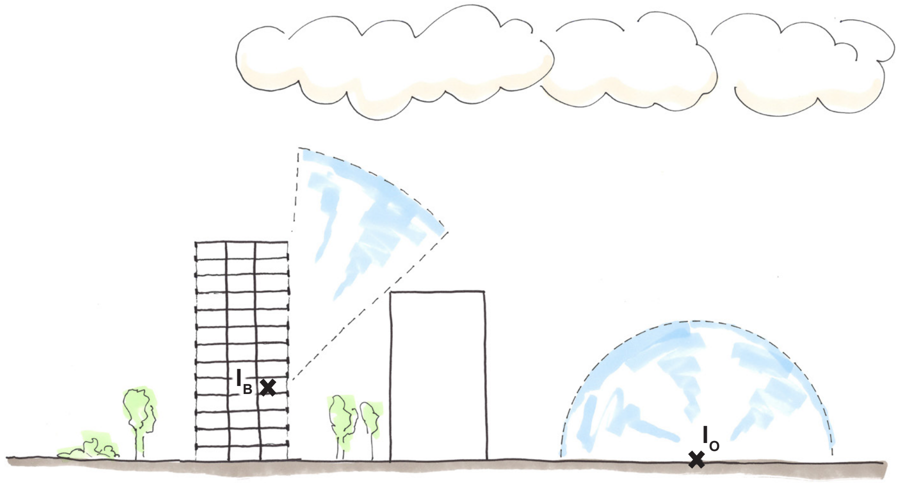


Figure 4 - Average Daylight Factor (ADF)

$DF_B = I_B / I_O$

Where,
- I_B is the illuminance at the point of interest (B) within the building
- I_O is the illuminance on an unobstructed horizontal plane
- Both under CIE Overcast Sky condition

To ensure better spatial uniformity DF results can be post-processed to determine the proportion of area which has DF ≥ 2%, this can be referred to as the Spatial Daylight Factor (sDF). The sDF is more comprehensive than the ADF because it accounts for the spatial uniformity of daylight within a building.

A new generation of climate-based daylight performance metrics has been developed over the last ten years. These metrics are based on the modelling of hourly internal illuminance taking into account the local sun path and variations in cloud cover. One of these metrics, the Daylight Autonomy (DA), is calculated as the percentage of time during annual occupied hours when the internal illuminance is above a target level, usually in the range of 100-300 lux [8]. The WELL Building Standard [9] recommends a minimum DA_{300} of 50% over 55% of occupied spaces. A variant of DA is the Useful Daylight Illuminance (UDI) which, like DA, has a minimum threshold, but also includes a maximum illuminance threshold to account for glare and potential overheating resulting from high levels of direct solar exposure [10]. UDI is more suited for office buildings where glare is unwanted. Climate-based metrics account for all factors affecting daylighting in buildings. However, their calculation is resource intensive and time consuming, and as such these metrics are generally used to assess daylight at building design stage rather than masterplanning stage.

A new tool, called Urban Daylight [11], has recently been developed by the Sustainable Design Lab at the Massachusetts Institute of Technology (MIT). Urban Daylight can calculate UDI and sDA within urban blocks relatively rapidly and with reasonable accuracy. It computes hourly radiation levels on façades and uses a correlation method that takes into account glazing and basic internal layout to convert external illuminance into internal illuminance levels. Urban Daylight is one of the modules in the Urban Modelling Interface (UMI) developed by MIT, which operates within Rhinoceros (3D modelling tool) and Grasshopper (its parametric modeler).

As part of this study, we have contacted Christoph Reinhardt at MIT who is one of the leading figures behind the development

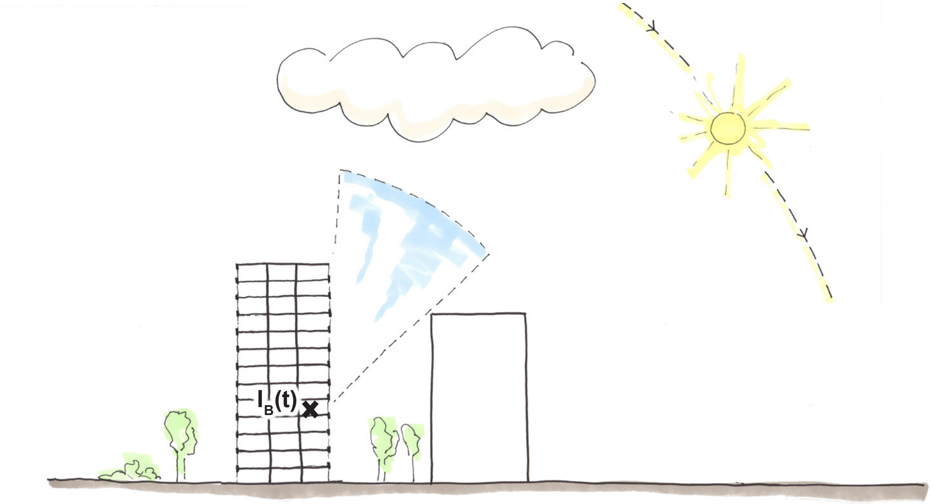


Figure 5 - Climate Based Daylight Metrics: Daylight Autonomy (DA) or Useful daylight Illuminance (UDI)

DA_B = Percentage of time throughout year when $I_B(t)$ is above minimum threshold (typically 100-300 lux).

UDI_B = Percentage of time throughout year when $I_B(t)$ is above minimum threshold (typically 300 lux) and below maximum threshold (typically 3,000lux).

Where, I_B (t) is the illuminance at the point of interest (B) within the building, at time t, with corresponding cloud cover and sun position

Aspects considered in calculations	Vertical Sky Component (VSC)	Average Daylight Factor (ADF)	Target Daylight Factor (DF_{300})	Spatial Daylight Autonomy (sDA)	Useful Daylight Illuminance (UDI)
External obstructions	x	x	x	x	x
External reflections	x	x	x	x	x
Glazing characteristics		x	x	x	x
Floor to ceiling height		x	x	x	x
Internal reflections		x	x	x	x
Orientation				x	x
Sun path / climate				x	x
Excessive daylight level					x
Spatial uniformity of daylight			x	x	x
Calculation speed	fast	fast	fast	slow but significantly faster with Urban Daylight	slow but significantly faster with Urban Daylight

Table 1- Comparison of daylight metrics

of Urban Daylight and climate based metrics in general. He indicated that to date there has been relatively little research conducted on the subject of daylight requirements within residential buildings. He provided a reference to a study on urban densities and access to daylight, carried out with Urban Daylight which evaluated high density massing alternatives using the benchmark of sDA_{300} [12].

Additionally, we have contacted John Mardaljevic at Loughborough University and Peter Raynham at UCL, who have also indicated that relatively little research had been carried out on daylight requirements within residential buildings in the UK.

Loughborough University are developing a modified method to calculate the daylight factor, which aims to deploy the benefits of climate based metrics without the calculation time penalty. It uses the same simulation methodology as ADF, but sets a target daylight factor based on site location and median external daylight levels. It requires that at least 50% of the area achieves that target daylight factor. This method considers the site specific sun path and variations in cloud cover without the lengthy simulation procedure associated with climate based metrics. This method has been published and proposed to the European Committee for Standardization as a new standard for daylight in buildings [13]. It has been referred to as Target Daylight Factor (DF_{300}).

A summary of the major daylight methods and how well they capture the aspects of daylighting is shown in Table 1.

Of the performance metrics that have been reviewed, sDA is the most comprehensive and applicable performance metric to evaluate daylight in residential buildings. We recommend evaluating sDA with a target illuminance of 200 lux.Using the WELL Building Standard as a template [9], the performance benchmark set for sDA is to achieve illuminance levels of 200 lux for 50% of occupied hours across 55% of the regularly occupied space. Regulary occupied space does not inculde areas of the floorplate used for circulation, services and core spaces. At the masterplanning stage, sDA should be evaluated using the Urban Daylight tool. At building or block levels, more accurate radiance-based sDA simulations should be carried out. Within a dense urban environment it may not be possible to achieve these levels of daylight in some areas, particularly ground and lower floors. This should be considered when planning space usage.

2.4. Internal sunlight

In addition to daylight, direct sunlight can contribute to making an indoor space pleasant and enjoyable. Sunlight also provides direct solar gains which can passively heat a space during the winter, but could also contribute to overheating in summer (Section 2.7).

Across several European countries guidelines have been defined for sunlight duration in living spaces for different times of the year. In Germany, 1 hour of sunlight per day is required in January, and 4 hours per day in March. The requirements of the BRE Guidelines [5] are based on Annual Probable Sunlight Hours (APSH) and set a minimum of 25% APSH over the entire year and 5% APSH during winter months. Although this criterion includes a temporal aspect of annual sunlight hours, the underlying metric lacks a quantitative value on how much sunlight is entering the space.

Recently, several UK daylight experts have proposed a new metric to measure sunlight in buildings called the Sunlight Beam Index (SBI) [14]. The SBI measures the quantity of sunlight in m^2*hour, considering the cross-sectional area of the sunlight entering the space. Although the SBI metric is more comprehensive than APSH, no performance benchmark has yet been defined. Therefore, we currently recommended to use the BRE Guidelines [5] for minimum APSH.

2.5. Outdoor sunlight

Whilst much of people's time is spent indoors, it is vital to provide a welcoming outdoor environment which encourages physical activity, social interaction and sense of community. Sunlight in the public realm plays a major role in encouraging the above activities because it can draw people outdoors to interact with others, nature and the built environment.

The primary metric used to assess outdoor sunlight access is direct sunlight hours falling on a space. The BRE Guide [5] recommends that outdoor spaces should receive at least

Figure 6 - Direct sunlight can contribute to making indoor spaces pleasant and enjoyable

Figure 7 - Outdoor sunlight encourage interactions with others, nature and the built environment

2 hours of sunlight over half the space on March 21st. Polish Regulations require that play areas receive 4 hours of sunlight on March 21st.

The researchers at MIT have also developed a unique Outdoor Comfort module as part of UMI, which conducts an annual simulation of sunlight hours and outdoor air temperatures. It produces results for the summer period when shade is preferred to direct sunlight, and for the winter months when direct sunlight is welcome. This method is still in development.

We therefore recommended using the BRE Guidance [5] to evaluate sunlight hours on external spaces.

2.6. Urban wind

Urban wind influences pedestrian comfort, flushing of pollution, reduction of the urban heat island effect and natural ventilation. It is often overlooked at the masterplanning stage because its prediction requires complex and resource intensive analysis such as Computational Fluid Dynamics (CFD) or wind tunnel testing.

The results of CFD modelling are generally analysed for pedestrian comfort in the public realm using the Lawson Comfort Criteria [15]. These criteria use wind speed and frequency of occurrence to determine the suitability of various pedestrian activities, and are based purely on the mechanical effects of wind on pedestrians' comfort.

A number of "light CFD analysis tools" are being developed such as Autodesk Vasari, and plug-ins to Rhinoceros and Grasshopper its parametric modeler. These tools are promising, but they are not considered mature enough to be usefully implemented on this project.

At early masterplanning stage, the method generally used remains the simple overlay of a wind rose on the plan and qualitative considerations based on best practice principles, such as those defined by the BRE 380 Guide [16].

We therefore recommend to consider the summer and winter wind roses alongside BRE 380 guidance (Figure 8) to identify potential problem areas, which would then require detailed CFD analysis.

