MAYOR OF LONDON

CREATING BENCHMARKS FOR COOLING DEMAND IN NEW RESIDENTIAL DEVELOPMENTS

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AECOM

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Glossary

Ach – air changes per hour: measure of ventilation rate

Albedo – ratio (0 to 1) quantifying the ability of a surface to reflect solar radiation. A high albedo means high reflectivity

CHP – Combined Heat and Power

Cooling demand – cooling energy (kWh) needed to reduce internal temperatures to an acceptable level. This is different from the units of electricity required to meet the cooling demand, as this will be dependent on the type and efficiency of plant used

DER – Dwelling Emission Rate (kgCO_2/m^2/year), i.e. parameter used to demonstrate compliance against criterion 1 of Part L1A to assess the carbon emissions of the dwelling against a target (TER)

DFEE – Dwelling Fabric Energy Efficiency (kWh/m^2/year), i.e. parameter used to demonstrate compliance against criterion 1 of Part L1A to assess the efficiency of the dwelling fabric against a target (TFEE)

EER - Energy Efficiency Ratio of a particular cooling device is the ratio of output cooling energy to input electrical energy at a given operating point

GLA – Greater London Authority

g-value – ratio (0 to 1) quantifying the ability of glass to allow solar heat through it. It is calculated as total solar heat gain over incident solar radiation. A low g value means that little heat gain goes through the glass.

IES – IES Virtual Environment is a dynamic thermal modelling software used to predict the energy demands for buildings

MVHR – Mechanical Ventilation with Heat Recovery

Overheating – According to the Zero Carbon Hub: ‘The phenomenon of a person experiencing excessive or prolonged high temperatures within their home, resulting from internal and/or external heat gains, and which leads to adverse effects on their comfort, health or productivity.’

SAP – Standard Assessment Procedure i.e. national calculation methodology for Part L compliance in dwellings

TFEE – Target Fabric Energy Efficiency (kWh/m^2/year), i.e. parameter used under criterion 1 of Part L1A to define the fabric energy efficiency target to be met by the design

TER – Target Emission Rate (kgCO_2/m^2/year), i.e. parameter used under criterion 1 of Part L1A to define the carbon emissions target to be met by the design

ZCH – Zero Carbon Hub

1.0 Introduction

1.1 Purpose of this report

This report describes the outcomes of the study carried out by AECOM for the Greater London Authority (GLA) aimed at developing good practice cooling energy demand set of benchmarks for typical apartment dwelling types currently being developed in London. The good practice benchmarks are based on the dwelling designs including reasonable design measures to reduce the need of active cooling and the risk of overheating in compliance with the cooling hierarchy identified in London Plan Policy 5.9[1].

The report is structured as follows:

Section 1.2 sets the context for the study, providing an overview of overheating as an issue and how cooling demands relate to it. The section also includes 3 case studies of recent residential projects in London and their issues / approaches to overheating risk.

Section 2.0 describes the methodology followed to produce the benchmarks and the modelling assumptions used.

Section 3.0 describes the outcome of the initial scoping study based on SAP

Section 4.0 describes the design measures included in the modelling to produce the good practice benchmarks and additional measures that could potentially be adopted to exceed the good practice level.

Section 5.0 presents the modelling outputs and proposed benchmarks.

Section 6.0 provides conclusions from the work and recommendations on the use of the findings

1.2 Purpose of this work

Overheating in homes is being increasingly recognised by the building industry as a significant and growing problem.

For the purposes of this report the Zero Carbon Hub definition of overheating in homes has been adopted, which defines it as ‘The phenomenon of a person experiencing excessive or prolonged high temperatures within their home, resulting from internal and/or external heat gains, and which leads to adverse effects on their comfort, health or productivity.’[2]

By its nature overheating is a very subjective issue, as the extent to which a person experiences overheating is affected by physical elements, such as temperature, humidity and air movement, but also by the individual’s characteristics such as clothing, metabolic rate, susceptibility to heat and ability or willingness to adjust.

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[1] https://www.london.gov.uk/sites/default/files/London%20Plan%20March%202015%20%28FALP%29%20-%20Ch5%20London%27s%20Response%20to%20Climate%20Change.pdf

[2] http://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-OverheatingInHomes-DriversOfChange.pdf

The main reasons why overheating in homes is becoming more important were identified in the ZCH's Overheating Evidence Review[3] as:

- Increasing average temperatures and hotter summers – due to climate change.
- Demographic changes – growing and ageing population.
- Urbanisation – increasing housing densities.
- Construction practices – improving energy efficiency to meet higher standards and air tightness for winter; increasing glazing proportions.

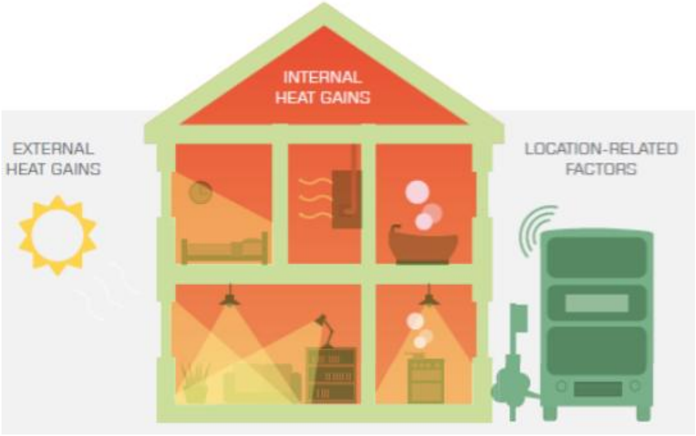

Figure 1: Drivers for overheating in homes (ref: Zero Carbon Hub)

These drivers for overheating are amplified in London where increasing air temperatures are exacerbated by the urban heat island effect and higher development densities, and unfavourable external conditions (noise and air quality) which result in dwellings being harder to ventilate.

The complex and subjective nature of overheating means that it is difficult to define for the purposes of building design and it cannot be addressed by design alone. A large body of research is currently underway by ZCH, GLA, BRE and others to better understand and define the issue. The intention is to provide building designers, operators and occupiers with better guidance (and possibly better regulations) on how to reduce the risk of overheating in homes during design and operation.

Policy 5.9 of the London Plan on Overheating and Cooling requires design teams to follow a cooling hierarchy in developing their designs to reduce both the risk of overheating and the energy demand associated with active cooling in new developments. While this policy can be referred to in pre-application discussions, compliance is currently assessed in a qualitative way, by a high level review of Design and Access Statements and requests for descriptions of what design measures have been implemented. It was therefore considered that cooling demand outputs from building energy modelling could be used as a proxy to understand in a more quantitative way the extent to which design teams are addressing the cooling hierarchy and are succeeding in reducing overheating risk.

The original aim of this study was to develop a set of good practice cooling benchmarks for apartment dwelling types that reflect reasonable endeavours to

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[3] http://www.zerocarbonhub.org/current-projects/tackling-overheating-buildings

address the cooling hierarchy and that could be used as a useful reference point in assessing planning applications. Through the analysis carried out to develop the benchmarks it has also been possible to identify the relative contributions of different design measures and limitations in tools available to designers in addressing this issue.

It should be noted that while this study was carried out on new build apartment dwellings, many of the design considerations mentioned in the report are transferable to other building types and could also potentially be applied retrospectively to existing buildings. Overheating in existing dwellings is likely to become an increasing issue as more homes are retrofitted to reduce heating demands in winter, without due consideration for the impacts on internal conditions in summer.

It should also be noted that this study focuses on the summer months only, as this is considered to be the cooling season and the focus of the work was on passive design measures aimed at reducing cooling loads. However it is worth noting that overheating has been found to occur even during winter months due to issues such as communal heating system heat losses and poor ventilation in communal areas. These issues are excluded from the scope of this study.

1.2.1 Overheating vs. cooling demand

In order to help designers address the drivers of overheating that relate to building characteristics the Chartered Institute for Services Engineers (CIBSE) has published a set of assessment criteria to quantify the risk of overheating.

An initial set of assessment criteria was published in CIBSE Guide A in 2006. This document stated that a dwelling would be considered to overheat if for more than 1% of occupied hours the living rooms and kitchens exceeded a temperature of 28ºC or the bedrooms exceeded a temperature of 26ºC.

Following application of this definition for a number of years it was acknowledged that it was not flexible enough in a number of ways. In particular it did not take into account by how much the temperature threshold was being exceeded, which in practice would have a significant impact on occupant thermal comfort. It also did not consider that people adapt to indoor environments depending on the external weather (e.g. people are more accepting of being in a warmer building on a warmer day). To address these issues, in 2013 CISBE TM52 “The limits of thermal comfort: avoiding overheating in European buildings” was published, which includes a revised set of criteria to assess building overheating risk. Under the new guidance a room or building is classed as overheating if it fails 2 of the following 3 criteria:

Criterion 1 – Hours of exceedance (He)

The numbers of hours during which the delta T (i.e. difference between operative temperature and threshold comfort temperature) is greater than or equal to one degree during the period May to September inclusive shall not be more than 3% of occupied hours [this is similar to the Guide A (2006) criterion but acknowledges that the comfort threshold temperature varies in relation to the external temperature and cannot be fixed at 26ºC or 28ºC]

Criterion 2 – Daily weighted exceedance (We)

To allow for the severity of overheating the weighted exceedance shall be less than or equal to 6 in any one day [This criterion basically accounts for the fact that there is a difference in terms of comfort if the threshold comfort temp is exceeded by 1 degree or by 10. It is based on Annex F Method B, Degree hours criteria in BS EN 15251 (BSI, 2007). It is the time (hours and part hours) during which the operative temperature exceeds the specified range during the occupied hours. The value of 6 is an initial assessment of what constitutes an acceptable limit of overheating on any single day. This initial assessment was made from observations of the temperature profiles from case studies of a range of free running buildings that are perceived to perform well at one end of the range and poorly at the other in regards to limiting overheating[4]]

Criterion 3 –Upper limit temperature (Tupp)

To set an absolute maximum value for the indoor operative temperature the value of delta T (i.e. difference between operative temperature and threshold comfort temperature) shall not exceed 4 degrees [this is to acknowledge that when temperatures are significantly higher than the comfort threshold normal adaptive measures are not sufficient to bring the situation back to acceptable levels and so there might be serious impacts e.g. health, productivity]

In order to apply these assessment criteria, the building needs to be modelled using dynamic thermal modelling software such as IES or TAS. This software allows for the use of half hourly weather tapes which can be changed as required. Therefore the assessment can take into account of local climate conditions, climate change projections and urban heat island considerations[5]. However this level of detailed thermal modelling is not currently standard practice for domestic developments, which tend to rely on the steady state Standard Assessment Procedure (SAP) to estimate energy demands, carbon emissions and inform design for homes.

SAP includes in Appendix P a simplified test to identify if a dwelling is at risk of high internal temperatures in summer. The calculation takes into consideration heat gains and fabric characteristics of the building to calculate monthly mean summer internal air temperatures that are then compared to a threshold monthly mean temperature. The level of risk associated with that temperature is as follows.

Temperature threshold	Risk definition
Less than 20.5ºC	“Not significant”
Between 20.5ºC and 22ºC	“Slight”
Between 22ºC and 23.5ºC	“Medium”
23.5ºC or higher	“High”

Table 1: SAP Appendix P overheating thresholds

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[4] See CIBSE TM52 for further details of how the daily weighted exceedance is calculated

[5] CIBSE TM49 provides specific weather tapes for different parts of London during different decades to allow a bespoke assessment

The temperature thresholds are significantly lower than those used by CIBSE TM52 or CIBSE Guide A (2006) as SAP thresholds are based on monthly means rather than hourly levels. It is widely acknowledged that the SAP test has significant limitations as its monthly calculations do not model the variations and peaks in temperature during the course of the day which impact on peoples' perceptions of thermal comfort.

Further information on definitions and methodology for assessing overheating risk can be found in the ZCH Defining Overheating Evidence Review[6]. The ZCH suite of Evidence Review documents also includes more details about the impacts of overheating on health and wellbeing and why an aging population and increasing environmental constraints are likely to exacerbate this issue in the future[7].

Given the complexities associated with assessing overheating and the fact that the intended purpose of this study is to provide a simple quantitative frame of reference to better understand how design teams respond to the London Plan's cooling hierarchy, this study concentrates on cooling demands rather than overheating risk. The two issues are linked in the sense that poorly designed buildings that have a high risk of overheating are also expected to have high cooling demands from the use of active cooling e.g. air conditioning.

Cooling demand for the purposes of this report is defined as the cooling energy (kWh) needed to reduce internal temperatures to an acceptable level. [This is different from the units of electricity required to meet the cooling demand, as this will be dependent on the efficiency of plant used].

In SAP, it is assumed that there is a need for active cooling if the temperature exceeds 24ºC. The cooling demand is calculated assuming that active cooling will be required 6 hours per day to part or all of the dwelling to maintain a temperature of 24ºC during the months of June, July and August. These assumptions are supported by a study carried out by Pathan et al[8] which monitored 13 dwellings with air conditioning in the South East of England and found that the cooling system was generally turned on when internal air temperatures reached 24-25ºC. The study also showed that the air conditioning systems run on average for 5 hours if used in daytime and for 7 hours if used at night time. Due to the limited sample in the study it is unclear however whether residents used air conditioning both during the day and at night (therefore resulting in twice the operating hours as assumed in SAP), or either during the day or during the night (depending on the system type installed and its location in the dwelling).

The energy and carbon emissions associated with meeting this cooling demand are only displayed in the modelling outputs and accounted for in the carbon compliance calculations if an air conditioning unit is specified to meet this demand. Therefore a design could result in a high cooling demand that remains undetected and unaddressed unless the designer specifies air conditioning. This can potentially create problems for affordable housing where air conditioning is unlikely to be

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[6] http://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-OverheatingEvidenceReview-Definitions.pdf

[7] http://www.zerocarbonhub.org/sites/default/files/resources/reports/ZCH-OverheatingEvidenceReview-Impacts.pdf

[8] Pathan, Young, Oreszczyn, 2008, UK Domestic air conditioning: A study of occupant use and energy efficiency

included in the Employers Requirements and therefore high cooling demands and likely overheating risk might go undetected.

Cooling demands are accounted for in the Dwelling Fabric Energy Efficiency (DFEE) calculation to meet the Target Fabric Energy Efficiency (TFEE). However, the contribution of cooling demands relative to the heating element is quite small so it is unlikely that cooling demands are considered very important to achieve compliance. As with the SAP overheating test, the fact that the cooling demand is calculated with monthly average external temperatures is likely to underestimate the real cooling demand that would be associated with severe events.

The SAP overheating test is completely separate from the cooling demand calculation. Design measures can potentially affect the cooling demand but not the outcome of overheating assessment and vice-versa. For example a naturally ventilated flat with a glazing g value of 0.6 might have quite high cooling demands but no risk of overheating. The same flat with a reduced g value of 0.3 (i.e. with reduced solar gains) but limited cross ventilation results in lower cooling demands (as these are affected by the g value) but a high risk of overheating (as this is affected by the reduced ventilation).

Cooling demand in homes is an issue of growing concern in its own right (separate to overheating). It could represent a new building energy demand that did not previously exist in the UK and that could potentially have a significant negative impact on carbon emissions abatement efforts.

A study carried out by Day et al[9] in 2009 identified that the London residential sector could be responsible for an extra 100,000 tonnes CO_2 per year by 2030 as a result of active cooling. This forecast could well be exceeded if the current trend for high density and highly glazed luxury developments is set to continue and if climate change and the urban heat island exacerbate external conditions.

The Day study concluded that where possible, mechanical cooling solutions should be avoided or reduced, but that the uncertainty in how climate change will manifest itself may mean that it is better to design in high efficiency cooling solutions now, rather than risk individual (low efficiency) units being installed ad-hoc in response to warming conditions. This is a particular issue in the residential market where ad-hoc retrofit with portable air conditioning units is a higher risk. This view is supported by the findings of the Pathan study, which identified a massive discrepancy in the efficiency of fitted air conditioning systems (centralised or dwelling specific split units installed in new build) and portable units (as can be bought in a department store as an easy retrofit solution). EERs for the former were measured in the range of 5-10, while the latter performed far worse than advertised with an EER of less than 1.

The threat of additional carbon emissions as well as the potential health implications of overheating in homes highlight the need to better understand how to design buildings to help reduce the risk of overheating. This report intends to help GLA assess developer response to the cooling hierarchy and take a more informed view about the extent to which passive measures can address the issue, and also if and when active cooling may be a necessary element of the cooling strategy.

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[9] Day, Jones, Maidment, 2009, Forecasting future cooling demand in London

1.2.2 Case studies

Given below are two case studies of recent developments built in London that were monitored following occupation and were identified to have overheating issues.

Both developments were built at a time when the focus was on meeting stringent efficiency and carbon reduction targets, but when the implications of this on summer conditions were not given too much consideration. Therefore both schemes did not integrate specific design measures to reduce the risk of overheating beyond those included in the design for also other purposes e.g. balconies providing amenity space but also shading to windows below.

The overheating issues found were partly due to operational problems but also to design issues that could have been avoided if considered at early design stages. Interestingly it was also found that even when temperatures did not exceed the set points identified in industry guidance, surveyed occupants often reported that conditions were uncomfortable, highlighting the difficulty in quantifying overheating due to its inherent subjective nature.

Name: Norfolk House, Seager Distillery **-** Post Occupancy Evaluation Study

Location: Deptford, London Borough of Lewisham
Year built: 2011

Site description
Block of 58 flats constructed as post-tensioned reinforced concrete frame. There is a Metsec stick support system with insulation panels and a rainscreen cladding finish for the external envelope, and internal walls of the apartments are dry wall construction. The apartments have a high percentage glazing. The site has a communal Combined Heat and Power (CHP) heating and hot water system, and the flats are equipped with MVHR (mechanical ventilation heat recovery) systems.

Post-occupancy evaluation
Post-occupancy evaluation of three flats including internal temperature monitoring by Lim, Ross and Harper (2015)[10] found that overheating was a significant problem on the site. The three flats monitored (small single aspect, medium dual aspect, medium duplex single aspect) exhibited summer air temperatures in excess of 28°C (i.e. the CIBSE Guide A (2006) overheating threshold temperature).

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[10] Lim, M.C.N., Ross, D. and Harper, S. 2015. Building performance evaluation of dwellings – A case study of the Seager Distillery development. *CIBSE Technical Symposium*, London, UK 16 – 17 April 2015.

Air flow rates of the MVHR units in the flats were also measured on the supply and extract terminal. All were below the values reported in the commissioning certificates, and at normal mode operation the flow rates did not appear to achieve the recommended ventilation rates in Part F 2006 of the Building Regulations for two of the flats. The poor performance on the MVHR units was mostly due to dirty filters and long ductwork runs, and was identified as one of the contributing factors to the dwellings overheating.

Other contributing factors to high summer temperatures in the apartments were identified as:

- Significant distribution losses from the communal heating system
- Lack of external shading built into the design of the facade
- High glazing percentage (flats with double height glazing in living areas leading onto balconies)
- Occupant reluctance to open windows due to noisy exterior.

The distribution losses from the communal heating system also resulted in overheating of the access corridors and cores. While temperatures in the corridors was not monitored as part of the project, overheating in a 26-storey residential tower on the same site was such a serious issue that it had to be remediated by the retrofit of an automatic opening vent system in the smoke shaft.

Name: Bridport House – Post Occupancy Evaluation Study

Location: Colville Estate, London Borough of Hackney
Year built: 2011

Description
41 flats over two timber framed apartment blocks: one eight storeys, one five storeys. Cross-laminated timber was used to make the building as light as possible due to weight restrictions caused by the location of the site over a storm sewer. All of the flats are dual aspect, and façade design includes large areas of glazing, particularly in corner flats.

(Ref http://www.bdonline.co.uk/bridport-house-east-london-by-karakusevic-carson-architects/5036283.article)

Post-occupancy evaluation

Post-occupancy evaluation was carried out by Adekunle and Nikolopoulou in 2014[11]. Summer temperature data were collected for seven flats between 29th June and 12th July 2014, and occupants completed questionnaires on their thermal comfort three times a day during the same period. The results are presented below:

Average thermal sensation (1 = cold, 7 = hot)	5.88
Average thermal comfort (1 = very uncomfortable, 7 = very comfortable)	2.85
Average internal temperature 08.00 – 22.00 (living areas)	22°C
Maximum measured internal temperature (living areas)	25.4°C
Proportion of time 25°C exceeded	1%
Proportion of time 28°C exceeded	0%

Despite the flats not exceeding the CIBSE (2006)[12] maximum air temperature of 25°C for 5% and 28°C for 1% of occupied hours, the low thermal comfort scores suggest that the building is overheating according to the CIBSE (2010)[13] definition: “overheating within a dwelling occurs when the actual indoor temperature for any given day is hot enough to make the majority of people feel uncomfortable”. Similar findings for other timber frame dwellings in the same study led the authors to

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[11] Adekunle, T. and Nikolopoulou, M., 2014. Post-occupancy and indoor monitoring surveys to investigate the potential of summertime overheating in UK prefabricated timber houses. Proceedings of 8th Windsor Conference: *Counting the Cost of Comfort in a changing world,* Cumberland Lodge, Windsor, UK, 10 – 13 April 2014.

[12] CIBSE, 2006. Guide A, Environmental Design, 7th ed. CIBSE, London, UK.

[13] CIBSE, 2010. How to manage overheating in buildings: a practical guide to improving summertime comfort in buildings. *CIBSE Knowledge Series*, CIBSE, London, UK.

conclude that their low thermal mass was a significant contributing factor to overheating risk.

Since Norfolk House and Bridport House were built, the building industry has become aware of the implications that progressive improvements in energy efficiency to address heating demands in winter can have on internal conditions in summer. This has coincided with growing concerns around the impact that climate change will have on our buildings and how we can design buildings today that are resilient or adaptable to future changes in external conditions.

In a bid to tackle this issue the Government has recently funded through the Technology Strategy Board (now InnovateUK) a programme of research projects challenging the industry to develop methodologies to develop climate change adaptation strategies for buildings being designed today. The Design for Future Climate Programme run between 2010 and 2014 and funded 45 projects for domestic and non-domestic buildings. Many of these projects identified overheating as a major risk associated with climate change and the design teams developed methodologies to assess this risk and considered design approaches to ensure buildings are future proofed. The final reports from the 45 projects are published and provide a useful reference library for design teams dealing with this issue for the first time[14]. A book summarising the main learning from the programme has also been published.

Given below is a case study of a project carried out by AECOM as part of the Design for Future Climate Programme, which included an overheating assessment and resulted in a set of recommendations of design measures for inclusion in the design. This case study demonstrates that overheating needs to be considered as early as outline masterplan stage so that green infrastructure, materials palette and other issues outside of the building envelope are considered and as far as possible integrated in the development design to become part of the solution.

Name: Acton Gardens Masterplan - Climate Change Adaptation Strategy

Location: South Acton, London Borough of Ealing
Year built: 2014 (masterplan developed 2013)

Site description

The site comprises the existing South Acton estate, which is being upgraded and increased in density. The masterplan developed for phases 3 – 11 included the provision of approximately 2,600 homes and some associated community uses. The tenure will be a mixture of private ownership, private rentals, social rentals, sheltered housing and housing for over-55s.

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[14] https://connect.innovateuk.org/web/design-for-future-climate

(ref: HTA Architects)

Modelling approach

A risk assessment was carried out for the site with respect to exposure to current and future climate risks. The assessment identified overheating as one of the main risks due to the location of the site in a densely populated area and within the London urban heat island. The project then focussed on quantifying the overheating risk in current and likely future climate conditions and identifying design measures that could mitigate this risk.

Probabilistic projections of climate scenarios derived from UK CP09 were used in the form of weather tapes containing hourly data from the Prometheus project at Exeter University. The climate scenarios used were the 50th percentile for the high emissions scenario for the 2050s (average of 2040 – 2069) and the 2080s (average of 2070 – 2099). The predicted effects of different green infrastructure strategies were quantified using ENVI-met thermodynamic modelling software, and building scale measures were modelled using IES.

Proposed design features

The results of the modelling were discussed with the design team and developer to determine which solutions could be integrated effectively into the design to address future overheating. The following measures and timescales were suggested as the most cost effective solutions which decreased the predicted overheating factor to below 1% in the 2050s and 2080s:

Masterplan:

- Select deciduous trees with reasonably large canopies along east-west streets to increase shading benefit on south facing windows in summer (at time of build, maintain through 2050s and 2080s).
- Select facade and hard landscaping materials with a palette of light and reflective colours to increase surface albedo (at time of build, maintain through 2050s and 2080s).
- Integrate green roofs wherever possible, prioritising lower level roofs (at time of build, maintain through 2050s and 2080s).

Buildings:

- Ensure that flats have windows with a significant proportion (66%) of their area that is openable (by 2050s).
- Integrate thermal mass in the living rooms and kitchens of all the dwellings (by

2050s).

- Fit shading to the windows: tree shading could be used for the lower floors and shutters or similar would be needed to ground floors to allow secure ventilation. Other forms of shading such as overhangs, external blinds, venetian or roller blinds could be used to the upper floors (by 2050s).
- Upper floor flats could be fitted with venetian blinds by 2050s (cheaper than shutters), but shutters would likely be required to avoid overheating by the 2080s.

2.0 Methodology

2.1 Overall approach

The original intention was to produce cooling energy demand benchmarks that can be reconciled with outputs from SAP version 2012, given that this is the calculation methodology used as the basis for demonstrating compliance of domestic buildings with Part L of the Building Regulations and with London Plan policy 5.2.

It was however acknowledged that SAP is a steady state compliance tool rather than a design tool. Hence, dynamic thermal modelling (IES) is also used as it is better able to identify key design features that would represent good practice design. The intention was to transpose the identified design features into SAP to derive cooling demand benchmarks that can be compared to data already being produced as part of the preparation of planning applications.

After an initial scoping study (see later), it was determined that the SAP calculation methodology is inadequate to sufficiently represent the impact of design measures on the building’s cooling demand. The benchmarks were therefore produced in IES version 2014.2.1.0 (Virtual Environment 2014 Feature Pack 2 (Hotfix 1)).

Figure 2 below summarises the steps taken to derive the cooling demand benchmarks.

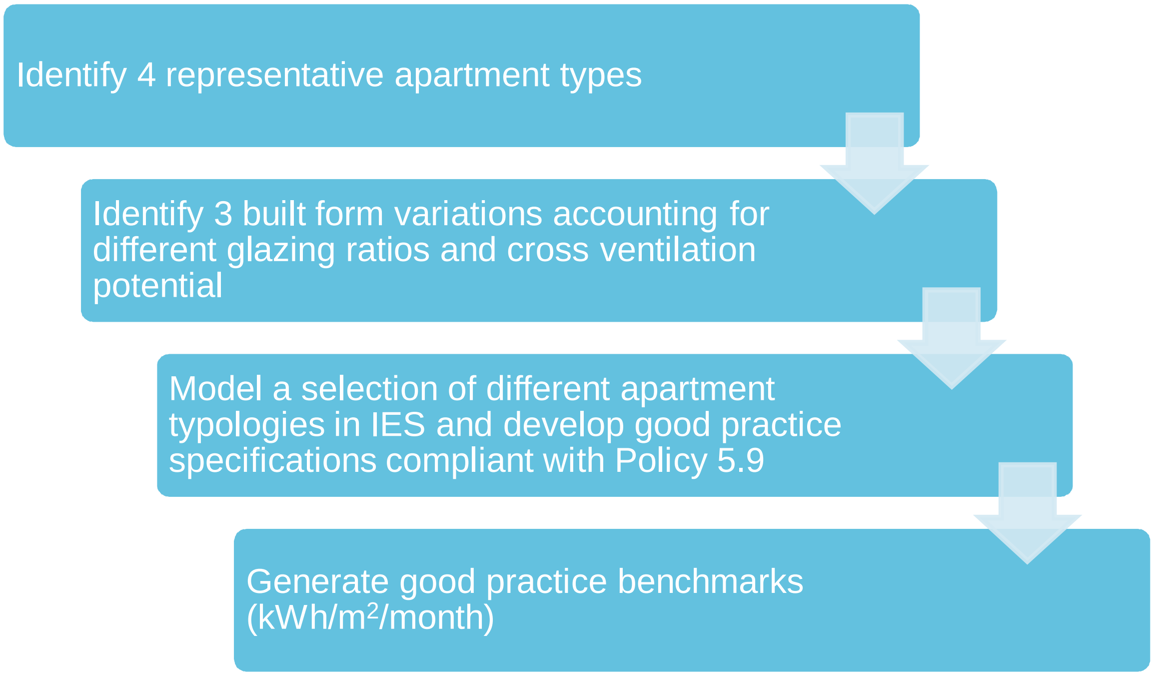

Figure 2: Overall methodology approach

It is important to note that whilst the IES results illustrate the benefits from the different strategies and design options, and suggest good practice designs, care is needed in using the benchmark values for assessing planning applications. This is because IES is a dynamic thermal modelling software which is based on a bespoke calculation methodology so the outputs will be different from other software packages (e.g. TAS). While the applied building physics is similar between different software packages, the details of the calculation methodology differ somewhat and thus the absolute outputs (i.e. kWh of demand) will be different. So care should be taken in using outputs from a single software package as benchmarks that may be viewed and used by users of other software packages.

2.2 Dwelling design selection

Four dwelling types representative of most common typologies being built in London were identified by AECOM and agreed with the GLA. They were selected from projects that AECOM has been working on in recent years to ensure that they reflect realty. Typologies of different size, construction and location within the building were selected to be representative for different types of development coming forward in London at present.

The four dwelling types are summarised in Table 2. Illustrations of the dwelling types are provided in Appendix A.

Type	1	2	3	4
	Curtain walled flat	Traditional build flat	Penthouse	Traditional build duplex
Size	2 bedroom	1 bedroom	3 bedroom	4 bedrooms
Floor area (m^2)	99	58	219	146
Location in building	Mid floor, double aspect	Mid floor, double aspect but with no cross ventilation	Top floor, triple aspect	Ground and First floor, double aspect
Floor to ceiling height (m)	2.7m	2.5m	2.6m	2.6m
Orientation of majority of living room windows	East	South West	North	South East

Table 2: Dwelling types modelled

The following variations of the four dwelling types were also modelled to account for the variations that may occur across a typical development:

- Amended aspect – type 1 and 4 (both double aspect with cross ventilation) were amended to produce single aspect variations, type 2 (double aspect but with no cross ventilation) was amended to increase the window size and allow some cross ventilation, type 3 was amended from triple to double aspect.

- Orientation - each unit type was modelled in its original orientation and then in other 3 orientations (i.e. 90deg from original, 180deg, 270 deg)
- External conditions - Worst case: External conditions that don’t allow windows to be opened for long periods of time (due to air quality, noise or security) and no shading from surrounding buildings; Best case: External conditions allow windows to be opened and some shading is provided by surrounding building / vegetation

  The shading provided by surrounding buildings was assumed to be equivalent to a building located across the road from the living room of the unit and extending to at least 2 storeys above the level of the modelled dwelling. While this is considered to be a reasonable assumption for many developments in central London, it is likely to be optimistic (in terms of free shading benefit) for developments in the outer boroughs.

A further physical dwelling variation was modelled to assess the benefits from reducing solar gains by limiting the extent of glazed areas (i.e. step 2 in the cooling hierarchy):

- The dwellings as designed have average glazing proportions ranging from 27% to 48% which, in most cases, significantly exceed the Housing SPG good practice requirement for 20% of internal floor area to be glazing to allow good levels of daylighting. A reduced glazing option has been modelled assuming a glazed proportion of 25% of internal room floor area.

This gave a total of 96 combinations of dwelling typologies that are considered to be a reasonable representation of apartments being delivered in London at present. Houses have been excluded from the scope of this study as they are a less common dwelling typology in London and are also considered less prone to both experiencing overheating and requiring active cooling.

2.2.1 Typology identifier description

For ease of reference, each dwelling typology has been given a short identifier code. The full list of identifiers and what typology they refer to is given in Appendix B. Given below is a brief description of how the identifiers were developed.

Number 1 to 4	DA / SA / (D)A / TA	LG	N / S / E / W / NW /NE /SE /SW	pec / gec
Identifies the dwelling type, i.e. 1 – curtain walled flat 2 – masonry flat 3 – penthouse 4 - duplex	Identifies the aspect, i.e. DA – double aspect SA – single aspect (D)A – double aspect but no cross vent i.e. window on one facade not openable TA – triple aspect	Identifies units with a reduced glazing proportion	Identifies the orientation of the majority of the living room windows	Identifies the assumptions made on external conditions, i.e. pec – poor external conditions gec – good external conditions

Figure 3: Typology identifier system

So for example, unit “1 DA LG E pec” will be the curtain walled flat with dual aspect, reduced glazing ratio, with the living room facing mostly east and under the poor external conditions assumptions (i.e. (i.e. issues of air quality, noise or security not allowing windows to be opened and no free shading from surrounding buildings).

2.3 Baseline modelling assumptions

2.3.1 Fabric assumptions

The starting fabric and service specification for all the dwellings was that detailed in Appendix R of SAP2012[15], which includes the reference values used to calculate the Target Fabric Energy Efficiency (TFEE) and the Target Emission Rate (TER) for Part L 2013 compliance. This specification was modified to include a MVHR system with an air permeability of 3 m^3/m^2h @50Pa as the adoption of MVHR appears to be standard practice for high density developments in London.

This is considered to be a reasonable baseline that should allow dwellings to meet the requirements to meet Part L 2013 by efficiency alone in line with the first step of the energy hierarchy identified in London Plan Policy 5.2.

The key specifications are shown in the table below.

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[15] http://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf

Building element	Specification
Roof and floor U values	0.13 W/m²K
Wall U-value	0.18 W/m²K
Window U value	1.4 W/m²K
Window g value	0.63
Air tightness	3 m³/m²h @50Pa
Ventilation system	MVHR
Heating	Gas boiler 89.5%
Lighting	100% low energy
Air conditioning	None

Table 3: Summary of baseline assumptions

The DER and TER outputs for the baseline models are as follows. The dwellings perform significantly better than the TER baseline (i.e. DER < TER) so represent a reasonable worse case in terms of tackling cooling demands.

It is noted that the baseline specifications are mainly aimed at reducing heat loads so the glazing g value is quite high (compared to what might be common on residential developments in London), which is good for winter performance but not necessarily for summer. The glazing U value is also very good and, for curtain walling in particular, better than standard practice. All unit typologies except the masonry flat have very good thermal bridging with Y values of 0.04 to 0.09 compared to the default of 0.15. The assumption of MVHR and low air permeability results in considerable savings compared to the TER, as the reference specifications used for setting the TER are based on natural ventilation.

	DER ($kgCO_2/m^2$/year)	TER ($kgCO_2/m^2$/year)	Improvement on Part L 2013
1 – curtain walled flat	12.61	15.37	18%
2 – masonry flat	18.67	21.42	12%
3 – penthouse	12.61	14.03	10%
4 – masonry duplex	13.38	15.80	15%

Table 4: Part L 2013 outputs for baseline assumptions

2.3.2 Internal gains

The SAP standard assumptions that affect internal heat gains (e.g. occupancy levels, occupied hours) have been used when carrying out the modelling in IES. As SAP assumptions were devised for the purpose of a compliance tool rather than a design tool, it is widely accepted that they do not necessarily closely reflect reality of how London apartments may be occupied today. To quantify the impact of internal gains and how they affect cooling demands, a sensitivity test has been carried out amending the internal gains in IES to more realistic assumptions. Details on the outcome of this test are provided in section 5.2.1.

2.4 SAP scoping study

Before commencing the benchmarking exercise, an initial scoping study was run using SAP to determine whether:

- The SAP methodology is flexible enough to allow the design approaches applied in IES to be transposed in SAP in an effective way.
- The cooling demands calculated in SAP actually change sufficiently between different dwelling typologies and design approaches to make SAP useful to set benchmark values;

This analysis was also used to assess the significance of the cooling demands in the context of other energy demands within dwellings.

In order to carry out the assessment, 2 dwelling typologies were selected that were considered in principle to be extremes in terms of expected cooling demands. Both units were modelled under good and under poor external conditions to acknowledge the impact that openable windows could have on the strategy. The typologies used for the study are given in Table 5.

Typology identifier	Unit type	Aspect	Glazing ratio	Living room window orientation	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings
1 SA S pec	1 – curtain walled flat	Single aspect	43%	S	No	No
1 SA S gec	1 – curtain walled flat	Single aspect	43%	S	Yes	Yes
4 DA NW pec	4 - duplex	Dual aspect (as designed)	29%	NW	No	No
4 DA NW gec	4 - duplex	Dual aspect (as designed)	29%	NW	Yes	Yes

Table 5: Unit typologies used for initial SAP scoping study

To consider the extremes in terms of likely variation in cooling demand the following was modelled:

(i) The units with good external conditions were assumed to include the following design measures:

- Low energy lighting,
- Shutters or external blinds to all windows (no internal shading),
- g-value of 0.63,
- Natural cross ventilation,
- MVHR as per baseline assumptions

(ii) The units with bad external conditions were assumed to have no additional measures beyond what might be considered a standard design today:

- Low energy lighting,
- Internal shading,
- g-value of 0.5,
- MVHR as per baseline assumptions

The results from the scoping study can be found in section 3.0.

