UK climate resilience roadmap.
Overheating risk analysis.
UKGBC.

SUSTAINABILITY
TECHNICAL REPORT

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Contents.

Executive summary

The UKGBC UK Climate Resilience Roadmap provides a science-led basis for understanding the impacts of climate change on the UK built environment, with recommendations for industry stakeholders and policy makers to achieve a more resilient built environment by 2050. Increasing resilience of the built environment will protect people from the negative effects of climate changes, including limiting overheating risk and discomfort. Hotter conditions with have detrimental impacts on wellbeing with socio-economic consequences arising from loss of productivity and negative health outcomes.

This report focuses on the impact that higher temperatures will have on overheating risk in buildings in the UK. Overheating risk has increased in recent years and is predicted to get even worse if the global average warming increases beyond the 1.5 degree target set by over 190 signatory countries of The Paris Agreement.

To understand the impact of climate change on overheating risk Hoare Lea has used thermal dynamic modelling to assess the impact of three global warming scenarios on a range of building types. The thermal modelling shows an increased risk of overheating for all building types that have been assessed. We also used thermal modelling to assess the benefit of a range of climate adaptation measures. These interventions include passive measures, such as the introduction of the solar shading and increased window openings to improve ventilation rates, and active adaptation measures, such as the introduction of mechanical cooling in buildings.

The results of the overheating assessments show that the severity of overheating risk depends on a range of factors, including the following:

- The climate change scenario – with the greatest severity of overheating risk observed for the highest global warming projection, i.e. 4°C scenario, although overheating risks are also identified for the 2°C and 3°C global warming projections.
- Building construction characteristics – with the greatest severity of overheating risk observed for buildings that are highly glazed, lightweight, with highly occupied spaces and insufficient ventilation rates (often characterised by lack of adequate window openings).
- Location – with the greatest severity of overheating risk being in Greater London and Southern England, although increased risk of overheating is observed in all regions.

The most effective passive adaptation measures, which can reduce overheating risk are:

- Reducing solar heat gains (the key options are retrofitting solar shading, reducing areas of glazing and replacing clear glass with solar control glass).
- Increasing ventilation rates, such as increasing window opening areas or converting fixed windows to be openable.

Other passive mitigation measures include:

- Reducing internal heat gains from equipment, e.g. switching off equipment when not required in buildings.
- Exposing the thermal mass of the building fabric, where feasible, to enable night cooling to pre-cool structures so occupants feel cooler during the daytime.
- Incorporating blue/green external landscaping features around buildings to reduce the urban heat island effect.
- Influencing occupant behaviours, such as closing blinds during the daytime to reduce solar gains and opening windows at night.

Priority should be given to passive adaptation measures as these don't increase energy consumption, but when this is not sufficient building owners and landlords can implement active adaptation measures to reduce overheating risk in buildings. These measures include:

- Introducing mechanical cooling, e.g. comfort cooling combined with mechanical ventilation or air conditioning (it should be noted that this will increase operational costs and may not be affordable for the occupants in all building applications).
- Extending the hours of operation of mechanical ventilation systems to enable night cooling of the building fabric, i.e. using the mechanical ventilation systems to cool the structure with cool night air, so the building is cooler during the daytime.

1. Introduction

This report summarises the overheating risk analysis undertaken by Hoare Lea for the UKGBC UK Climate Resilience Roadmap project.

To understand the climate change impact on the overheating risk of the built environment Hoare Lea has used thermal dynamic modelling to assess the impact of climate change scenarios on a range of building types and building age ranges.

Standard industry practice for assessing overheating risk was followed. To assess the impact of future climate projections we used future weather projects provided by the Chartered Institution of Building Services Engineers (CIBSE) for thermal modelling purposes. Future global warming projections are available for three scenarios:

- Low global warming scenario (2˚C temperature increase)
- Medium global warming scenario (3˚C temperature increase)
- High global warming scenario (4˚C temperature increase)

To investigate the benefits of retrofit interventions we used the same thermal modelling techniques to assess methods to reduce overheating risk. These interventions include passive adaptation measures such as the introduction of the solar shading, increased use of window openings and active adaptation measures, such as the introduction of mechanical cooling to buildings. Generally, it is found that adaptation measures can reduce the risk of overheating.

1.1 Defining overheating risk

Overheating in a building occurs when occupants feel discomfort and feel uncomfortably hot.