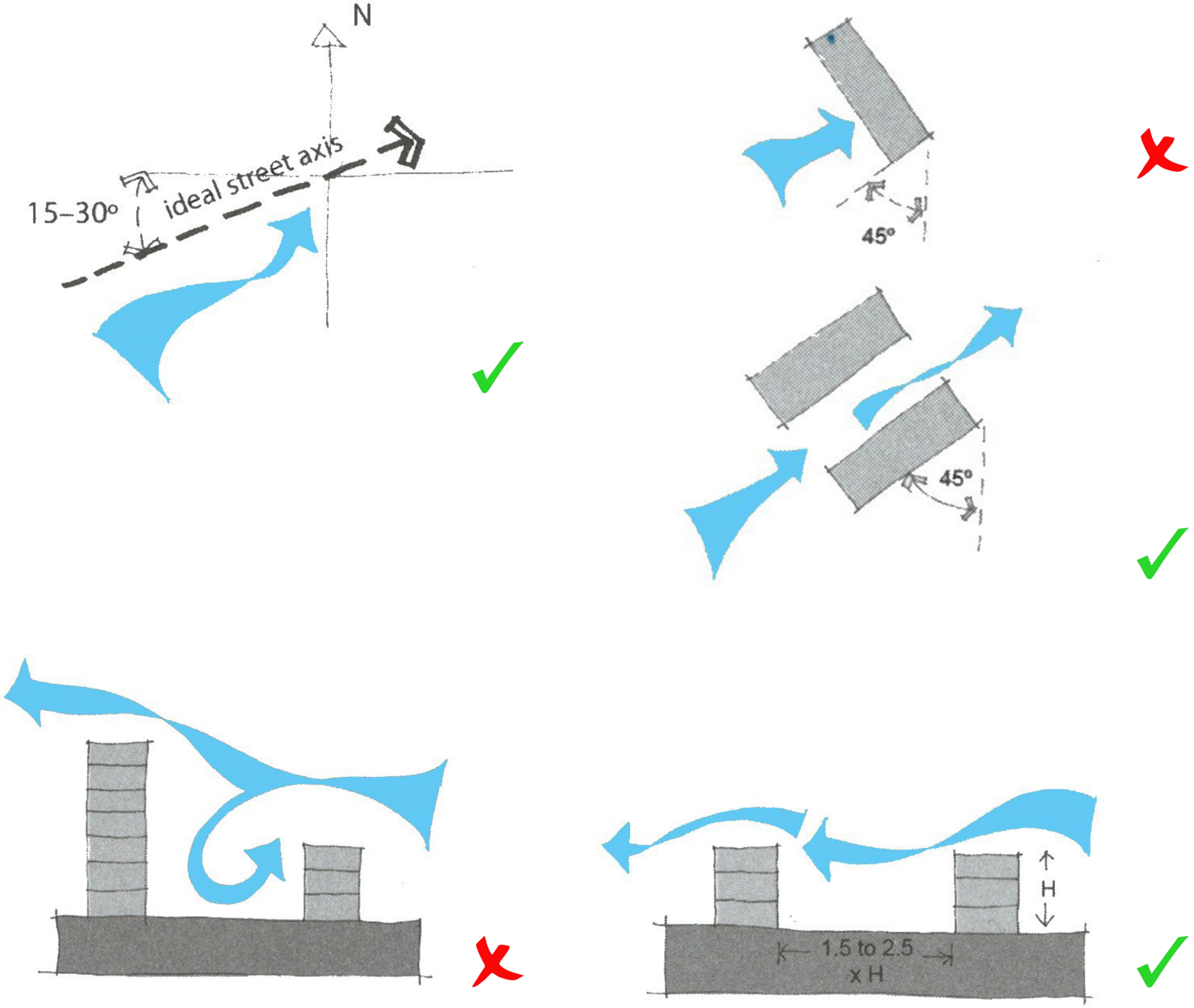


Figure 8 - BRE 380 Best Practice Guidance for designing with the wind

2.7. Energy efficiency

Whilst ensuring adequate daylight and solar access is essential in providing a healthy built environment, this must be considered alongside energy efficiency and thermal comfort.

Space Heating

On the one hand, a consequence of designing for improved daylighting is the potential increase in building heat losses through the fabric due to higher glazing ratios and greater envelope-to-space ratio. This can result in increased space heating energy use. On the other hand, maximising access to sunlight will likely increase winter solar gains and reduce space heating energy use.

Whilst the control of envelope heat losses can be addressed largely at the building design stage, with insulation and glazing specification, it is necessary to understand the potential consequences of the design decisions made at masterplanning stage on space heating energy use.

The assessment of the effect of winter solar gains and envelope heat losses on space heating energy use is generally carried out using dynamic thermal simulations. These simulations are resource intensive and require significant amount of input data. They are therefore generally carried out for individual buildings at building design stage, rather than multiple buildings at masterplanning stage.

However, the UMI software developed by MIT also includes an energy assessment module allowing thermal analysis to be carried out rapidly and with reasonable accuracy [17]. The method discretises the urban form into several small “shoebox” energy models and uses the industry standard EnergyPlus simulation engine to calculate energy use per unit floor areas for the different shoeboxes. It then extrapolates the results to provide urban scale energy analysis.

Another approach generally used at masterplanning stage is to use the steady-state degree-day method. However, this method does not take into account winter solar gains.

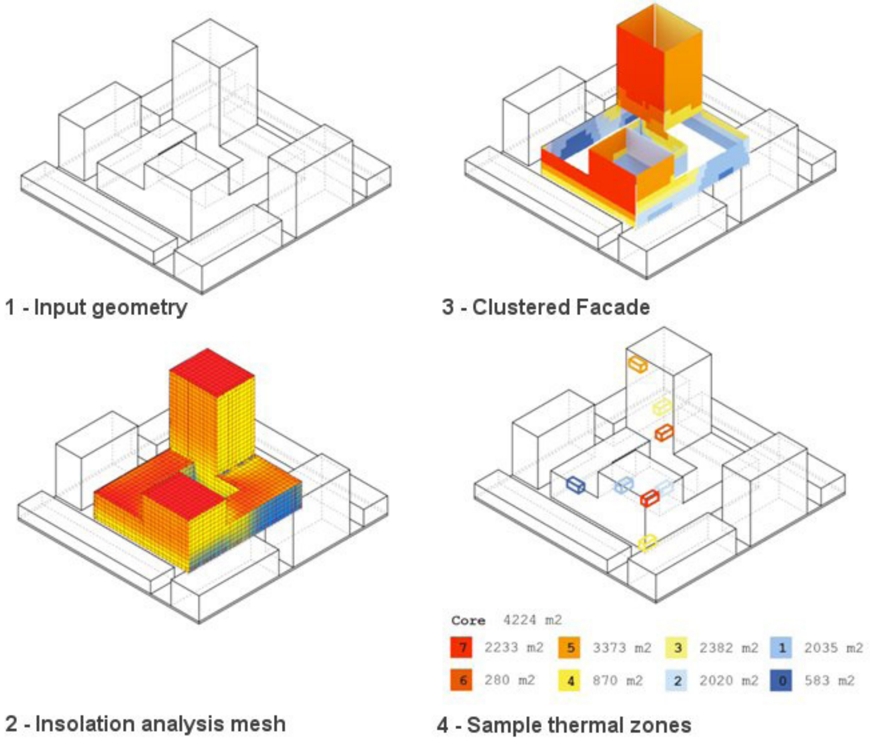


Figure 9 - Urban Modelling Interface (UMI) ‘Shoeboxer’ and building energy modelling approach

Summer Solar Gains and Overheating

Increased summer solar gains can result in overheating in naturally ventilated buildings and increased energy use in mechanically cooled buildings. The control of solar gains can be mitigated at building design stage with shading and an appropriate glazing specification. But again, it is necessary to understand the potential consequences of the design decisions made at masterplanning stage on cooling energy use or thermal comfort.

The assessment of overheating or increased energy use as a consequence of solar gains is also generally carried out by dynamic thermal simulations.

As discussed above, the UMI software does calculate cooling energy use for mechanically cooled buildings. However the thermal comfort assessment for naturally ventilated buildings is still in development. A good indicator of the risk of overheating or high cooling energy use is summer irradiance levels.

At masterplanning stage we recommend using:

- The UMI ‘shoeboxer’ to evaluate space heating energy use, and cooling energy use in mechanically cooled buildings and compare it against energy use targets for the development of other Part L, Zero Carbon or PassivHaus benchmarks;
- Façade irradiation as an indicator of potential overheating issues, until the UMI software is fully operational. There

are no guidelines for summer solar gains in residential buildings but Criterion 3 in Part L2A of the Building Regulations provides a limit for solar gains in non-domestic buildings which can be used as a reference value.

At building or block-level, detailed thermal analysis is required to assess space heating and cooling energy use and the risk of summer overheating. There are several methods to assess overheating such as SAP Appendix P [18], ASHRAE 55 [19], Passive House Planning Package (PHPP) [20] and CIBSE TM52 [21]. The industry best practice is to use CIBSE TM52 which requires hourly internal operative temperatures to be tested against three overheating criteria.

2.8. Synthesis

Table 2 summarises the considerations discussed above and provides recommendations on appropriate performance metrics, benchmark scales and assessments to be used for each criteria. We differentiate between the masterplanning stage, when several building blocks need to be tested without detailed information being available, and the building design stage when more detailed calculations are feasible.

<table>
<tr><th>Criteria</th><th>Masterplanning stage</th><th>Building design stage</th></tr>
<tr><td rowspan="2">Daylight</td><td colspan="2">Metric: Spatial Daylight Autonomy, 200 lux target illuminance (sDA$_{200}$)
Benchmark: WELL Building Standards (2016) min. 50% sDA$_{200}$ for 55% of occupied space</td></tr>
<tr><td>Method: Calculate sDA using Urban Daylight module within UMI</td><td>Method: Detailed calculations with Radiance-based engine</td></tr>
<tr><td>Internal sunlight</td><td colspan="2">Metric: Annual Probable Sunlight Hours (APSH)
Benchmark: BRE 209 (2011) min. 5% APSH between equinoxes and 25% annually
Method: APSH on façades withing +/- 90° of South using aRadiance-based model</td></tr>
<tr><td>Outdoor sunlight</td><td colspan="2">Metric: Sunlight hours in external space
Benchmark: BRE 209 (2011) 2 hour sunlight on 21 March over half the area and 4 hour in play areas (Polish Regulations). Also consider seasonal sunlight throughout the year in combination with air temperatures.
Method: Radiance-based model. Use UMI's Outdoor Comfort Module to perform seasonal analysis of sunlight hours and temperatures when available</td></tr>
<tr><td rowspan="2">Urban Wind</td><td colspan="2">Metric: Wind speeds and associated frequencies</td></tr>
<tr><td>Benchmark: Follow BRE 380 best practice guidance.
Method: Wind rose-based assessment</td><td>Benchmark:: Lawson Wind Comfort Criteria and consideration of dispersion of pollution and urban heat island effect
Method: CFD or wind tunnel testing</td></tr>
<tr><td>Energy Efficiency - Control of Solar Gains</td><td>Metric: Summer façade irradiation
Benchmark: None. Compare with Part L reference case to identify potential issues
Method: Radiance-based model</td><td>Metric: Internal temperatures (naturally ventilated) or cooling energy use (mechanically cooled)
Benchmark: Pass two of CIBSE TM52 overheating criteria or minimise cooling energy use.
Method: Thermal simulation at building level</td></tr>
<tr><td rowspan="2">Energy Use - Space Heating</td><td colspan="2">Metric: Space heating energy use
Benchmark: Minimise energy use beyond compliance with Part L</td></tr>
<tr><td>Method: UMI 'shoeboxer' or degree-day approach for comparative assessment</td><td>Method: Thermal simulations at building level</td></tr>
</table>

Table 2- Analysis framework: metrics, benchmarks and methods - for residential buildings

3. Analysis of current masterplan

We tested a portion of the Old Oak Common Masterplan using the proposed framework defined in Section 2 (criteria, metrics, benchmarks and methods) and the different tools within the Rhinoceros 3D modelling platform. The area around the proposed HS2 station was chosen owing to its range of densities, from 300 dwellings per hectare (dph) along the Wormwood Scrubs edge (Block A) to 650 dph around the station (Block C). This area is shown on Figure 10. The buildings in yellow were selected for detailed daylight analysis.