2.5 Modelling methodology

2.5.1 Main design options

In determining good practice cooling demand benchmarks it is important to ensure that they are not dependent on a single strategy. Hence, three potential strategies that are considered to be broadly in compliance with the cooling hierarchy have been modelled.

Strategy 1, which was considered at the outset to likely be the most effective at reducing cooling demand, has been applied to all 96 typologies. Strategies 2 and 3 have been applied to a sample of 8 typologies identified as representative following review of the outputs from strategy 1.

The strategies are defined in detail in section 4.1 and Appendix B but can broadly be summarised as follows:

- Strategy 1 focuses on maximising external shading and using natural cross ventilation wherever possible;
- Strategy 2 includes reducing glazing ratios, minimising glazing g value and using natural cross ventilation wherever possible and boosting MVHR where external conditions do not allow natural ventilation;
- Strategy 3 includes reduced glazing ratios, a combination of some external shading and lower g values and assumed lower levels of natural cross ventilation.

The typologies were selected to cover the spectrum of dwelling types and external conditions variations. The orientation was selected as the one that gave the mid range result when modelling strategy 1. The characteristics of unit types selected for strategy 2 and 3 are shown in Table 6 below.

Typology identifier	Unit type	Aspect	Glazing ratio	Living room window orientation	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings
1 DA LG E pec	1 – curtain walled flat	Dual aspect (as designed)	25%	E	No	No
1 DA S LG gec	1 – curtain walled flat	Dual aspect (as designed)	25%	S	Yes	Yes
2 (D)A LG SE pec	2 – masonry flat	Dual aspect but no cross vent (as designed)	25%	SE	No	No
2 (D)A LG SW gec	2 – masonry flat	Dual aspect but no cross vent (as designed)	25%	SW	Yes	Yes
3 TA LG NE pec	3 - penthouse	Triple aspect (as designed)	50% in living room, 25% elsewhere	NE	No	No
3 TA LG NW gec	3 - penthouse	Triple aspect (as designed)	50% in living room, 25% elsewhere	NW	Yes	Yes
4 DA LG SW pec	4 - duplex	Dual aspect (as designed)	25%	SW	No	No

4 DA LG SW gec	4 - duplex	Dual aspect (as designed)	25%	SW	Yes	Yes

Table 6: Typologies used to test strategy 2 and 3

2.5.2 Step by step assessment

In order to quantify the relative contribution of different design measures within the cooling hierarchy, for 4 dwelling typologies under strategy 1, 2 and 3 the cooling demand was assessed after each individual design measure was included. The typologies used for this assessment were selected to cover one of each dwelling type and different external conditions assumptions. They are listed in Table 7.

Typology identifier	Unit type	Aspect	Glazing ratio	Living room window orientation	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings
1 DA LG E pec	1 – curtain walled flat	Dual aspect (as designed)	25%	E	No	No
2 (D)A LG SW gec	2 – masonry flat	Dual aspect but no cross vent (as designed)	25%	SW	Yes	Yes
3 TA LG NW gec	3 - penthouse	Triple aspect (as designed)	50% in living room, 25% elsewhere	NW	Yes	Yes
4 DA LG SW pec	4 - duplex	Dual aspect (as designed)	25%	SW	No	No

Table 7: Typologies used for step by step analysis

2.5.3 Sensitivity testing

Following the main modelling exercise, two sensitivity tests were carried out.

Internal gains

The first test was to determine the extent to which changes in internal gains assumptions impact on the cooling demand figures.

For this test a reasonable number of appliances was assumed to be present in the dwelling and the average internal gains across the 4 dwelling types was changed from 12.8W/m^2 to 13.6W/m^2. The details of the appliances assumed in the internal gains test are given in Appendix D.

The occupancy pattern was also changed by adding to the original assumptions a person in the living room from 8 am to 10 pm to reflect a worst case scenario of a vulnerable person being at home all day.

The test was run on the 8 typologies identified in Section 2.5.1 and with the design measures used in strategy 1. The impact of changes in internal gains assumptions is likely to be the similar irrespective of the passive design measures applied therefore it is expected that the same impact would be recorded for the models under strategy 2 and 3.

Climate change and urban heat island

The second test was to determine the extent to which climate change and the urban heat island effect may impact on the cooling demand figures. As agreed with the GLA, the modelling was carried out using weather tapes from CIBSE Guide TM49.

- For the bulk of the modelling the Design Summer Year (DSY) weather tape for the current climate for a suburban location (i.e. Heathrow weather station) was used.
- To test the likely impact on cooling demands of climate change and the urban heat island effect, the sensitivity test was carried out using the DSY weather tape for a suburban location (i.e. Heathrow) and a central London location (i.e. London Weather Centre – Holborn) under the climate projection for the 2050s assuming a medium emissions scenario.

The test was run on the 8 typologies identified in section 2.5.1 and with the design measures used in strategy 1, 2 and 3 as it may be that changes in external conditions would make some passive design strategies less effective than others.

2.5.4 Integrity of the modelling

The modelling was undertaken using the IES accredited dynamic thermal modelling software which is commonly used in the building design industry and it was carried out by experienced modellers. IES is not the only software available so the benchmark figures will not be directly comparable with outputs from different modelling software. However the trends identified in this report and the relative impacts of different design measures are expected to be similar when modelling using other dynamic thermal modelling software packages.

The dwelling typologies were selected in consultation with GLA with the aim to cover a representative range of typical dwelling types being built in London at the moment. In practice, inevitably the typologies cannot cover every possible variation of residential development in London.

Similarly the design solutions included in the exercise could not cover every possible option. They were selected as reasonable contrasting approaches based on our experience of design solutions currently being proposed in real developments and our understanding of the effectiveness of different solutions.

We believe that the range of typologies and design measures modelled cover a wide enough range of variations and options to help the GLA further their understanding of cooling demands in dwellings and identify ways to encourage developers to improve their response to the cooling hierarchy.

3.0 SAP scoping study

3.1 SAP results

The unit typologies identified in section 2.4 were modelled in SAP2012 to quantify the cooling demand[16].

In the SAP methodology the cooling load is calculated for the months of June, July and August only, and it is then normalised to give a total cooling demand for the dwelling for the year in kWh/m²/year. As in reality it is likely that some dwellings would also have a cooling demand in other months of the year (e.g. May and September) and to facilitate the presentation and discussion, the SAP outputs have been converted into average monthly cooling demands per m², rather than assuming the SAP results represent annual cooling demand.

Figure 4 below shows the average (for June, July and August) monthly cooling demand per m² for the dwelling typologies described in section 2.4. It confirms that SAP does identify a reasonable variation in cooling loads depending on the type of dwelling and design measures included with up to a 66% variation recorded between the extremes in availability of window use for ventilation.

This suggests that investigating how different design approaches and measures affect cooling demands is a worthwhile exercise.

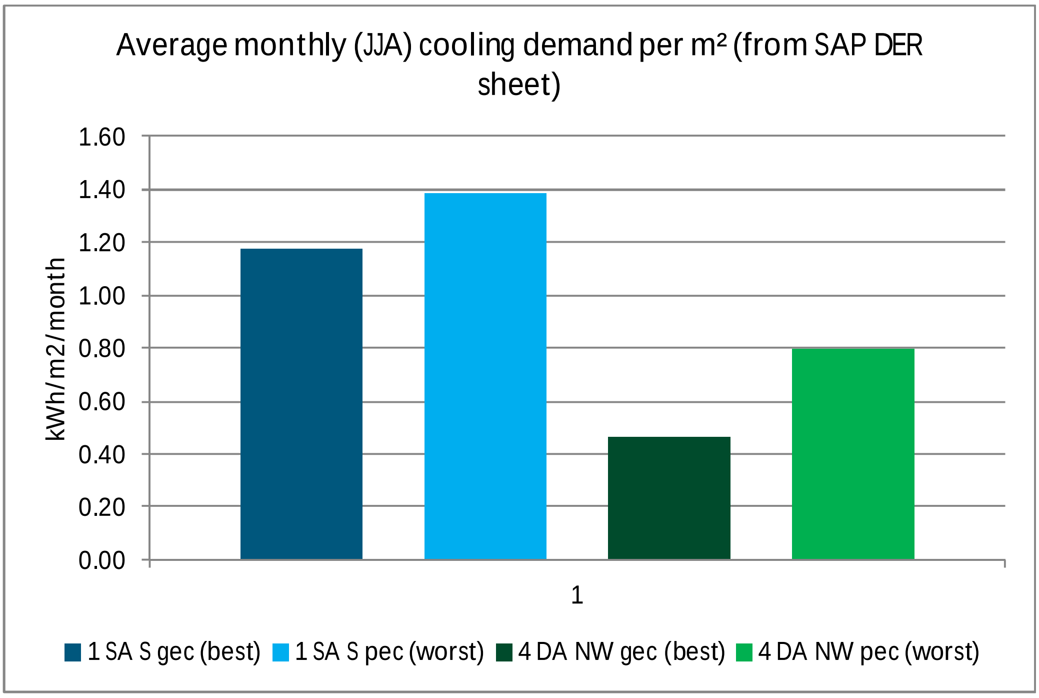

Figure 4: Average (June, July and August) monthly cooling demand from SAP DER sheet for 2 dwelling typologies under 2 different design scenarios

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[16] In order to obtain the cooling demand as an output an indicative air conditioning unit had to be included in the model, otherwise the DER worksheet (main SAP output) does not show the cooling load).

Table 8 shows the cooling demand figures and the outcome of the SAP Appendix P overheating test for the different options. While the overall trends are as expected, with cooling demand being higher for the “worst case” design options and the overheating test showing a high risk for the “worst case” and no risk for the “best case”, it is interesting to note that the overheating risk does not appear to correlate to the kWh of cooling demand. Typology 1 SA S gec (best) in fact shows a “not significant” risk of overheating even though it has a cooling demand per m² that is 47% higher than unit 4 DA NW pec (worst) which is identified at having a high risk of overheating. The reason for this in the context of SAP, is that the cooling demand calculation and the overheating test are not fully linked. For example, some of the design options available in the assessment of overheating risk (e.g. blinds, opened windows) are not accounted for in the cooling demand calculation but would, in practice, have the benefit of reducing the cooling demand.

Typology identifier	Spec summary	Average (JJA) monthly cooling demand (kWh/m²/month) DER sheet	July cooling demand (kWh/m²/month) DER sheet	Average monthly overheating risk
1 SA S gec (best)	Low energy lighting, shutters or external blinds to all windows (no internal shading), g-value of 0.63, natural cross ventilation, MVHR as per baseline assumptions	1.18	1.29	Not significant
1 SA S pec (worst)	Low energy lighting, Internal shading, g-value of 0.5, MVHR as per baseline assumptions	1.39	1.51	High

4 DA NW gec (best)	Low energy lighting, shutters or external blinds to all windows (no internal shading), g-value of 0.63, natural cross ventilation, MVHR as per baseline assumptions	0.47	0.57	Not significant
4 DA NW pec (worst)	Low energy lighting, Internal shading, g-value of 0.5, MVHR as per baseline assumptions	0.80	0.94	High

Table 8: Outputs from SAP analysis for the 4 dwelling typologies

3.2 Cooling demand in the context of other dwelling energy uses

When considering the cooling demands in the context of other energy uses within the dwelling, the study showed that carbon emissions associated with cooling demand (assuming it is met by air conditioning) are responsible for approximately 1-5% of the regulated carbon emissions of the dwelling. This is over an order of magnitude smaller than the emissions associated with heating and hot water, suggesting that cooling is a relatively minor issue compared to heating in terms of carbon.

However it should be noted that:

- This assumes that the cooling demand is met by an energy efficient air conditioning unit with a seasonal energy efficiency ratio in excess of 4. This is a reasonable assumption for systems installed at construction stage in new build but is considerably better than the actual performance of some portable air conditioning units being retrofitted in domestic buildings which were found in the Pathan study discussed in section 1.2 to achieve an EER of less than 1.
- The cooling demand calculation has only recently been introduced in SAP and it is thought to be conservative due to the use of monthly averages for external temperature rather than accounting for the variation in temperatures during the month, and periods of relatively high temperature, which trigger the use of air conditioning.

3.3 Scoping study conclusions

The study showed that there is sufficient variation in cooling demands between different types of units and design approaches to, in principle, make the evaluation of alternative design measures on cooling demand worthwhile. This is despite the fact that cooling demand has currently a relatively small impact on dwelling carbon emissions as predicted by SAP.

It is thought likely that the SAP calculation underestimates cooling demand as it limits the assessment to 3 months of the summer and its use of monthly average temperatures does not account for potential sharp rises in temperature that could significantly affect cooling demands i.e. a couple of days of very hot weather with air temperatures around 30ºC may not affect the monthly average temperature to significantly above the 24ºC set point however they are likely to result in significant, concentrated active cooling use.

The study has also made it apparent that the SAP calculation methodology is inadequate to assess sufficiently the range of design measures used in response to the cooling hierarchy on the building’s cooling demand. The main limitations associated with the SAP methodology in the context of assessing cooling loads are as follows:

- The SAP cooling demand calculation does not assess the impact of natural ventilation on cooling demand. It does not take into account the fact that openable windows or other ventilation strategies may successfully be used to reduce the cooling demand. This means that a SAP cooling demand benchmark would only be useful as a comparison, to assess how effective the design is at reducing solar and internal gains (i.e. the first part of the energy hierarchy), but not the ventilation strategy which is also an important element of the hierarchy. The reason for this is that the calculation was devised to quantify the cooling load that would need to be met by air conditioning, therefore it is based on the assumption that windows would be closed and the air conditioning unit would be on to bring the internal temperature down to 24ºC.
- The SAP cooling demand calculation does not sufficiently allow for the range of solar shading design measures. It does account for fixed shading systems such as window overhangs and sheltering from surrounding obstacles. However, it does not account for other measures such as external shutters and internal blinds.

As noted above, the SAP overheating test does take account of the use of natural ventilation and a wider range of solar shading devices, but these are not accounted for in the calculation of cooling demand.

In order to use SAP to assess a design’s response to the cooling hierarchy, it would have to be “moulded” for the purpose. For example, assumptions on passive vents and chimneys could be modified to better account for the effect of natural ventilation within the cooling calculation. In order to use this approach when assessing planning applications, the GLA would have to ask developers to produce SAP models for a fictitious “cooling case”. This would be based on the model to demonstrate compliance with the first step of the energy hierarchy but with modifications to better evaluate the cooling load. This would require the best ways to modify the SAP models for different cooling strategies to be defined and successfully communicated to developers through the GLA Energy Planning Guidance document to ensure a consistent approach across developments. This would add complexity to the process in designers implementing the solutions and it may result in confusion to the user as the modifications proposed may be counter-intuitive to “mould” SAP for these purposes.

Given that there is even now, after various years of implementation, often confusion amongst developers about the “energy efficiency” fictitious case in the first tier of energy hierarchy, it was deemed that it would be too difficult to effectively apply a fictitious “cooling case” in practice and that the complications with it would mostly defeat the point of using SAP as a tool to minimise developers’ efforts.

4.0 Good Practice design measures

4.1 Design measures included in the modelling

The intention was to select a set of design measures that would be considered a reasonable response to the requirement set in London Plan policy 5.9 to “*reduce potential overheating and reliance on air conditioning systems and demonstrate this in accordance with the [...] cooling hierarchy”.* This would provide the GLA both with a good practice set of design measures as well as forming the basis of benchmark cooling demand values.

Table 9 shows each step of the cooling hierarchy and the various design measures that have been investigated in the modelling to respond to them. In some instances, the measures identified are mutually exclusive or are providing a similar effect so there is no benefit in applying them together (e.g. external shading can have the same effect as specifying low g-value glazing). Therefore not all measures listed in Table 9 have been considered in combination or would be expected to feature in an individual dwelling to respond to London Plan policy 5.9.

Cooling hierarchy element	**Design measure**
1. Minimise internal heat generation through energy efficient design	LED lighting is assumed in all the models A rated white goods are now standard practice and are assumed in all the models
2. Reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls	Orientation – this is considered through modelling each dwelling in 4 different orientations. In practice, the architect’s ability to tackle dwelling orientation is often limited by site constraints Shading – External - This is more effective than internal as it stops solar radiation before it enters the building. Typical design solutions which have been considered for the modelling are as follows. Further details of which types of external shading have been used in each case are described in the design strategies below this table. • Brise soleil (good for south orientations) • Vertical fins (good for east / west orientations) • Overhang (e.g. from balcony above) • Windows with deep reveals • External blinds • Shutters

	Internal • Internal blinds Albedo – while this is an important aspect of tackling the urban heat island effect and so should be addressed during the planning process, it has been excluded from the modelling as it can't be accounted for in SAP and has a minor impact on IES results for the interior of buildings. Fenestration – • Glazing percentage - every dwelling type has been modelled with an option for a lower glazing proportion to reduce solar gains which still meets the daylight criteria in the Housing SPG. • Glazing g-value – As an alternative to solar shading, low g-value glazing has been modelled in some cases. Insulation – specifications have been taken from Appendix R of SAP2012 which are expected to be broadly equivalent to the requirements to meet the "be lean" tier of the energy hierarchy
3. Manage the heat within the building through exposed internal thermal mass and high ceilings	Thermal mass – the dwellings are assumed to have medium thermal mass as they were originally designed. Thermal mass can have a useful effect on limiting cooling needs but it needs to be carefully designed in combination with an effective ventilation strategy and with due consideration for occupancy patterns. Its effectiveness is very dependent on construction type and building characteristics and, if poorly implemented, can actually exacerbate overheating issues. High ceilings – this is assumed fixed at the design height (2.5-2.7m)
4. Passive ventilation	Cross ventilation from openable windows or passive stack through ventilation shafts have been considered for dwelling typologies that have this option (i.e. the ones with favourable external conditions – no noise, security, air quality issues)
5. Mechanical ventilation	Mechanical ventilation with heat recovery (MVHR) with summer bypass[17] is assumed as standard for all typologies Oversized MVHR (assuming twice the air change rate)

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[17] During winter the MVHR unit recovers the heat from extract air and bathrooms and kitchens and uses it to heat the incoming fresh air. With summer bypass, during summer the fresh air coming into the dwelling comes directly from the outside, bypassing the heat exchanger. If the external temperature is lower than the internal temperature (i.e. most of the time in the UK), the fresh air provides some cooling benefit.

	is assumed as an option for dwellings typologies with external conditions that don't allow openable windows
6. Active cooling systems (ensuring they are the lowest carbon options).	Excluded – the focus of the work is on reasonable passive measures to reduce the cooling demand

Table 9: Possible design measures to include in the models to address the cooling hierarchy

Three overall design strategies are given below which have been developed based on these potential design measures. The actual measures employed for each strategy are tailored slightly in the modelling to suit orientation, construction type and other dwelling features (full details of assumptions used for each modelling variation are provided in Appendix B).

Strategy 1

- Maximised external shading – external blinds have been adopted for the masonry units (type 2 and 4) and brise soleil and vertical fins have been adopted for the curtain wall unit and penthouse (type 1 and 3)
- Internal shading – this has been included for the unit types where the external shading is not fully effective. This comprises the curtain wall units and penthouse (type 1 and 3) where the external shading is fixed and hence not as effective as user-controlled shading systems like shutters or external blinds. For the typologies where internal shading is included, it has been applied to all facades.
- Natural cross ventilation – this has been modelled where external conditions allow for the opening of the windows. Where natural cross ventilation through windows cannot be achieved because of the aspect of the dwellings it is assumed that design solutions (e.g. passive stack methods) would be developed to achieve the same air change rates. The air change rates were based on SAP assumptions, which are further based on assumptions in Approved Document F of the Building Regulations, and are dependent on the percentage of glazed area that is openable. It would be the responsibility of the designers to ensure that the glazing types selected can meet these standards. Units that cannot open windows for ventilation due to poor external conditions are assumed to have the same (standard) MVHR system as used for units which can open windows.

Based on AECOM's experience of carrying out overheating assessments, this strategy which favours where possible user-controlled external shading and natural cross ventilation was thought to be the most reasonable and effective response to address overheating issues in today's climate and enabling the building's resilience to climate change. Hence, this strategy has been particularly focussed on in this study.

The external shading types were selected based on the likely design solutions that would be appropriate and reasonable for the type of construction of the dwelling (i.e. not using shutters on curtain walls). For the duplex it was assumed that the external blinds would be present on all facades allowing them to be closed at night while keeping windows open, therefore allowing secure cross ventilation even at ground floor. This assumption differs from the other dwelling types which, being on upper floors, do not have a security issue. For these typologies it was assumed that external shading would be installed on all facades except north facing ones, as it was assumed that shading on north facades would be an additional cost for limited benefit.

The cross ventilation was modelled assuming a target air change rate of between 2.5 and 6 air changes per hour (ach) as per SAP Table P1 (it defines the air exchange rate for different dwelling lay-outs). For the dwelling types where cross ventilation is partial (i.e. the windows are on two neighbouring, but not opposite, facades), the air change rate was assumed to be the mid-point between the SAP assumption for a dwelling with no cross ventilation and one with full cross ventilation.

To assess whether the air change rates proposed in SAP were reasonable, AECOM undertook a MacroFlo test on unit type 2 (masonry flat). The results of this test suggest that the SAP Table P1 assumptions are reasonable. The outputs from the test are given in Appendix C.

It should be noted that in some instances the air change rates targeted in the models may only be achievable with more innovative approaches to cross ventilation. For example, single aspect units at high storey heights may not be able to properly open windows for ventilation due to wind loading, safety or other issues. In these instances design measures such as ventilation shafts to achieve passive stack effects may be required to achieve the same level of air changes. These design solutions are not very common at the moment due to their impact on internal layouts and sound and fire insulation, but may need to become more common as ventilation grows in importance in tackling overheating issues.

As the 96 typologies include variations of the dwellings with a reduced glazing ratio, the results also show the impact of reducing glazing area, and lowering solar gains, on the core strategy 1 solution.

Strategy 2

- Glazing reduced – the dwellings as designed have average glazing proportions ranging from 27% to 48% which, in most cases, significantly exceed the Housing SPG good practice requirement for 20% of internal floor area to be glazing to allow good levels of daylighting. A reduced glazing option has been modelled for each dwelling assuming a glazed proportion of 25% of internal room floor area.
- Reduced g value – the SAP default g value of 0.63 has been reduced to 0.3 to reduce heat entering the dwelling in summer. The reduction in g value is beneficial in summer but it does also reduce solar gains in winter meaning that the heating demand is likely to be increased.
- Internal shading – this has been modelled in the form of light coloured blinds to all typologies and has been applied to windows on all facades.
- Natural cross ventilation – this has been modelled for units with openable windows and good external conditions. The ventilation rates have been assumed to be the same as for strategy 1 and in line with SAP Table P1.
- MVHR - Oversized MVHR with summer bypass have been included for options with poor external conditions. The air change rate is assumed to be double the rate of a standard size MVHR system (going from 0.5 ach to 1 ach)

This strategy was thought to be a closer reflection of the approach that an average design team currently takes as external shading features are often avoided on the grounds of visual impact and maintenance concerns.

A g-value of 0.3 is very low and therefore may not be appropriate due to the impacts on heating demands, daylighting and visual impact. This specification has been assumed here to assess the likely extreme in terms of g-value specification to address cooling loads.

In order to aim to meet the same level of cooling loads as strategy 1, it has been assumed that the glazing proportion would need to be reduced and the MVHR boosted. Boosting the MVHR would have spatial implications in the internal layouts of dwellings as it would require oversized ducting to be accommodated in the ceiling voids.

Strategy 3

- Glazing reduced – as per strategy 2.
- Partial external shading – a level that doesn’t have excessive visual implications (e.g. brise soleil, vertical fins, deep window reveals)
- Internal shading – internal blinds to all dwellings as the external shading will only be partly effective. The blinds are applied to windows on all facades.
- Glazing g-value -reduced to 0.45
- Reduced natural cross ventilation – cross ventilation assumed for dwellings where external conditions allow windows to be opened for ventilation. However, the air change rate is reduced to half that assumed for strategy 1 and 2
- MVHR with summer bypass in all cases, as per strategy 1

This strategy was thought to be a reasonable compromise between strategies 1 and 2. The external shading was halved in size simulating shading systems that could be more easily integrated within the facade of the building (e.g. deep window reveals, overhangs) without having excessive visual impact. The g-value was reduced compared to the SAP default but to a more reasonable level. Cross ventilation rates were reduced to levels that may be more realistic in practice for developments in London, where residents may be reluctant to open windows for long periods of time even when internal temperatures are high due to noise or security concerns.

4.2 Potential additional measures

This work has focussed on three alternative design strategies. Not all design measures that could be considered to respond to the cooling hierarchy have been included. They may still be useful as part of a holistic approach to reducing cooling loads and minimising the risk of overheating.

Measures that are located externally to the envelope of the dwelling cannot be effectively accounted for in an IES model. However, they can have significant benefits by affecting the local external conditions therefore mitigating the impacts of climate change and the urban heat island effect. These are:

Blue and green infrastructure surrounding the buildings – this can provide cooling through evapo- transpiration. Furthermore, strategically selected and positioned vegetation can provide shading to windows with a similar effect as external shading systems added to the building envelope.

Green roofs and walls – these contribute to green infrastructure and have similar cooling effects on the air surrounding the buildings they are installed on. They have the added benefit of potentially providing additional insulation value on the building elements they are applied to, although this will depend on the construction and the level of moisture content in the living element.

High albedo materials – selecting light coloured materials that reflect solar radiation rather than absorb it is a very important element of tackling the urban heat island effect, as it avoids heat absorbed during the day being radiated to the surrounding environment at night, when cool air is needed to purge ventilate buildings. High albedo materials also avoid heat being absorbed through the fabric into the dwellings, although it should be noted that for most well insulated buildings built today, heat gains through solid building fabric are approximately an order of magnitude smaller than heat gains through glazing or internal gains[18].

Other measures that are integral to the fabric of the building and can be part of a successful passive approach to reducing cooling demands are:

Thermal mass – this has the potential to help reduce cooling demands. However it is paramount that it is used in combination with effective night time ventilation. If reasonable levels of night time ventilation cannot be achieved to remove the heat being emitted by the thermal mass, the dwelling may well result in higher internal temperature as well as higher embodied carbon and heat demands[19].

High ceilings – the use of high ceilings increases the volume of air within the dwelling, therefore it is likely to take longer for temperatures to increase to uncomfortable levels. However, similarly to thermal mass the effectiveness of this measure is linked to a successful ventilation strategy and window design. It is also important to note that a larger volume of air will require more heating in winter to reach comfortable internal conditions.

Other shading methods - a standardised set of external shading methods was employed in this study to keep the modelling as consistent as possible across the typologies. In practice, there are many different ways of providing external shading and the solutions can become an integral part of the facade design, bringing interest to the facade as well as contributing to maintaining internal thermal comfort.

User operated shading mechanisms (e.g. shutters, blinds) are more effective than fixed solutions (e.g. overhangs, fins, deep reveals) because they can be operated when needed but kept open in winter to benefit from solar gains during the heating season.

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[18] Gething, Puckett, “Design for Climate Change”, 2013

[19] Gething, Puckett, “Design for Climate Change”, 2013
Pochee, Dawson, Burgon, Bentham, “An analysis of the benefits and drawbacks of exposed thermal mass in modern, well insulated buildings”, 2012

5.0 Modelling outputs and Benchmarks

5.1 Modelling outputs

Given below are the main outputs from the modelling exercise described in sections 2.0 and 4.0, represented in graphical form to illustrate some of the overall trends. The full outputs for every dwelling typology are provided in Appendix E.

5.1.1 Strategy 1

Overall trends

The modelling carried out for the 96 typologies applying strategy 1 identified that monthly cooling demands over the period from May to September vary from 0 to 16 kWh/m^2/month.

As expected, a considerable variation can be seen between the dwelling types modelled assuming good external conditions and those with poor external conditions. Those with good external conditions have on average a monthly cooling demand 86% smaller than those with poor external conditions, highlighting how important effective ventilation is in managing internal temperatures and reducing cooling demand. It should be noted that the modelling assumed high levels of ventilation through openable windows, based on SAP assumptions and design recommendations in Approved Document F of the Building Regulations. This will only be achieved in practice if the window types selected have sufficient areas that are openable rather than fixed panes.

Figure 5 compares the average monthly cooling demands of the 4 different dwelling types for the months of June, July and August. As expected the mid floor curtain walled flat (unit type 1) has the highest average and maximum cooling loads under poor and good (though less obviously so) external conditions. This is thought to be mainly due to the higher proportions of glazing than the other dwelling types allowing increased solar gains. The big variation in demand figures across the typology variations for this dwelling type is mostly due to the fact that this type has the biggest scope for reduction in glazing areas (from 48% of the floor area for the as designed dual aspect case to 25% for the low glazing case). The “as designed” glazing areas for other types were not as different from the 25% glazing target and therefore the scope for reduction in cooling due to reduced glazing was smaller.

As also expected, the duplex unit has the lowest average and maximum cooling demands with lower solar gains relative to the volume of air in the dwelling. However, the cooling demand may also be lower than the other dwelling types as the modelling assumes that all windows have shutters or external blinds to allow secure cross ventilation. This is a different assumption from the other 3 dwelling types where external shading was not included on north facing orientations and thus would result in greater solar gains.

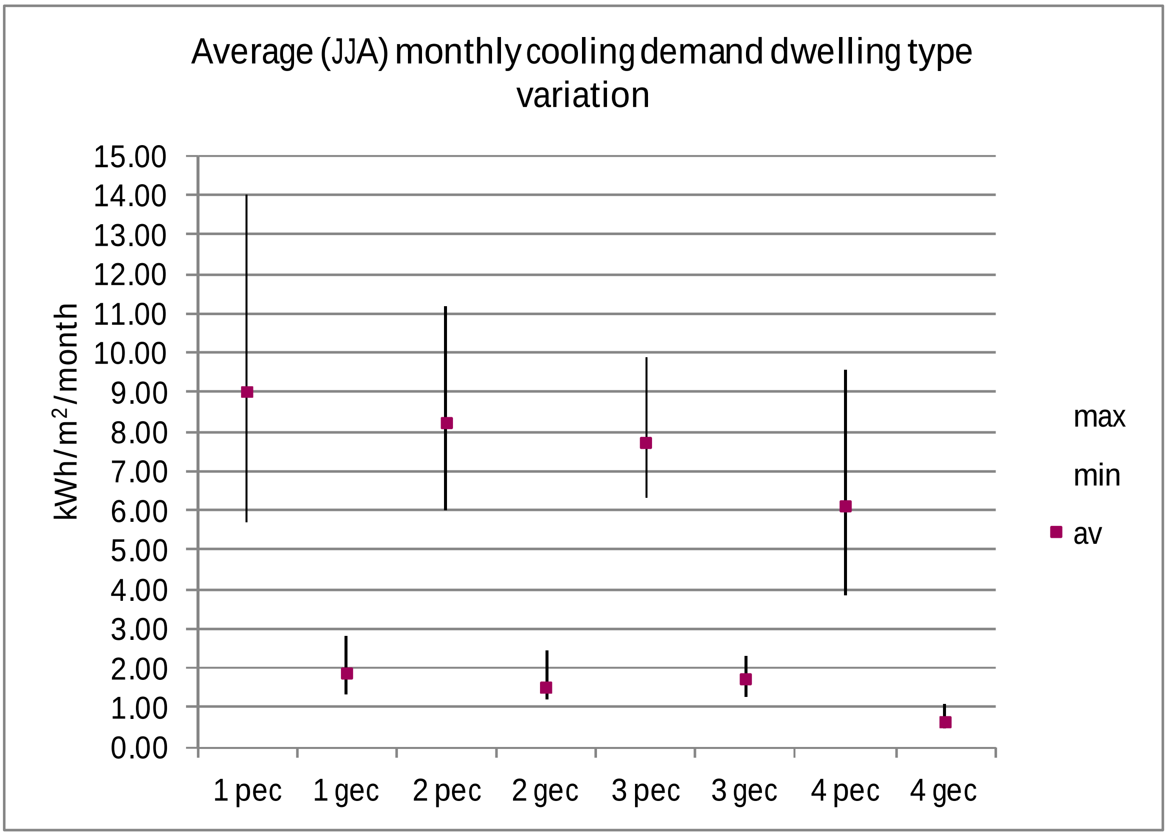


Figure 5: Average (JJA) monthly cooling demand per dwelling type

Figure 6 and Figure 7 present the average monthly cooling demand for the months of June, July and August, for each typology under poor external conditions and good external conditions respectively (please note that the two graphs have different scales on the y axis). The months of May and September have been excluded from the calculation of the average monthly demand as June, July and August are considered the main cooling season months. This approach also allows a high level comparison with the SAP outputs for cooling demand from the scoping study.

These provide some interesting findings:

- In most cases under poor external conditions, the cooling demands of units facing north appear to be significantly higher than those of units in other orientations. This is because the north / north west / north east facing facades have been modelled without external shading, with the exception of the duplex unit (type 4) under good external conditions. This finding suggests that solar gains are still significant even from north facing facades. This trend does not appear so clearly in the typologies with good external conditions, as ventilation rates mitigate the impact of solar gains to some extent.
- In most cases the change from dual (or triple for the penthouse) aspect to single (or dual) aspect appears to reduce the cooling demand. This suggests that the loss in solar gains from reducing the number of windows outweighs the reduction in ventilation rate. Based on SAP assumptions, the ventilation rate falls by 20-25% between a unit with partial cross ventilation and one with no cross ventilation.
- For the curtain walled flat (type 1) and the penthouse (type 3) where the glazing reduction from the “as designed” case to the “25%” case was significant, the

cooling loads were found to reduce significantly. The curtain walled flat could achieve a reduction in cooling load of over 30% by reducing the glazing ratio from 48% to 25%.