Thermal discomfort can have several negative consequences for building occupants including lethargy loss of sleep in residences, reduced learning capacity in schools, compromised healthcare services in hospitals and reduced productivity in workplaces.

In care homes overheating can lead to exhaustion and dehydration of residents, which can lead to heat-related deaths.

Overheating risk is projected to increase in severity and frequency as climate change leads to increased periods of hot weather including heatwaves, which pose a particular risk for occupants in the built environment.

According to the Met Office, a heatwave is an extended period of hot weather relative to the expected conditions of a region at that time of year.

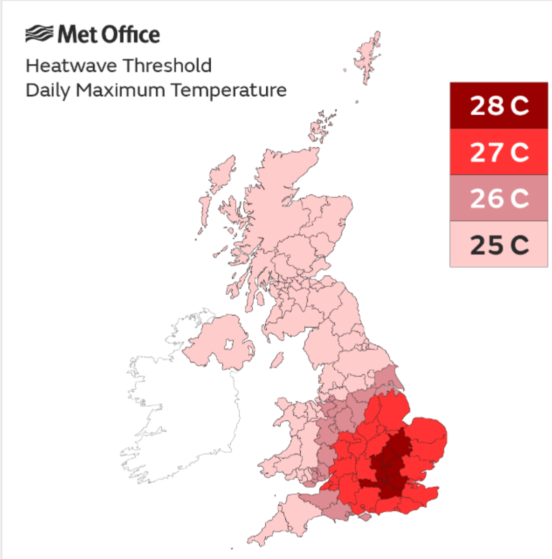


Figure 1 Met Office Heatwave Thresholds for the UK

A UK heatwave threshold is met when a location records a period of at least three consecutive days with daily maximum temperatures meeting or exceeding the heatwave temperature threshold. The threshold varies by UK region, displayed by the UK temperature threshold map shown here, prepared by the Met Office[1].

1.2 Assessing risk

Using thermal modelling we assessed overheating risk according to the extent to which acceptable internal environmental comfort criteria are exceeded.

This is based on assessing the risk that the internal temperature exceeds 28°C. This is recommended a limit for thermal comfort using CIBSE Guide A 2006[2], when using a design summer year weather file for a climatic model approach. 28°C degrees is also found to be the typical maximum recommended temperature limit across international regulatory comparisons.[3]

By comparison the World Health Organisation (WHO) recommends a lower limit of 25°C in their housing and health guidelines for UK cities.[4]

In our thermal modelling analysis, we have referred to 28°C as the acceptable comfort threshold. With 'low risk' meaning there is a relatively small exceedance of this internal operative temperature and 'extreme risk' being a significance exceedance, i.e. the indoor temperature exceeds this limit for a significant number of hours in the year.

[1] What is a heatwave? - Met Office

[2] CIBSE Guide A: Environmental Design, 2006

[3] Indoor air quality guidelines from across the world: An appraisal considering energy saving, health, productivity, and comfort, Dimitroulopoulou Environmental Design, 2023.1-s2.0-S0160412023004002-main 1 .pdf

[4] WHO housing and health guidelines, Appendix: Estimation of minimal risk and maximum acceptable temperatures for selected cities, 2018. WHO-CED-PHE-18.08-eng.pdf

1.3 Building types assessed

Overheating risk assessments have been undertaken for six building types, selected to consider building types whose occupants are likely to potentially experience more pronounced impacts of future climate change overheating in buildings:

- Houses
- High-rise residential buildings
- Care homes
- Healthcare
- Offices
- Schools

We have also assessed the influence of the age of construction, since methods of construction, material specifications and levels of thermal insulation have changed over time and these factors can influence the vulnerability of buildings to overheating risk. For example, modern building designs more generally tend to have larger areas of glazing and more lightweight construction, which can them more vulnerable to overheating, than older designs. The UK has a relatively old building stock compared to most European countries. For example, 36% of UK homes were built before 1945 and 55% were built before 1965.[5]

[5] The housing stock of the United Kingdom, BRE Trust, 2020 The-Housing-Stock-of-the-United-Kingdom_Report_BRE-Trust.pdf

2. Climate change scenarios

2.1 Climate change projections

We have used thermal dynamic modelling to assess overheating risk and used Integrated Environmental Solutions (IES) software.

We have followed CIBSE guidance, which provides the appropriate standards for assessing overheating risk in buildings and used design summer year weather files available at the time of the study.