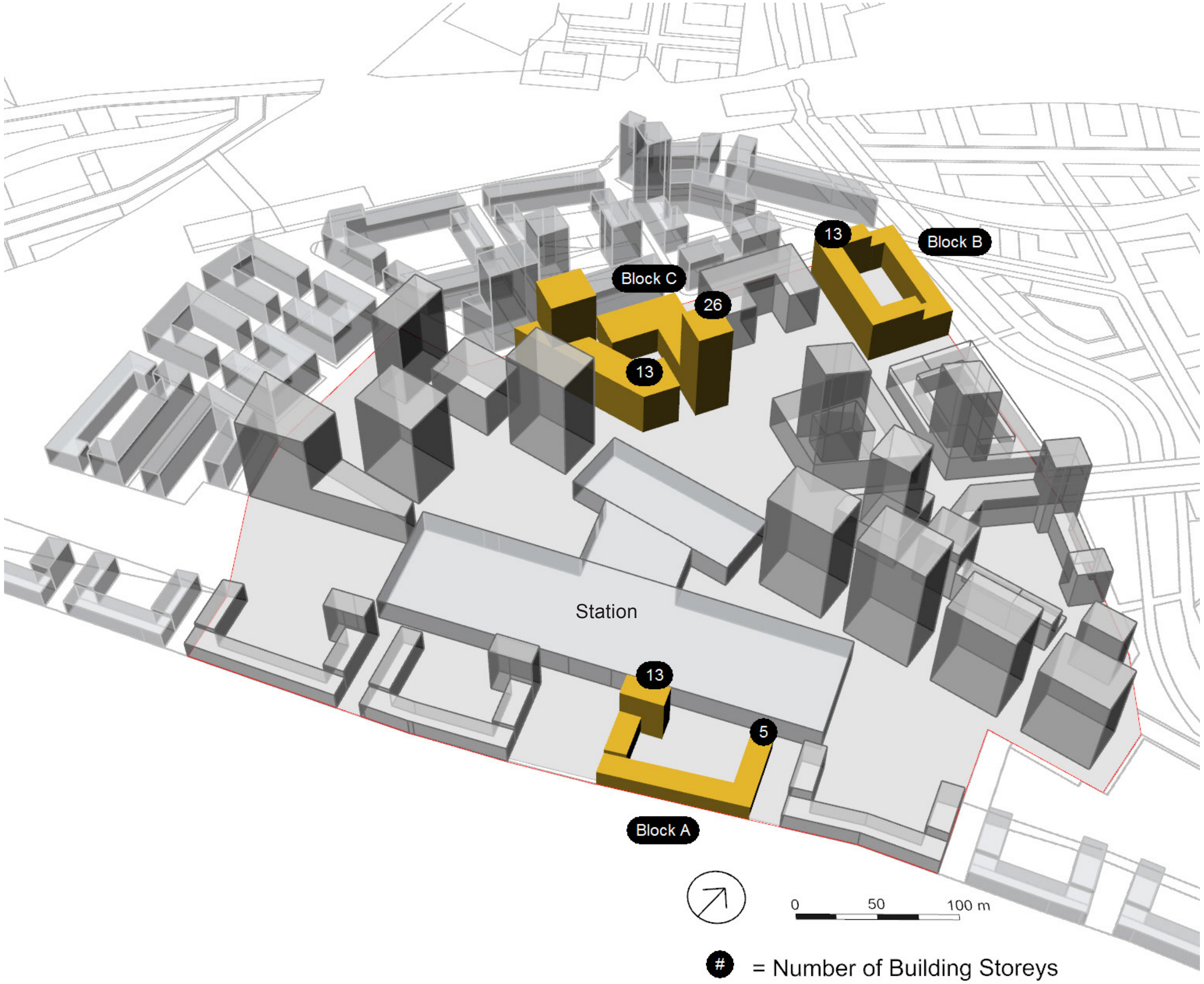


Figure 10 - Tested part of the Old oak Common masterplan

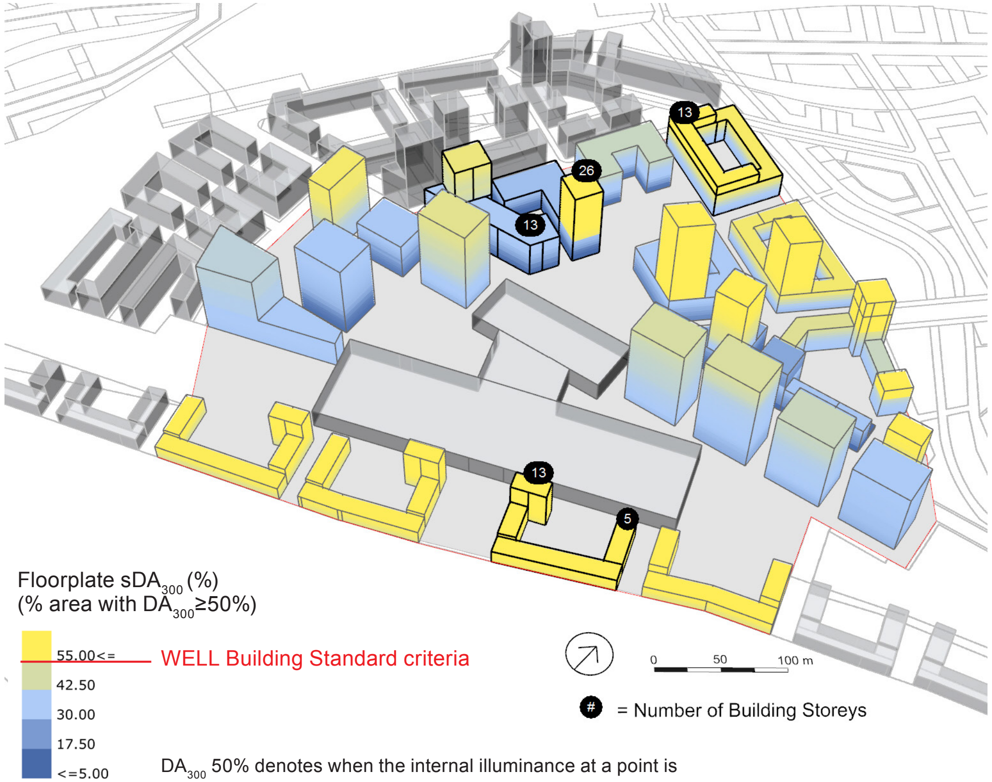
3.1. Daylight

In Figure 11 the results of the daylight analysis show the Spatial Daylight Autonomy (sDA) for each floor in the plan. The sDA was calculated with the assumption of a 40% glazing ratio on all elevations. Overall the performance benchmark established by the WELL Building Standard is achieved for 22% of the floorplates.

The floorplates not achieving the benchmark either have a large amount of external obstructions adjacent to their façades or have very deep plans. In the denser areas, the lower floors have poor daylighting owing to high amounts of neighbouring obstructions blocking out access to the sky.

In Figure 12 the VSC on the building façades is shown for the masterplan. According to the BRE 209 criteria, 60% of the façade area has a VSC above 27% which will provide reasonable daylighting using conventional window design. Additionally, 23% of façade area has VSC between 15 and 17%, which will provide good daylighting with increased window proportions.

The VSC analysis provides optimistic results when compared with sDA because it simply determines daylight availability on the façade taking into account only external obstructions. VSC analysis does not consider glazing proportions, floorplate depth, floor to ceiling height, orientation and climate.



DA_{300} 50% denotes when the internal illuminance at a point is above 300 lux for 50% of occupied hours during the year.

Figure 11 - Spatial Daylight Autonomy by floorplate

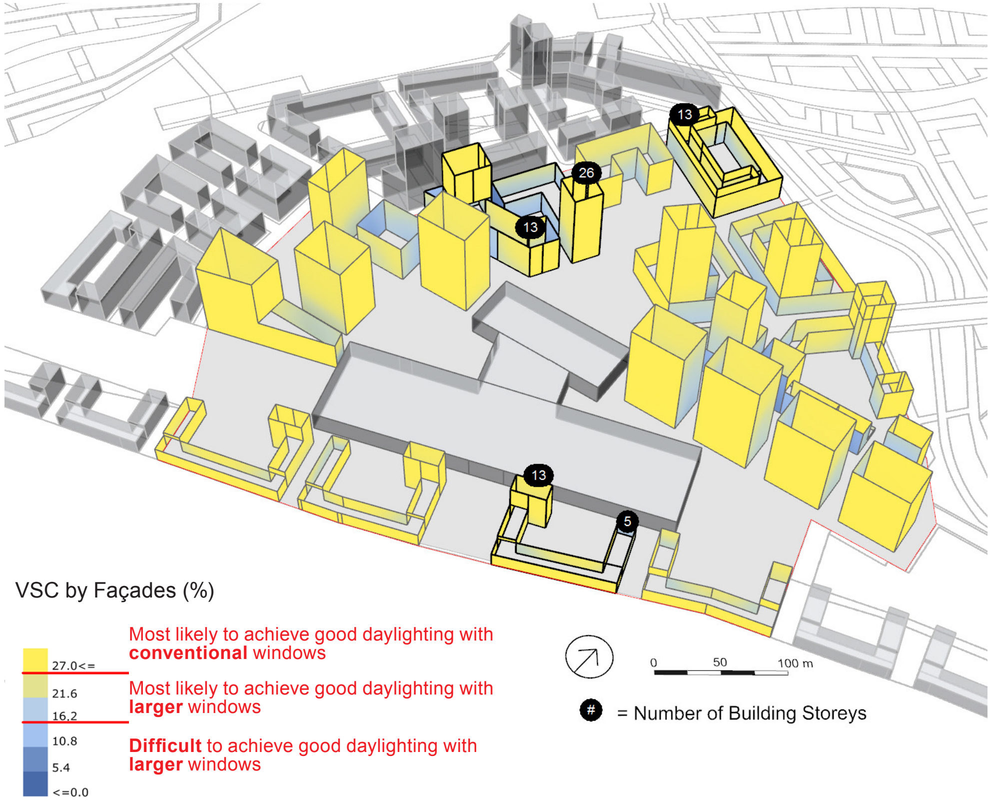


Figure 12 - Vertical Sky Component on façades

Figure 13 shows detailed continuous Daylight Autonomy results for particular floors of key buildings, representative of different densities. Continuous Daylight Autonomy (cDA) has been plotted in this case as it shows continuous results, whilst sDA plotted on a floorplate would show binary results, positive for areas meeting the criteria and negative otherwise. cDA is the proportion of time when the internal illuminance is above a threshold, giving partial credit to timesteps with illuminances below that threshold. Both results can be readily obtained from UMI.

These results illustrate the effect of the depth of the floorplan on internal daylight distributions. The poor daylight in the high density block is a consequence of the deep floor plan rather than surrounding obstructions, as there is relatively little difference between the ground floor and top floor.

The effect of the surrounding obstructions is noticeable on the medium and high density blocks. Ground level daylight levels are affected by the adjacent block to the south, and by the block itself with its enclosed central courtyard and relatively high number of floors.

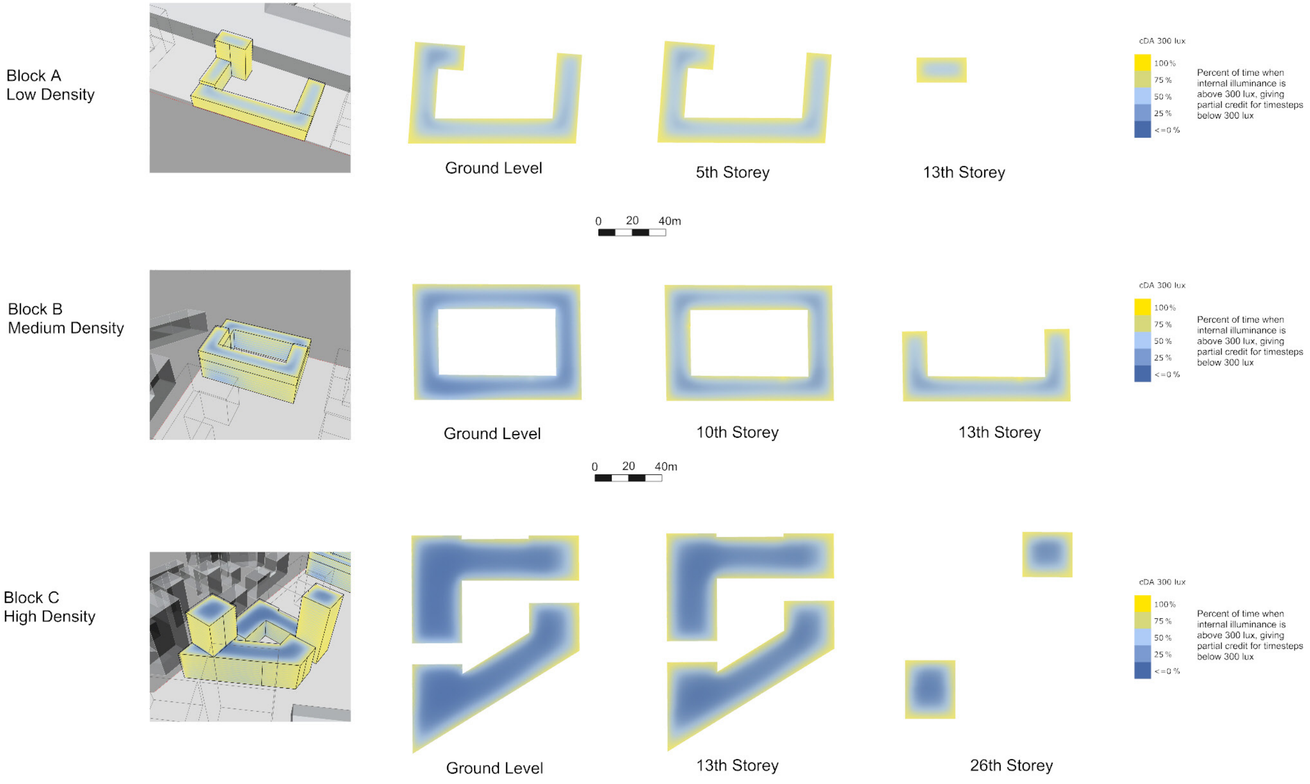


Figure 13 - Continuous Daylight Autonomy results for particular floors of representative buildings

3.2. Internal sunlight

On an annual basis (Figure 14), most façades receive adequate sunlight. However, façades within internal courtyards and behind tall towers on the high street suffer from reduced access to sunlight and the BRE 209 [5] criteria is not met.