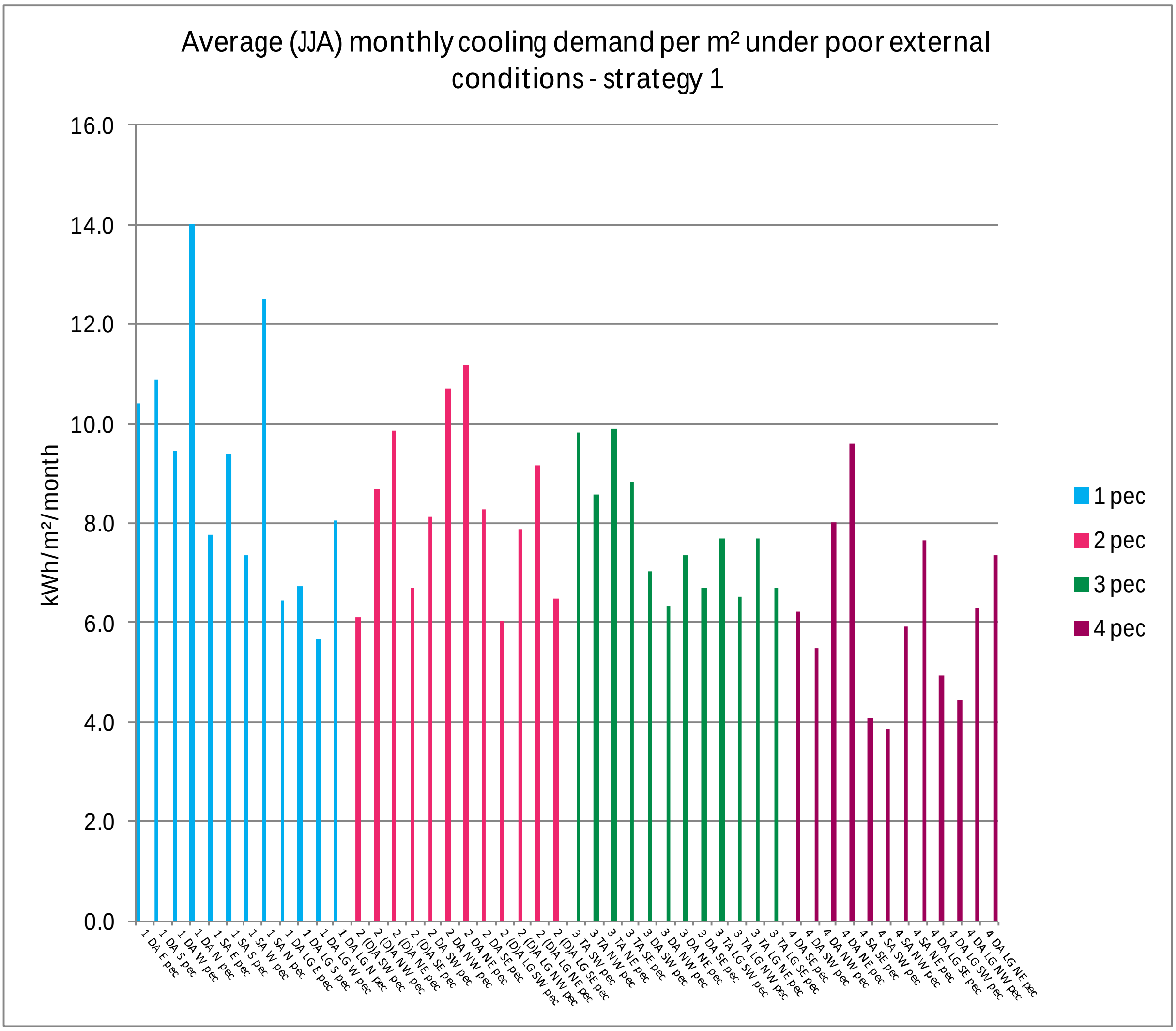


Figure 6: Average monthly cooling demand for each typology under poor external conditions

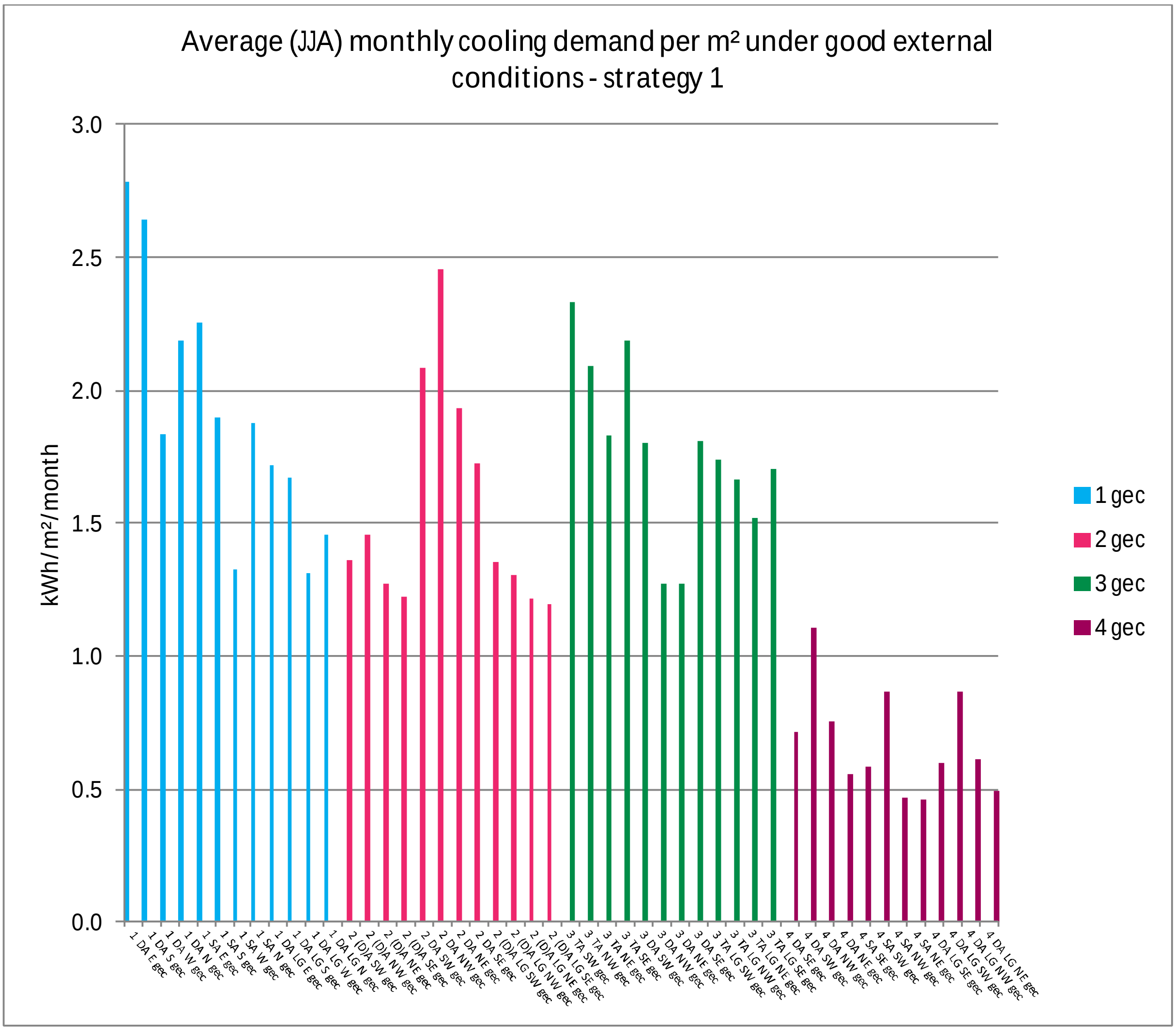


Figure 7: Average monthly cooling demand for each typology under good external conditions

Monthly variations

Figure 8 and Figure 9 show the monthly cooling demands for dwelling type 1 for the months May to September under poor external conditions and good external conditions respectively. The equivalent graphs for the other 3 dwelling types are provided in Appendix E.

As can be seen the lines show less absolute variation for the “good external conditions” cases, where orientation and aspect (i.e. the different typology options) appear to have a smaller influence than in the “poor external conditions” cases. This again demonstrates the significant influence of natural ventilation on the cooling load. The extent of monthly variation in the “good external conditions” case also highlights that cooling loads in the months of May and September are very small when cross ventilation is possible.

Monthly variations appear smallest for the units with East facing living rooms. In particular, the cooling demand shows limited decrease from July to September. This is likely due to the balance of solar gains for this particular dwelling type as the other dwelling types do not show the same trend for this particular orientation (see Appendix E).

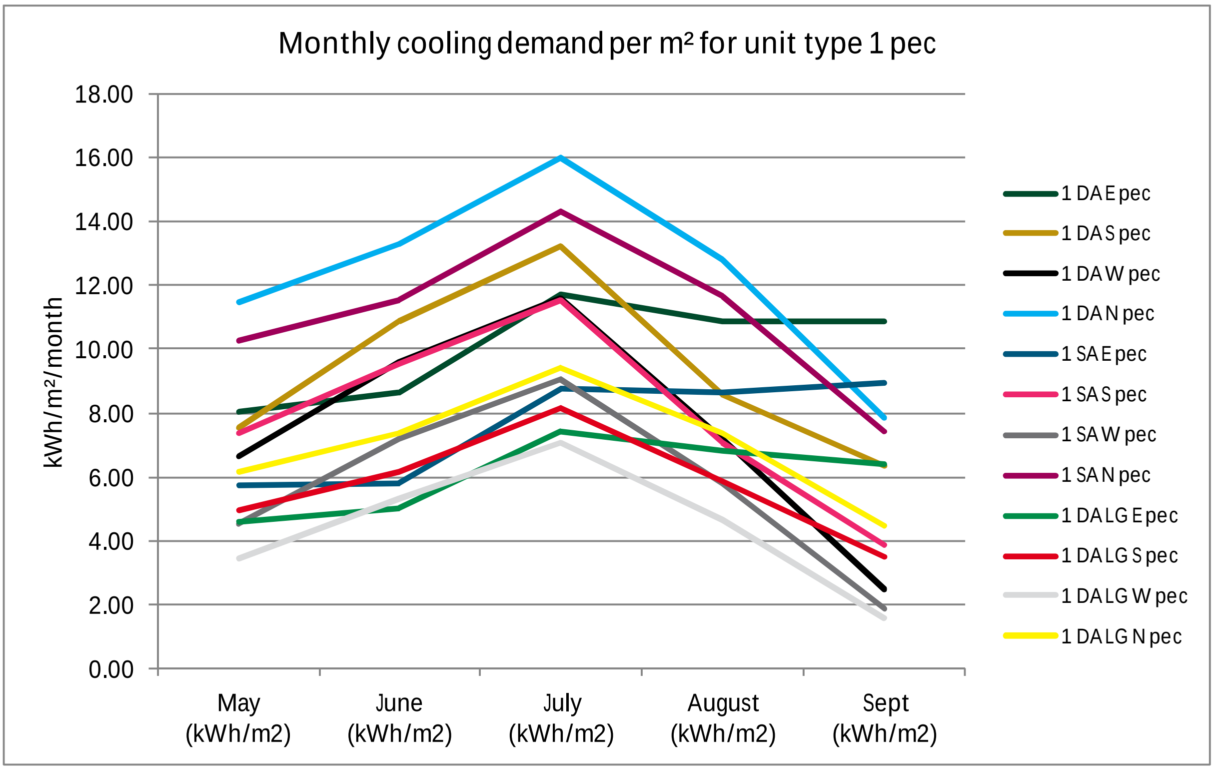


Figure 8: Monthly cooling demand per m² for the variations for unit type 1 (curtain wall mid floor flat) under poor external conditions

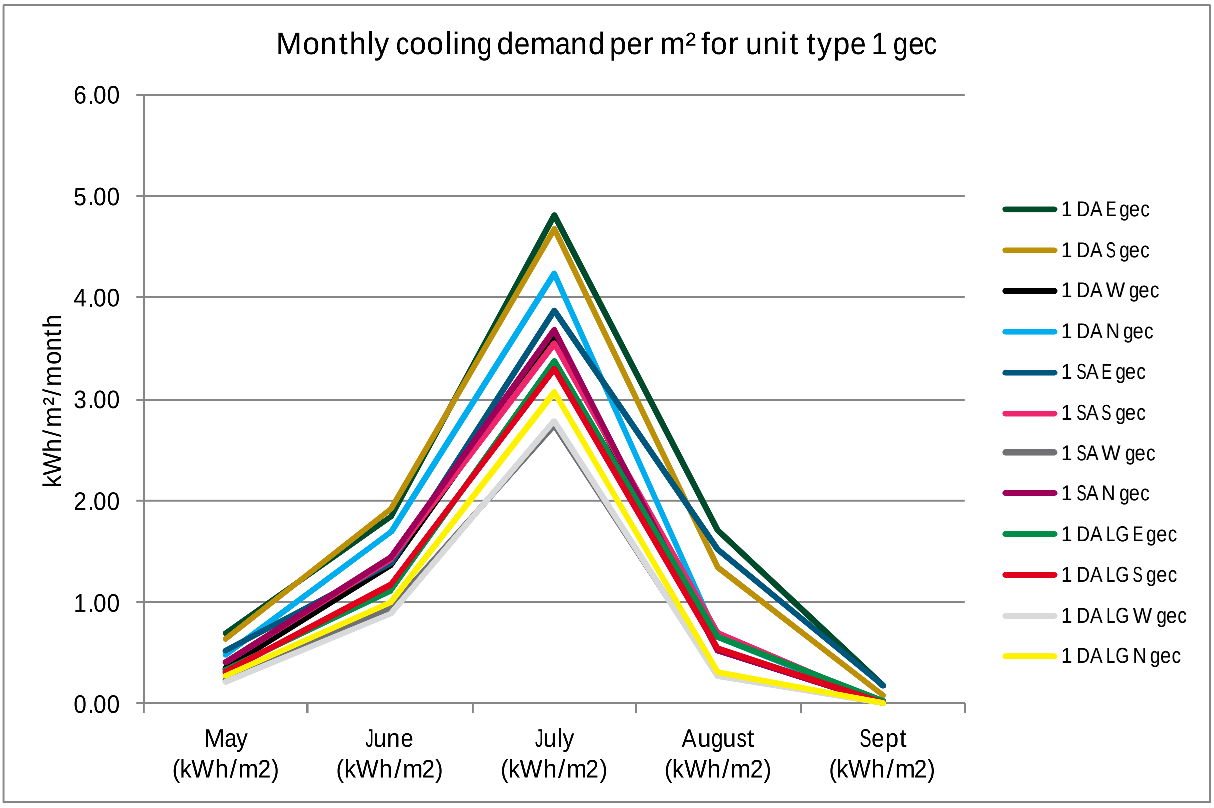


Figure 9: Monthly cooling demand per m² for the variations for unit type 1 (curtain wall mid floor flat) under good external conditions

5.1.2 Comparison with Strategy 2 and strategy 3

To help evaluate whether cooling benchmarks could be developed based on the outputs from strategy 1, two alternative strategies were modelled on 8 sample typologies. Benchmark values should be sufficiently stringent to reasonably control cooling demand but not overly stringent so that they continue to allow other reasonable design strategies.

Figure 10 compares the average monthly cooling demand for the three strategies.

As can be seen, setting a maximum cooling demand based on strategy 1 does allow alternative strategies as noted by strategies 2 and 3 exhibiting a lower cooling demand.

Indeed, it is worth considering why the alternative strategies demonstrate greater performance than strategy 1. Reasons include the following:

- The external shading mechanisms modelled under strategy 1 were based on reasonable assumptions of what might be visually and structurally acceptable, not on maximising shading benefit. So for example brise soleil and vertical fins were assumed for the curtain walled unit and penthouse, as this is the type of shading often used on these types of buildings even if it’s not the most effective. Other shading mechanisms such as blinds integrated within the glazing unit, or awnings (for the penthouse) may be more effective but less common.

- The external shading under strategy 1 was not applied to north facing facades while the g value reductions under strategies 2 and 3 were applied to all glazing in the dwelling. The results for strategy 1 showed that, unexpectedly, considerable solar gains are still absorbed from north facades.
- Strategy 3 includes some external shading of smaller dimensions than strategy 1 to reflect what might be more common in current designs. The external shading however is combined with lower g values on all windows compared to strategy 1.

Indeed, it suggests that a benchmark value would be better based on strategy 3 rather than strategy 1 as modelled. As noted, both strategy 2 and strategy 3 are predicted to perform better than strategy 1, but strategy 3 is seen to be a more pragmatic alternative.

The results show that, on average across the 3 months of summer, strategy 2 is more effective at reducing cooling demands than strategy 1. The fact that all the dwelling types show a significant reduction to similar demand figures suggests that the reduced g value minimises the effect of different built form and orientation.

It is however worth remembering that reducing the g value is beneficial for summer but has a detrimental effect in winter as it results in higher heating demands. It also generally results in lower light transmittance, therefore reducing daylight levels within the dwellings. To illustrate this point, dwelling type 1 and 4 used for the SAP scoping study were modelled with external shading in the form of overhangs of at least 1m depth on each window and the default g value of 0.63 (to simulate the solar control element of strategy 1), and with no external shading and a g value of 0.3 (to simulate the solar control element of strategy 2). The outputs showed that for the original curtain walled dwelling (dwelling type 1), strategy 1 had no impact on the 18% improvement on the TER while strategy 2 resulted in the dwelling failing to meet the TER. For the original masonry duplex (dwelling type 4), the results showed again that strategy 1 had no effect on the 15% improvement on the TER, while strategy 2 resulted in the improvement falling by more than half to 6%. The impact of strategy 2 is likely less for dwelling type 4 as it has significantly less glazing. This analysis highlights the need to consider design options holistically, and the need to balance winter and summer requirements. Overall, the results suggest that external shading options may provide a better overall balance in terms of tackling cooling loads without having negative implications on winter loads.

Under “poor external conditions” strategy 3 always performs between strategy 1 and 2. This is to be expected as strategy 3 was mainly aimed at achieving a compromise between the other two strategies. Interestingly this trend does not persist in the cases under “good external conditions” where for type 1 and 3 (the curtain walled units) it is found to be the best strategy. This is likely to be due to the combination of external shading and lower g value providing the best approach to controlling solar gains.

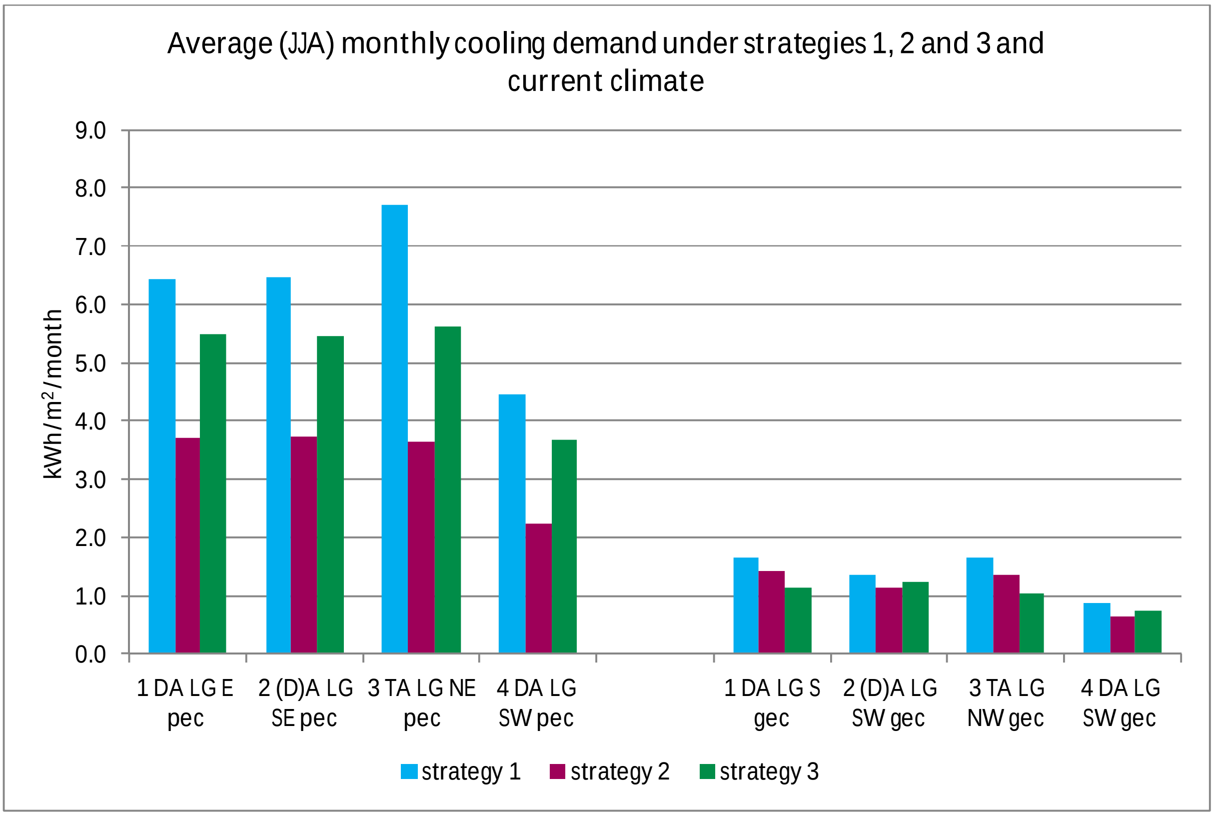


Figure 10: Average (for June, July and August) cooling demand for strategies 1, 2 and 3 for 8 sample typologies

Overall the test shows that the design approach taken can have a significant effect on cooling loads, with the results varying by up to 50% between different approaches to the cooling hierarchy. This suggests that it would be very difficult to set hard benchmarks to test designs against. However cooling demand ranges could still be developed to help understand the performance of different development proposals against the design approaches considered in this study.

5.1.3 Step by step assessment for strategy 1, 2, 3

Cumulative results

For 4 dwelling typologies the contribution of each measure within each strategy was quantified individually, to better understand the relative contributions that different design measures can make in developing a successful passive response to overheating risk. The results are shown in Figure 11 to Figure 14 below. For ease of representation the percentage contribution from each measure within each strategy was calculated based on the average monthly cooling demands for June, July and August. The baseline against which the percentage reductions have been calculated is based on the dwellings already including LED lighting as this has been assumed to apply to all dwelling typologies modelled.

It is important to note that the order in which the measures are applied does have a significant influence on their likely percentage contribution within a given strategy, as the measures proposed may be addressing part of the same issue (e.g. solar gains) and are often interlinked. So for example under strategy 3, a reduced g value glass is combined with external shading with both measures tackling internal gains to some extent. The measure that is applied first (in this case g value) will have the biggest impact on the results just because it tackles the worse of the internal gains, leaving less to be dealt with by the second measure (external shading). If the measures were applied in a different order, the results would probably show that external shading provides a bigger reduction than the g value. This highlights that the findings shown in the figures below are not absolute and can only be considered within the context of the strategy they are part of.

Figure 11 and Figure 12 which consider two typologies under poor external conditions and so with limited opportunities for increasing purge ventilation rates show that the majority of the reduction in cooling demand is achieved by tackling solar gains, whether it is via external shading or glazing g value specification. It should be noted that strategy 1 only included external shading but no g value improvements, while strategy 2 included a g value strategy and no external shading. Strategy 3 included a combination of both and the results would suggest that a reduction in g value is more effective than external shading, however as stated previously, this is probably simply due to the order in which the measures were applied. The outcomes of strategy 1 and 2 in fact suggest that the impact of the two approaches is comparable.

In absolute terms the reduction in g value to 0.3 appears to have the biggest impact however it should be highlighted that reducing the g value to this level is expected to have considerable impacts on the heating demand of the dwelling in winter.

Unsurprisingly, the impact of internal blinds is minor as the use of external shading or glazing specification means that most of the solar gains are addressed before they reach the inside of the dwelling.

Oversizing the MVHR system to achieve an air change rate of 1 air changes per hour does have a reasonable impact on the cooling load but it is small compared to addressing solar gains.

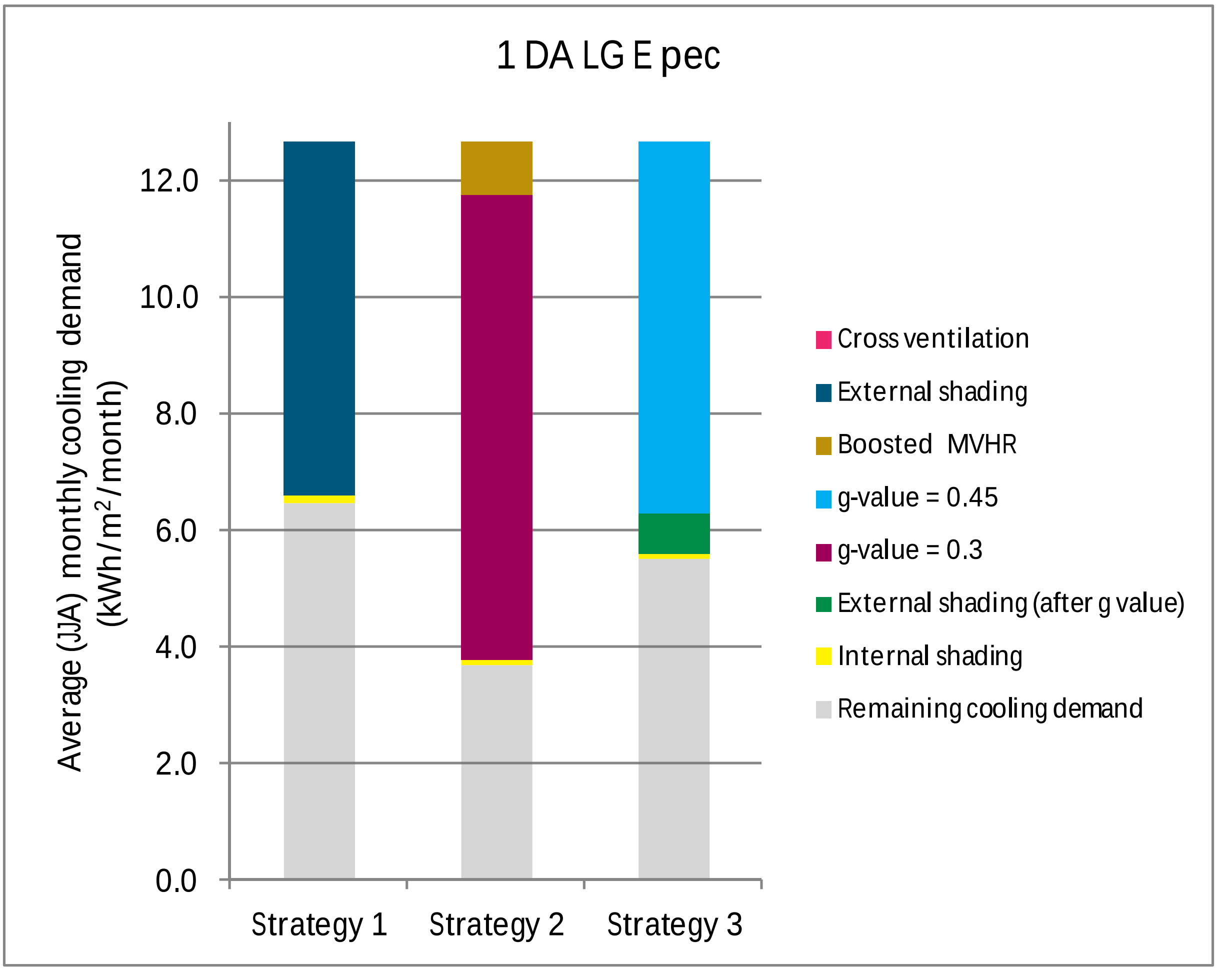


Figure 11: Reduction in cooling demand achieved by individual measures under each strategy for typology 1 DA LG E pec (curtain walled mid floor flat, dual aspect, reduced glazing, east facing and with poor external conditions)

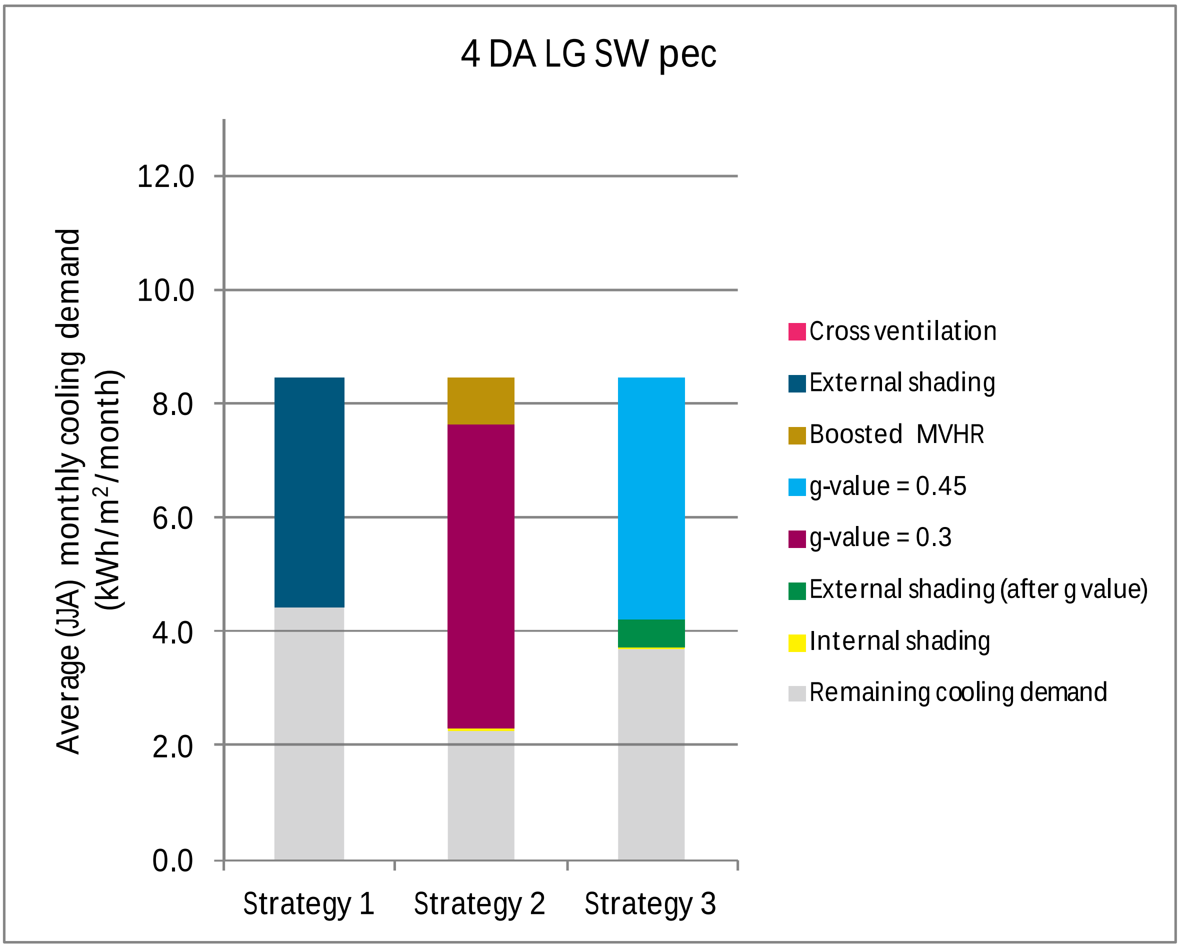


Figure 12: Reduction in cooling demand achieved by individual measures under each strategy for typology 4 DA LG SW pec (masonry duplex unit, dual aspect, reduced glazing, south west facing and with poor external conditions)

Figure 13 and Figure 14 relate to two typologies modelled under good external conditions and show that in these cases cross ventilation from openable windows have the biggest impact on reducing cooling loads, with external shading and glazing specification.

It is also worth noting that these two types have overall a lower starting cooling load than the two types under poor external conditions. This is partly due to the shape of the dwelling but it is expected to be in the most part due to the fact that it was assumed that under good external conditions the dwelling would be partly shaded by an adjacent building. The fact that the reduction is mainly due to the surrounding obstacles is highlighted by the fact that the penthouse (type 3) also shows a relatively low starting demand, even if it is not a particularly efficient dwelling design in terms of cooling compared to the other typologies.

External shading and glazing specification also provide a considerable contribution to reducing the cooling load, and similar trends can be seen between the three strategies as was seen in the units modelled under poor external conditions.

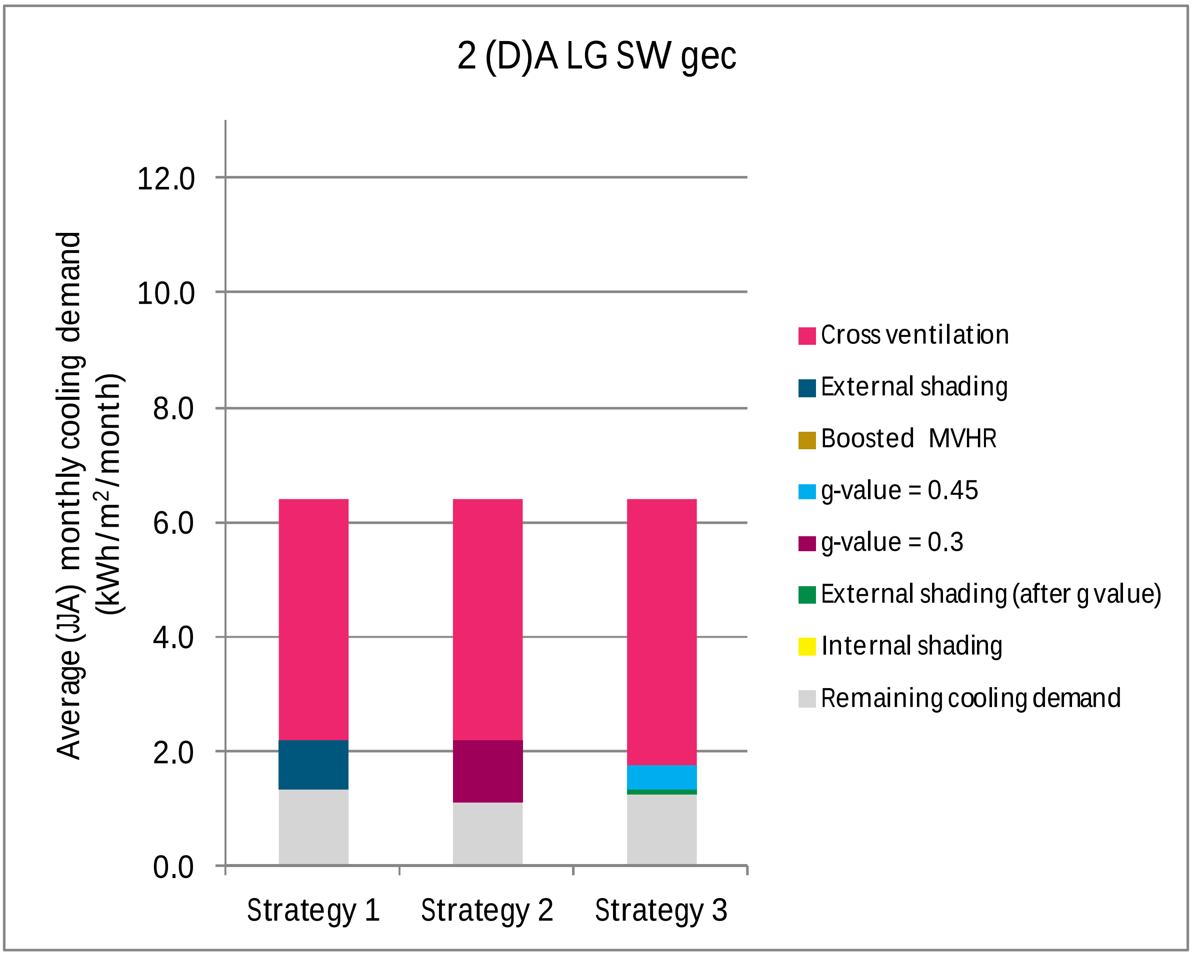


Figure 13: Reduction in cooling demand achieved by individual measures under each strategy for typology 2(DA) LG SW gec (masonry mid floor flat, dual aspect but with no cross ventilation, reduced glazing, south west facing and with good external conditions)

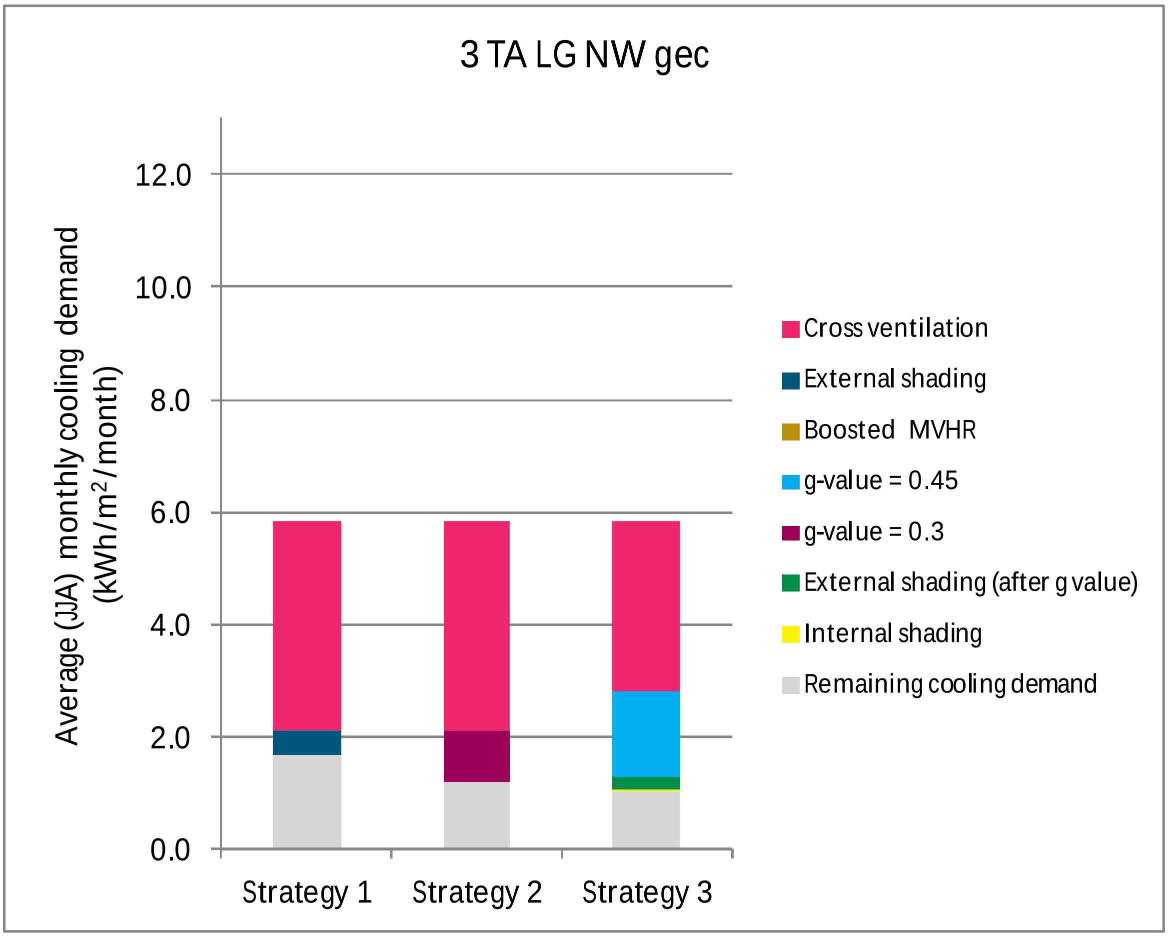


Figure 14: Reduction in cooling demand achieved by individual measures under each strategy for typology 3 TA LG NW gec (penthouse, triple aspect, reduced glazing, north west facing and with good external conditions)

Results per individual measure

In order to better understand the relative impact of the different design measures irrespective of the order in which they are applied to a building, the measures used for strategies 1, 2 and 3 were also modelled individually.

Figure 15 and Figure 16 show the percentage reduction in cooling demand for the curtain walled flat (dwelling type 1) under poor external conditions and the masonry flat (dwelling type 2) under good external conditions.