The weather files available from CIBSE at the time of undertaking the assessment represent the 2 degree, 3 degree and 4 degree global warming scenarios using the UK Climate Change Projections from IPCC 2012.

1. Low warming projection - DSY1 2080 Low 50^{th} Percentile – a 2°C warming scenario.
2. Medium warming projection - DSY1 2080 Medium 50^{th} Percentile – a 3°C warming scenario.
3. High warming projection - DSY1 2080 High 50^{th} Percentile – a 4°C warming scenario.

DSY refers to a 'design summer year', defined by CIBSE for thermal modelling purposes.

CIBSE are in the process of developing updated future weather files from the IPCC 2018 climate change projections but are not available at the time of writing and therefore not able to be used for this report.

2.2 Locations and weather files

We have assessed overheating risk for the three global warming scenarios for six locations.

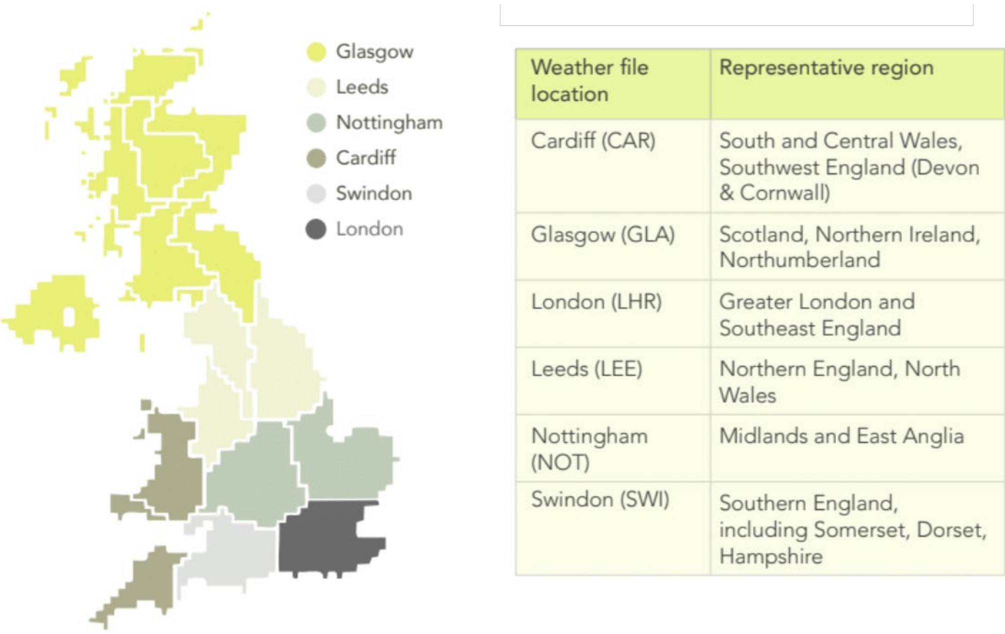
Research published in March 2024 identified six climatic regions[6] in the UK. This has been used to assign the most appropriate weather files to six regions in the UK. For example, the weather files for Glasgow are suitably representative of both Scotland and Northern Ireland, and weather files for Cardiff are representative of Wales and Southwest England (Devon and Cornwall). The weather files for London, based on a weather station at London Heathrow, are representative of Greater London and Southeast England.

[6] Creating granular climate zones for future-proof building design in the UK - ScienceDirect

The selected locations are shown in the table below (for comparison, the maximum observed temperature for each location is shown for 2022, which was notable for extreme temperatures).

Table 1 Selected weather file locations and maximum temperatures for DSY1 2080 weather files for 2˚, 3˚ and 4˚C warming scenarios

Location of CIBSE weather files (with abbreviated designation)	Representative regions	2˚C warming scenario. CIBSE weather file ref: DSY1 2080 (Low50)	3˚C warming scenario. CIBSE weather file ref: DSY1 2080 (Med50)	4˚C warming scenario. CIBSE weather file ref: DSY1 2080 (High50)	Maximum temperatures in 2022[7]
Leeds (LEE)	Northern England, North Wales	32.1°C	32.5°C	33.2°C	37°C
Nottingham (NOT)	Midlands and East Anglia	34.2°C	35.3°C	36.1°C	38°C
London (LHR)	Greater London and Southeast England	36°C	37.0°C	38.4°C	39°C
Glasgow (GLA)	Scotland, Northern Ireland, Northumberland	29.2°C	29.7°C	30.1°C	32°C
Cardiff (CAR)	South and Central Wales, Southwest England (Devon & Cornwall)	30.3°C	30.9°C	31.6°C	32°C
Swindon (SWI)	Southern England, including Somerset, Dorset, Hampshire	32.4°C	33.1°C	33.7°C	37°C