When considering the winter period (Figure 15), these issues are worse: The winter sunlight criterion is more difficult to meet because of the lower sun angles which cast longer shadows across the site. The impact of tall buildings is more severe.

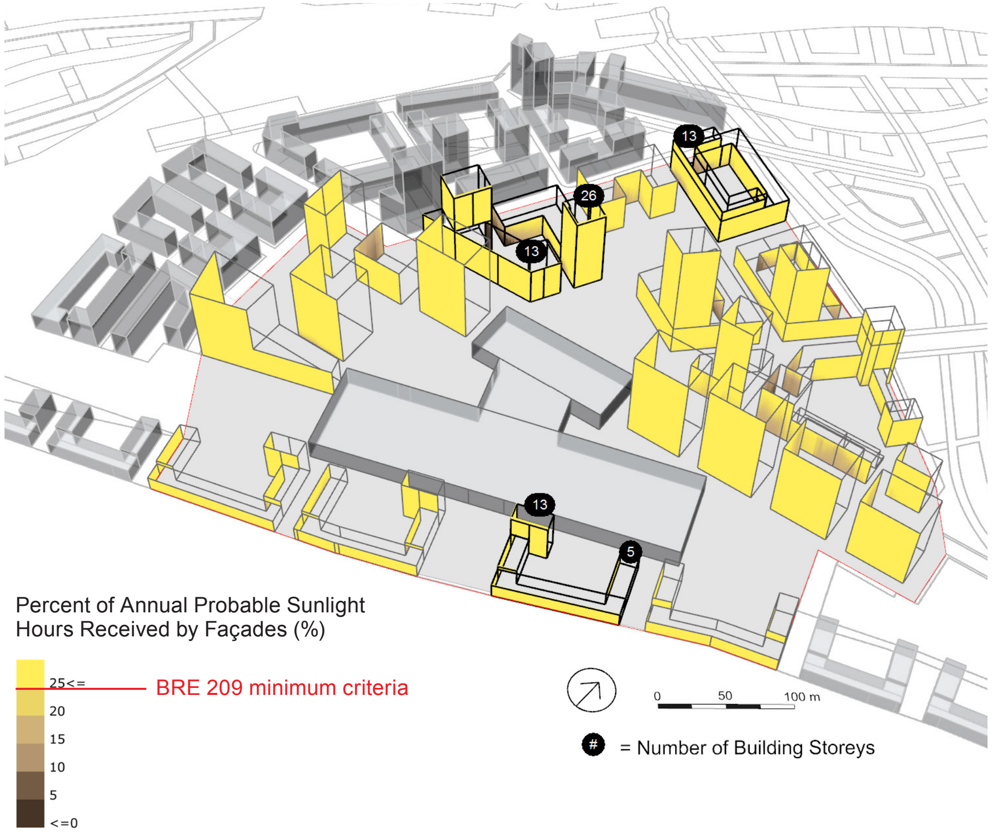


Figure 14 - Annual Probable Sunlight Hours

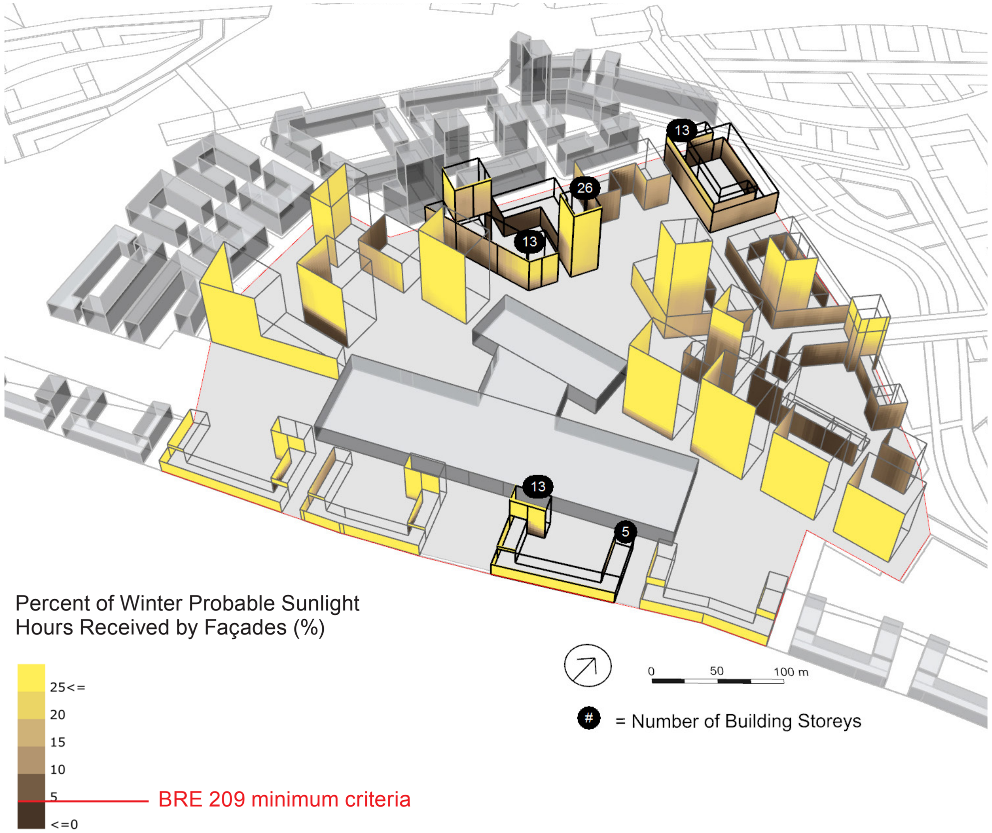


Figure 15 - Winter Probable Sunlight Hours

3.3. Outdoor sunlight

Figure 16 illustrates the results of the outdoor sunlight analysis and shows sunlight hours on March 21st. Overall, the proposed layout passes the BRE 209 requirement by achieving 60% of outdoor space with at least 2 hours of sunlight. A proposal could be developed to adapt the design of the public realm and landscaping to these sunlight patterns. However, at the block level there are several courtyards that receive no sunlight in winter. Also, the tall commercial blocks overshadow the high street and the adjacent blocks significantly.

3.4. Wind

In Figure 17, the summer and winter wind roses are shown along with the site plan. The predominant wind direction is from the South West, with some winter winds from the East. Wind speeds are higher during the winter.

Generally, for this part of the site, there is little risk of significant wind corridors. However, the high street (A), is likely to occasionally be a windy corridor in winter. The main SW-NE streets to the north of the station (B) may also be subject to funnelled strong winds. The large tower blocks may cause significant downdraught and this could be an issue for pedestrian comfort in parts of the site.

Although some of the streets are deep and narrow, the dispersion of air pollutants is unlikely to be much of an issue as buildings do not form a continuous street canyon.

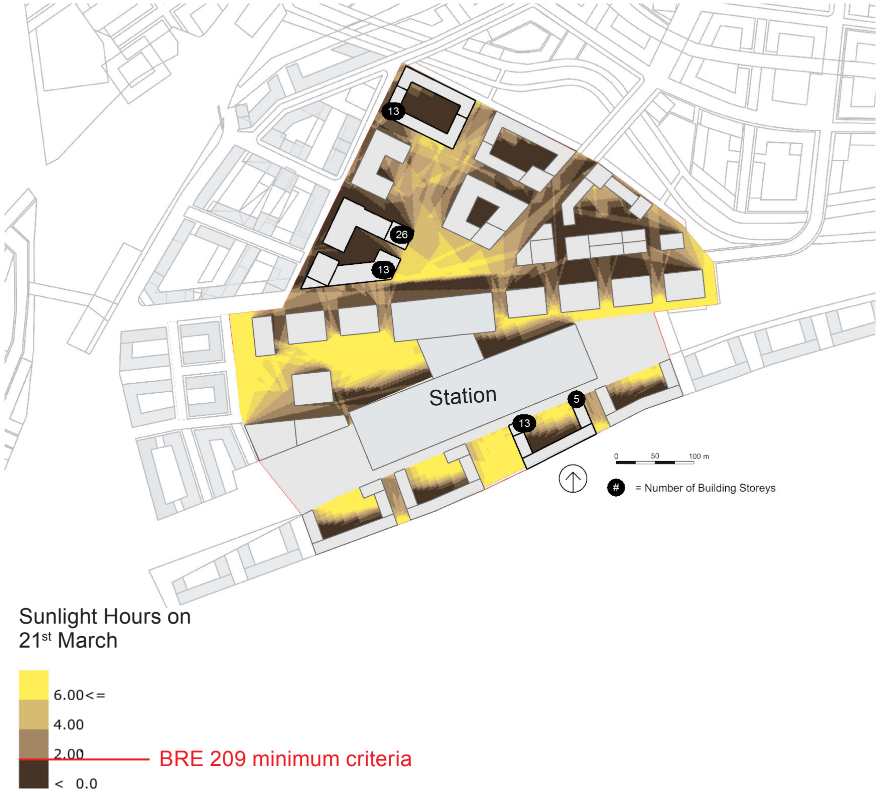


Figure 16 - Outdoor sunlight

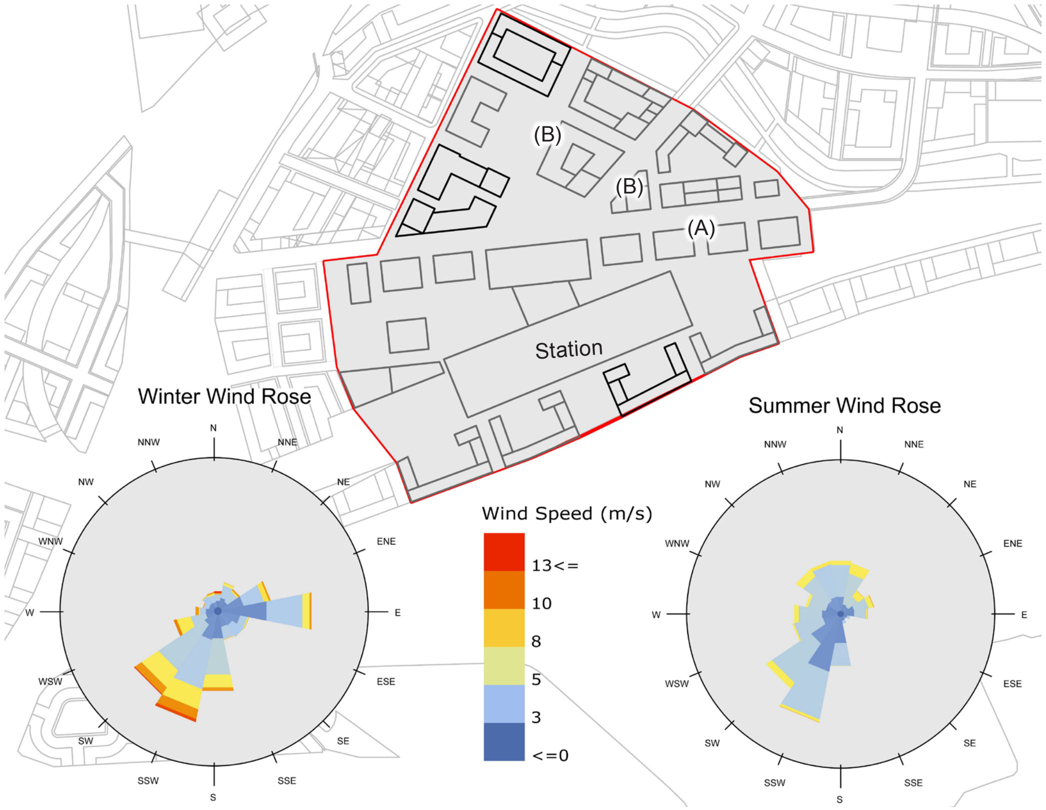


Figure 17 - Urban wind

3.5. Energy efficiency

Figure 18 shows the summer solar irradiation on façades. The façades on the tall towers and large commercial blocks are at the highest risk of overheating or increased cooling energy use owing to their unobstructed southern exposure. These façades would require an efficient summer shading strategy to reduce solar gains while maintaining daylight availability. Unsurprisingly, ground level façades, in particular, along the high street are well shaded.