The findings show that specifying low energy lighting and appliances has a very low impact on reducing the cooling demand. The saving is so small because the baseline assumption was already for low energy lighting (i.e. fluorescent bulbs), which were assumed to be replaced with even more efficient fittings (i.e. LEDs).

External shading implemented in strategy 1 was found to have a high impact on reducing cooling demand (25% for dwelling type 1 and 45% for dwelling type 2). This compares to a reduction of approximately 50% for both dwelling types from reducing g values to 0.3 in strategy 3. The difference in impact is influenced by the fact that the g value was applied to all windows and therefore the changes affected the whole window areas of the dwelling while the effectiveness of external shading is dependent on the size and type used.

The impact of different types of external shading is further illustrated by the difference in savings from strategy 1 and strategy 3 shading options for the two dwelling typologies. For type 1 the difference between strategy 1 and strategy 3 shading was simply the size of the fins used and as expected, reducing the size of the fins (in strategy 3) resulted in approximately halving of the benefit. For type 2 strategy 1 assumed shutters to all windows except northern facades and strategy 3 assumed fixed fins, and it can be seen that the shutters are significantly more effective than the fins achieving nearly an order of magnitude greater reduction. This is partly to do with the fact that shutters can provide 100% shading on demand while fixed fins provide significantly less shading than that, and partly because the orientation of the particular typology means that fins are not as effective as on east/west orientations.

Internal blinds were also found to have a considerable impact (25-30% reduction) and in the curtain walled flat (dwelling type 1) they appear to have a bigger impact than external shading. This is probably again due to the fact that fins and brise soliel applied to curtain walls shade only a proportion of the glazed area while the internal blinds can be used to cover the whole window. In the masonry flat (dwelling type 2) the internal blinds can provide a significant contribution but lower than that achieved by external blinds/shutters (i.e. strategy 1 shading). This is because if only internal shading is used, some heat gains will be entering the building before the solar radiation hits the shading mechanism.

As expected by the overall trends discussed in section 5.1.1, natural cross ventilation is also found to have a major impact, reducing the cooling demand by 65% for dwelling type 2. Boosting the MVHR system is a relatively ineffective way of reducing cooling loads achieving only a 7% reduction when implemented for dwelling type 1. This is because the MVHR unit is intended to provide background ventilation for the control of indoor air quality rather than the purge ventilation required in hot summer conditions.

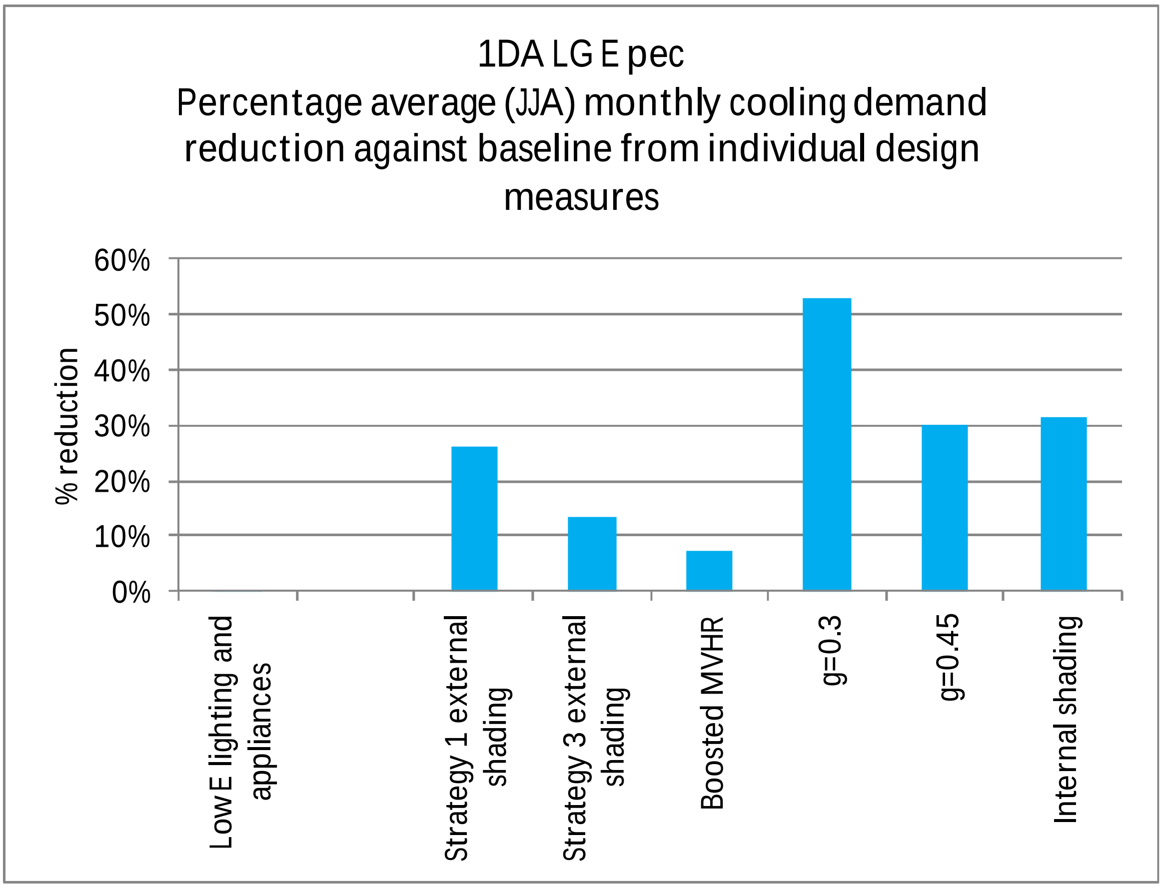


Figure 15: Percentage reduction in monthly average cooling demand (for June, July and August) for each individual design measure used under either strategy 1, 2 or 3 for typology 1 DA LG E pec

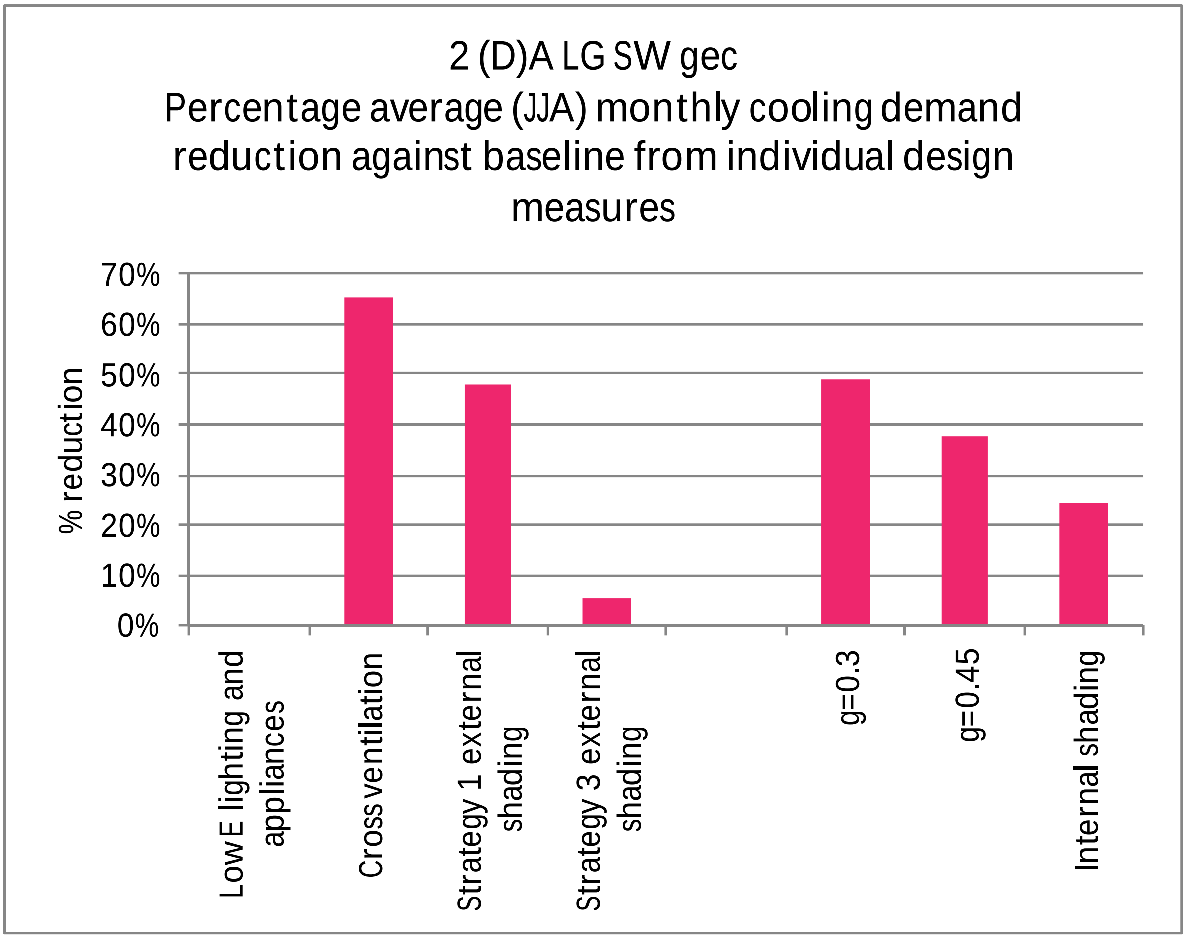


Figure 16: Percentage reduction in monthly average cooling demand (for June, July and August) for each individual design measure used under either strategy 1, 2 or 3 for typology 2 (D)A LG SW gec

The effect of reducing the glazing ratio was also determined by comparing the outputs from typologies 1 DA E pec and 1 DA LG E pec, and 2(D)A SW gec and 2(D)A LG SW gec. It was found that for typology 1, the change from 48% glazing to 25% glazing resulted in a 38% reduction in cooling demand and for typology 2, the change from 27% glazing to 25% glazing resulted in a 1% reduction in cooling demand. These findings highlight the importance of also considering glazing ratios as part of an integrated strategy to addressing the cooling hierarchy as the impact can be comparable to the best measures identified above.

Appendix E provides the results for the other two dwelling types, demonstrating the impacts of the individual measures on cooling demand.

5.2 Sensitivity testing

5.2.1 Internal gains test

Internal gains have considerable impact on the dwelling cooling demand and overheating risk. However, the amount of internal gains can vary significantly due to the different way in which people use their homes. In order to assess the impact of different occupancy on internal gains, two alternative options were evaluated for each of the 8 typologies investigated for strategies 2 and 3.

- The SAP assumptions on internal gains, as used in the previous modelling
- An assumption of an additional one person living in the dwelling all day and including a reasonable number of appliances within the unit.

The monthly cooling demands were determined for the months May to September for each of the 8 typologies and for each of the two sets of internal gain assumptions. To facilitate the representation of the results, the outputs for the 4 dwelling types were averaged to give a single value under good external conditions and another value for poor external conditions for each of the two sets of internal gain assumptions.

Figure 17 shows that in both instances, the SAP assumptions result in lower cooling demands. In the case of poor external conditions, the different internal gains resulted in a difference of around 20% in the cooling demand. Internal gains assumptions appear to be less of an issue under good external conditions, presumably as the higher ventilation rate is much more effective at cooling the dwelling..

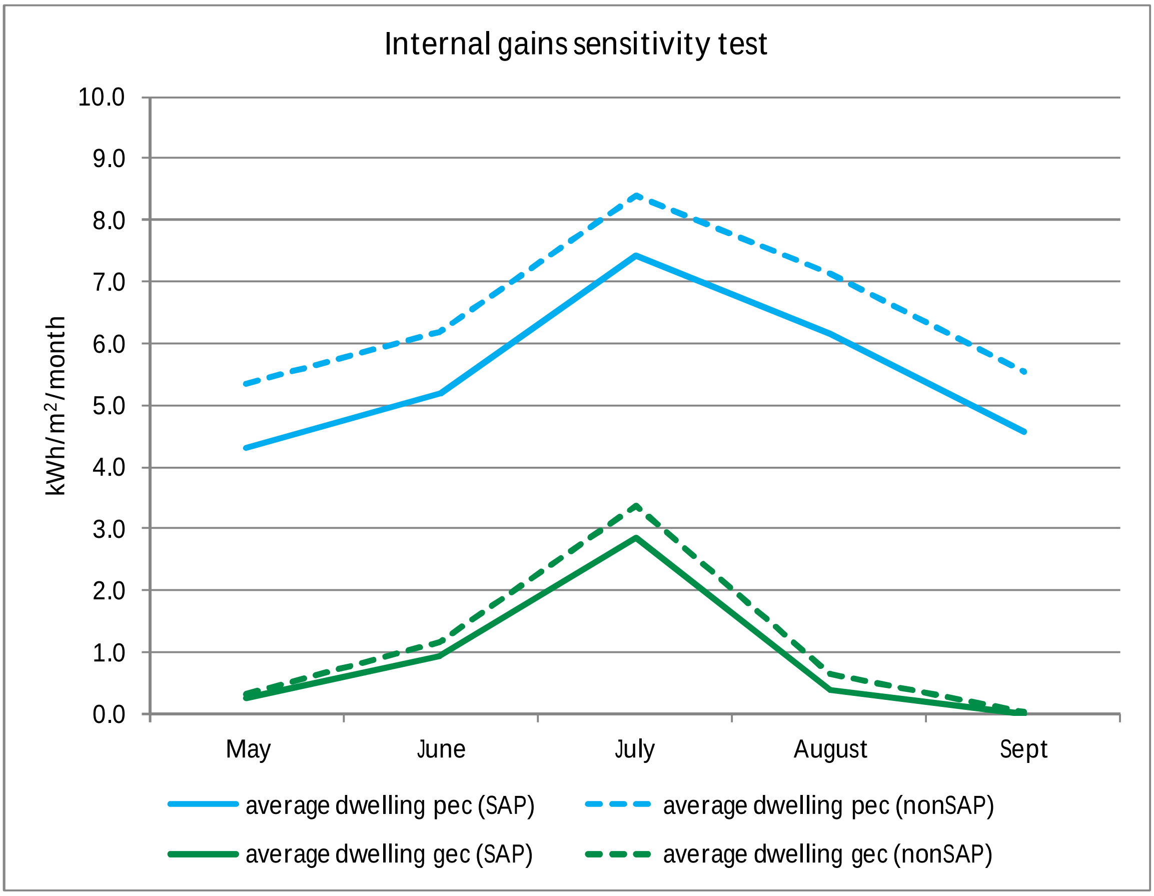


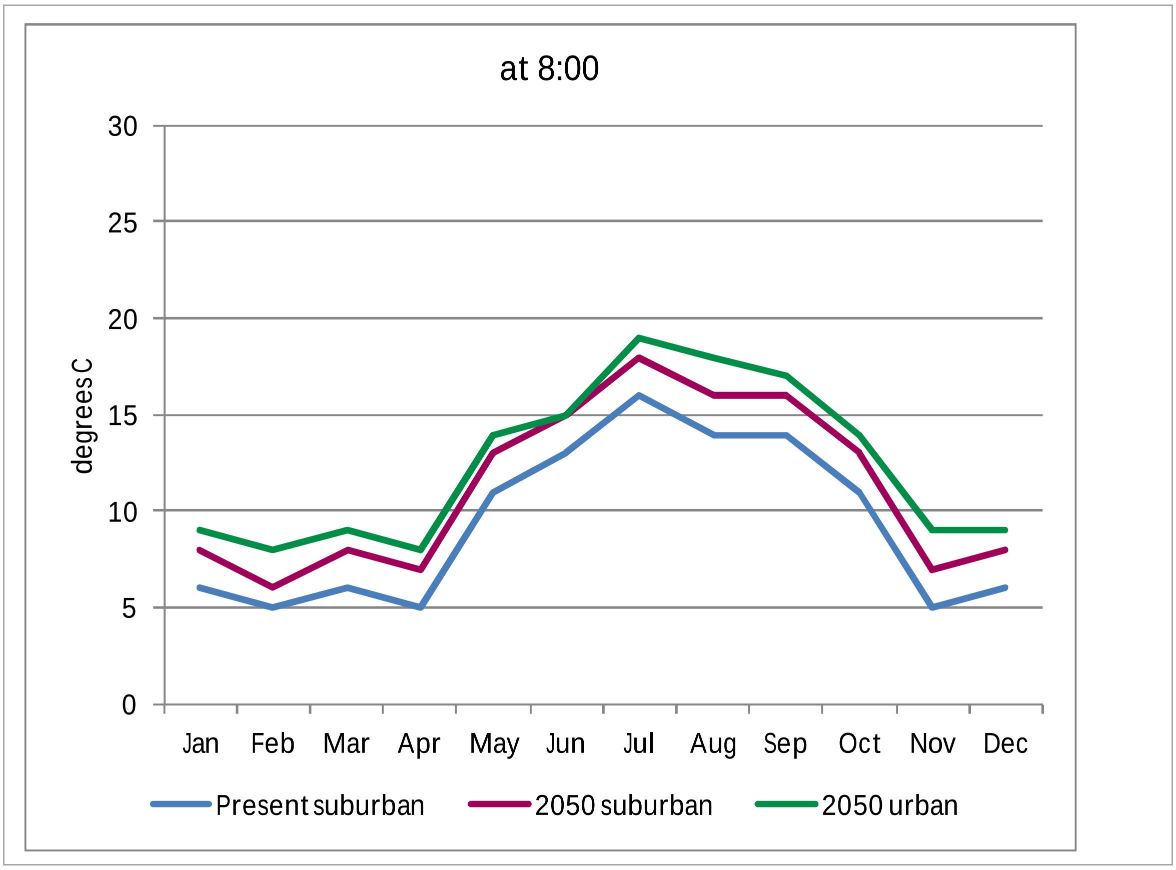
Figure 17: Internal gains sensitivity test results averaged over the 4 dwelling types (based on strategy 1)

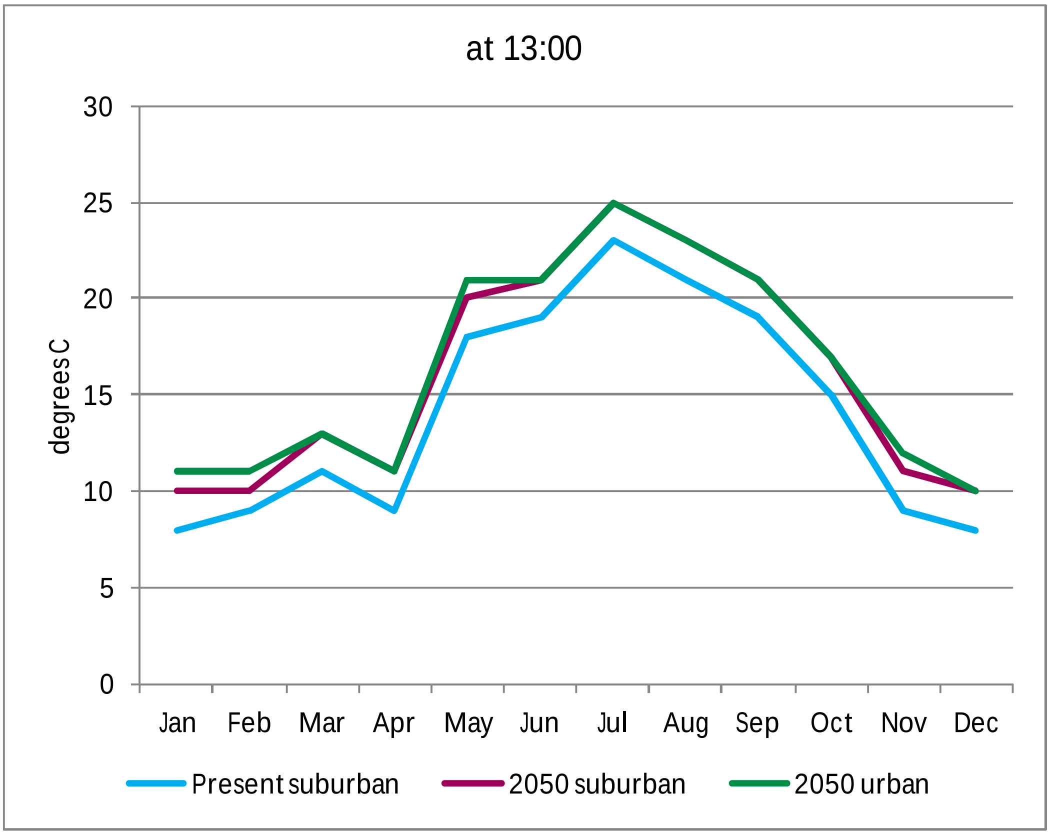
These findings highlight the importance of making realistic assumptions about internal gains, especially when designing buildings for vulnerable users such as residents in care homes and where opportunities to achieve significant ventilation through windows is limited.

5.2.2 Climate change and Urban Heat Island test

The cooling demands were also assessed for their sensitivity to exacerbating factors such as climate change and the urban heat island effect. In a similar manner to above, 8 typologies were investigated both with the standard weather tape used for the main modelling (present day, suburban location) and with a weather tape for a suburban and urban location under the climate projection for the 2050s assuming a medium emissions scenario. Again, the results for the 4 dwelling types were averaged for ease of graphical representation.

Figure 18 below shows the difference in air temperatures at four different times of day between the weather tape used for the bulk of the modelling and the weather tapes used for the sensitivity tests. The graphs suggest an increase of approximately 1-4 degrees between present and future scenarios. The difference is reasonably consistent throughout the day but particularly evident early in the morning. The change in location from suburban to urban for the future weather tapes appears to have limited impact compared to the likely impact of climate change.

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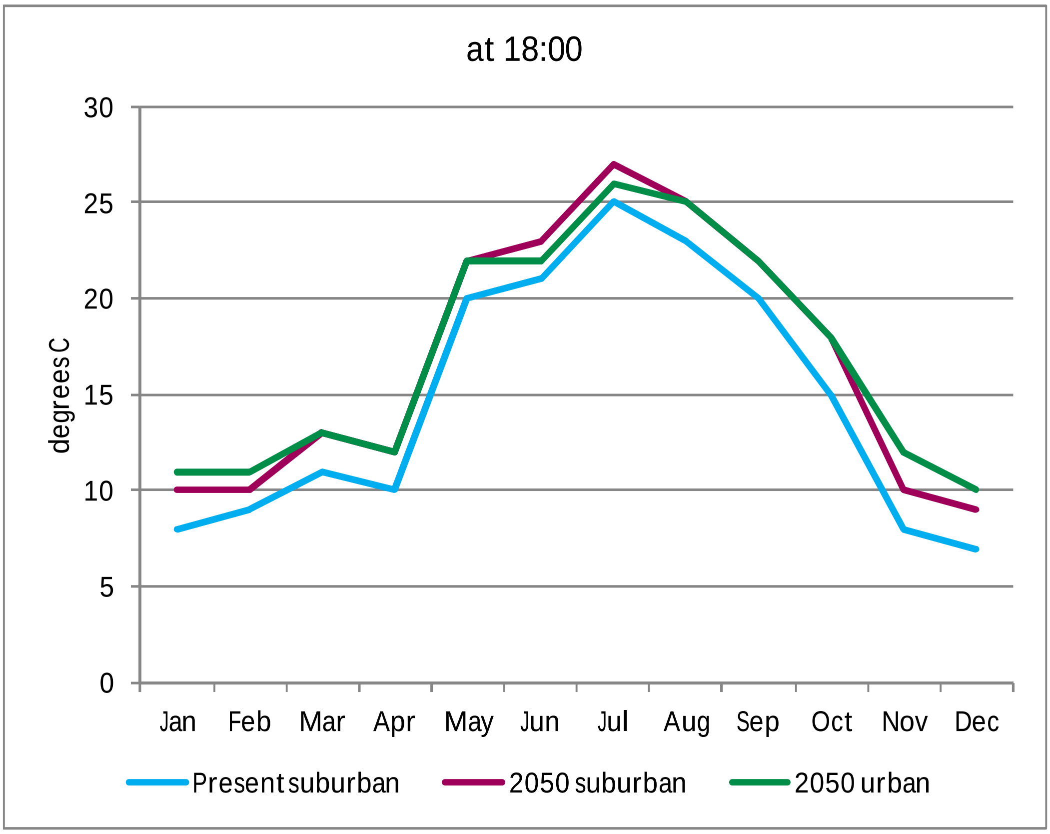
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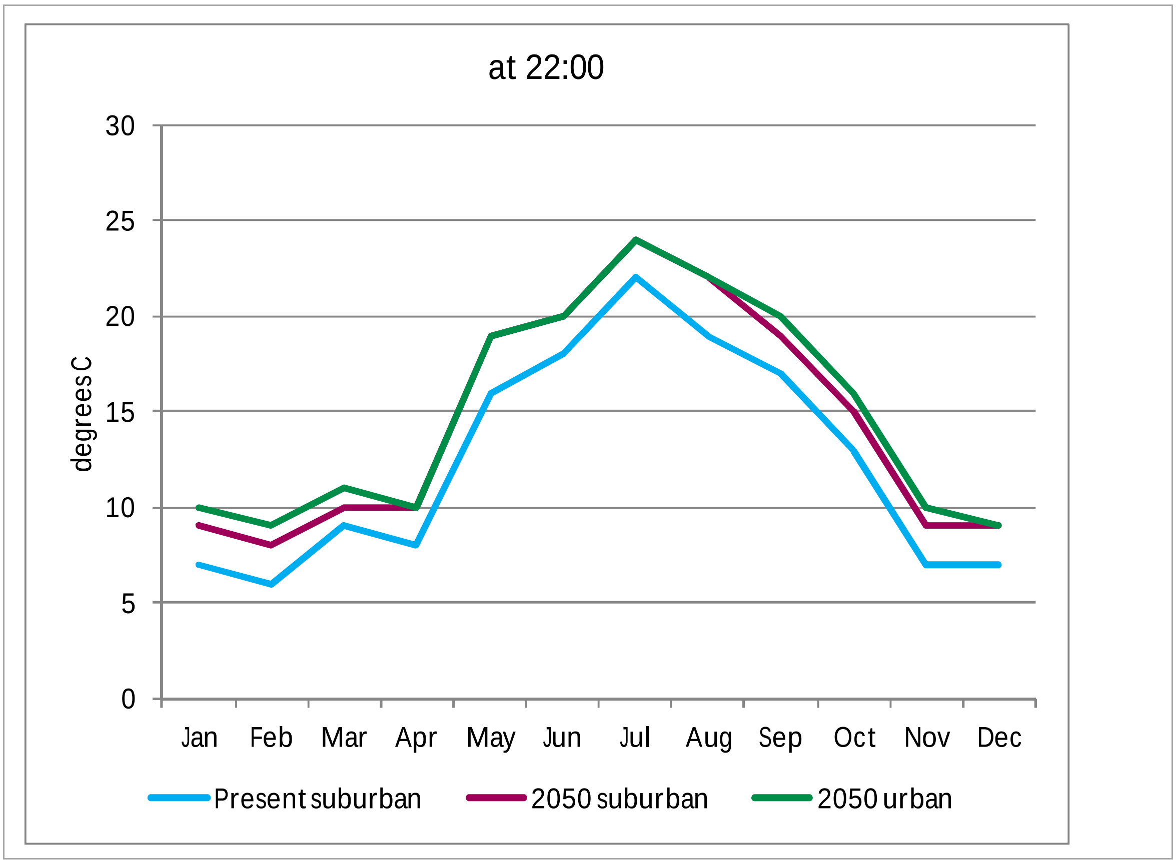
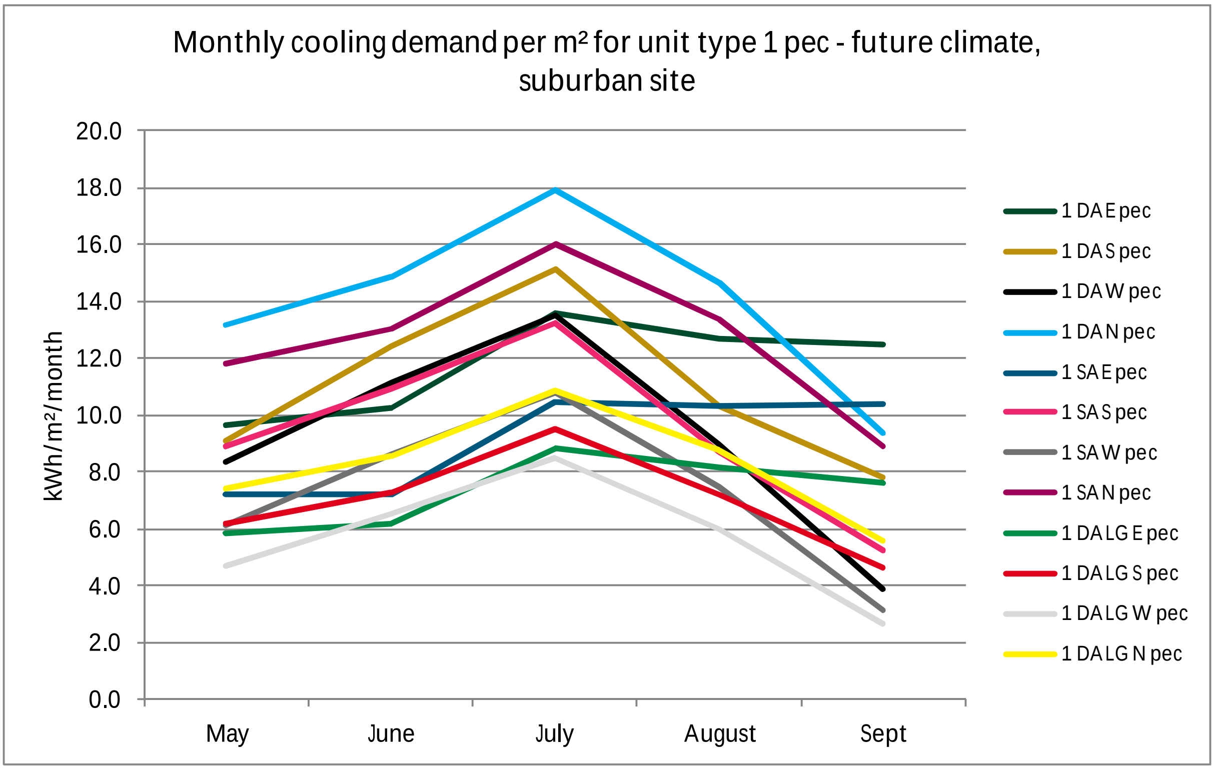


Figure 18: Comparison between yearly air temperatures at 4 different times of day for the present day London Heathrow weather tape and the 2050s Central London weather tape

Figure 19 shows that the overall trends in terms of monthly variation in demand under future climate conditions is not significantly different from those identified in the main modelling. However, it is clear that the absolute cooling demand under good conditions has significantly increased.



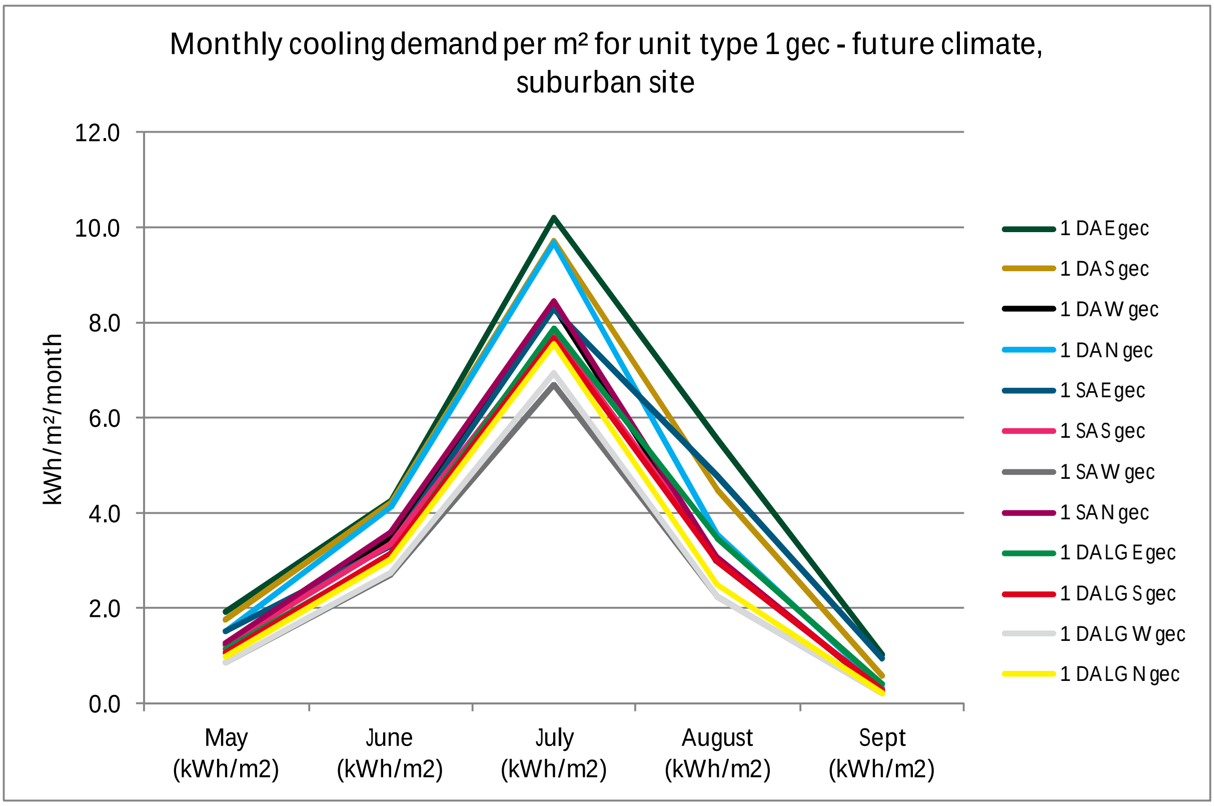


Figure 19: Monthly cooling demand per m² for the variations for unit type 1 (curtain wall mid floor flat) under poor and good external conditions and under a future climate scenario

To examine this in more detail, the results for the 4 dwelling types were averaged as for the internal gains sensitivity test. Figure 20 below compares the monthly cooling load under the current and future warmer scenarios for a suburban site and a future warmer central London site.

- Under poor external conditions, warmer external conditions (due to climate change and urban heat island) result in an average of around 20% increase in cooling demand.
- Of greater concern, the dwelling units under good external conditions show a much bigger increase, with cooling demands more than doubling on average and reaching the levels equivalent to those at present in dwellings without effective natural ventilation. This is due to the fact that with rising external temperatures, the cooling benefit of opening windows and introducing external air is significantly reduced. This becomes an even bigger issue in urban locations where the urban heat island effect does not allow external air temperatures to drop significantly at night therefore reducing the effectiveness of using natural cross ventilation to purge warm air accumulated within dwellings during the day. If external factors mean that external temperatures are higher than internal temperatures, natural cross ventilation can even become counter-productive as opening windows results in warmer air entering the dwelling.
- The urban location modelling results are very similar to those for the suburban location indicating that climate change is expected to have a much bigger impact than the urban heat island effect.

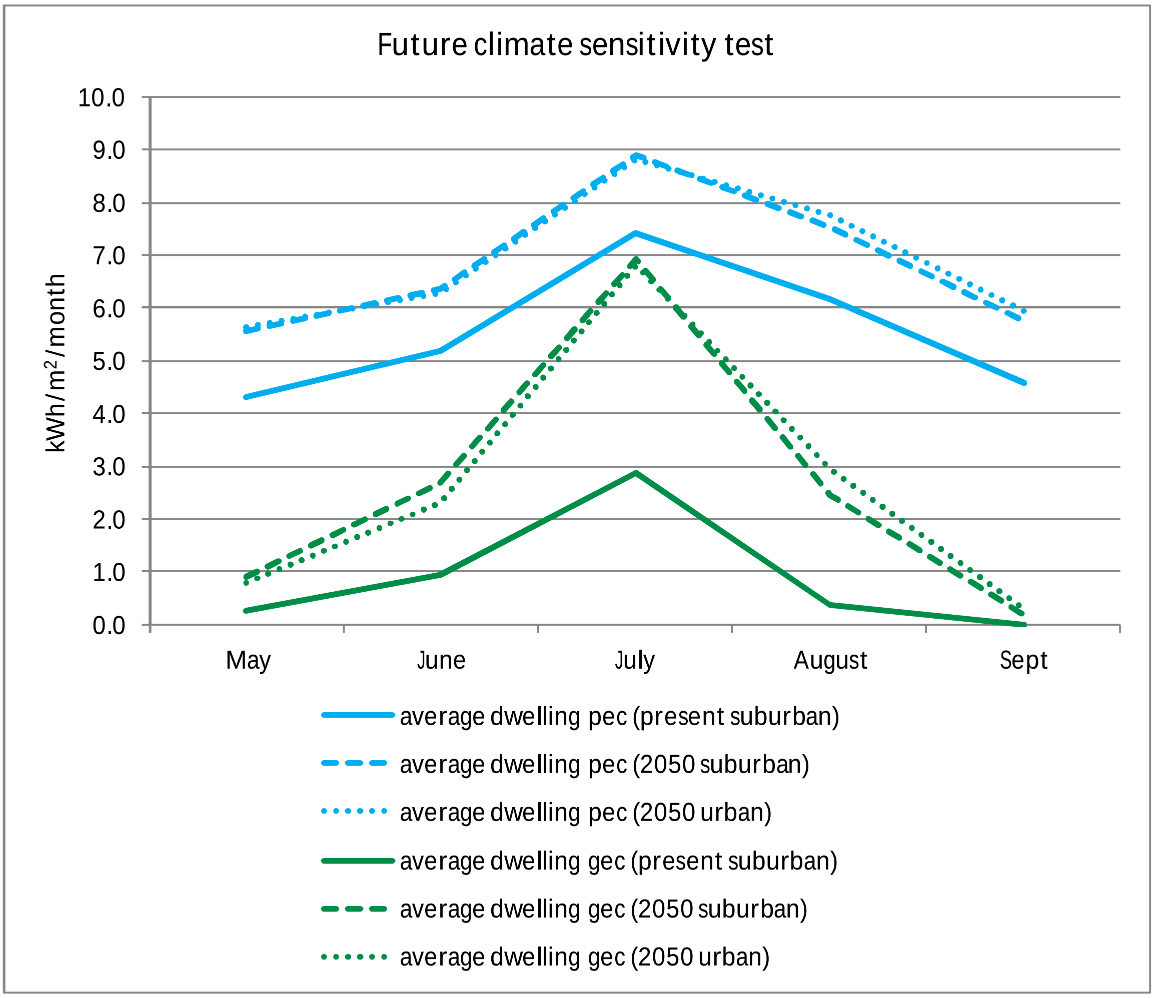


Figure 20: Climate change sensitivity test results averaged over the 4 dwelling types (based on strategy 1)

Given below are the outputs for strategy 1, 2 and 3 under the future climate and suburban location weather assumptions, i.e. the equivalent to Figure 10 but using the alternative weather tape. All three strategies show the loss of benefit from natural cross ventilation as external temperatures increase, however they still show overall lower cooling demands for the typologies under good external conditions. This may now be mostly due to the assumed “free” shading provided by surrounding buildings under the “gec” typologies.

Under warmer conditions the best performing strategy under good external conditions appears to generally be strategy 3, which assumes lower ventilation rates than strategy 1 and 2. This suggests that under these conditions, external temperatures are higher than internal ones so natural cross ventilation may at times be counterproductive.

The findings suggest that there may be a point in time when, if natural ventilation is no longer effective during certain periods of the year, it may be worth installing air conditioning at the outset, to avoid the installation of poor performing portable systems for the times when passive measures are no longer sufficient.

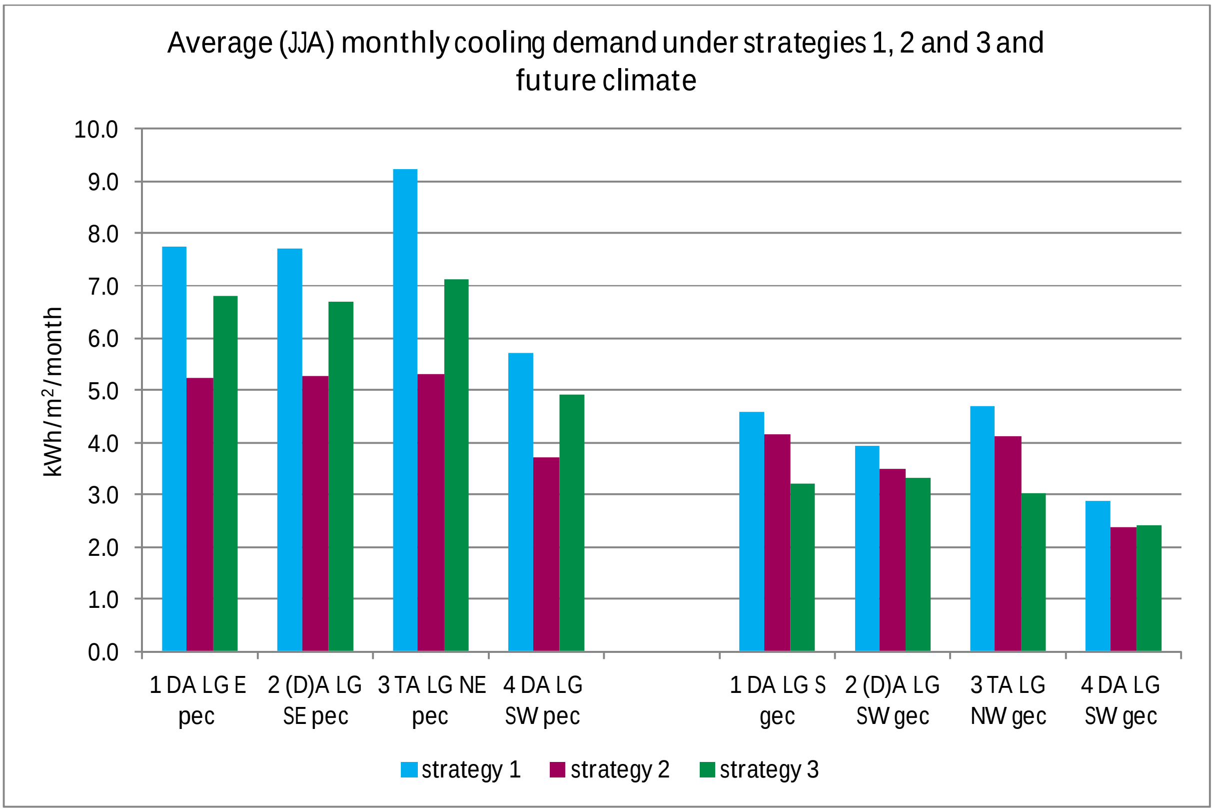


Figure 21: Average (for June, July and August) cooling demand for strategies 1, 2 and 3 for 8 sample typologies under the future climate scenario and suburban location

The results in this section identify that climate change is likely to have a considerable impact on cooling loads, highlighting the need to tackle these as much as possible via passive measures to avoid additional carbon emissions.

The urban heat island effect, when considered cumulatively with climate change, appears to have a relatively small exacerbating effect, however it does increase cooling demands highlighting that the location of the site should be given due consideration when approaching the cooling hierarchy,

5.3 Good practice measures ranking

The modelling exercise suggests the following indicative priority list of design measures based on effectiveness at reducing cooling demand without excessive negative effects on winter loads:

1. Designing dwelling and block layouts that allow natural cross ventilation wherever possible and ensuring that window designs or passive stack systems allow for sufficient air changes to be delivered.
2. Applying user controlled external shading methods appropriate to the orientation and construction type of the dwelling.

3. Where full external shading can’t be implemented, a combination of reduced glazing g values (but being mindful of impacts on winter energy loads) and partial external and/or internal shading can have the same effect.
4. Reducing glazing ratios to sufficient amounts to achieve good daylighting without resulting in excessive solar gains (e.g. glazing ratios of 25-30% of internal floor area).
5. Where natural ventilation is not possible, boosting mechanical ventilation to achieve higher air change rates when required.
6. Specifying low energy lighting and appliances to reduce internal gains.

5.4 Benchmarks

The variation in outputs between dwelling types is less significant that the variation between good and poor external conditions. Hence, two benchmarks have been proposed. Each is applicable to the different dwelling types. One is for developments that can take advantage of natural ventilation and the other is for those that can’t due to their location.

Furthermore, the benchmarks have been proposed for the cooling demand during the month of July which has been found to be the peak cooling month across the year.

The comparison between strategies 1, 2 and 3 suggested that strategy 1 can be bettered by other design approaches and should be stretched further. Strategy 3 appears to be a reasonable mid position between the three strategies, both in consideration of both cooling and heating loads, and a pragmatic option to develop the benchmarks. However strategy 3 was only modelled for 8 typologies, which do not cover all variations for orientation, aspect etc.

In order to develop a benchmark range that accounts for variations in orientation, aspect and glazing ratios it is proposed to use the average percentage reduction in July cooling demand between strategy 1 and strategy 3 and apply the reduction to the July demands calculated for the 96 typologies under strategy 1.

This approach gives the following benchmark figures based on the averages across the typologies. An upper maximum figure was also identified, this is based on the full range of typologies with the exception of the north facing ones as these were found to have excessively high cooling demands due to the modelling assumption that no shading was provided to north facades.

Dwelling type	Average for July (kWh/m²/y))	Maximum (kWh/m²/y)
Average dwelling under good external conditions	2.3	3.7
Average dwelling under poor external conditions	7.8	11.1

Table 10: Proposed cooling demand benchmarks

The position of the benchmarks proposed in Table 10 relative to the July demands for the unit typologies under good and poor external conditions are illustrated in Figure 22 and Figure 23 respectively.

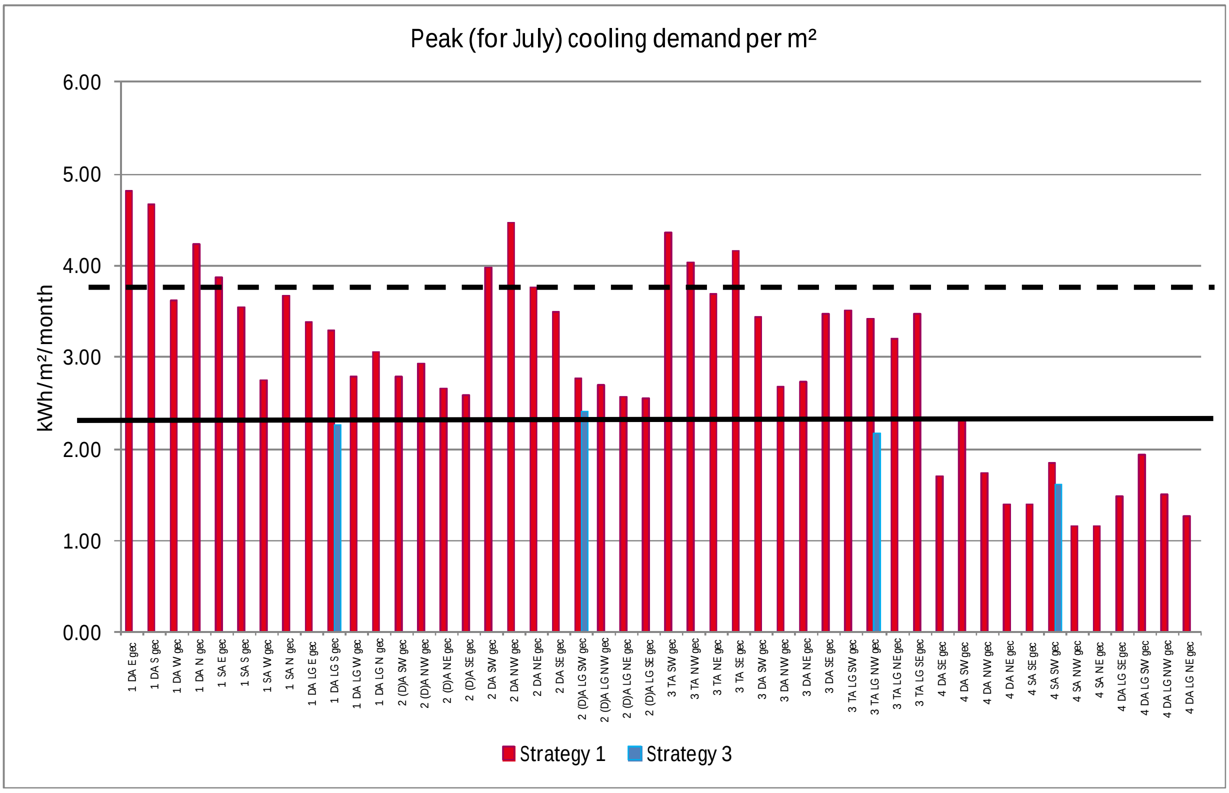


Figure 22: Proposed benchmark range against July cooling demand figures for typologies under good external conditions

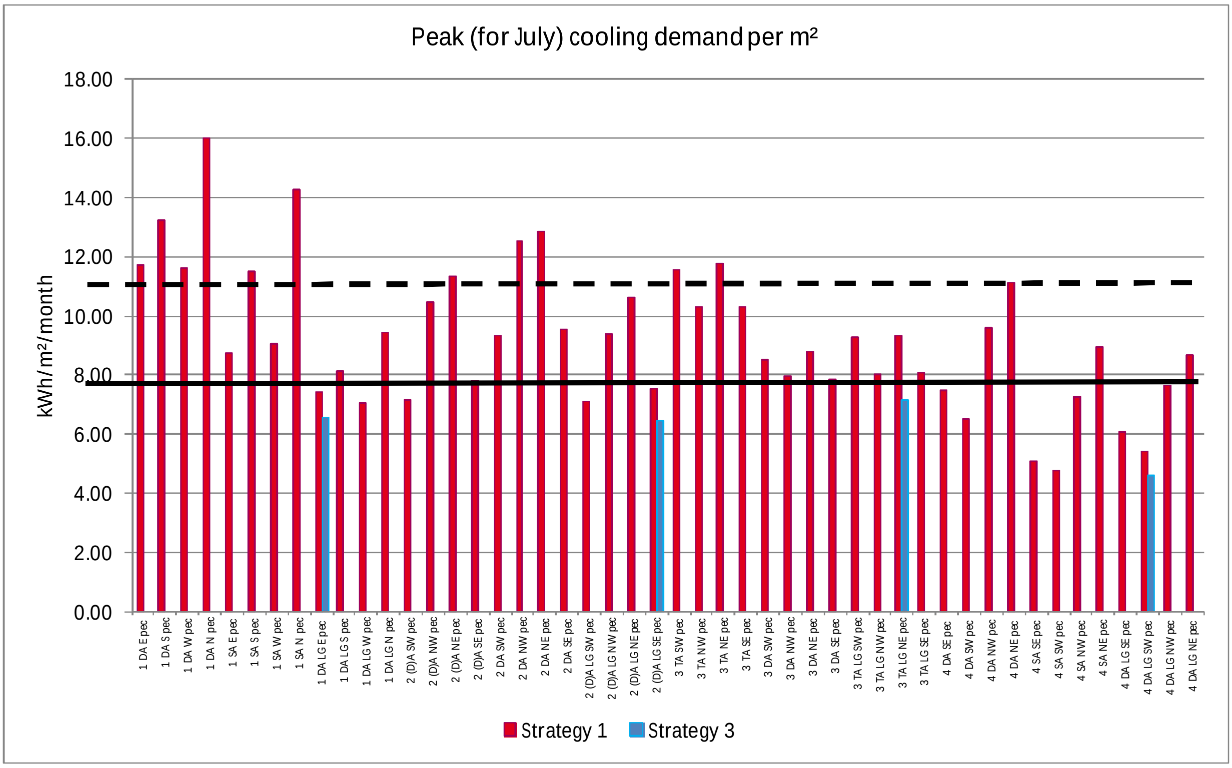


Figure 23: Proposed benchmark range against July cooling demand figures for typologies under poor external conditions

6.0 Conclusions and recommendations

The outputs from the analysis suggest some key findings, including:

- The ability to naturally ventilate a dwelling has a major impact on its cooling demand. Across the typologies tested naturally ventilated dwellings have around 20% to 35% of the cooling demands of units without openable windows or with restricted ventilation options. The benefits from natural ventilation as a design solution however reduce as external conditions warm due to climate change or the urban heat island effect.
- Reducing glazing to floor area ratio has a considerable impact on reducing cooling demands. The extent of this impact depends on the glazing reduction. The greatest impact was observed for the curtain walled flat where the glazing ratio was reduced from 48% to 25% which resulted in a 38% reduction on cooling load. Note that is has been assumed in the modelling that the ventilation rate stays consistent as per SAP assumptions e.g. with less glazing, the window is open wider.
- Single aspect units with good levels of natural ventilation have slightly lower cooling demands than dual aspect units with partial cross ventilation (i.e. windows on two facades but not opposite ones). The greater ventilation rate from partial cross ventilation is balanced by increased solar gains from greater amount of glazing. The same trend was found for the penthouse which is the only typology with full cross ventilation (i.e. windows on opposite facades) where the aspect was changed from triple to double.
- The use of methods to limit solar gains is one of the most effective measures to reduce cooling demand, with modelled reductions of over 50%. Applying external shading or reducing glazing g value have similar levels of effectiveness. Furthermore, internal blinds provide a significant alternative solution albeit limited benefit if additional to either external shading or reduced g-values. However, it is noted that reducing the g value can significantly increase heating demands in winter (and hinder compliance with the TER) and potentially impact on daylighting levels.
- Internal gains assumptions can have a significant impact on the outputs, especially for dwellings where natural ventilation is constrained. Under poor external conditions the sensitivity testing suggested a 20% potential increase in cooling when changing internal gains assumptions. This highlights the importance of the assumptions made when carrying out overheating assessments using dynamic thermal modelling, as the assumptions are at the discretion of the modeller. It also highlights a key limitation of SAP as a design tool when addressing overheating as the assumptions on internal gains are fixed and intended for consistency (as SAP is a compliance tool) rather than to be a true reflection of the internal gains in a particular dwelling.
- Climate change will affect cooling demands especially for naturally ventilated dwellings and will consequently have a big influence on the ability of a passive design strategy to be effective in the long term.

These findings suggest that a good practice approach to the cooling hierarchy would be as follows:

- Develop a design approach that is bespoke to the type of building, occupants, expected lifetime and location to account for differences in external climatic conditions, need for resilience and occupancy profiles and vulnerability of residents.
- Assume realistic internal gains for the intended residents of the dwellings and reduce these as much as possible by specifying energy efficient lighting and appliances.
- Limit glazing amounts to levels required to achieve a good balance of daylighting, ventilation and solar gains. Differentiate the approach depending on the facade and room use (e.g. bedrooms don't necessarily need the same levels of daylighting as living rooms and kitchens).
- Maximise opportunities for natural cross ventilation by designing windows with large openable areas, and dwelling layouts that allow cross ventilation either via windows or ventilation shafts.
- Where necessary and possible, mitigate poor external conditions. At building level through the use of winter gardens or noise treatment to windows, ventilation grates with filters to address poor air quality etc. At development / masterplan level through the use of vegetation, light coloured materials and green roofs to counter the urban heat island effect and improve local air quality.
- Develop an effective strategy to minimise solar gains in summer without negatively affecting winter heating loads and daylighting levels. User controlled external mechanisms (e.g. shutters, external venetian blinds, sliding screens) will be the most effective at achieving this as they provide shading only when needed but can be kept open during the winter.

6.1 Conclusions

- SAP methodology does not allow to properly account for design response to the cooling hierarchy
- SAP cooling demands are significantly lower than those identified in IES
- Variation in cooling demands per m^2 between dwelling types appears mostly related to the proportion of glazing relative to the volume of the dwellings. In the typologies where the glazing ratio was reduced to 25% the variations between dwelling types were considerably reduced
- Ensuring that dwellings can be naturally ventilated is vital to keeping cooling demands low in current and future climate conditions so every effort should be made by designers to design block and dwelling typologies that allow dwellings to be naturally ventilated. Design teams should also focus on mitigating external

conditions that may hinder the use of natural ventilation such as air and noise pollution.

- Developing a successful method of controlling solar gains is the other most important action to reduce cooling demand. The most effective method to address solar gains in summer without losing the benefit of solar gains in winter is through the use of user controlled external shading mechanisms so designers should be encouraged to develop innovative and aesthetically pleasing approaches to external shading. Fixed external shading and reduced g value glazing are also effective and can contribute to a successful response to the cooling hierarchy.
- Internal gains assumptions can have a significant effect on cooling demand. Realistic assumptions are particularly important when considering the risk of overheating in buildings with vulnerable users with intense occupancy patterns such as care homes.

Climate change will result in significantly higher cooling demands so designers should include passive design measures at the outset to ensure that buildings are resilient throughout their lifetime.

6.2 Recommendations

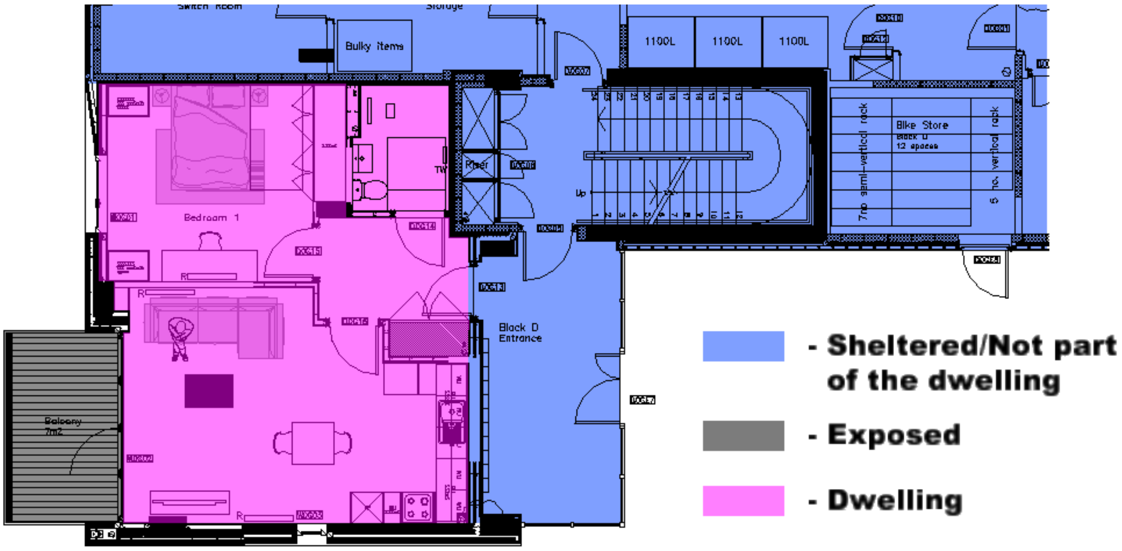
- Where overheating modelling is required, provide clearer guidance about what dwelling typologies should be modelled, what internal gains assumptions should be used and what climate change scenarios should be tested. This would allow a more systematic assessment of developer responses as currently the extent and approach to the overheating modelling is left at the discretion of the energy consultant and therefore can vary significantly across developments.
- Where dynamic thermal modelling is carried out, request average July cooling demand across dwelling types modelled to compare against the benchmark range. It would be expected that outputs from other modelling software should fall within the range identified in section 5.4, however this will need to be determined when assessing the first applications.
- GLA could produce a checklist for developers to complete with information about glazing ratios, shading methods, ventilation options etc. to help determine whether the development is likely to have overheating problems that should be investigated further. It could be used to identify when detailed modelling is required and could help monitor typical responses to the cooling hierarchy.
- GLA could work with architects and ventilation engineers to identify a range of window typologies and ventilation solutions that maximise the potential for natural cross ventilation.

Appendix A: Floor plans of dwelling types modelled

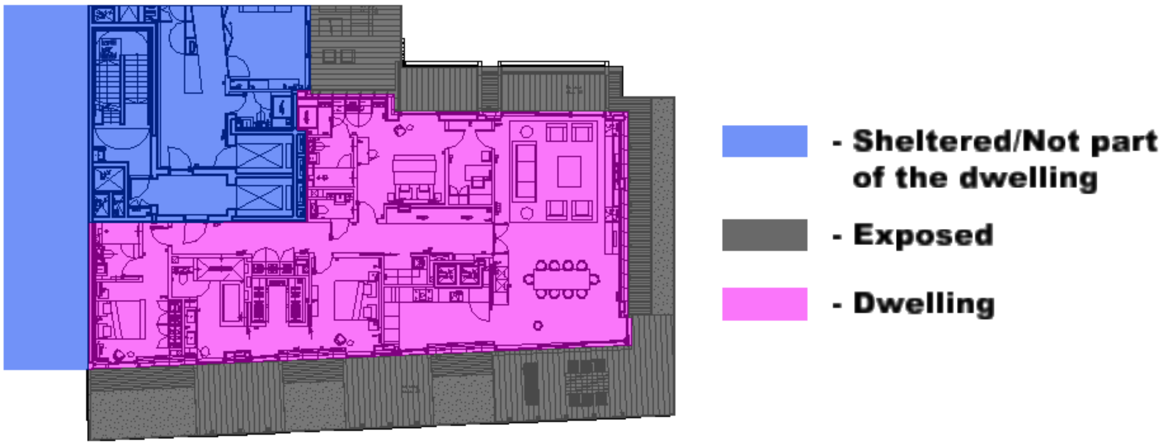
3D sketches of the dwelling types and the aspect and glazing variations used for the different typologies are shown in Appendix D.

Curtain walled unit - 2 bed mid floor – 99m^2

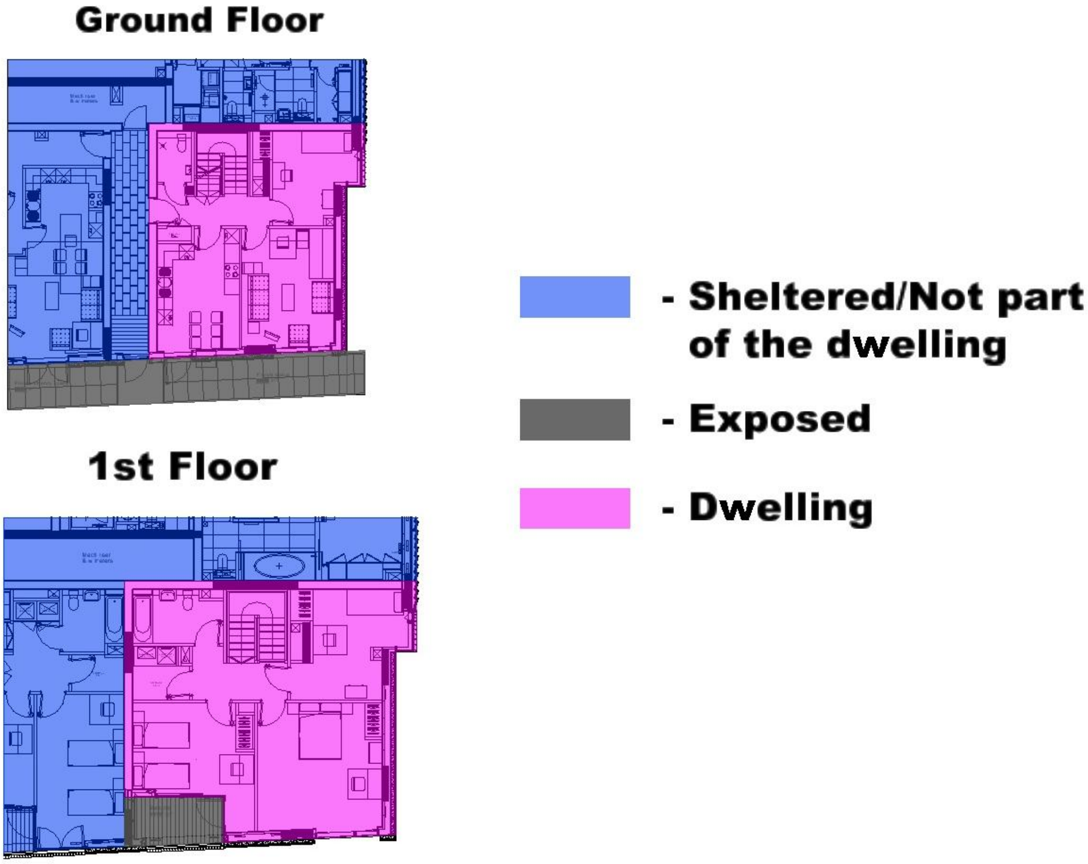
Traditional build unit – 1 bed, mid floor – 58m^2



Penthouse – 3 bed, top floor – 219m^2



Duplex masonry construction – 4 bed, ground and first floor – 146m^2



Appendix B: Packages of modelled measures per dwelling typology

Strategy 1

	Typology features							Design measures							
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
1 DA E pec	1	Curtain walled 2 bed mid floor	Double (as designed)	48%	E	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 DA S pec	1	Curtain walled 2 bed mid floor	Double (as designed)	48%	S	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 DA W pec	1	Curtain walled 2 bed mid floor	Double (as designed)	48%	W	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 DA N pec	1	Curtain walled 2 bed mid floor	Double (as designed)	48%	N	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 SA E pec	1	Curtain walled 2 bed mid floor	Single	43%	E	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 SA S pec	1	Curtain walled 2 bed mid floor	Single	43%	S	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 SA W pec	1	Curtain walled 2 bed mid floor	Single	43%	W	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 SA N pec	1	Curtain walled 2 bed mid floor	Single	43%	N	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 DA LG E pec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	E	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 DA LG S pec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	S	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 DA LG W pec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	W	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N
1 DA LG N pec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	N	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	N	Y	N	N

	Typology features							Design measures							
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
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1 DA S gec	1	Curtain walled 2 bed mid floor	Double (as designed)	48%	S	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
1 DA W gec	1	Curtain walled 2 bed mid floor	Double (as designed)	48%	W	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
1 DA N gec	1	Curtain walled 2 bed mid floor	Double (as designed)	48%	N	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
1 SA E gec	1	Curtain walled 2 bed mid floor	Single	43%	E	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 4 ach	Y	N	N
1 SA S gec	1	Curtain walled 2 bed mid floor	Single	43%	S	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 4 ach	Y	N	N
1 SA W gec	1	Curtain walled 2 bed mid floor	Single	43%	W	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 4 ach	Y	N	N
1 SA N gec	1	Curtain walled 2 bed mid floor	Single	43%	N	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 4 ach	Y	N	N
1 DA LG E gec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	E	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
1 DA LG S gec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	S	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
1 DA LG W gec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	W	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
1 DA LG N gec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	N	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max vertical fins on east / west facades max brise soleil on south facade nothing on north facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N

Typology features							Design measures							
Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N

Typology features							Design measures							
Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	27%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 5ach	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 5ach	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 5ach	Y	N	N
2	Trad build 1 bed mid floor	Double wt cross vent	28%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 5ach	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N
2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	Y - 4 ach	Y	N	N

	Typology features								**Design measures**						
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
3 TA SW pec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 TA NW pec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 TA NE pec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 TA SE pec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 DA SW pec	3	Penthouse 3 bed top floor	Double	21%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 DA NW pec	3	Penthouse 3 bed top floor	Double	21%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 DA NE pec	3	Penthouse 3 bed top floor	Double	21%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 DA SE pec	3	Penthouse 3 bed top floor	Double	21%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 TA LG SW pec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 TA LG NW pec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 TA LG NE pec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N
3 TA LG SE pec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	N	Y	N	N

	Typology features							Design measures							
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
3 TA SW gec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N
3 TA NW gec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N
3 TA NE gec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N
3 TA SE gec	3	Penthouse 3 bed top floor	Triple (as designed)	38%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N
3 DA SW gec	3	Penthouse 3 bed top floor	Double	21%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
3 DA NW gec	3	Penthouse 3 bed top floor	Double	21%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
3 DA NE gec	3	Penthouse 3 bed top floor	Double	21%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
3 DA SE gec	3	Penthouse 3 bed top floor	Double	21%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 5ach	Y	N	N
3 TA LG SW gec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N
3 TA LG NW gec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N
3 TA LG NE gec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N
3 TA LG SE gec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	max brise soleil on SE, SW facade nothing on NE NW facades	internal light coloured blinds	0.6	Y - 6ach	Y	N	N

	Typology features							Design measures							
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
4 DA SE pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 DA SW pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 DA NW pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 DA NE pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 SA SE pec	4	Trad build duplex 4 bed ground and first floor	Single	19%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 SA SW pec	4	Trad build duplex 4 bed ground and first floor	Single	19%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 SA NW pec	4	Trad build duplex 4 bed ground and first floor	Single	19%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 SA NE pec	4	Trad build duplex 4 bed ground and first floor	Single	19%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 DA LG SE pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 DA LG SW pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 DA LG NW pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	NW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N
4 DA LG NE pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on SE, SW facades, nothing on NE and NW facades	N	0.6	N	Y	N	N

Note: the single aspect variation of this dwelling results in a glazing ratio of 19% which is slightly below the good practice 20% target set in the Housing SPG for good daylighting levels.

	Typology features							Design measures							
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
4 DA SE gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N
4 DA SW gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N
4 DA NW gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N
4 DA NE gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	30%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N
4 SA SE gec	4	Trad build duplex 4 bed ground and first floor	Single	19%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 2.5 ach (with vent shaft and secure grate/blind)	Y	N	N
4 SA SW gec	4	Trad build duplex 4 bed ground and first floor	Single	19%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 2.5 ach (with vent shaft and secure grate/blind)	Y	N	N
4 SA NW gec	4	Trad build duplex 4 bed ground and first floor	Single	19%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 2.5 ach (with vent shaft and secure grate/blind)	Y	N	N
4 SA NE gec	4	Trad build duplex 4 bed ground and first floor	Single	19%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 2.5 ach (with vent shaft and secure grate/blind)	Y	N	N
4 DA LG SE gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N
4 DA LG SW gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N
4 DA LG NW gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N
4 DA LG NE gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	NE	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	shutters / external blinds on all facades (even NE and NW facades if it allows secure cross vent)	N	0.6	Y - 3 ach (with secure vent grate/blind)	Y	N	N

Strategy 2

	Typology features							Design measures							
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
1 DA LG E pec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	E	N	N	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	N	Y	Y - 1ach	N
1 DA LG S gec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	S	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	Y - 5ach	Y	N	N
2 (D)A LG SE pec	2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	N	Y	Y - 1ach	N
2 (D)A LG SW gec	2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	Y - 4 ach	Y	N	N
3 TA LG NE pec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	N	Y	Y - 1ach	N
3 TA LG NW gec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	Y - 6ach	Y	N	N
4 DA LG SW pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	N	Y	Y - 1ach	N
4 DA LG SW gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	N	internal light coloured blinds	0.3	Y - 3 ach (with secure vent grate/blind)	Y	N	N

Strategy 3

	Typology features							Design measures							
Typology identifier	Unit type		Aspect	Average glazing ratio	Orientation of majority of living room windows	Windows can be opened for comfort (i.e. No noise / pollution issues)	There is some shading from surrounding buildings	Low E lighting and appliances	External shading	Internal shading	Glazing g value	Natural cross ventilation	MVHR with summer bypass	mechanical ventilation boost for purge vent	Active cooling
1 DA LG E pec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	E	N	N	Y assume improvement from CLFs (in baseline) to LEDs	standard vertical fins on east / west facades (or deep window reveals); standard brise soleil on south facade (or overhangs); nothing on north facades	internal light coloured blinds	0.45	N	Y	N	N
1 DA LG S gec	1	Curtain walled 2 bed mid floor	Double (as designed)	25%	S	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	standard vertical fins on east / west facades (or deep window reveals); standard brise soleil on south facade (or overhangs); nothing on north facades	internal light coloured blinds	0.45	Y - 2.5ach	Y	N	N
2 (D)A LG SE pec	2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	standard vertical fins on SE / SW / NE/ NW facades (or deep window reveals)	internal light coloured blinds	0.45	N	Y	N	N
2 (D)A LG SW gec	2	Trad build 1 bed mid floor	Double no cross vent (as designed)	25%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	standard vertical fins on SE / SW / NE/ NW facades (or deep window reveals)	internal light coloured blinds	0.45	Y - 2 ach	Y	N	N
3 TA LG NE pec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NE	N	N	Y assume improvement from CLFs (in baseline) to LEDs	standard brise soleil on SE /SW facade; standard vertical fins on NE / NW facades	internal light coloured blinds	0.45	N	Y	N	N
3 TA LG NW gec	3	Penthouse 3 bed top floor	Triple (as designed)	50% in living 25% other rooms	NW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	standard brise soleil on SE /SW facade; standard vertical fins on NE / NW facades	internal light coloured blinds	0.45	Y - 3 ach	Y	N	N
4 DA LG SW pec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SW	N	N	Y assume improvement from CLFs (in baseline) to LEDs	standard vertical fins on SE / SW / NE/ NW facades (or deep window reveals)	internal light coloured blinds	0.45	N	Y	N	N
4 DA LG SW gec	4	Trad build duplex 4 bed ground and first floor	Double (as designed)	25%	SW	Y	Y	Y assume improvement from CLFs (in baseline) to LEDs	standard vertical fins on SE / SW / NE/ NW facades (or deep window reveals)	internal light coloured blinds	0.45	Y - 1.5 ach	Y	N	N

Appendix C: MacroFlo ventilation test

Introduction

The ventilation strategy is an important consideration when predicting the cooling energy required in a dwelling. For this work, rather than define the cooling energy benchmarks using a specific window arrangement, we intend to use air change rates taken from industry guidance. This will allow the design teams flexibility in deciding how to achieve the necessary ventilation, or even adopt alternative design measures. Nonetheless, to ensure that these ventilation assumptions are appropriate, we have tested an example dwelling. The dwelling under consideration is a 58m², mid-floor flat, as illustrated in Figure 1.