Figure 19 shows the space heating energy use, calculated with UMI and considering envelope heat losses and winter solar gains. As expected, the more compact blocks have a lower space heating demand than the narrow plan blocks. The space heating requirements of the blocks to the north of the large towers along the high street are relatively high as they have poor winter solar access.

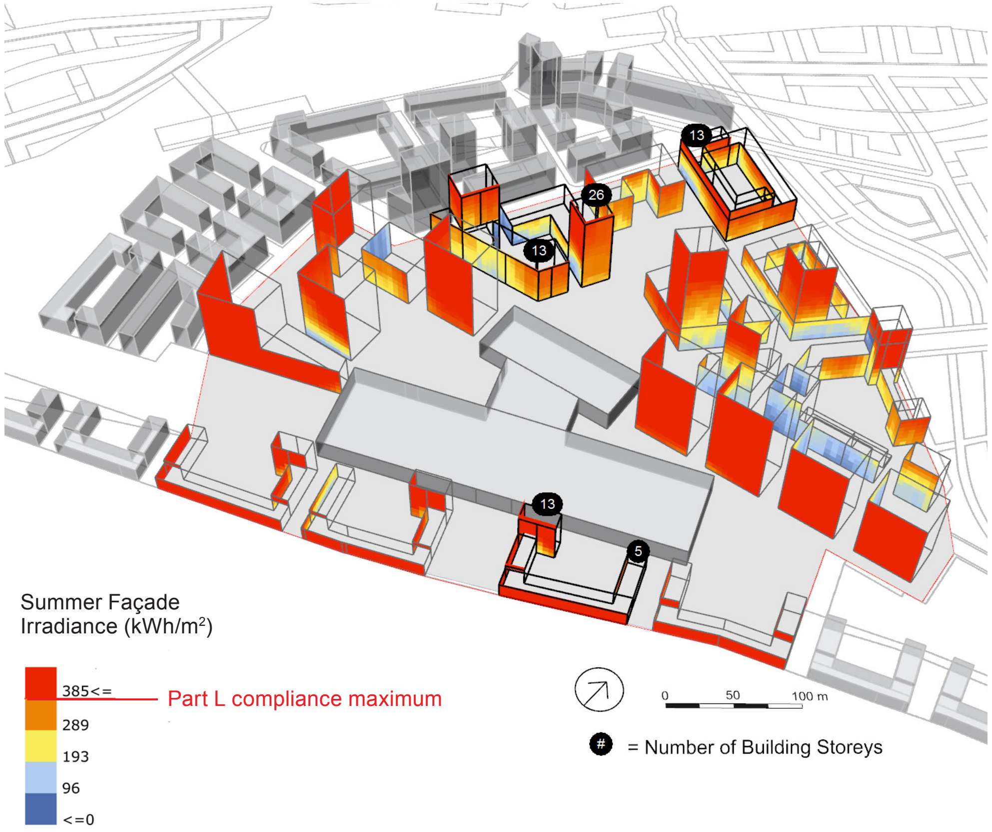


Figure 18 - Summer façade solar irradiation

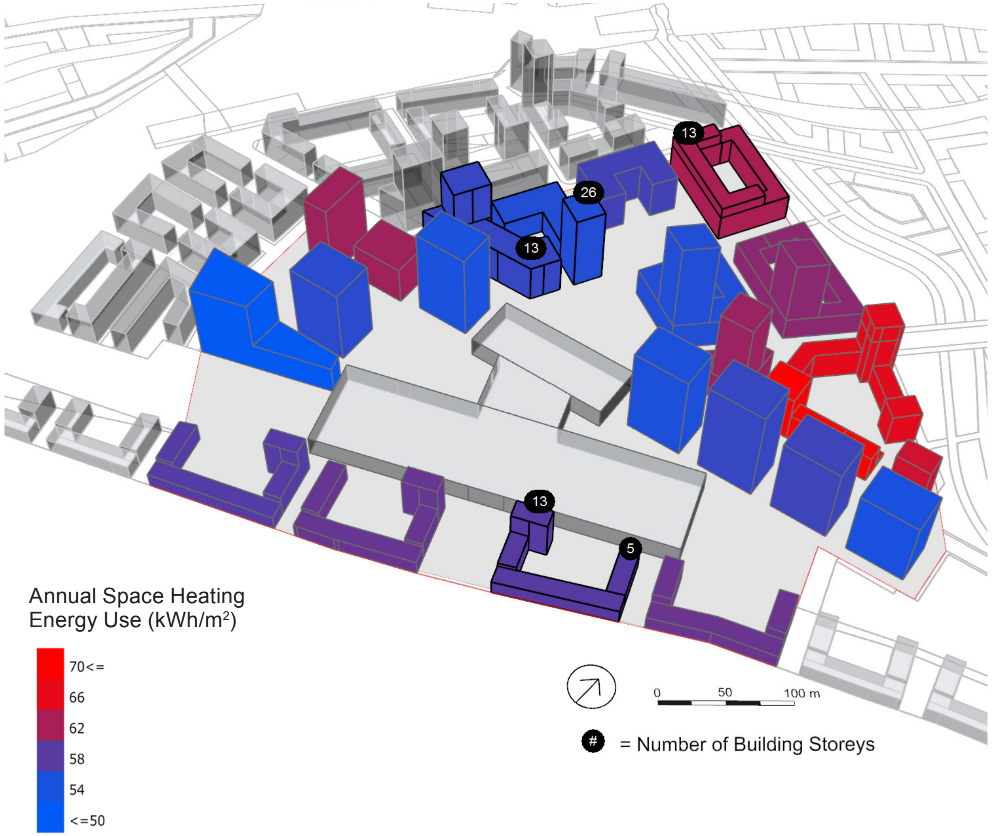


Figure 19 - Space heating energy use

4. Potential improvements

4.1. Alternative layouts considered

To illustrate the workings of the proposed framework and modelling tool several alternative massing arrangements have been tested using the tools within the Rhinoceros 3D modelling platform.

Three building groups, varying from low to high density, were chosen for detailed analysis, as shown in Figure 18-20. Each alternative massing arrangement had the same floor area ratio (FAR) as the original plan, to provide consistent density targets. The parameters altered were plan depth, height, glazing ratio and compactness, as summarised in Table 3 and Figures 20 to 22.

Base case	Alternative 1	Alternative 2	Alternative 3
• Courtyard and tower typology. • Plan depth up to 30m. Glazing ratio 40% everywhere.	• Courtyard opened to South. • Depth of floorplan does not exceed 20m. • Building heights increased. • Glazing ratio 40% everywhere	• “Finger-like” building massing • Depth of floorplan does not exceed 15m. • Building heights increased. Glazing ratio 40% everywhere	• As base case. • Glazing ratios increasing to 80% at ground floor to 40% at top floor.

Table 3- Alternative layouts

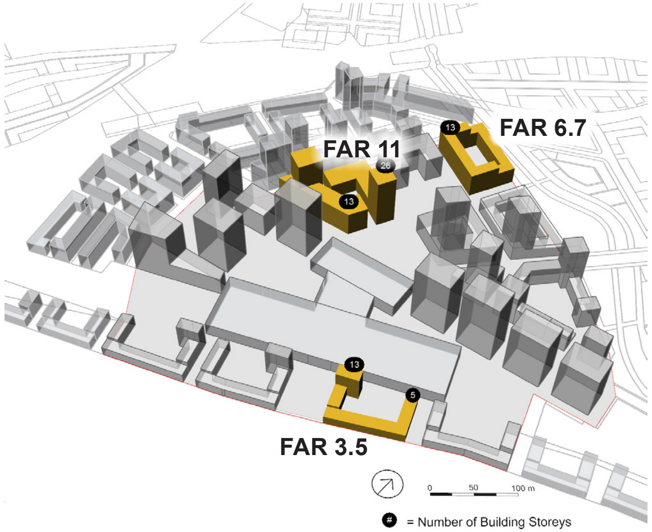


Figure 20 - Current masterplan (and Alternative 3)

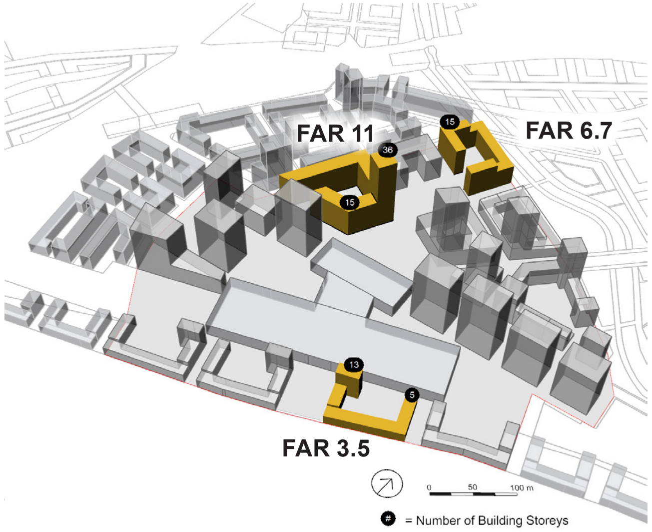


Figure 21 - Alternative 1 - “Opened courtyards”

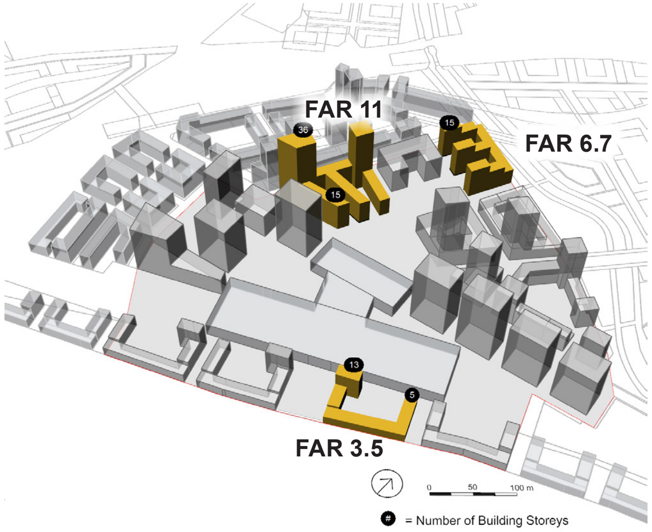


Figure 22 - Alternative 2 - “Fingers”

4.2. Results

The results of the alternative massing configurations for the key environmental criteria are shown in Figure 23, as a way to illustrate the application of the proposed approach. Daylight distribution shows the greatest magnitude of change against the base case. Detailed daylight results are presented in Figure 24. Other detailed results are presented in Appendix A.

Alternative 1, which consists of opening the courtyards to the south and reducing the depth of the floor plan shows good improvements in daylighting. Space heating energy use is reduced as a consequence of increased winter solar gains. Improvements in access to sunlight are also achieved.

Alternative 2, which consists of adopting a finger-like massing and reducing the depth of the floor plan further also shows good improvements in daylight due to the reduction of floor plan depth. However, space heating energy use is also increased as a consequence of the significant increase in envelope area, without a commensurate increase in winter solar gains.

Alternative 3, which consists of increasing the glazing ratios, shows a small improvement in daylight provision. However, space heating energy used is increased as a consequence of the increase in envelope heat losses.

The above analysis, although limited in scope, illustrates that significant improvements to daylight and sunlight access can be achieved by modifying the shape of the blocks and glazing ratios. It is nevertheless important to consider the effects on the other criteria mentioned previously.