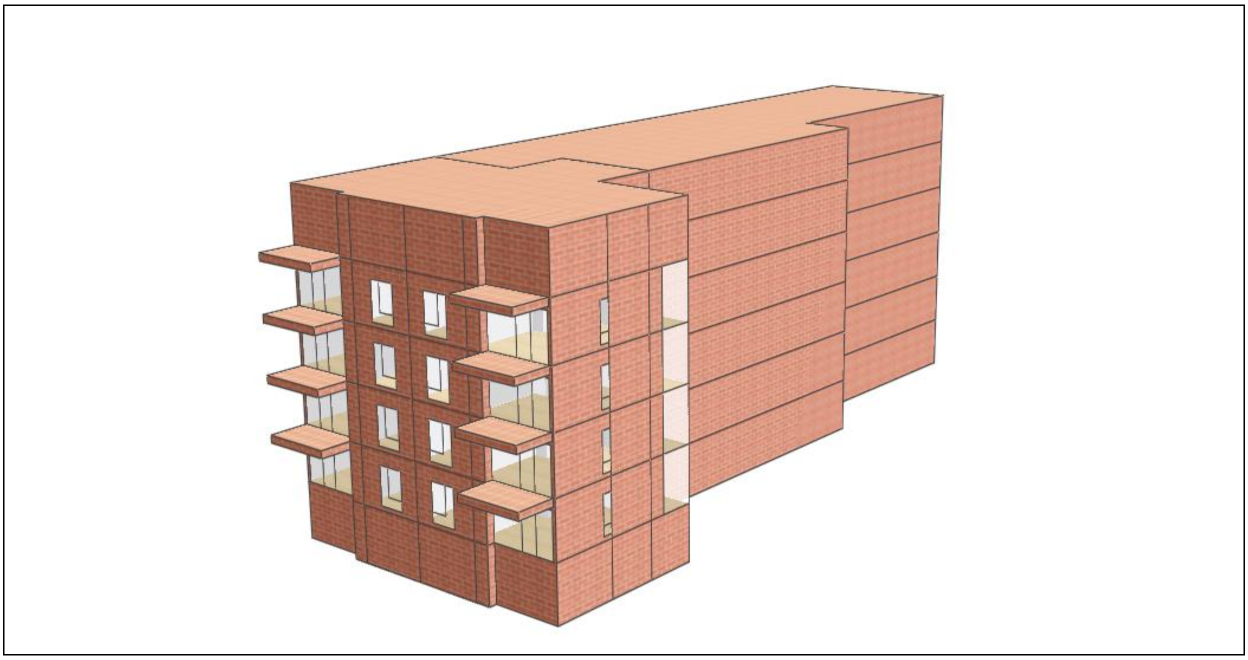


Figure 1: The example mid-floor flat

Methodology

The example dwelling was assessed in the IES Virtual Environment dynamic thermal modelling software using the MacroFlo module. For this test, all windows were assumed to have a 10% openable area, which were opened when the internal temperature exceeded 20ºC. In practice, the openable area is dependent on the type and design of the windows, as well as the overall dimensions. MacroFlo calculates the ventilation through these openings based on the external environment conditions, which in this case were based on the London TRY weather tape.

Results

This dwelling is predominately single-sided and the results indicate that 4 ach should be achievable during the summer months (see Figure 2). In mid-season, the ventilation rate is lower since the internal temperature means that the windows are not opened as often. It should be noted that at 10% the openable area is not insignificant and various site or design constraints may mean this is difficult to achieve.

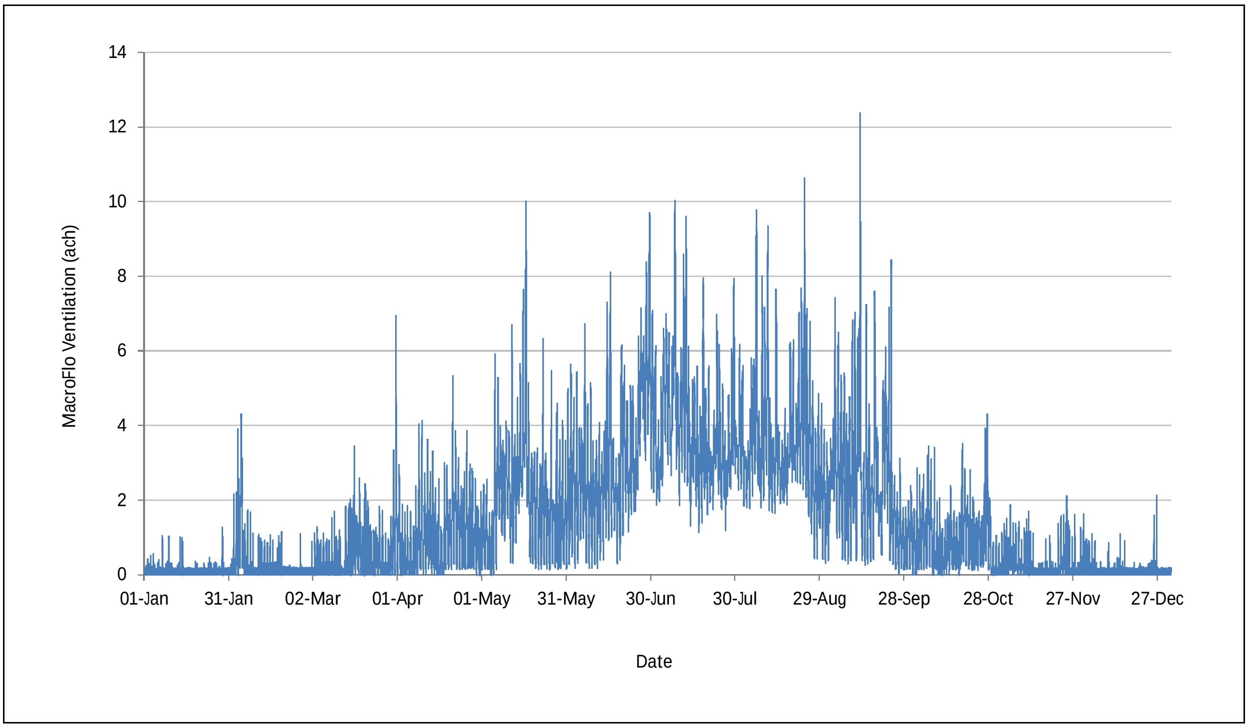


Figure 2: The MacroFlo ventilation rate

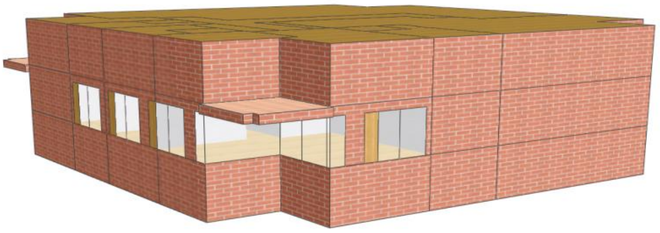
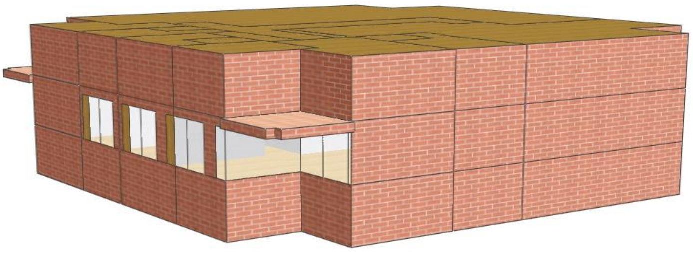
Appendix D: Detailed modelling assumptions

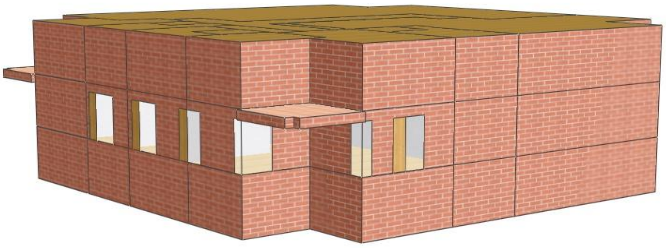
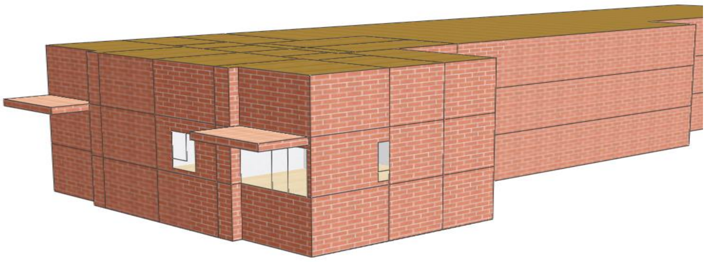
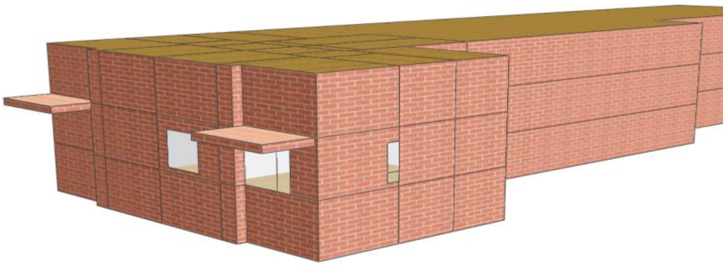
Introduction

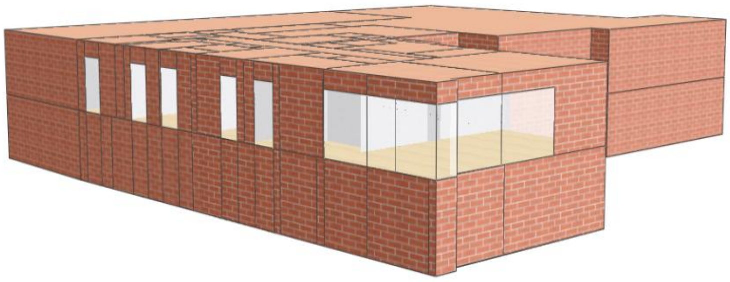
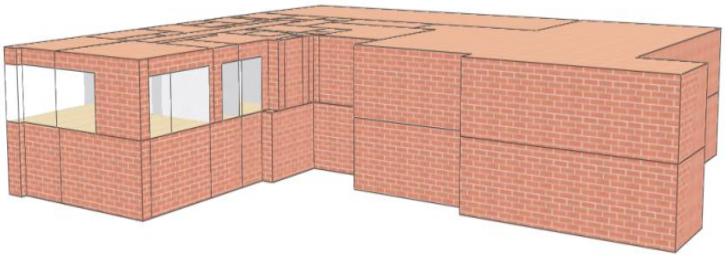
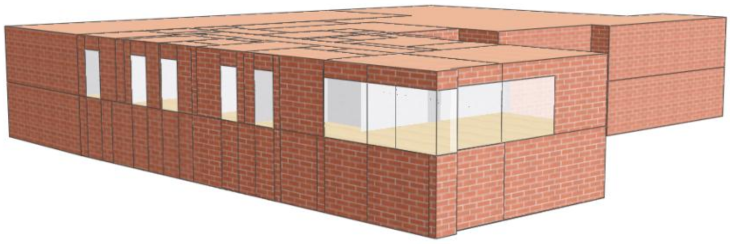
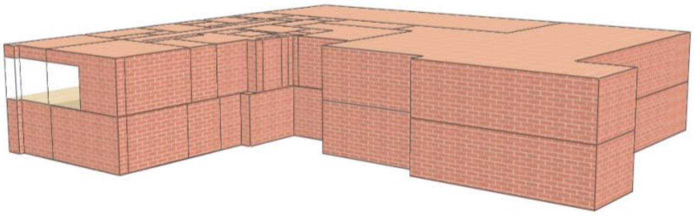
This document consists of the inputs for the cooling benchmarking study for 4 types of flats. The 4 types of flats are curtain walled unit – 2 bed mid floor, traditional build unit- 1 bed mid floor, penthouse unit – 3 bed top floor and duplex flat – 4 bed ground and first floor. A number of flats from recent AECOM projects were used in this exercise. A base model for the 4 types of flat will be built and a number of design iterations will be applied to the models to determine to test the cooling demand of each design measure and improve it.

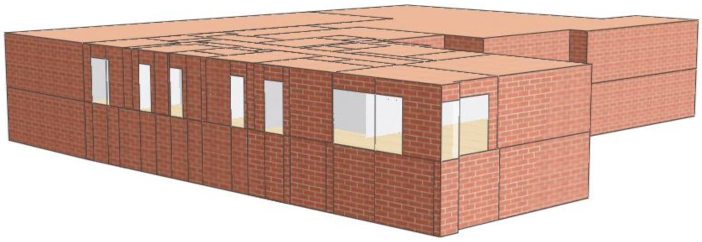
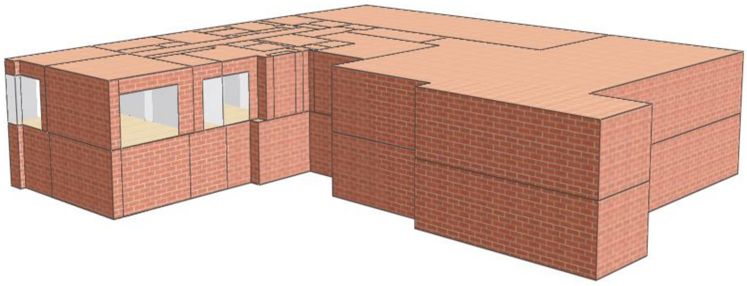
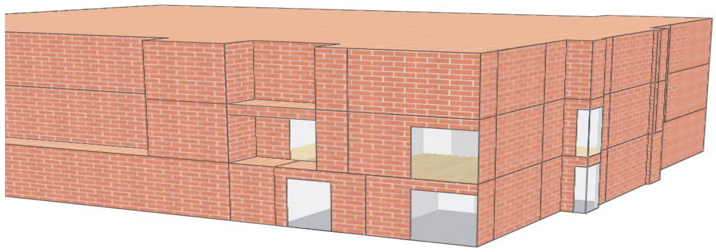
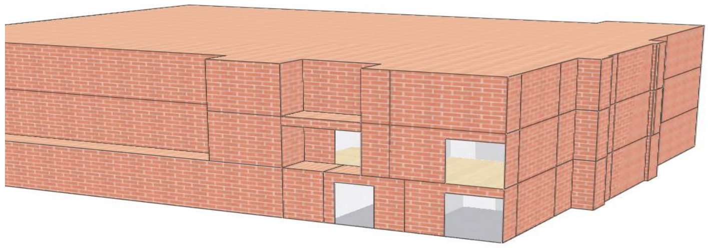
Geometry and Unit types

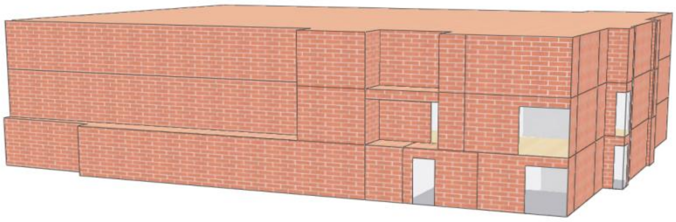
The following unit types and typologies have been agreed with the GLA on the 8th of May 2015. There are 12 dwelling types to be modelled in IES as based models and these are:

Flat type	Option
Curtain walled unit – 2 bed mid floor	Dual aspect (as designed):  *Southeast view of the model*
	Single aspect – it has been assumed that another flat is now adjacent to the unit removing the windows on the eastern facade and making the wall sheltered. The Adjacent unit is not shown. 
	Amended glazing (25% of internal room floor areas in

	each room) – the original dual aspect unit was amended by reducing the window widths to reach the targeted 25% glazing ratio: 
Traditional build unit – 1 bed, mid floor	Dual aspect (as designed) but with no cross ventilation - it was assumed that the existing window on the south west facade would be too small to provide ventilation:  *West view of the model*
	Dual aspect with cross vent – same layout as the original but the small window on the south west facade was made the same size as the smaller window on the south facade (i.e. the bedroom window) to allow partial cross ventilation
	Amended glazing (25% of internal room floor areas in each room) – the window sizes from the original design were reduced to reach the target 25% glazing ratio: 
Penthouse – 3 bed, top floor	Triple aspect (as designed):

	 *North view of the model*  *North east of the model*
	Dual aspect – the original design was amended to remove the windows from one facade to make the unit dual aspect:  
	Reduced glazing (50% of floor area in living room and 25% of floor area in other rooms) – the original as designed unit was amended reducing the widths of windows to achieve a reduced glazing ratio:

	 
Duplex masonry construction – 4 bed, ground and first floor	Dual aspect (as designed):  *North view of the model*
	Single aspect – it was assumed that another unit would be located to the east of the dwelling therefore removing the windows on the eastern facade and making the wall sheltered. The adjacent unit is not shown: 
	Reduced glazing (25% of internal room floor areas in each room) – the windows from the original design were reduced in width to achieve the targeted

	reduced glazing ratio: 

Constructions
The U-values for each construction were applied to all the unit types. The build-up of constructions were based on previous models where available, otherwise typical build-ups were used. The following constructions were used for the base models:

Construction	U-value (W/m^2K)	g-value (EN410)	Light transmittance (%)
Roof	0.13	-	-
Ground floor/Exposed floor	0.13	-	-
External wall	0.18	-	-
External glazing	1.4	0.63	67

Room conditions, Internal gains and Ventilation

Room conditions

All occupied areas in the flats had a cooling setpoint of 24°C based on SAP Assumptions. This allows the associated cooling load to be determined.

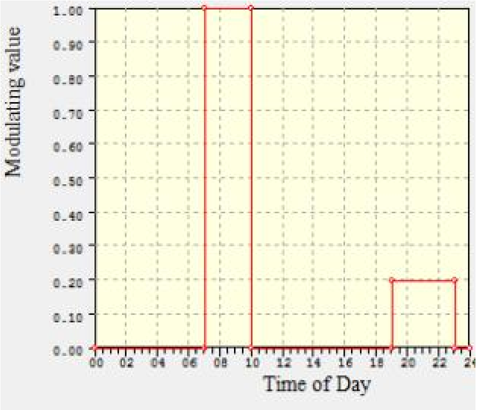
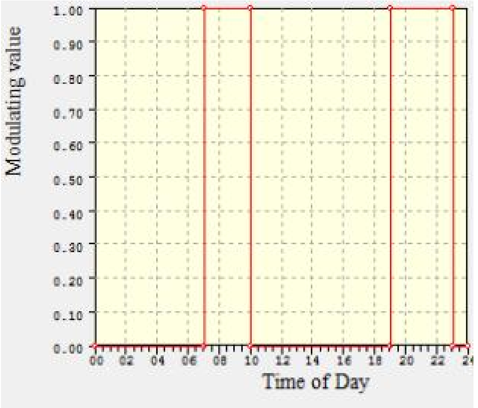
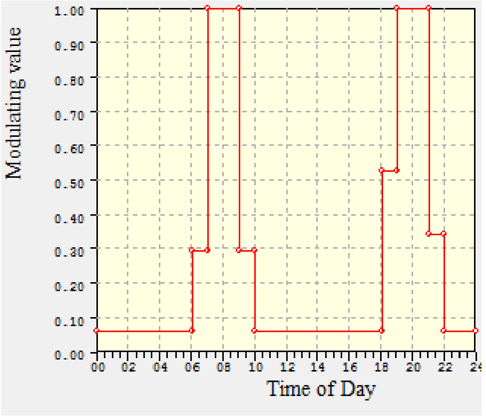
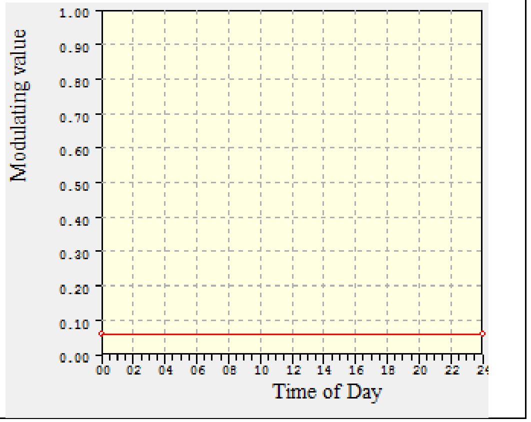
Internal gains

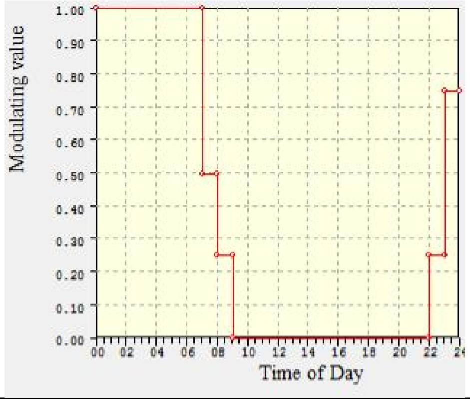
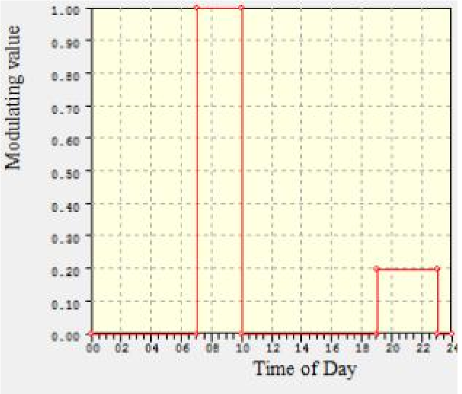
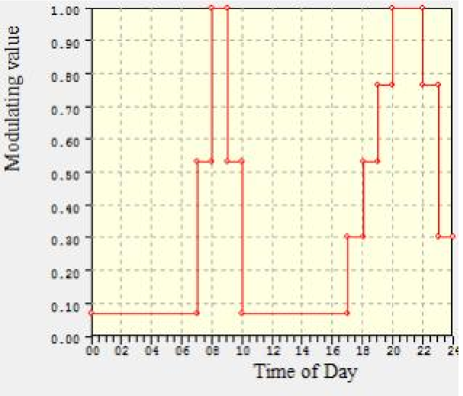
The internal gains were based on SAP assumptions, apart from the sensible and latent occupancy gain which was based on NCM figures. These were applied to all the areas of the flat, using the SAP assumptions. The following internal gains have been used:

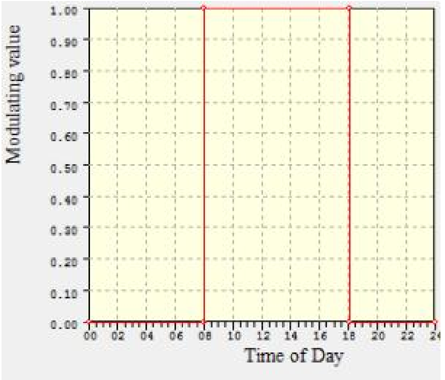
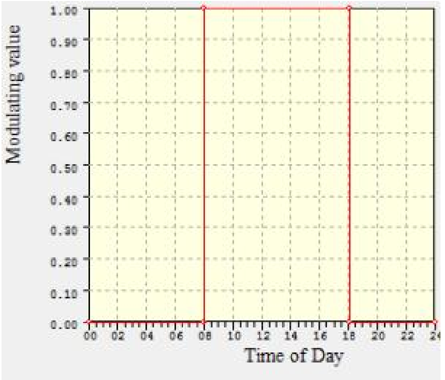
Flat type	Room type	Lighting gain (W/m^2)	Small power gain (W/m^2)	Occupancy density (m^2/person)	Max occupancy gain (Sensible|Latent) (W/person)
Curtain walled flat	Bathroom	0.43	10.3	12.8	60|60
	Bedroom				67.5|22.5
	Flat Circulation				90|90
	Kitchen/Dining				56|104

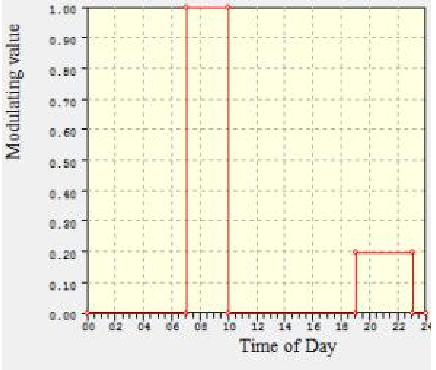
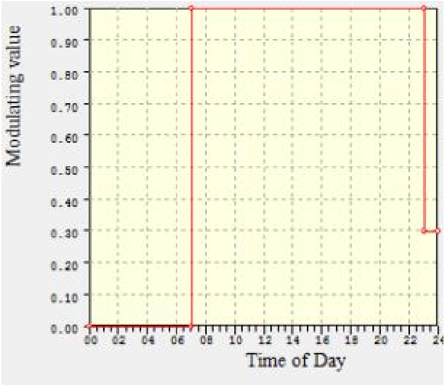
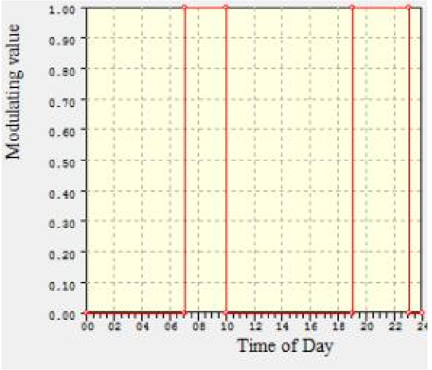
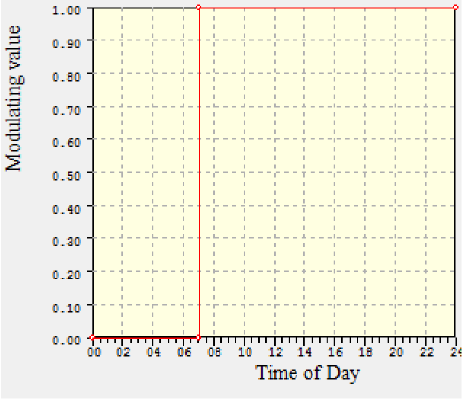
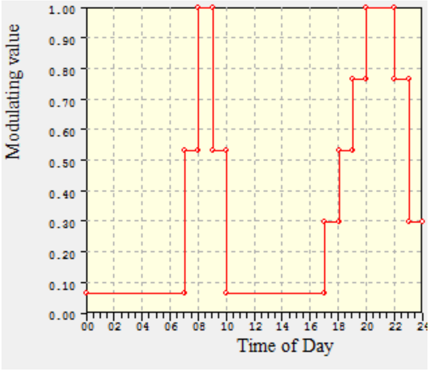
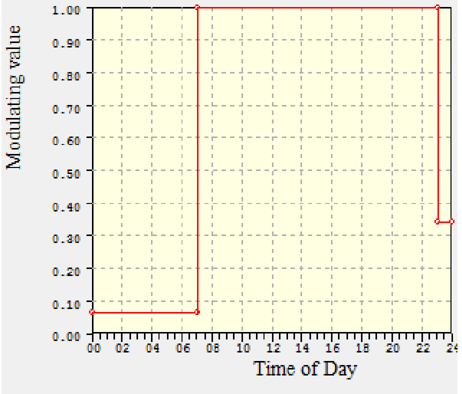
Flat type	Room type	Lighting gain (W/m²)	Small power gain (W/m²)	Occupancy density (m²/person)	Max occupancy gain (Sensible|Latent) (W/person)
	Room				
	Living Room				67.1|42.9
Traditional build unit	Bathroom	0.45	12.3	11.1	60|60
	Bedroom				67.5|22.5
	Flat Circulation				90|90
	Kitchen/Dining Room				56|104
	Living Room				67.1|42.9
Penthouse	Bathroom	0.28	6.7	24	60|60
	Bedroom				67.5|22.5
	Cupboard				70|70
	Dining Room				67.1|42.9
	Flat Circulation				90|90
	Kitchen				56|104
	Living Room				67.1|42.9
	Study Room				67.1|42.9
	WC				70|70
Duplex	Bathroom	0.359	7.69	20.58	60|60
	Bedroom				67.5|22.5
	Flat Circulation				90|90
	Kitchen				56|104
	Living Room				67.1|42.9

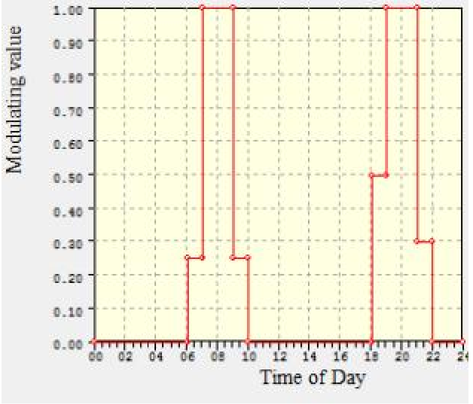
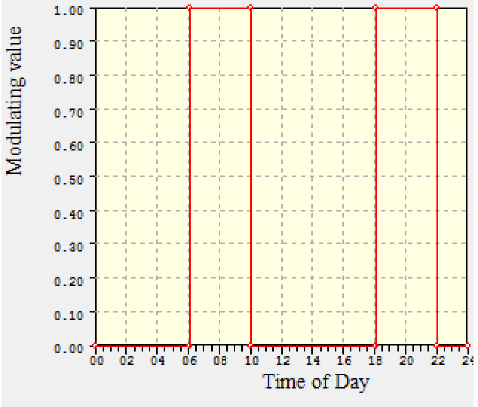
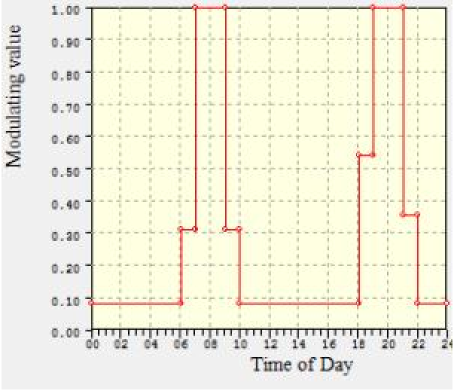
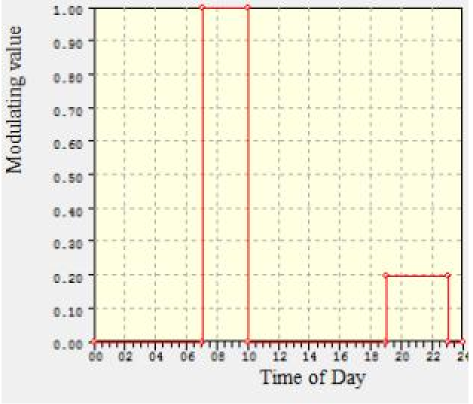
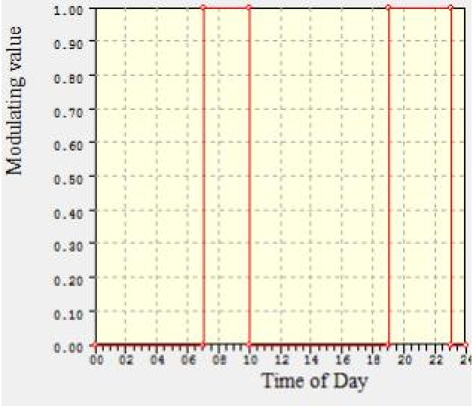
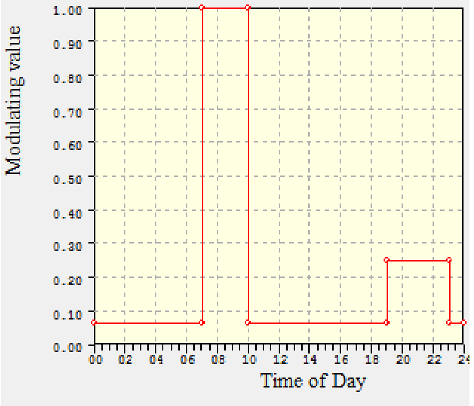
The following profiles have been used for each room type:

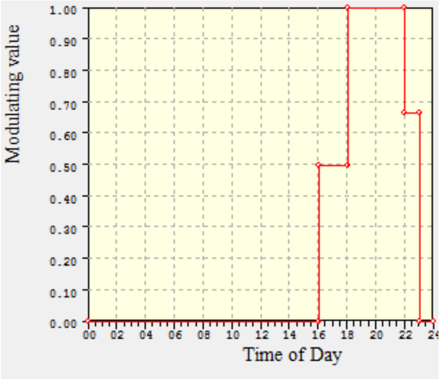
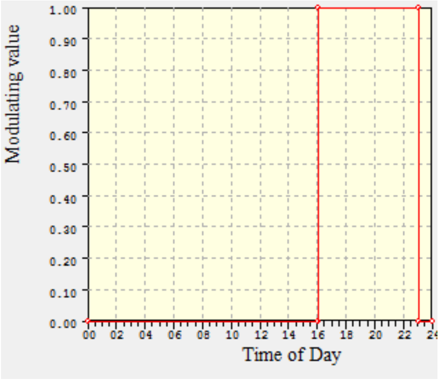
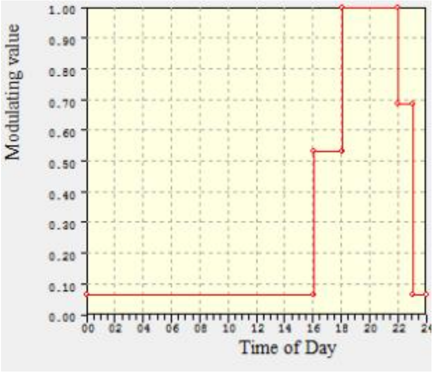
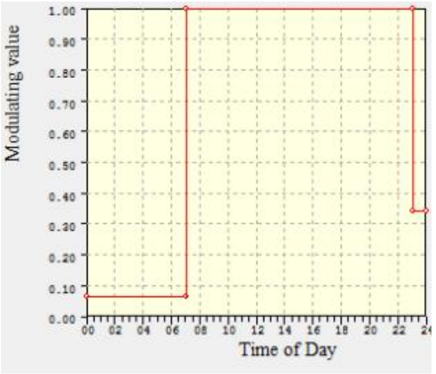
Room type	Occupancy profile	Lighting profile	Equipment profile
Bathroom	Weekday and weekend  	Weekday and weekend  	Weekday  Weekend 

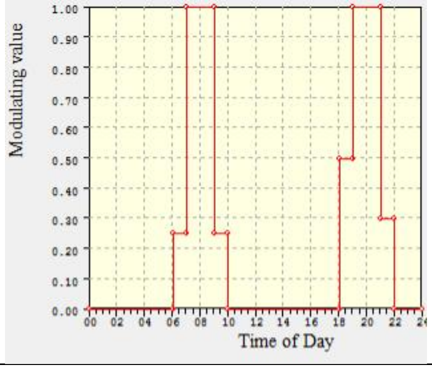
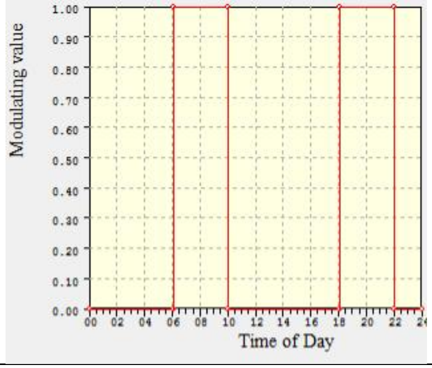
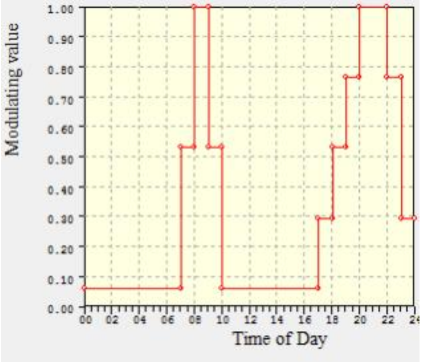
Room type	Occupancy profile	Lighting profile	Equipment profile
Bedroom	Weekday and weekend  	Weekday and weekend  	Weekday and weekend 

Room type	Occupancy profile	Lighting profile	Equipment profile
Cupboard	Weekday  Weekend: Off continuously	Weekday  Weekend: Off continuously	Weekday and weekend: Off continuously

Room type	Occupancy profile	Lighting profile	Equipment profile
Flat Circulation	Weekday  Weekend 	Weekday  Weekend 	Weekday  Weekend 

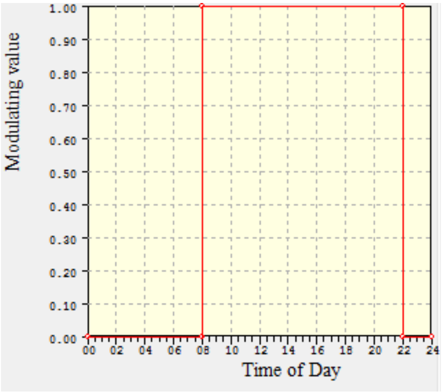
Room type	Occupancy profile	Lighting profile	Equipment profile
Dining Room	Weekday and weekend 	Weekday and weekend 	Weekday and weekend 
Kitchen	Weekday and weekend 	Weekday and weekend 	Weekday and weekend 

Room type	Occupancy profile	Lighting profile	Equipment profile
Living Room/ Study Room	Weekday and weekend  	Weekday and weekend  	Weekday  Weekend 

Room type	Occupancy profile	Lighting profile	Equipment profile
WC	Weekday and weekend 	Weekday and weekend 	Weekday and weekend 

Extended Occupancy for sensitivity test

For the sensitivity analysis of extended occupancy, the following profile was applied to the occupancy, lighting and equipment gains in the living rooms.