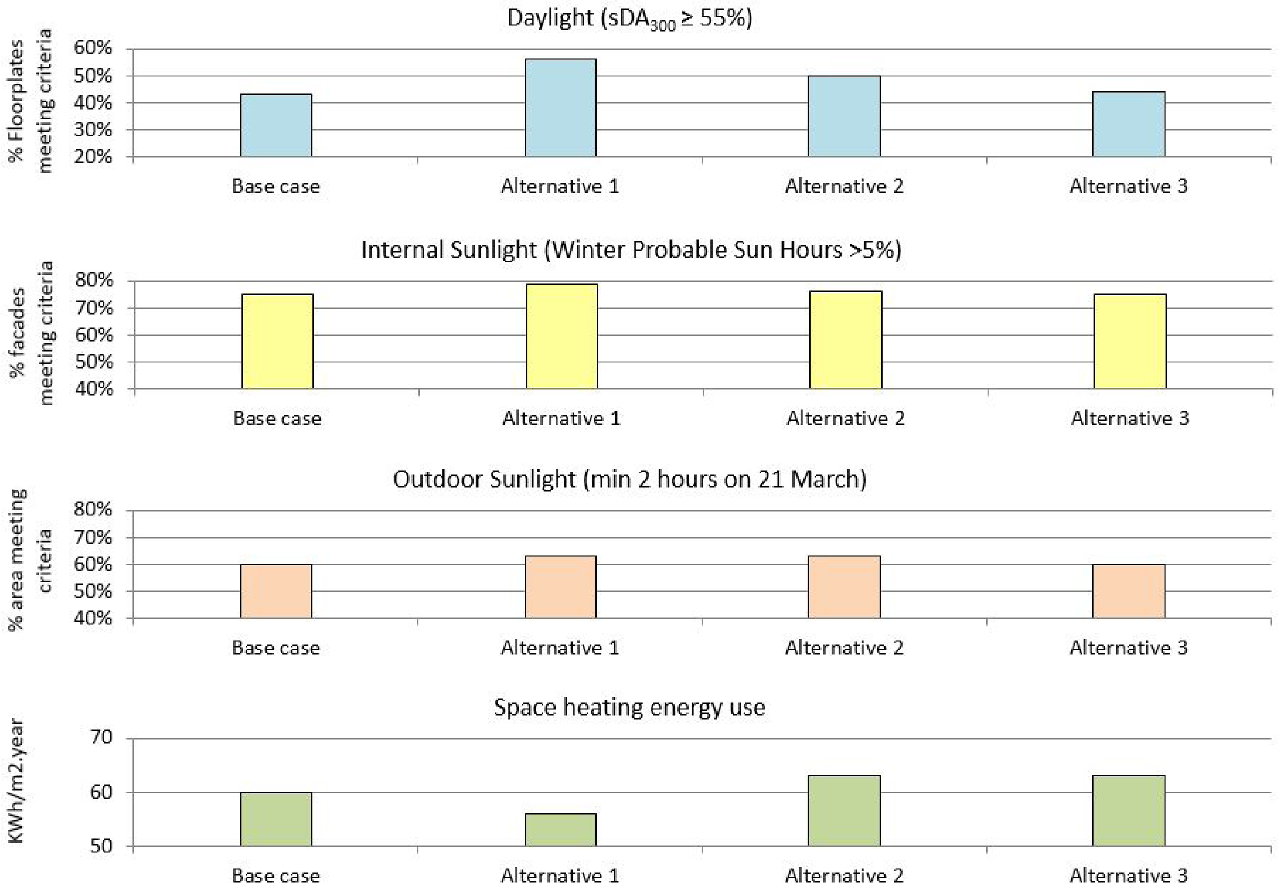
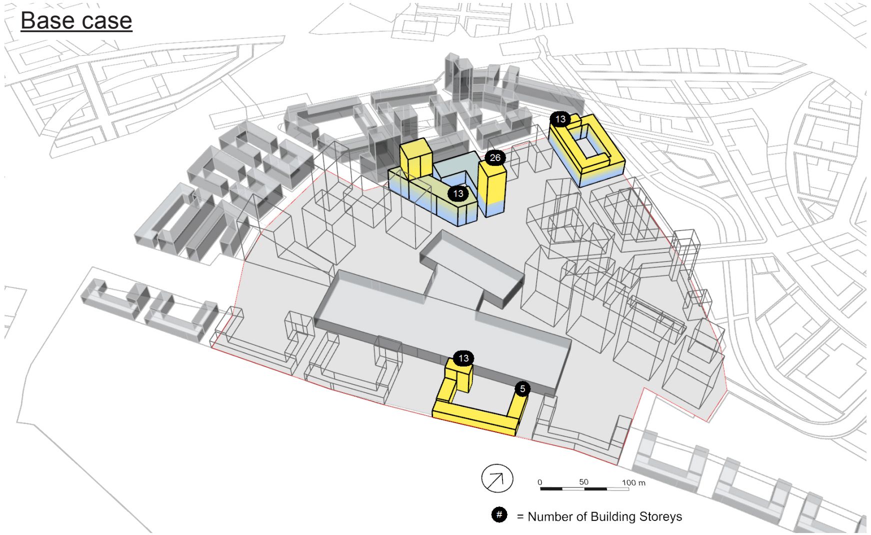


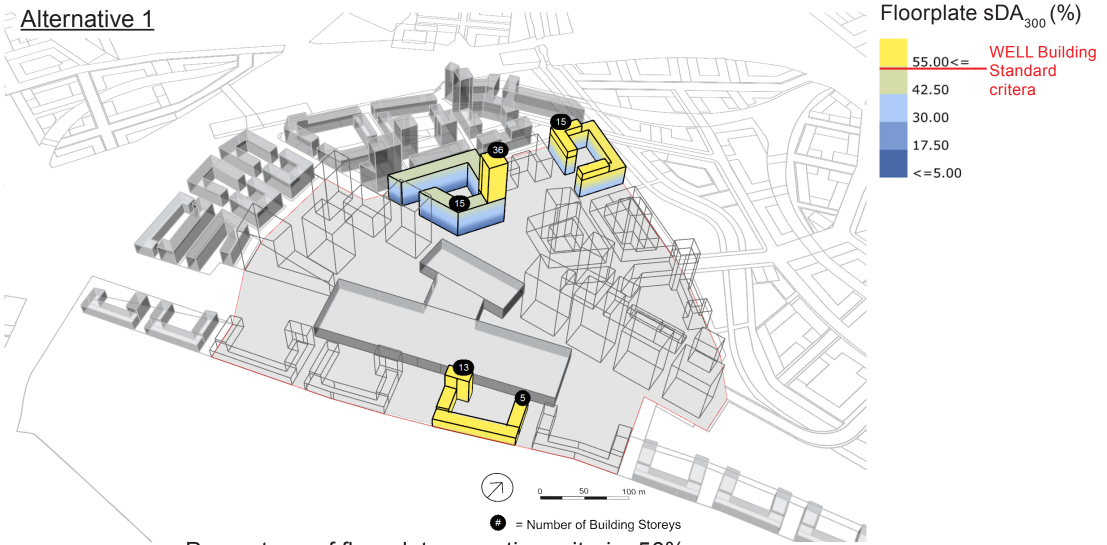
Figure 23 - Comparison of key metrics for alternatives

Base case



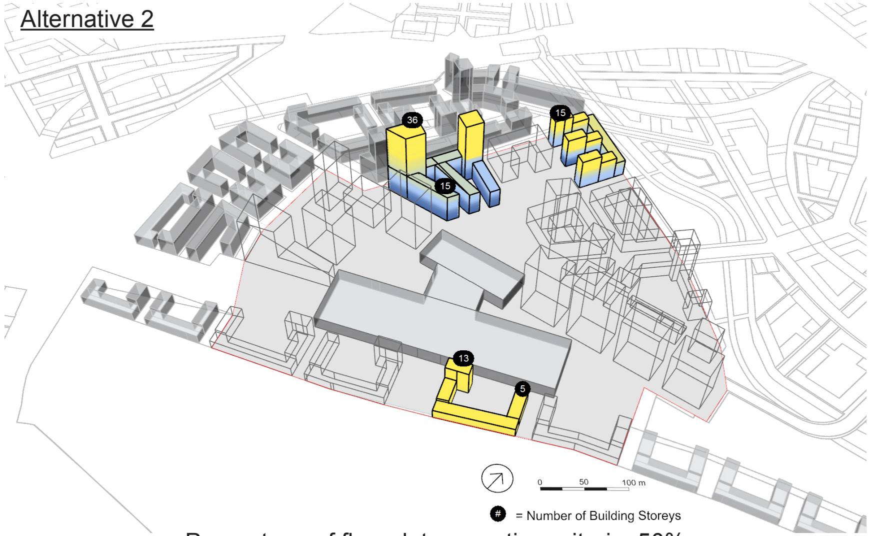
Percentage of floorplates meeting criteria: 43%

Alternative 1



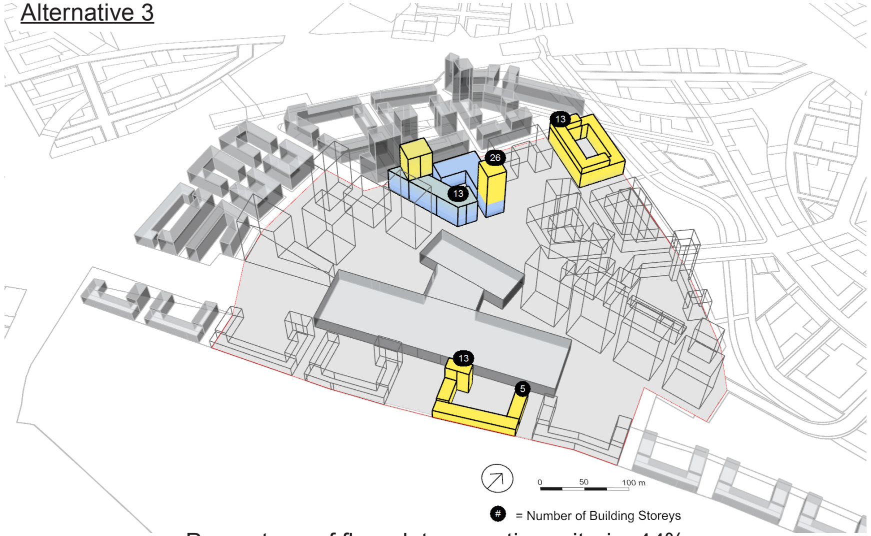
Percentage of floorplates meeting criteria: 56%

Alternative 2



Percentage of floorplates meeting criteria: 50%

Alternative 3



Percentage of floorplates meeting criteria: 44%

Figure 24 - Daylight results

5. Conclusions

The main output of this study is the development and testing of an analysis framework for the assessment of 3D masterplans against several environmental criteria.

This framework has been developed based on a review of published research, design guides, modelling tools and consultation with experts. It consists of performance metrics, benchmark scales and an appraisal method for daylight within buildings, internal sunlight, outdoor sunlight, urban wind and energy efficiency.

This framework can be used as a tool to compare alternative designs, by providing an objective and systematic means to evaluate them. It should be used in conjunction with other aspects of urban design such as design for amenity, quality of space and access to services to provide a holistic design approach.

Many of the proposed tools and methods form part of the Urban Modelling Interface (UMI) being developed by the Massachusetts Institute of Technology (MIT) on modelling daylight, energy use, and outdoor comfort at the urban scale. These innovative tools are being developed further, and it is recommended to closely follow the next evolution of these promising tools.

Future areas of research would be to conduct case study assessments of existing urban developments which are perceived well and comparing the results of occupant surveys with modelling results, to see how modelling outcomes compare to people's perceived experience. Also, this study revealed several new methods for evaluating daylight and sunlight such as Spatial Daylight Autonomy which require more testing and use in industry to determine suitable performance benchmarks for residential buildings.

Applying the framework to a sample of the masterplan illustrated how the tool can be used to influence design variables and explore the trade-offs between multiple objectives.