This analysis also revised the equipment gains to reflect a more realistic upper limit. The following table summarises the changes to the equipment gains in each room type:

	LCD TV	**Microwave**	**Fridge freezer**	**Laptop**	**Desktop (no monitor)**	**LCD monitor (19 inch LCD)**	**Kettle**	**Cooker**	**DVD Player**	**Digital TV adapter box**	**Video recorder**	**Component stereo**	
Source/taken from	**TM37**	**TM37**	**TM37**	**TM37**	**TM37**	**TM37**	***see notes**	**CIBSE Guide A**	**TM37**	**TM37**	**TM37**	**TM37**	
Sensible gain and Max Power consumption (W)	50	1390	36	15	55	104	2200	1520	17	9	17	44	**Max total power (W)**
Room types													
Bathroom	-	-	-	-	-	-	-	-	-	-	-	-	0
Bedroom	1	-	-	1	-	-	-	-	-	-	-	1	109
Cupboard	-	-	-	-	-	-	-	-	-	-	-	-	0
Dining Room	-	-	-	-	-	-	-	-	-	-	-	-	0
Flat Circulation	-	-	-	-	-	-	-	-	-	-	-	-	0
Kitchen	-	1	1	-	-	-	1	1	-	-	-	1	1000W during occupied hours and the fridge freezer on all

	LCD TV	Microwave	Fridge freezer	Laptop	Desktop (no monitor)	LCD monitor (19 inch LCD)	Kettle	Cooker	DVD Player	Digital TV adapter box	Video recorder	Component stereo	
Source/taken from	**TM37**	**TM37**	**TM37**	**TM37**	**TM37**	**TM37**	***see notes**	**CIBSE Guide A**	**TM37**	**TM37**	**TM37**	**TM37**	
Sensible gain and Max Power consumption (W)	50	1390	36	15	55	104	2200	1520	17	9	17	44	**Max total**
													the time
Living Room	1	-	-	1	-	-	-	-	1	1	1	1	152
Study Room	1	-	-	1	-	-	-	-	-	-	-	1	109
WC	-	-	-	-	-	-	-	-	-	-	-	-	0

Specific modelling assumptions

This section outlines the specific assumptions made when modelling the measures outlined in the main report.

Ventilation

An infiltration rate of 0.25 Ach-1 was applied to all the unit types. It was converted from an air tightness of 3 m^3/m^2h @50Pa using CIBSE Guide A table 4.2A. Since the base units have mechanical ventilation with heat recovery, 0.5 Ach-1 was used to model the MVHR units, based on SAP assumptions for air changes achieved by MVHR.

Weather tape

The Heathrow (1989) DSY weather tape from the CIBSE TM49 set was used to simulate the cooling demand, assuming a warm summer. The climate sensitivity used the London Weather Centre (1989) prediction for 2050 (Med, 50%), also taken from the CIBSE TM 49 set.

Shading

In some cases, the impact of higher surrounding buildings on cooling demand was also considered. For instance, a taller building across the road, directly facing the dwelling, will provide significant solar shading at certain times of the day. To simulate this, a shading factor was introduced to represent a building standing 3 storeys taller across the road from the dwelling under consideration.

Fins and brise soleil

The vertical fins have a depth of 600mm and a distance of 1500mm (see image 1) and the brise soleil has a depth of 900mm (See image 2). Both have been based on previous AECOM projects.

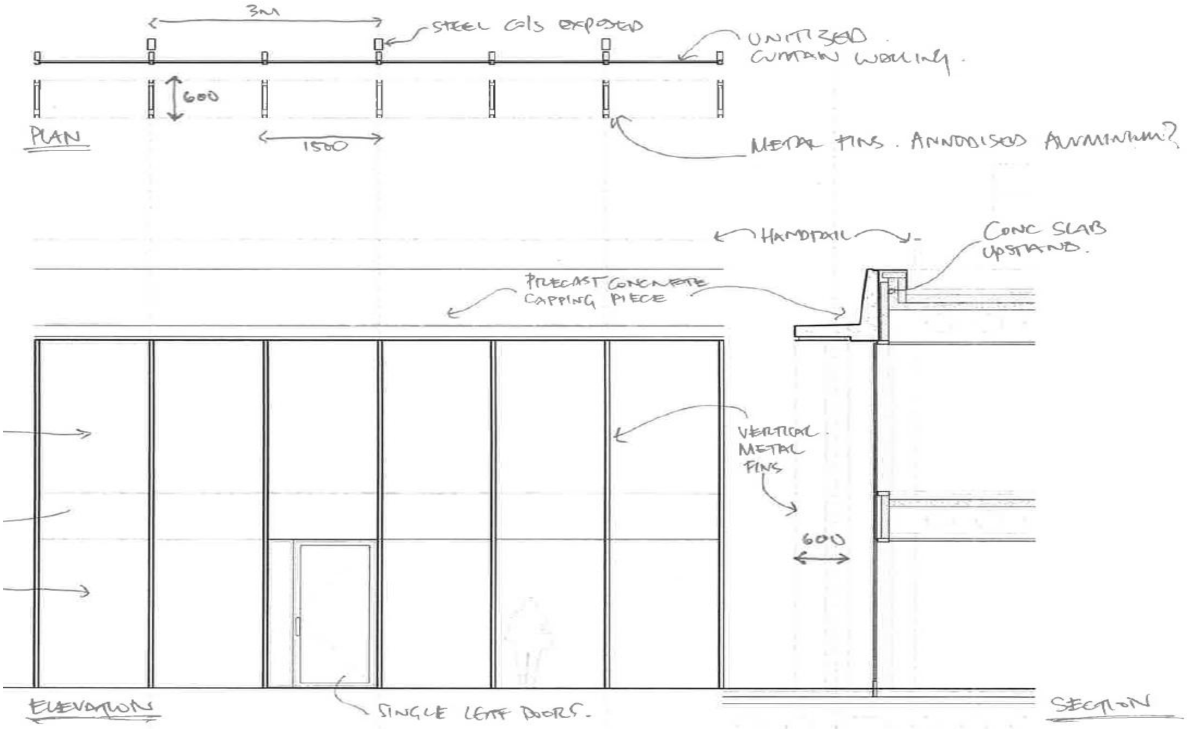


Image 1: Max vertical fins depth and distance

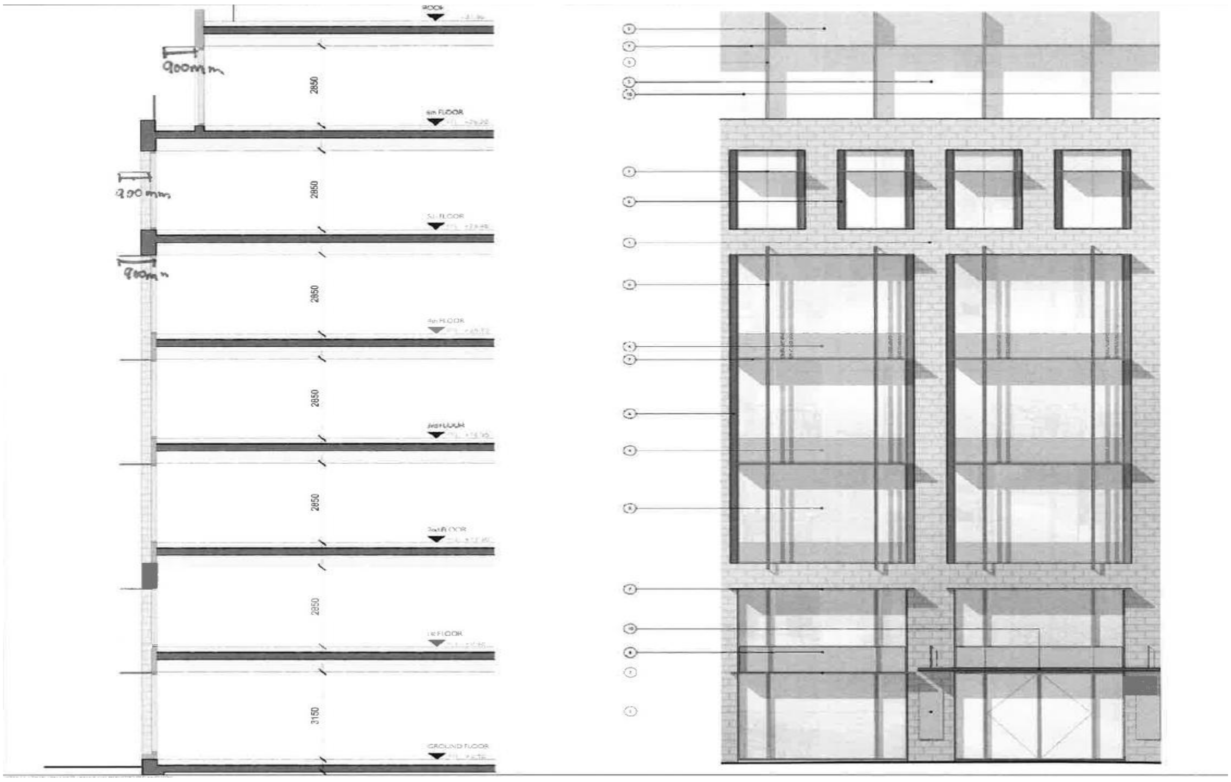


Image 2: Max brise soleil depth

Shutters

External shutters were modelled by assuming a shading factor of 0.5.

Internal shading

Internal shading assumed a light coloured blind with shading coefficient of 0.58 and a short-wave radiant fraction 0.52.

Natural ventilation

The natural cross ventilation was modelled by assuming an appropriate air change rate per hour. For the curtain walled flat and traditional build flats, 4 (single-aspect) and 5 (dual-aspect) Ach^{-1} were assumed. For the penthouse flat, 5 (double-aspect) and 6 (triple-aspect) Ach^{-1} were assumed. For the duplex flat, 2.5 (single-aspect) and 3 (double-aspect) Ach^{-1} were assumed. These assumptions were verified using the annualised predictions of sample flats modelled in IES using the bulk-flow ventilation calculation engine.

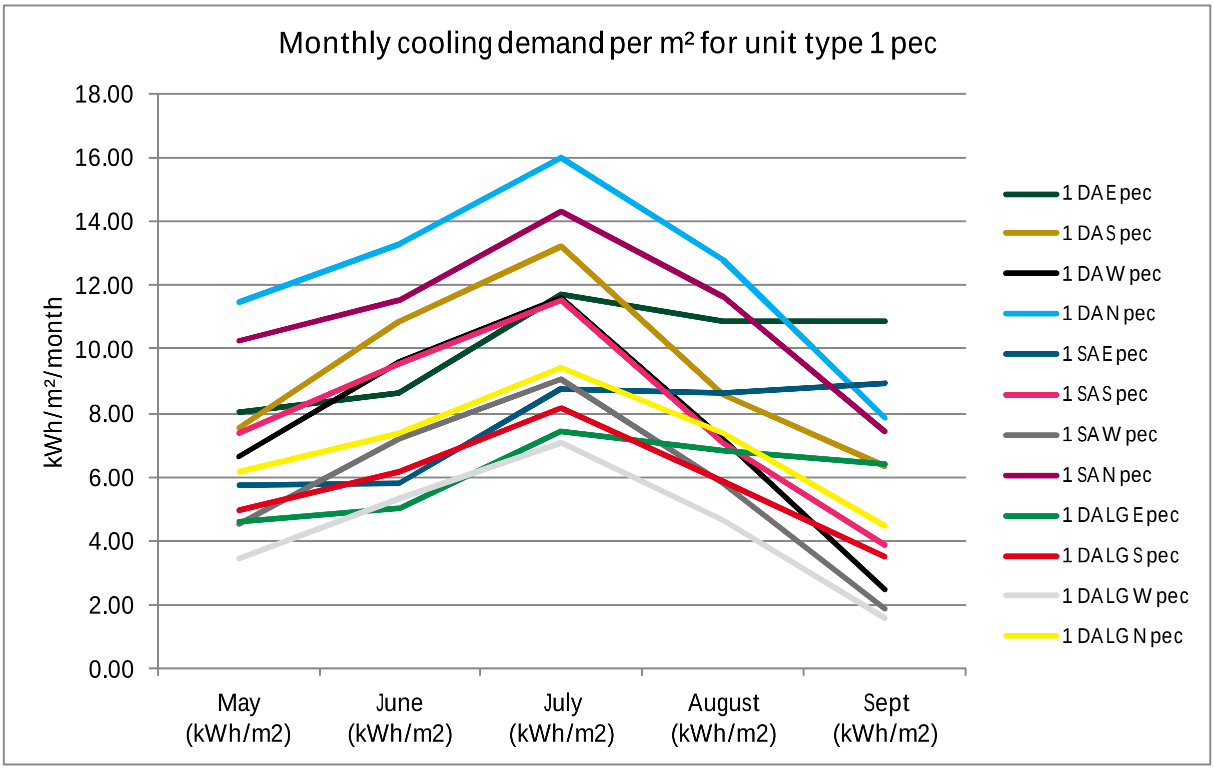
Mechanical ventilation

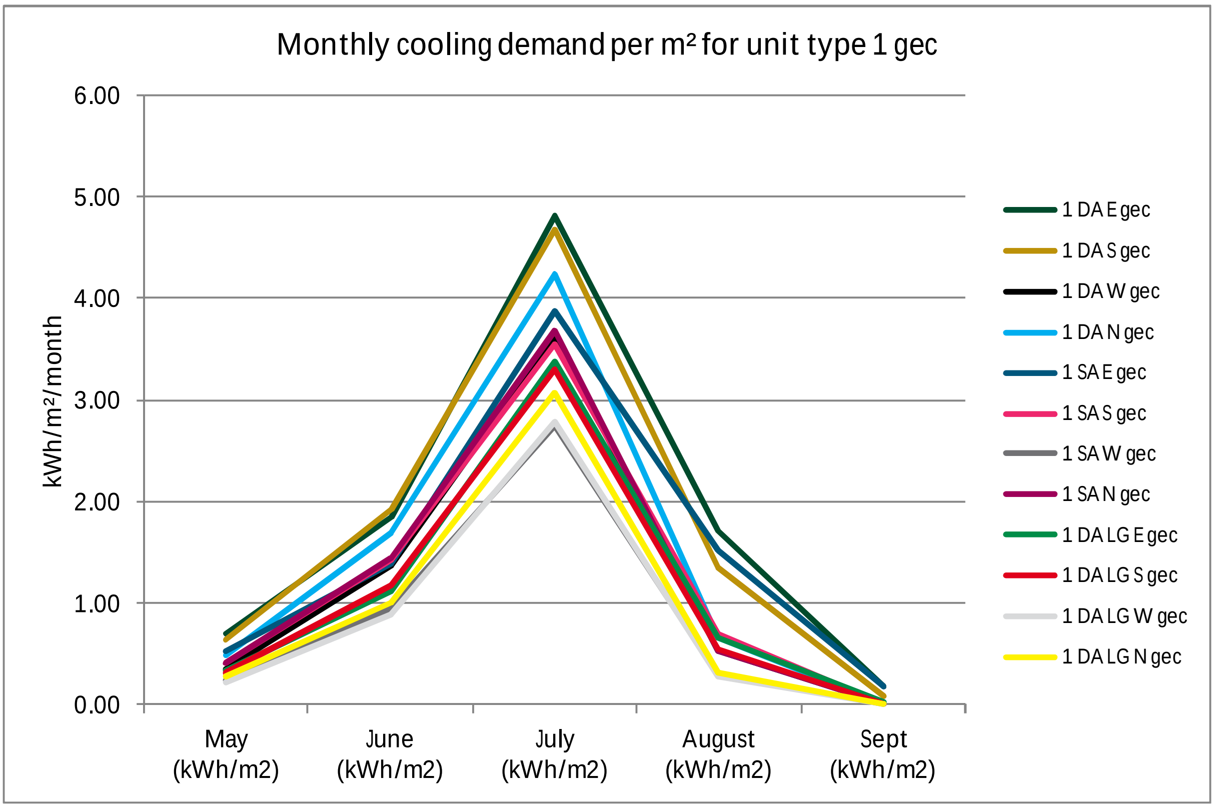
Boosted MVHR for purging was modelled as 1 Ach^{-1}.

Appendix E: Cooling demand outputs

Strategy 1

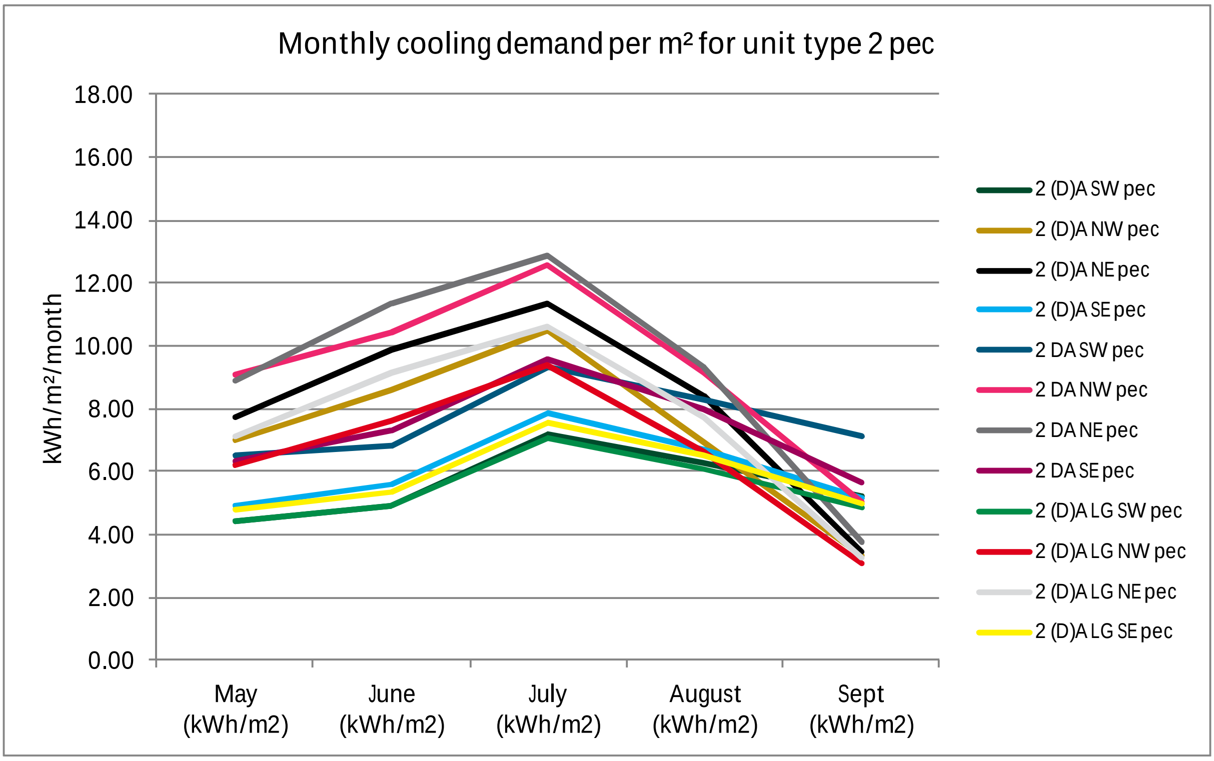
Type 1 – Curtain walled mid floor flat

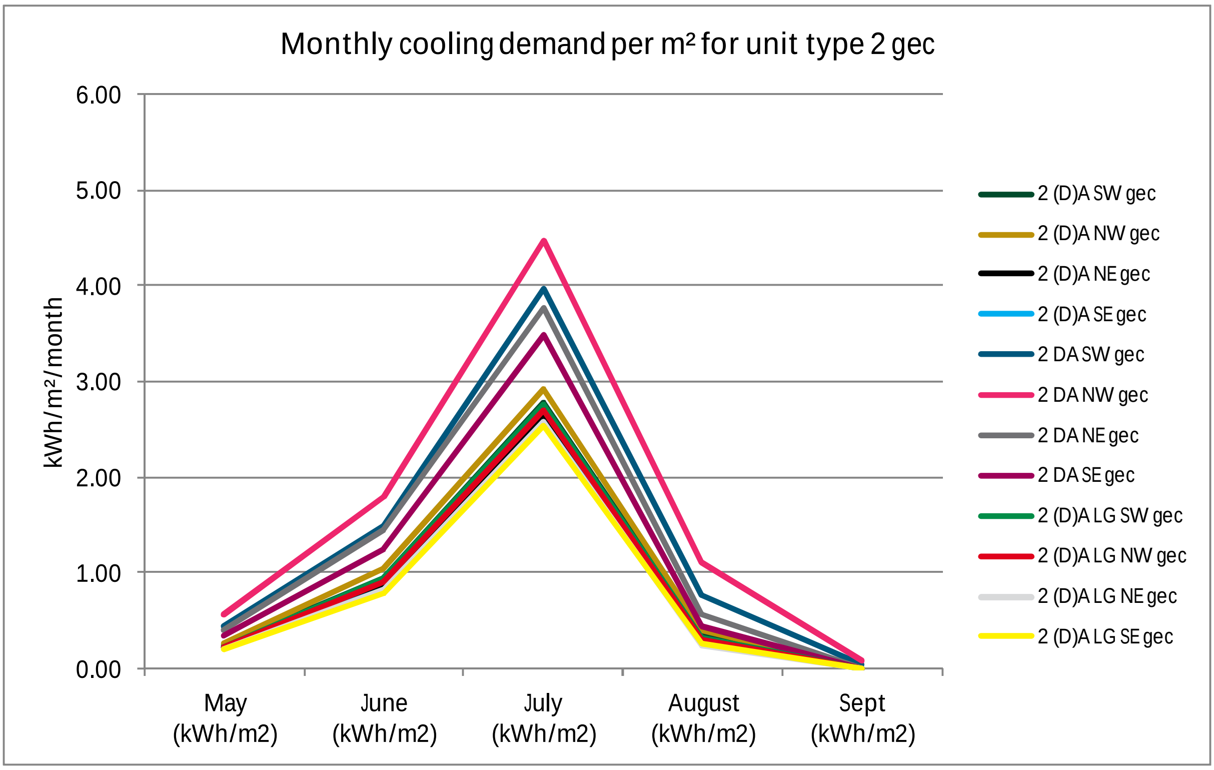



Monthly cooling demand per m² for unit type 1 gec
kWh/m²/month
6.00
5.00
4.00
3.00
2.00
1.00
0.00
May (kWh/m2)
June (kWh/m2)
July (kWh/m2)
August (kWh/m2)
Sept (kWh/m2)
1 DA E gec
1 DA S gec
1 DA W gec
1 DA N gec
1 SA E gec
1 SA S gec
1 SA W gec
1 SA N gec
1 DA LG E gec
1 DA LG S gec
1 DA LG W gec
1 DA LG N gec

Typology identifier	May (kWh/m²)	June (kWh/m²)	July (kWh/m²)	August (kWh/m²)	Sept (kWh/m²)
1 DA E pec	8.04	8.67	11.70	10.87	10.87
1 DA S pec	7.53	10.86	13.24	8.56	6.35
1 DA W pec	6.63	9.58	11.61	7.17	2.46
1 DA N pec	11.48	13.25	16.01	12.78	7.82
1 SA E pec	5.72	5.83	8.76	8.65	8.93
1 SA S pec	7.37	9.54	11.53	7.09	3.89
1 SA W pec	4.55	7.17	9.06	5.79	1.88
1 SA N pec	10.29	11.55	14.27	11.66	7.43
1 DA LG E pec	4.62	5.05	7.45	6.83	6.40
1 DA LG S pec	4.93	6.16	8.14	5.87	3.53
1 DA LG W pec	3.42	5.34	7.07	4.63	1.61
1 DA LG N pec	6.14	7.37	9.43	7.38	4.45
1 DA E gec	0.69	1.84	4.81	1.71	0.19
1 DA S gec	0.64	1.91	4.67	1.35	0.08
1 DA W gec	0.36	1.36	3.61	0.52	0.01
1 DA N gec	0.49	1.68	4.23	0.65	0.01
1 SA E gec	0.52	1.38	3.87	1.51	0.17
1 SA S gec	0.41	1.43	3.55	0.70	0.01
1 SA W gec	0.23	0.94	2.75	0.30	0.00
1 SA N gec	0.42	1.44	3.67	0.52	0.00
1 DA LG E gec	0.33	1.12	3.38	0.66	0.02
1 DA LG S gec	0.31	1.17	3.30	0.55	0.01
1 DA LG W gec	0.22	0.89	2.78	0.27	0.00
1 DA LG N gec	0.27	1.00	3.06	0.31	0.00

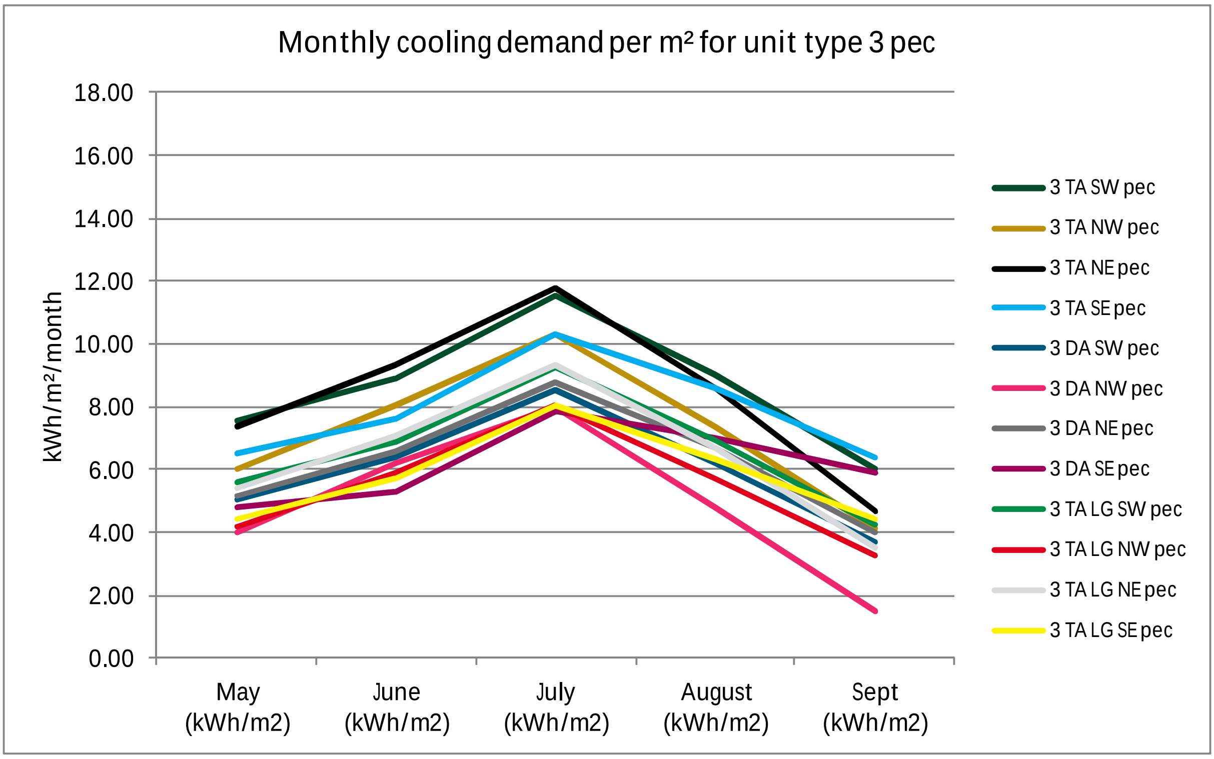
Type 2 – masonry mid floor flat

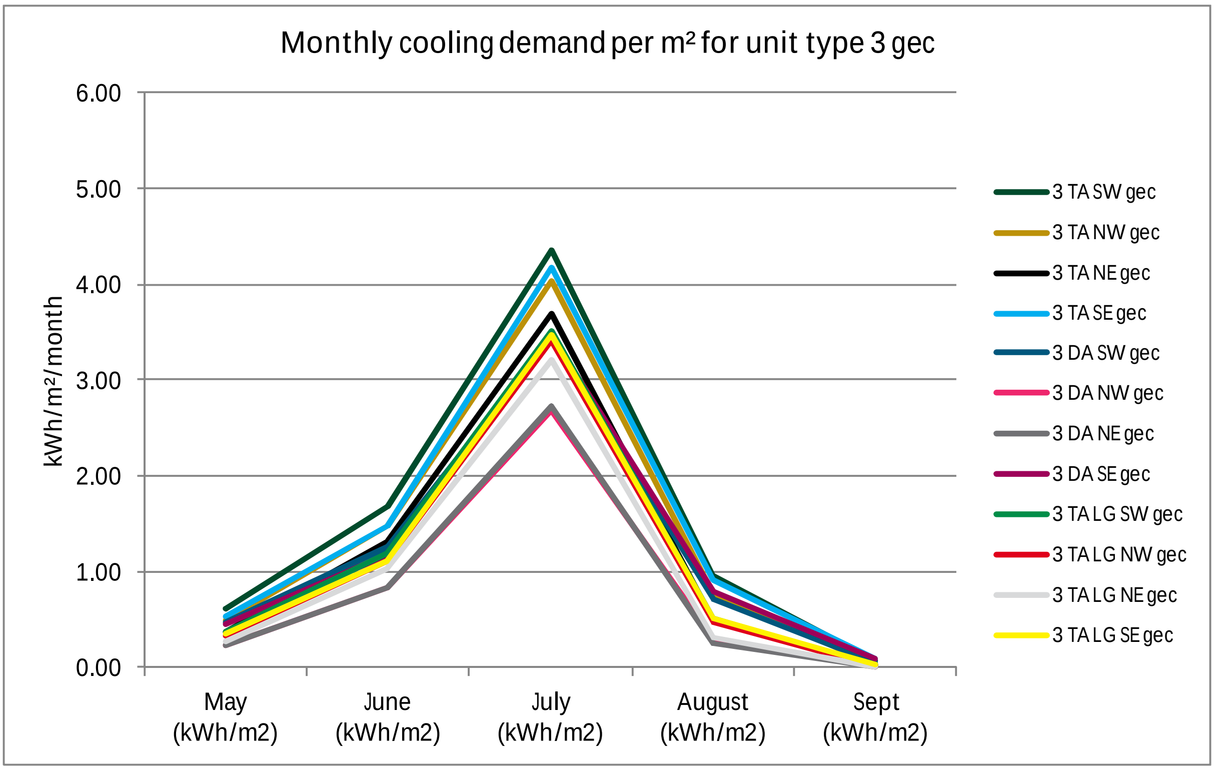




Typology identifier	May (kWh/m^2)	June (kWh/m^2)	July (kWh/m^2)	August (kWh/m^2)	Sept (kWh/m^2)
2 (D)A SW pec	4.44	4.94	7.16	6.25	5.21
2 (D)A NW pec	6.96	8.61	10.47	6.94	3.31
2 (D)A NE pec	7.72	9.85	11.36	8.37	3.43
2 (D)A SE pec	4.94	5.59	7.83	6.72	5.16
2 DA SW pec	6.48	6.78	9.31	8.26	7.13
2 DA NW pec	9.06	10.42	12.56	9.12	5.04
2 DA NE pec	8.89	11.34	12.88	9.29	3.75
2 DA SE pec	6.31	7.29	9.54	7.96	5.67
2 (D)A LG SW pec	4.43	4.92	7.08	6.05	4.87
2 (D)A LG NW pec	6.19	7.60	9.41	6.65	3.10
2 (D)A LG NE pec	7.14	9.15	10.61	7.75	3.27
2 (D)A LG SE pec	4.76	5.37	7.51	6.50	4.98
2 (D)A SW gec	0.24	0.95	2.78	0.35	0.00
2 (D)A NW gec	0.26	1.05	2.93	0.40	0.00
2 (D)A NE gec	0.22	0.87	2.66	0.28	0.00
2 (D)A SE gec	0.22	0.82	2.59	0.27	0.00
2 DA SW gec	0.45	1.50	3.98	0.77	0.03
2 DA NW gec	0.56	1.80	4.47	1.10	0.09
2 DA NE gec	0.40	1.46	3.77	0.57	0.01
2 DA SE gec	0.34	1.25	3.49	0.45	0.01
2 (D)A LG SW gec	0.23	0.96	2.77	0.33	0.00
2 (D)A LG NW gec	0.22	0.92	2.70	0.30	0.00
2 (D)A LG NE gec	0.20	0.83	2.57	0.24	0.00
2 (D)A LG SE gec	0.21	0.79	2.55	0.26	0.00

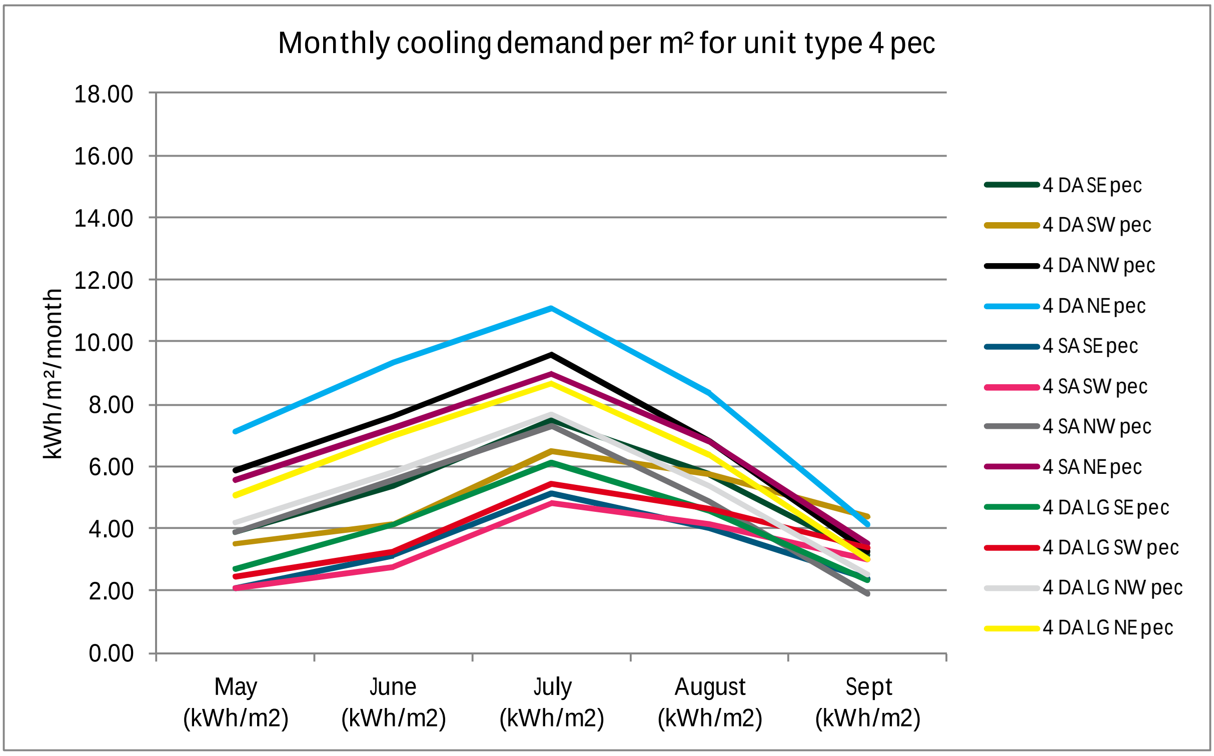
Type 3 - Penthouse

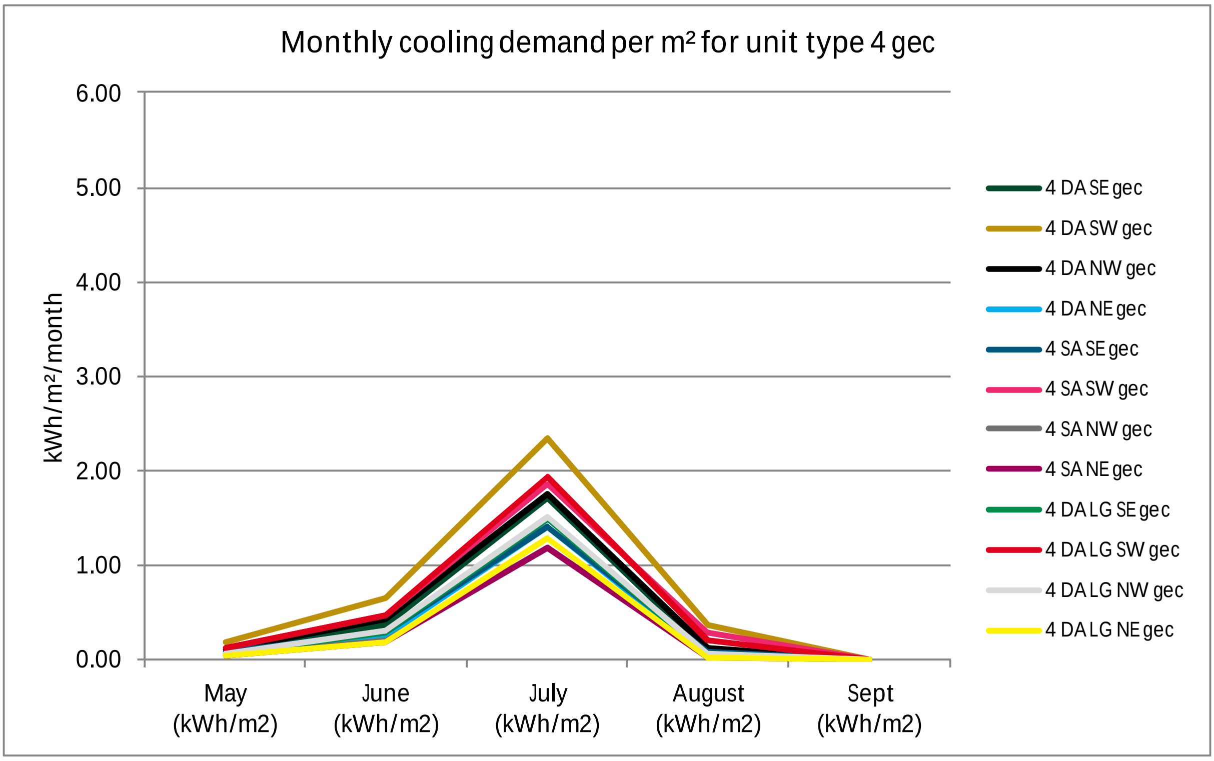




Typology identifier	May (kWh/m²)	June (kWh/m²)	July (kWh/m²)	August (kWh/m²)	Sept (kWh/m²)
3 TA SW pec	7.55	8.90	11.55	9.00	5.99
3 TA NW pec	6.02	8.02	10.32	7.35	4.13
3 TA NE pec	7.37	9.33	11.76	8.56	4.68
3 TA SE pec	6.48	7.62	10.33	8.59	6.41
3 DA SW pec	5.06	6.37	8.53	6.20	3.70
3 DA NW pec	3.97	6.20	7.97	4.77	1.48
3 DA NE pec	5.18	6.57	8.80	6.68	4.00
3 DA SE pec	4.81	5.28	7.85	6.98	5.88
3 TA LG SW pec	5.56	6.90	9.27	6.92	4.23
3 TA LG NW pec	4.20	5.87	8.03	5.69	3.23
3 TA LG NE pec	5.40	7.08	9.34	6.66	3.52
3 TA LG SE pec	4.45	5.69	8.06	6.34	4.39
3 TA SW gec	0.62	1.67	4.36	0.96	0.07
3 TA NW gec	0.48	1.47	4.03	0.77	0.03
3 TA NE gec	0.38	1.31	3.69	0.50	0.02
3 TA SE gec	0.54	1.47	4.16	0.92	0.08
3 DA SW gec	0.47	1.26	3.44	0.71	0.04
3 DA NW gec	0.23	0.84	2.69	0.29	0.01
3 DA NE gec	0.23	0.83	2.73	0.26	0.01
3 DA SE gec	0.45	1.16	3.48	0.79	0.08
3 TA LG SW gec	0.36	1.20	3.52	0.50	0.02
3 TA LG NW gec	0.32	1.12	3.42	0.47	0.01
3 TA LG NE gec	0.27	1.03	3.21	0.32	0.00
3 TA LG SE gec	0.34	1.11	3.48	0.52	0.02