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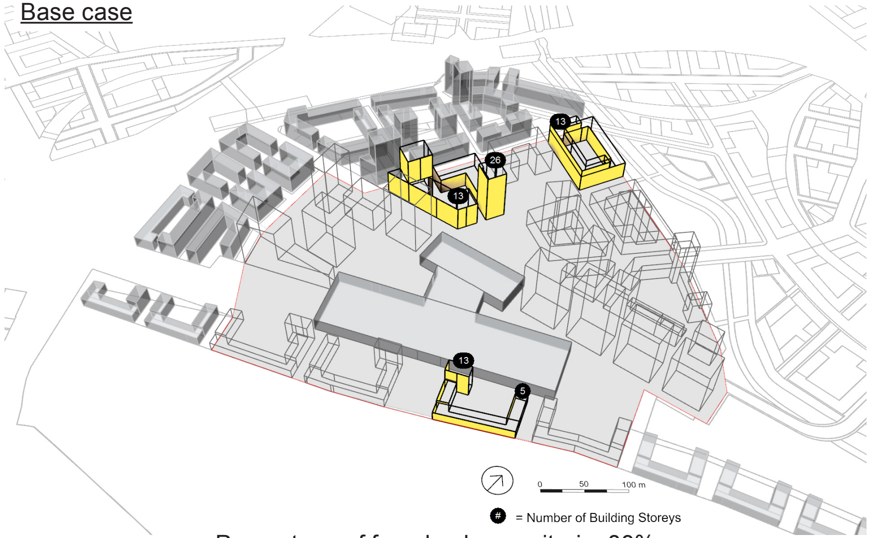
Appendix - Alternative configurations - Detailed results

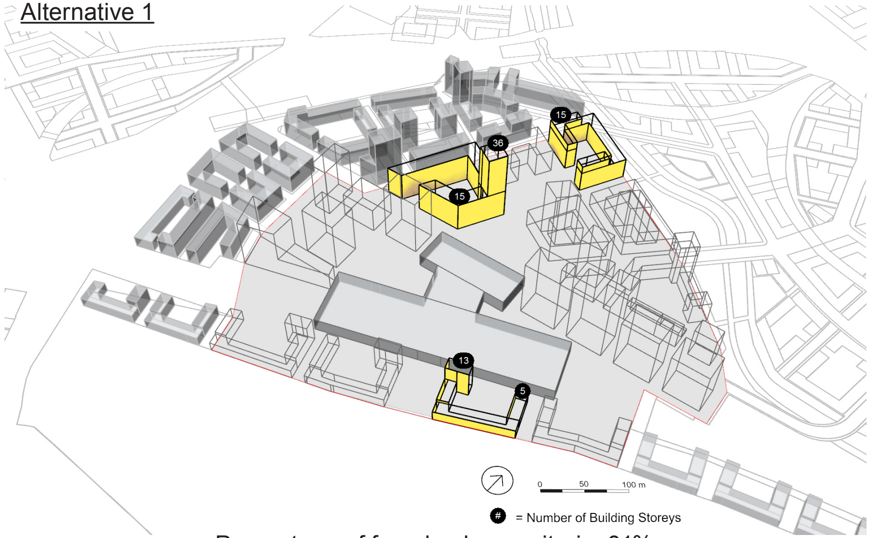
Internal Sunlight - Annual

Base case



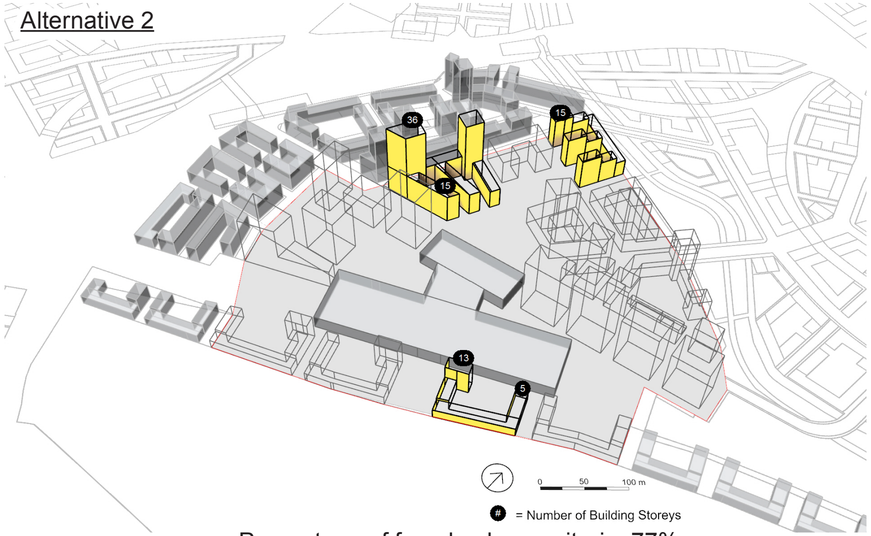
Percentage of façade above criteria: 83%

Alternative 1



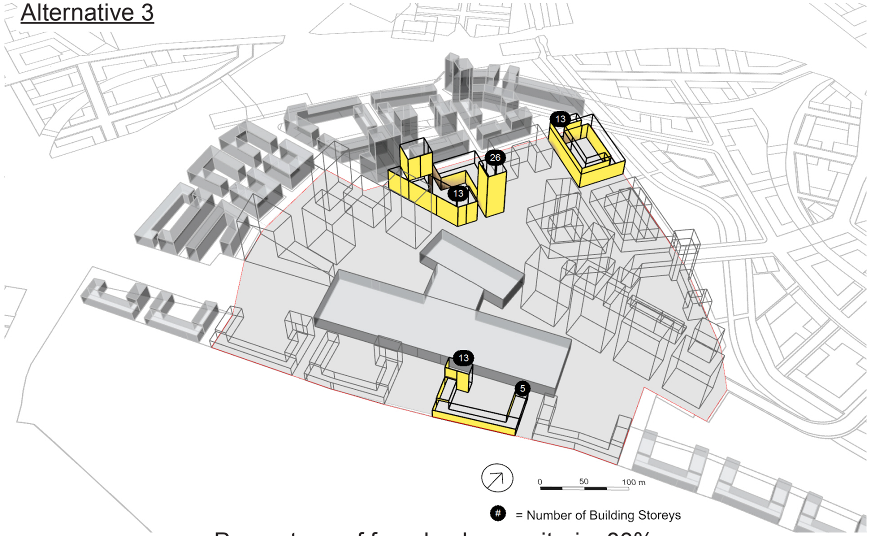
Percentage of façade above criteria: 81%

Alternative 2



Percentage of façade above criteria: 77%

Alternative 3



Percentage of façade above criteria: 83%

Percent of Annual Probable Sunlight Hours Received by Façades (%)

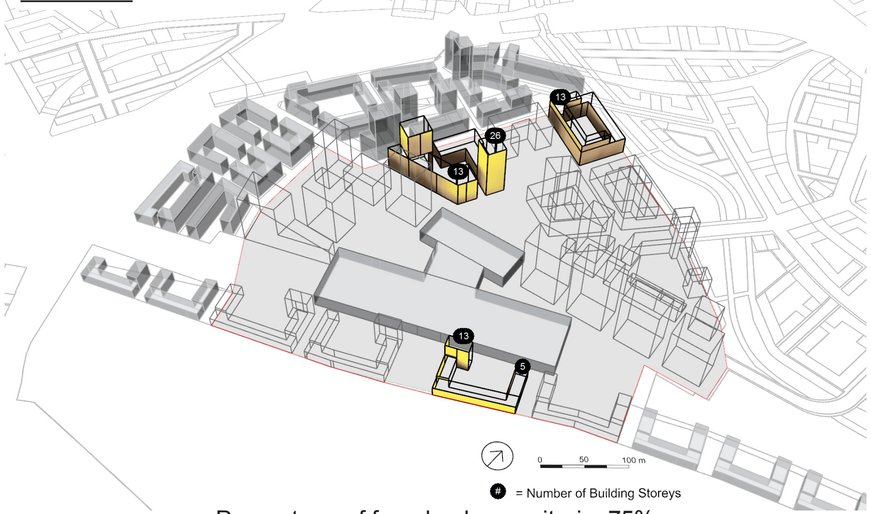
- 25<= — BRE 209 minimum criteria
- 20
- 15
- 10
- 5
- <=0

Internal Sunlight - Winter

Percent of Annual Probable Sunlight Hours Received by Façades (%)

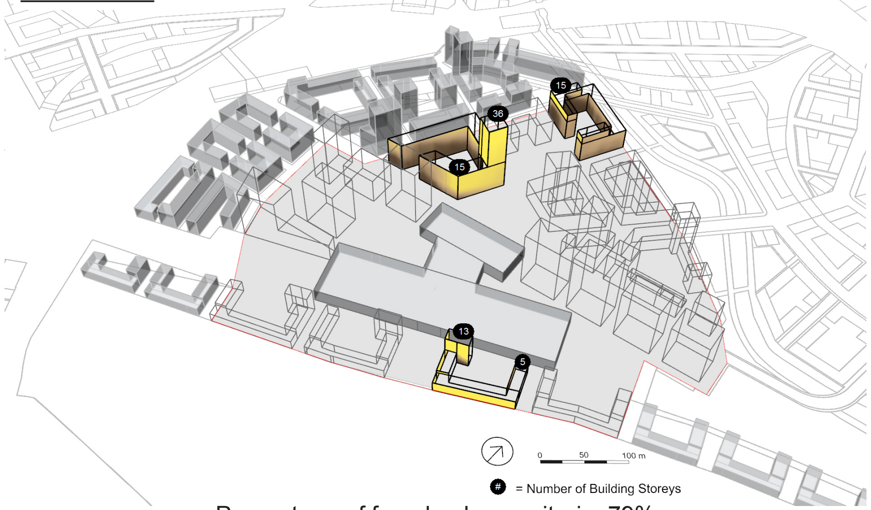
- 🟨 25<=
- 20
- 15
- 10
- 5 — BRE 209 minimum criteria
- ■ <=0

Base case



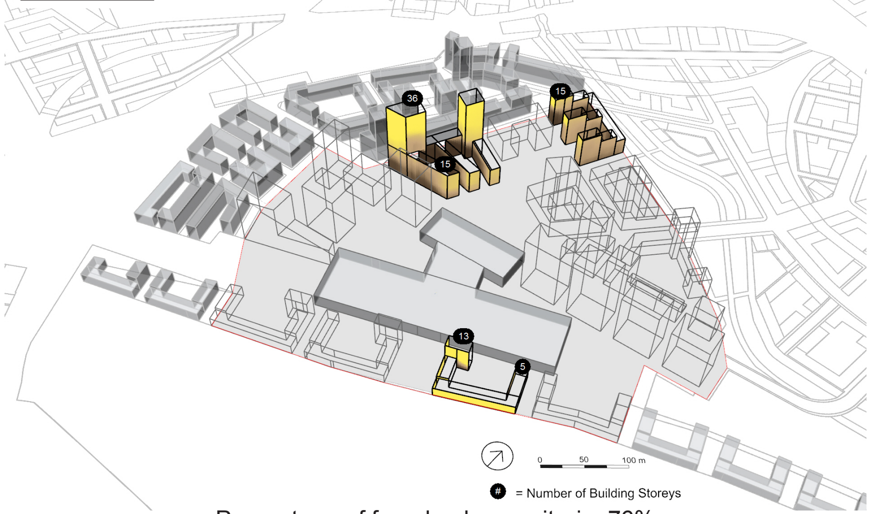
Percentage of façade above criteria: 75%

Alternative 1



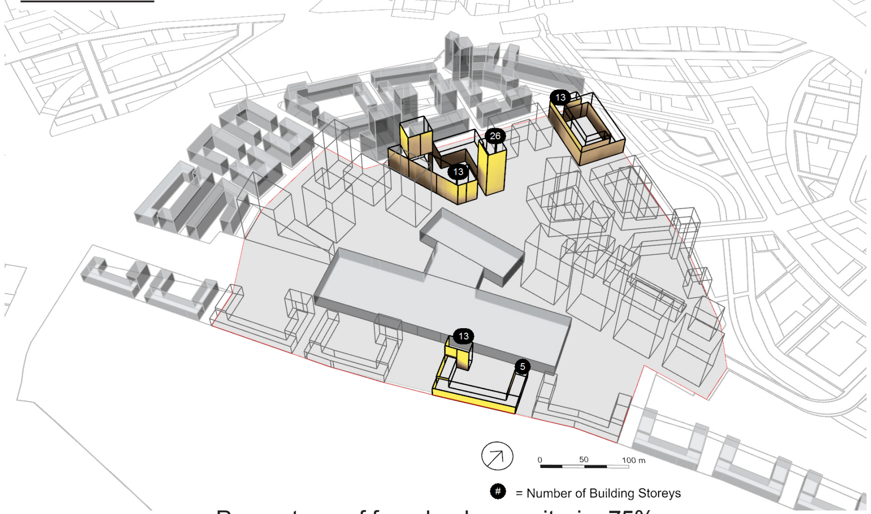
Percentage of façade above criteria: 79%

Alternative 2



Percentage of façade above criteria: 76%

Alternative 3



Percentage of façade above criteria: 75%

Outdoor Sunlight

Base case

Percentage of area above criteria =60%

Alternative 1

Percentage of area above criteria =63%

Sunlight Hours on 21st March

🟨 6.00<=
▨ 4.00
▨ 2.00
■ < 0.0

BRE 209 minimum criteria

Alternative 2

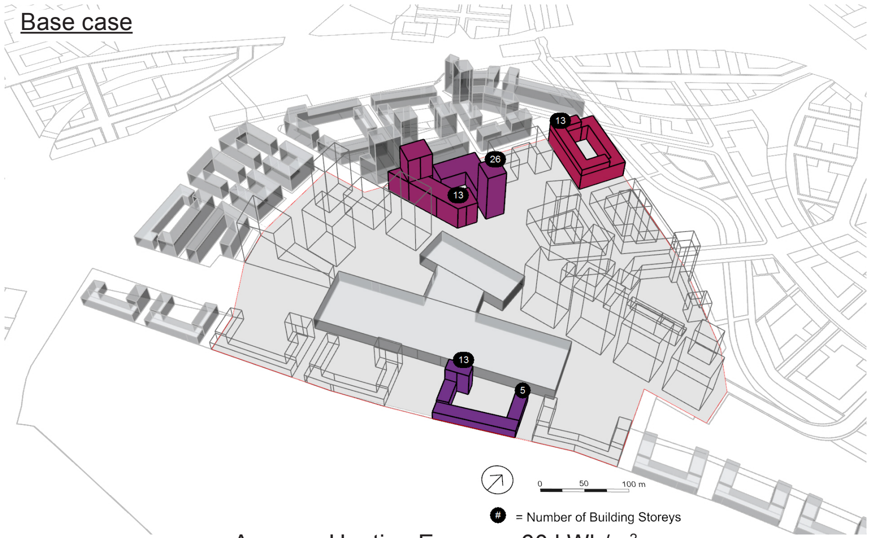
Percentage of area above criteria =63%

Alternative 3

Percentage of area above criteria =60%

Space Heating Energy Use

Base case



Average Heating Energy = 60 kWh/m^2

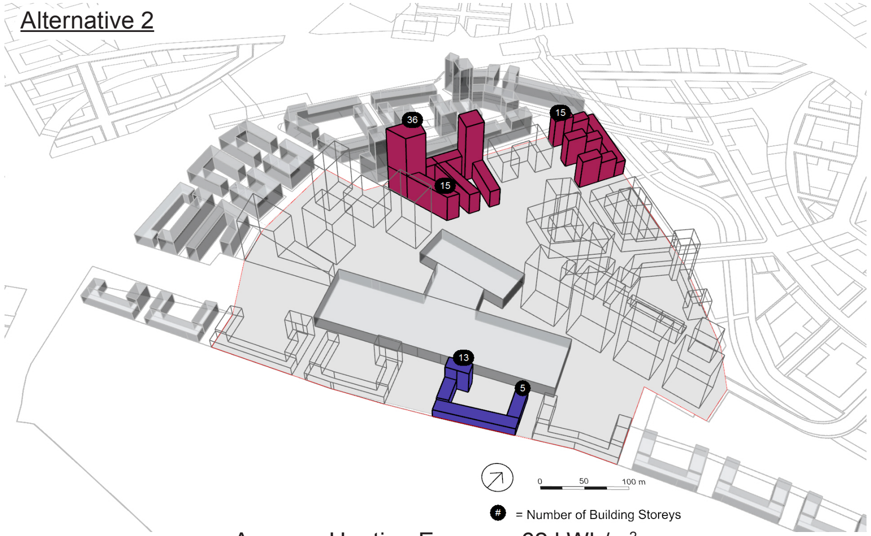
Alternative 1

Average Heating Energy = 58 kWh/m^2

Annual Space Heating Energy Use (kWh/m^2)

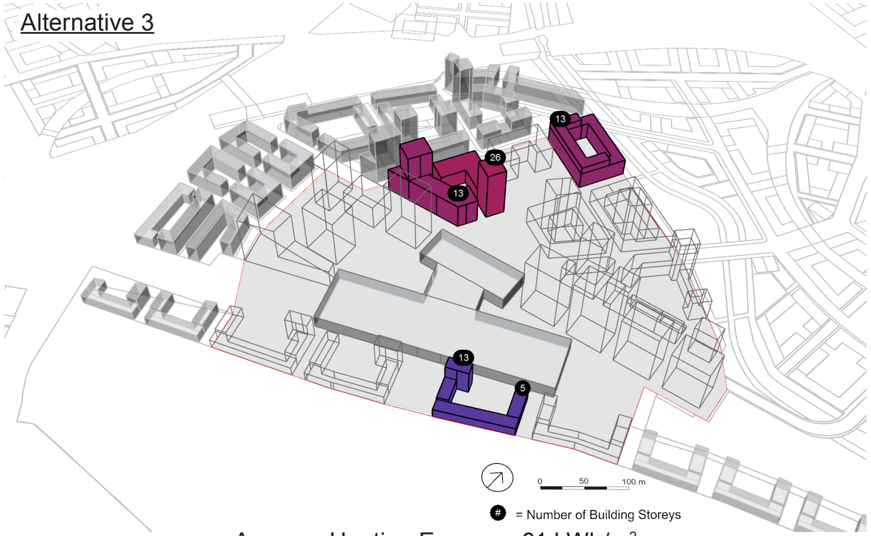
- 🟥 70<=
- 🟥 66
- 🟪 62
- 🟪 58
- 🟦 54
- 🟦 <=50

Alternative 2



Average Heating Energy = 62 kWh/m^2

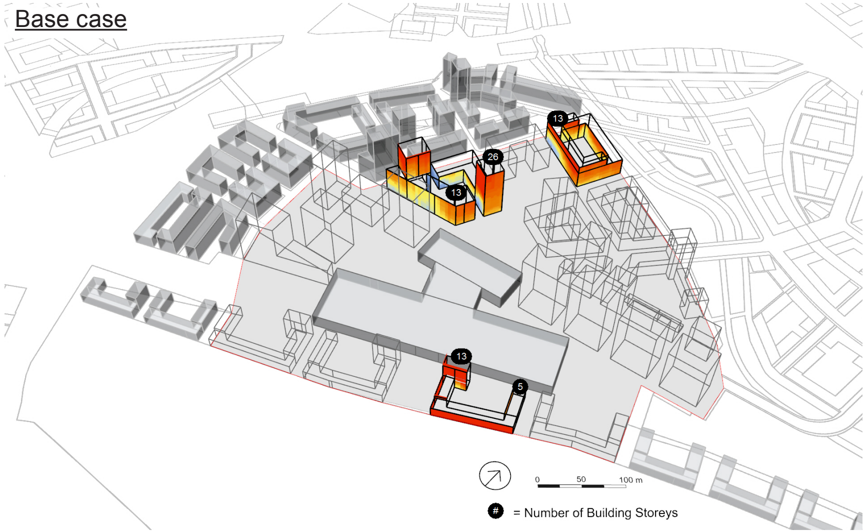
Alternative 3



Average Heating Energy = 61 kWh/m^2

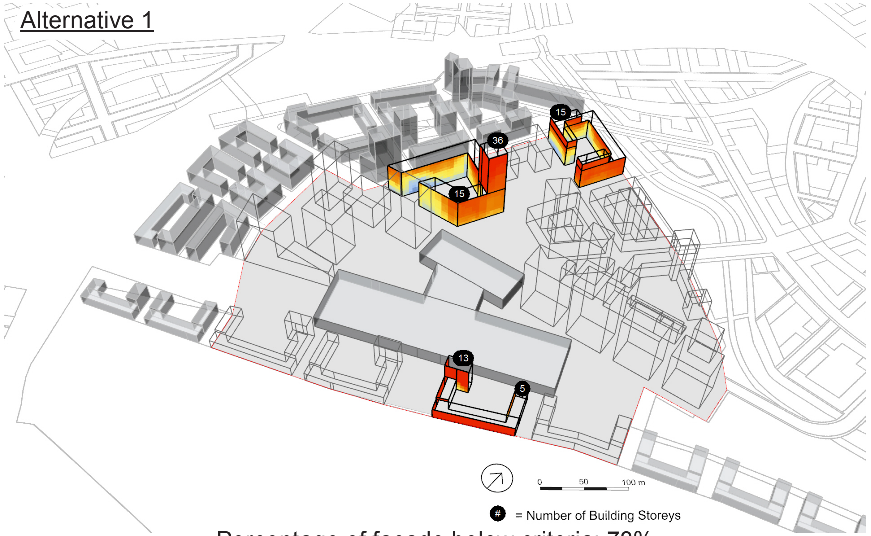
Summer Solar Irradiation

Base case



Percentage of façade below criteria: 78%

Alternative 1

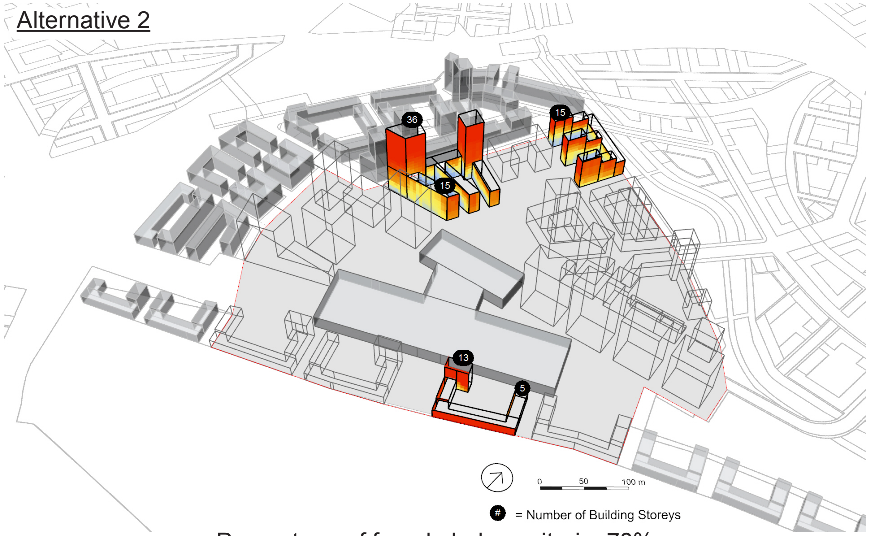


Percentage of façade below criteria: 78%

Summer Façade Irradiance (kWh/m^2)

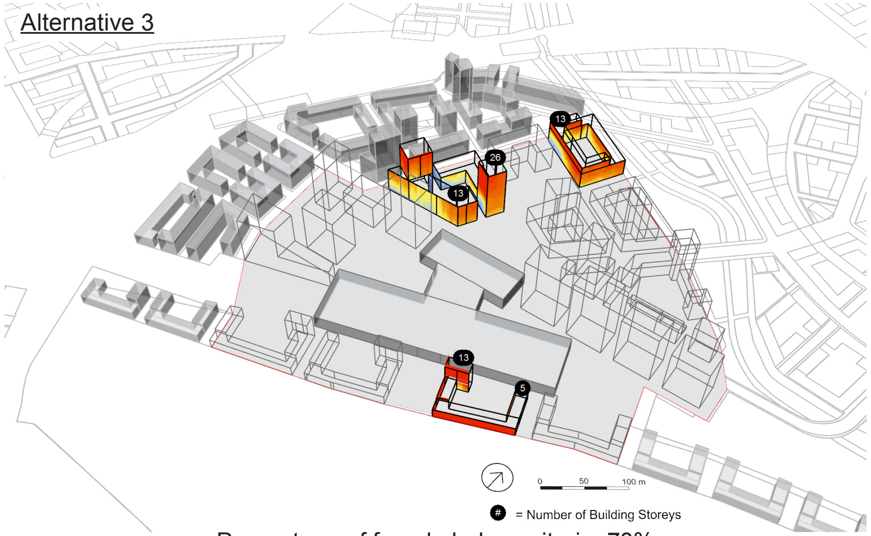
🟥 385<= — Part L compliance maximum
🟧 289
🟨 193
🟦 96
🟦 <=0

Alternative 2



Percentage of façade below criteria: 78%

Alternative 3



Percentage of façade below criteria: 78%

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