Type 4 – Masonry duplex





Typology identifier	May (kWh/m²)	June (kWh/m²)	July (kWh/m²)	August (kWh/m²)	Sept (kWh/m²)
4 DA SE pec	3.89	5.39	7.49	5.76	3.13
4 DA SW pec	3.50	4.15	6.50	5.76	4.38
4 DA NW pec	5.85	7.60	9.60	6.81	3.27
4 DA NE pec	7.13	9.34	11.10	8.32	4.14
4 SA SE pec	2.11	3.15	5.11	4.02	2.39
4 SA SW pec	2.07	2.74	4.79	4.12	3.04
4 SA NW pec	3.87	5.58	7.29	4.85	1.90
4 SA NE pec	5.57	7.25	8.95	6.81	3.49
4 DA LG SE pec	2.69	4.16	6.10	4.55	2.33
4 DA LG SW pec	2.49	3.25	5.43	4.65	3.37
4 DA LG NW pec	4.19	5.79	7.66	5.37	2.51
4 DA LG NE pec	5.06	7.00	8.69	6.40	3.04
4 DA SE gec	0.09	0.37	1.70	0.07	0.00
4 DA SW gec	0.18	0.64	2.33	0.35	0.00
4 DA NW gec	0.09	0.41	1.74	0.11	0.00
4 DA NE gec	0.05	0.24	1.40	0.03	0.00
4 SA SE gec	0.07	0.29	1.40	0.06	0.00
4 SA SW gec	0.12	0.47	1.84	0.29	0.00
4 SA NW gec	0.03	0.20	1.17	0.03	0.00
4 SA NE gec	0.04	0.18	1.17	0.02	0.00
4 DA LG SE gec	0.06	0.27	1.49	0.04	0.00
4 DA LG SW gec	0.12	0.45	1.94	0.19	0.00
4 DA LG NW gec	0.06	0.29	1.50	0.06	0.00
4 DA LG NE gec	0.04	0.18	1.28	0.02	0.00

Strategy 1 – future climate, future climate + urban location

	Cooling demand (kWh/m²) - LHR-1989-2050Med50pc DSY					Cooling demand (kWh/m²) - LWC-1989-2050Med50pc DSY				
Typology identifier	May	June	July	August	Sept	May	June	July	August	Sept
1 DA LG E pec	5.82	6.19	8.84	8.17	7.57	5.94	6.15	8.87	8.43	7.78
1 DA LG S gec	1.08	3.13	7.68	2.96	0.29	0.93	2.66	7.49	3.41	0.39
2 (D)A LG SE pec	5.95	6.47	8.85	7.80	6.12	6.02	6.39	8.81	7.98	6.28
2 (D)A LG SW gec	0.88	2.70	6.75	2.36	0.16	0.79	2.34	6.67	2.94	0.30
3 TA LG NE pec	6.79	8.43	11.00	8.23	4.79	6.77	8.24	10.87	8.38	4.97
3 TA LG NW gec	1.14	3.22	8.13	2.69	0.22	0.97	2.70	7.97	3.18	0.33
4 DA LG SW pec	3.72	4.35	6.82	5.98	4.51	3.82	4.29	6.81	6.20	4.70
4 DA LG SW gec	0.57	1.73	5.14	1.78	0.05	0.51	1.50	5.20	2.33	0.14

Strategy 2

	Cooling demand (kWh/m²) - LHR-1989-Baseline DSY					Cooling demand (kWh/m²) - LHR-1989-2050Med50pc DSY					Cooling demand (kWh/m²) - LWC-1989-2050Med50pc DSY				
Typology identifier	May	June	July	Aug	Sept	May	June	July	Aug	Sept	May	June	July	Aug	Sept
1 DA LG E pec	1.5	2.5	4.9	3.7	2.7	2.7	3.7	6.6	5.4	4.1	2.8	3.6	6.6	5.6	4.2
1 DA LG S gec	0.2	1.0	2.9	0.4	0.0	0.9	2.8	7.1	2.5	0.2	0.8	2.4	6.9	3.0	0.3
2 (D)A LG SE pec	1.5	2.6	5.0	3.7	2.3	2.8	3.8	6.7	5.3	3.6	2.8	3.7	6.6	5.5	3.8
2 (D)A LG SW gec	0.2	0.8	2.4	0.2	0.0	0.7	2.4	6.1	2.0	0.1	0.6	2.0	6.1	2.5	0.2
3 TA LG NE pec	1.4	2.8	5.2	2.9	0.9	2.6	4.2	7.2	4.6	2.0	2.5	3.9	6.9	4.8	2.1
3 TA LG NW gec	0.2	0.9	2.9	0.3	0.0	0.9	2.8	7.4	2.2	0.2	0.7	2.3	7.2	2.6	0.2
4 DA LG SW pec	0.5	1.3	3.3	2.2	1.1	1.2	2.3	5.0	3.8	2.3	1.3	2.2	4.9	4.0	2.4
4 DA LG SW gec	0.1	0.3	1.5	0.1	0.0	0.4	1.4	4.4	1.3	0.0	0.4	1.2	4.5	1.8	0.1

Strategy 3

	Cooling demand (kWh/m²) - LHR-1989-Baseline DSY					Cooling demand (kWh/m²) - LHR-1989-2050Med50pc DSY					Cooling demand (kWh/m²) - LWC-1989-2050Med50pc DSY				
Typology identifier	May	June	July	Aug	Sept	May	June	July	Aug	Sept	May	June	July	Aug	Sept
1 DA LG E pec	3.7	4.2	6.5	5.7	5.1	4.9	5.4	7.9	7.1	6.2	5.0	5.3	7.9	7.3	6.4
1 DA LG S gec	0.2	0.8	2.3	0.4	0.0	0.7	2.1	5.3	2.2	0.2	0.7	1.9	5.3	2.7	0.3
2 (D)A LG SE pec	3.7	4.3	6.5	5.6	4.4	4.9	5.4	7.8	6.9	5.5	4.9	5.3	7.7	7.0	5.6
2 (D)A LG SW gec	0.2	0.9	2.4	0.4	0.0	0.7	2.2	5.5	2.3	0.2	0.7	2.1	5.5	2.8	0.4
3 TA LG NE pec	3.4	4.9	7.2	4.8	2.3	4.7	6.2	8.8	6.4	3.5	4.6	6.0	8.6	6.5	3.6
3 TA LG NW gec	0.2	0.7	2.2	0.3	0.0	0.7	2.0	5.3	1.7	0.1	0.6	1.8	5.3	2.1	0.2
4 DA LG SW pec	1.7	2.5	4.6	3.8	2.7	2.9	3.6	6.0	5.2	3.8	2.9	3.5	6.0	5.3	4.0
4 DA LG SW gec	0.1	0.4	1.6	0.3	0.0	0.4	1.3	4.1	1.8	0.1	0.4	1.2	4.2	2.3	0.2

Internal gains sensitivity test

	monthly cooling demand current climate, strategy 1, SAP and nonSAP internal gains				
	kWh/m2/month	kWh/m2/month	kWh/m2/month	kWh/m2/month	kWh/m2/month
typology identifier	May	June	July	August	Sept
1 DA LG E pec (SAP)	4.62	5.05	7.45	6.83	6.40
1 DA LG E pec (nonSAP)	5.60	6.06	8.46	7.84	7.40
2 (D)A LG SE pec (SAP)	4.76	5.37	7.51	6.50	4.98
2 (D)A LG SE pec (nonSAP)	7.10	7.68	9.86	8.85	7.29
3 TA LG NE pec (SAP)	5.40	7.08	9.34	6.66	3.52
3 TA LG NE pec (nonSAP)	5.83	7.45	9.67	7.03	3.96
4 DA LG SW pec (SAP)	2.49	3.25	5.43	4.65	3.37
4 DA LG SW pec (nonSAP)	2.87	3.58	5.62	4.82	3.58
1 DA LG S gec (SAP)	0.31	1.17	3.30	0.55	0.01
1 DA LG S gec (nonSAP)	0.37	1.30	3.60	0.71	0.03
2 (D)A LG SW gec (SAP)	0.23	0.96	2.77	0.33	0.00
2 (D)A LG SW gec (nonSAP)	0.42	1.49	3.88	0.84	0.11
3 TA LG NW gec (SAP)	0.32	1.12	3.42	0.47	0.01
3 TA LG NW gec (nonSAP)	0.35	1.17	3.55	0.53	0.01
4 DA LG SW gec (SAP)	0.12	0.45	1.94	0.19	0.00
4 DA LG SW gec (nonSAP)	0.19	0.67	2.40	0.47	0.02

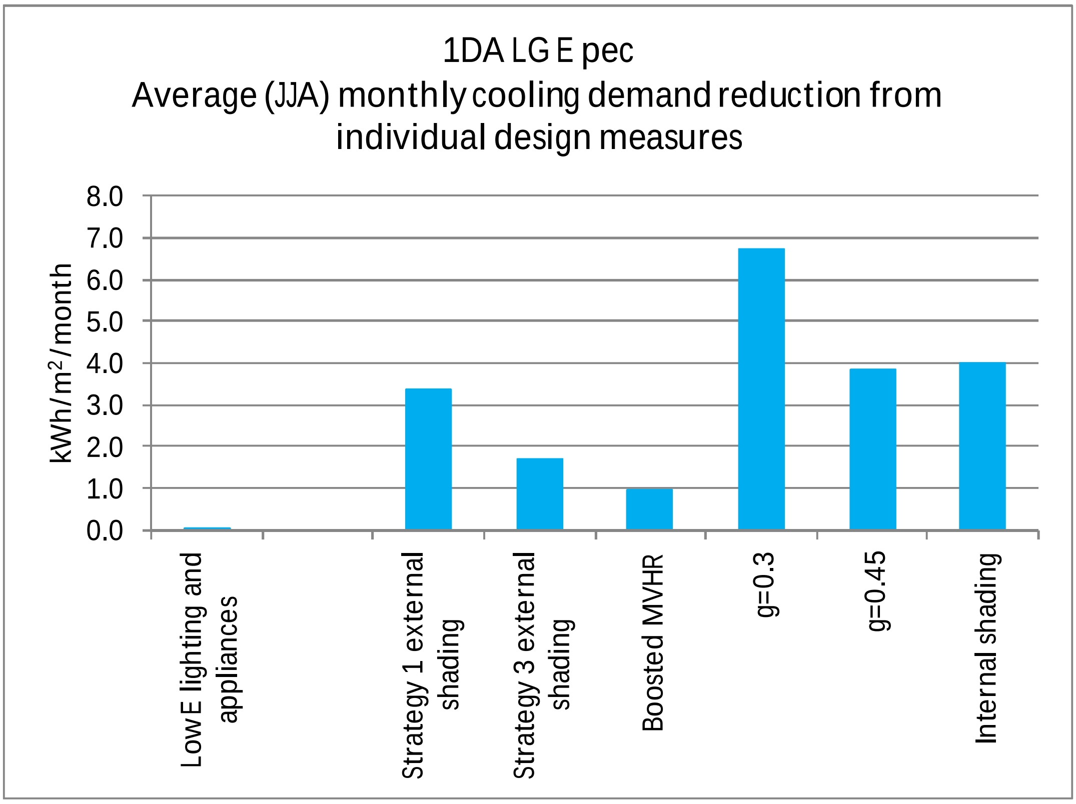
Future climate sensitivity test

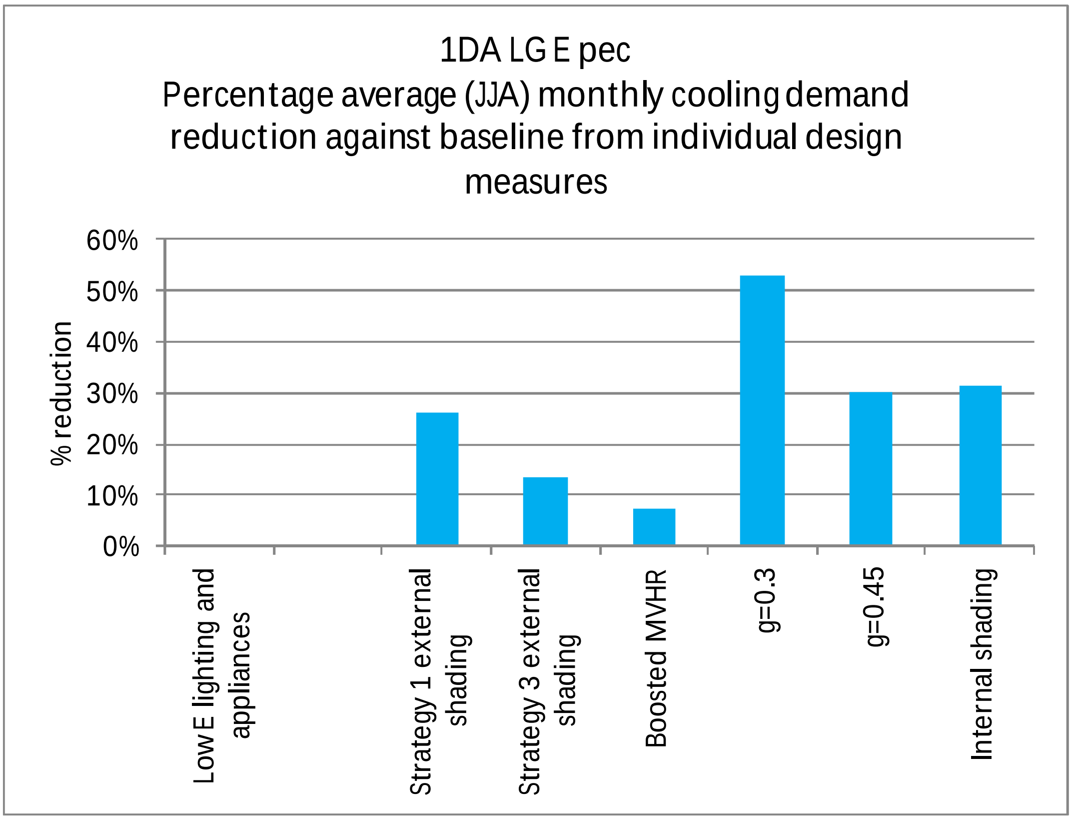
	monthly cooling demand, strategy 1, present and future climate				
	kWh/m2/month	kWh/m2/month	kWh/m2/month	kWh/m2/month	kWh/m2/month
typology identifier	May	June	July	August	Sept
1 DA LG E pec (present)	4.62	5.05	7.45	6.83	6.40
1 DA LG E pec (future)	5.82	6.19	8.84	8.17	7.57
2 (D)A LG SE pec (present)	4.76	5.37	7.51	6.50	4.98
2 (D)A LG SE pec (future)	5.95	6.47	8.85	7.80	6.12
3 TA LG NE pec (present)	5.40	7.08	9.34	6.66	3.52
3 TA LG NE pec (future)	6.79	8.43	11.00	8.23	4.79
4 DA LG SW pec (present)	2.49	3.25	5.43	4.65	3.37
4 DA LG SW pec (future)	3.72	4.35	6.82	5.98	4.51
1 DA LG S gec (present)	0.31	1.17	3.30	0.55	0.01
1 DA LG S gec (future)	1.08	3.13	7.68	2.96	0.29
2 (D)A LG SW gec (present)	0.23	0.96	2.77	0.33	0.00
2 (D)A LG SW gec (future)	0.88	2.70	6.75	2.36	0.16
3 TA LG NW gec (present)	0.32	1.12	3.42	0.47	0.01
3 TA LG NW gec (future)	1.14	3.22	8.13	2.69	0.22
4 DA LG SW gec (present)	0.12	0.45	1.94	0.19	0.00
4 DA LG SW gec (future)	0.57	1.73	5.14	1.78	0.05

Future climate and urban heat island sensitivity test

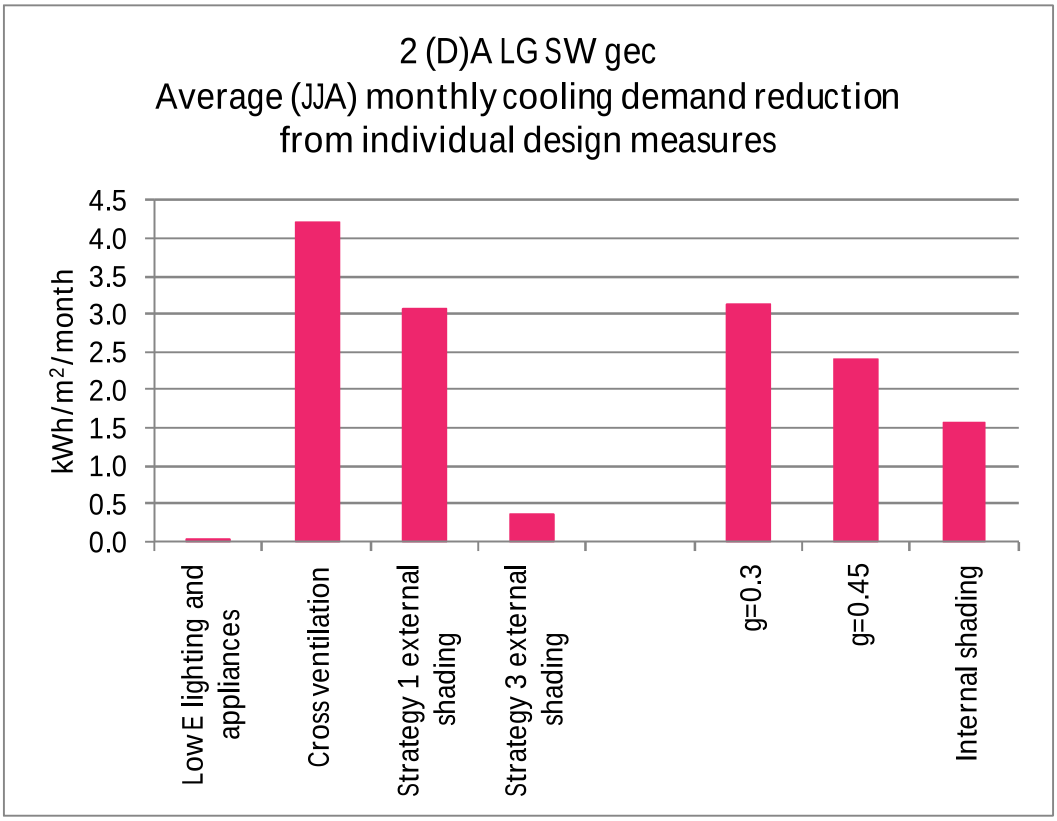
	monthly cooling demand, strategy 1, present suburban and future climate urban				
	kWh/m2/month	kWh/m2/month	kWh/m2/month	kWh/m2/month	kWh/m2/month
typology identifier	May	June	July	August	Sept
1 DA LG E pec (present suburban)	4.62	5.05	7.45	6.83	6.40
1 DA LG E pec (future urban)	5.94	6.15	8.87	8.43	7.78
2 (D)A LG SE pec (present suburban)	4.76	5.37	7.51	6.50	4.98
2 (D)A LG SE pec (future urban)	6.02	6.39	8.81	7.98	6.28
3 TA LG NE pec (present suburban)	5.40	7.08	9.34	6.66	3.52
3 TA LG NE pec (future urban)	6.77	8.24	10.87	8.38	4.97
4 DA LG SW pec (present suburban)	2.49	3.25	5.43	4.65	3.37
4 DA LG SW pec (future urban)	3.82	4.29	6.81	6.20	4.70
1 DA LG S gec (present suburban)	0.31	1.17	3.30	0.55	0.01
1 DA LG S gec (future urban)	0.93	2.66	7.49	3.41	0.39
2 (D)A LG SW gec (present suburban)	0.23	0.96	2.77	0.33	0.00
2 (D)A LG SW gec (future urban)	0.79	2.34	6.67	2.94	0.30
3 TA LG NW gec (present suburban)	0.32	1.12	3.42	0.47	0.01
3 TA LG NW gec (future urban)	0.97	2.70	7.97	3.18	0.33
4 DA LG SW gec (present suburban)	0.12	0.45	1.94	0.19	0.00
4 DA LG SW gec (future urban)	0.51	1.50	5.20	2.33	0.14

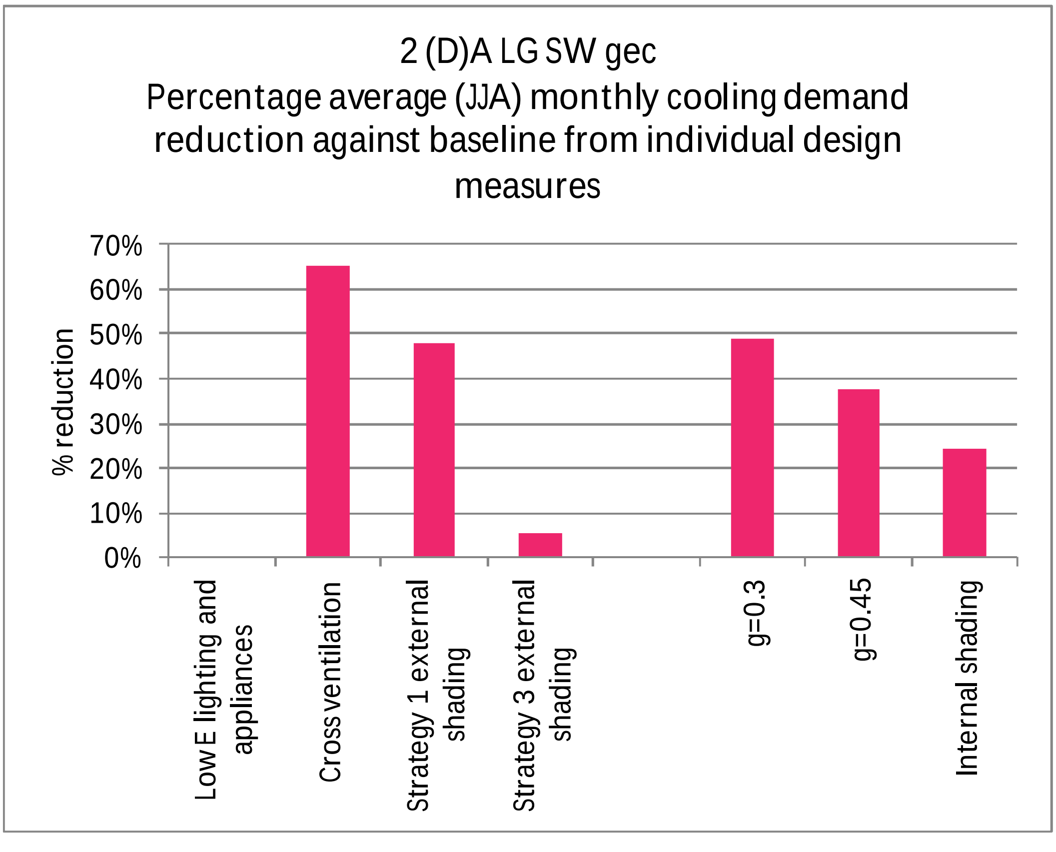
Individual savings outputs



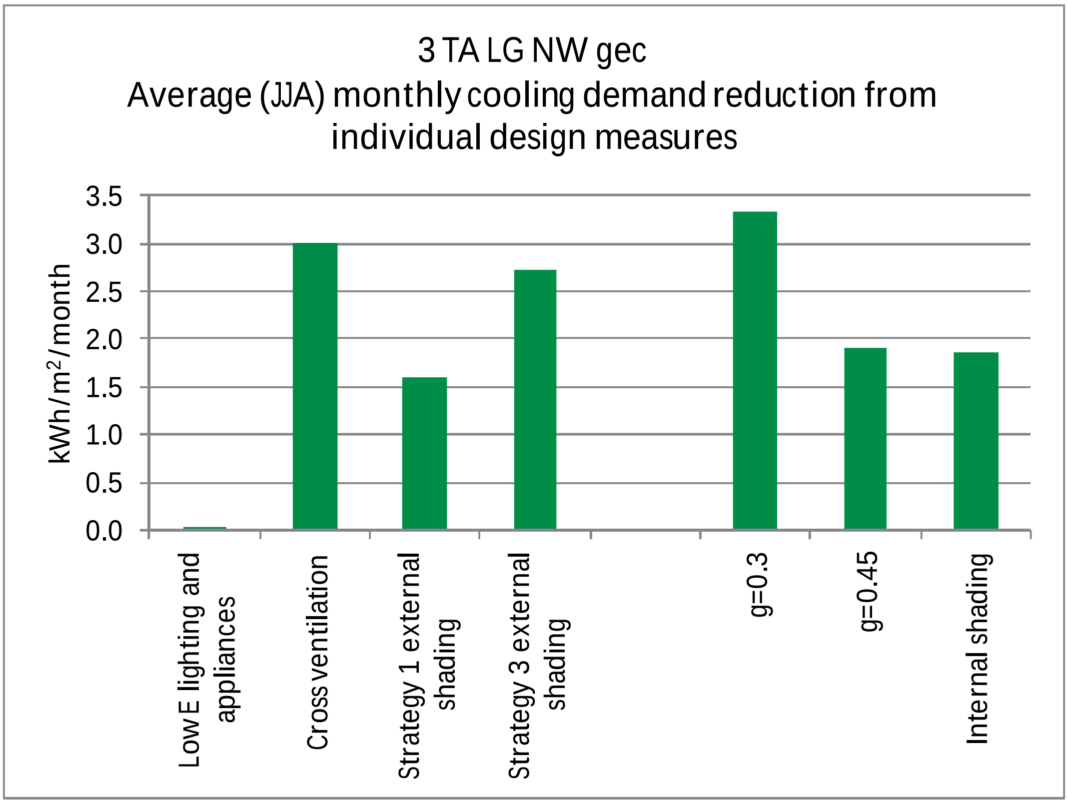


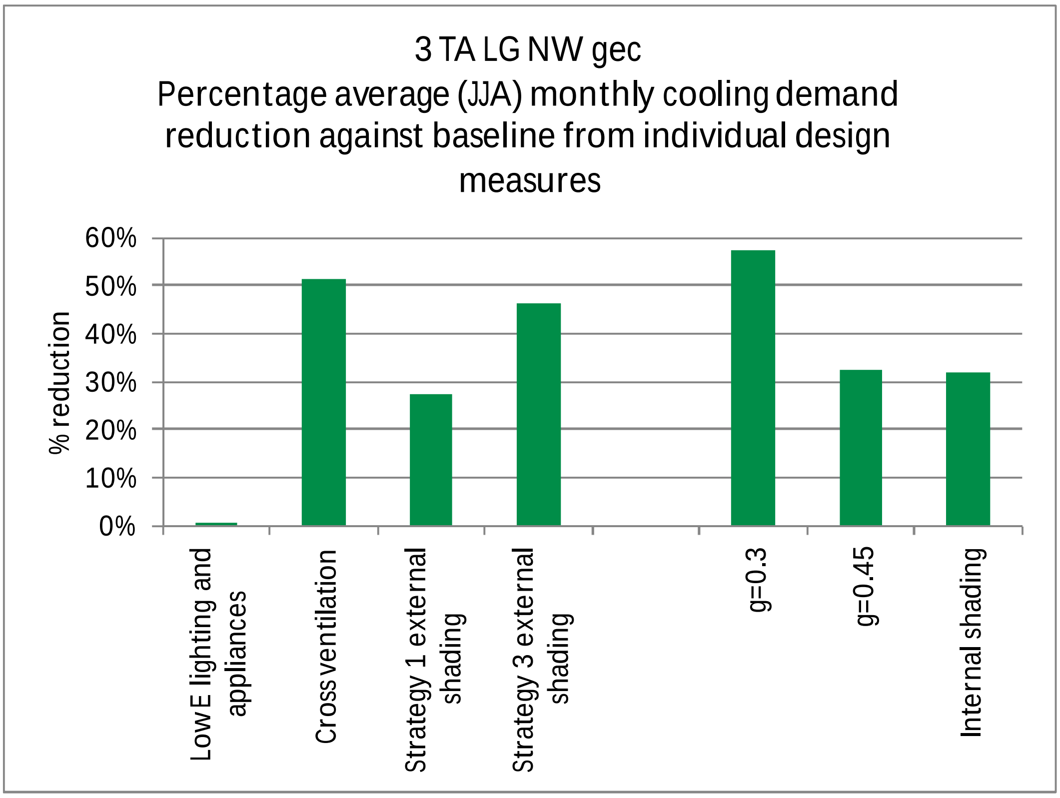
Cooling demand reduction from glazing reduction from 48% to 25% - 38%





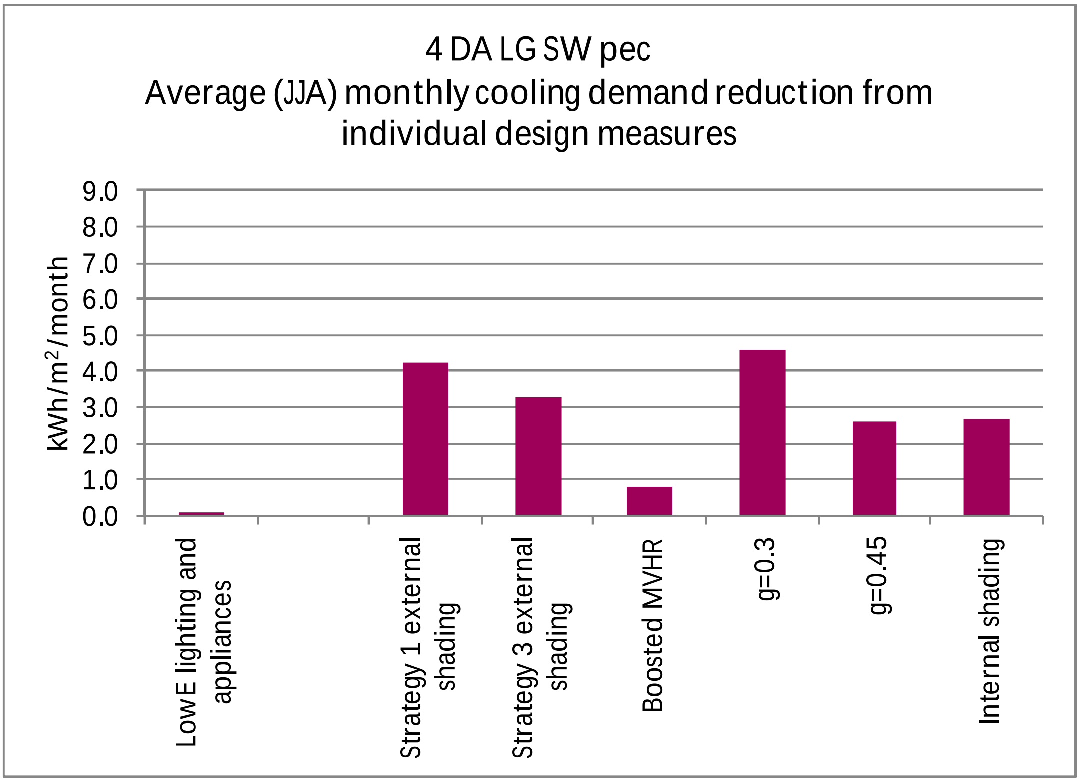
Cooling demand reduction from glazing reduction from 27% to 25% - 1%

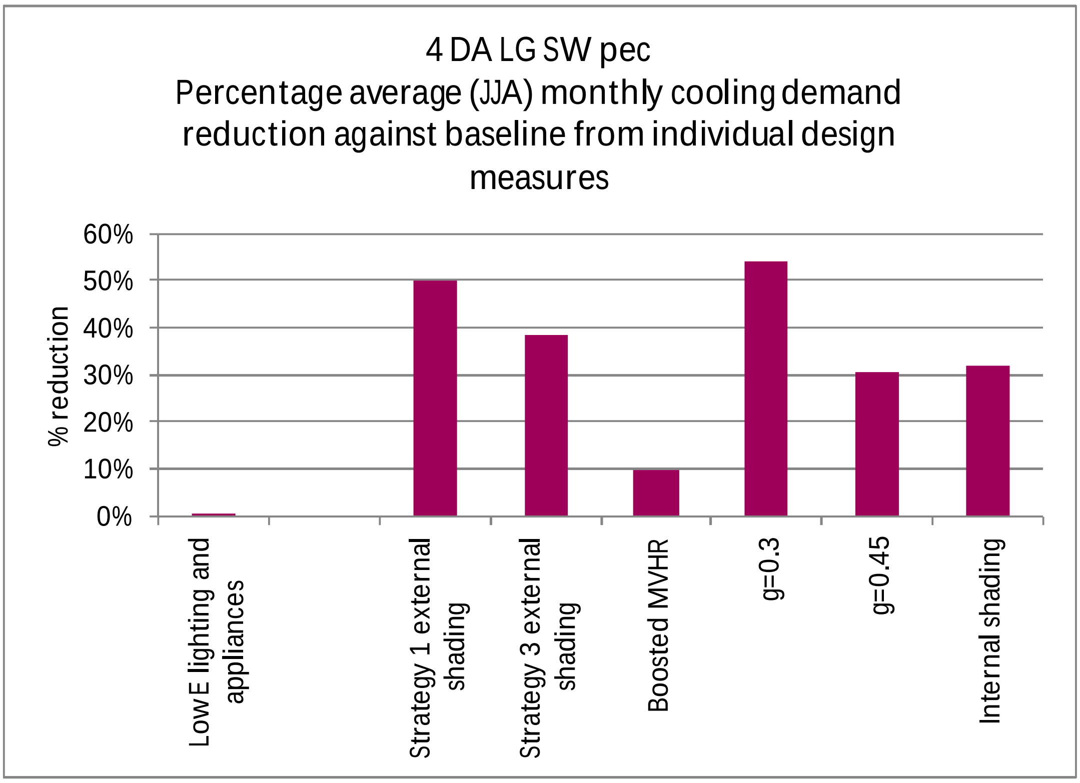




Note: in this instance strategy 1 shading is less effective than strategy 3 shading because strategy 1 assumed shading only on south facade while strategy 3 assumed shading on all facades.

Cooling demand reduction from glazing reduction from 38% to 50% in living room and 25% in other rooms- 20%





Cooling demand reduction from glazing reduction from 30% to 25% in living room and 25% in other rooms- 19%