Weather file location	Representative region
Cardiff (CAR)	South and Central Wales, Southwest England (Devon & Cornwall)
Glasgow (GLA)	Scotland, Northern Ireland, Northumberland
London (LHR)	Greater London and Southeast England
Leeds (LEE)	Northern England, North Wales
Nottingham (NOT)	Midlands and East Anglia
Swindon (SWI)	Southern England, including Somerset, Dorset, Hampshire

Figure 2 Assignment of weather files to represent six regions in the UK

[7] The Weather Year Round Anywhere on Earth - Weather Spark

3. Modelling methodology

3.1 Indoor temperature criteria

As mentioned earlier, an indoor operative temperature limit of 28°C has been applied as a discomfort threshold to all building types with a risk rating allocated, ranging from 'low' risk to 'extreme' risk according to how many hours this threshold is exceeded.

When assessing impacts of overheating risk in buildings where people sleep (housing, care homes and healthcare buildings) we should be aware that there is growing evidence that sleep is disrupted by hot temperatures, which can cause stress, anxiety and loss in productivity at work[8].

3.2 CIBSE TM52 vulnerability categories

Occupants in different built environments have different levels of vulnerability, based on their ability to adapt and cope with overheating.

Figure 3 shows the CIBSE TM52 vulnerability categories.

For example, occupants in care homes, schools and healthcare buildings are considered to be particularly vulnerable to overheating and are in category 1, whereas occupants in houses and offices are considered to have greater opportunities to adapt and tolerate warmer temperatures and are classed as category 2 or 3.

These vulnerability categories are referenced in the following sections for each building type.

Category	Explanation	Suggested acceptable range (K)	Suggested acceptable limits (K)
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2	±0.2
II	Normal expectation (for new buildings and renovations)	±3	±0.5
III	A moderate expectation (used for existing buildings)	±4	±0.7
IV	Values outside the criteria for the above categories (only acceptable for limited periods)	>4	>0.7

Figure 3 CIBSE TM52 vulnerability categories (Source: CIBSE TM52)

[8] Public health impacts of heat', Parliamentary POST, 2024 POST-PN-0723.pdf

3.3 Housing (houses and high-rise residential buildings)

All housing other than new builds are assessed as CIBSE TM52 category 3. All new builds are assessed as category 2.

The tables show the overheating risk rating we have set for housing in terms of the number of days exceeding the adaptive and fixed temperature overheating criteria. Thus, the risk rating is 'extreme' when there is a high number of days exceeding the overheating criteria.

Table 2 Overheating risk ratings for housing

Overheating risk ratings for housing		
Overheating risk rating	Risk description	Number of days assessed as overheating
1	Low risk	0-3 days
2	Medium risk	3-6 days
3	High risk	6-9 days
4	Very high risk	9-12 days
5	Extreme risk	12 days +

3.4 Care homes

Care homes are assessed as CIBSE TM52 category 1, i.e. vulnerable/infirm due to the occupants having very low ability to adapt.

The table below shows the overheating risk rating we have set for care homes in terms of the number of days exceeding the adaptive and fixed temperature overheating criteria. Thus, the risk rating is 'extreme' when there is a high number of days exceeding the overheating criteria.

Table 3 Overheating risk ratings for care homes

Overheating risk ratings for care homes			
Fixed temperature threshold % hours above 28°C	Overheating risk rating	Risk description	Number of days assessed as overheating
0-<1%	1	Low risk	1-2 days
=>1-<3%	2	Medium risk	3-4 days
=>3-<5%	3	High risk	4-5 days
=>5-<7%	4	Very high risk	5-6 days
>7%	5	Extreme risk	6 days +

3.4 Healthcare buildings

Healthcare buildings are assessed for CIBSE TM52 category 1 risk, i.e. vulnerable/infirm due to the occupants being the most vulnerable to the impacts of overheating.

The table below shows the overheating risk rating we have set for healthcare buildings in terms of the number of days exceeding the adaptive and fixed temperature overheating criteria. Thus, the risk rating is 'extreme' when there is a high number of days exceeding the overheating criteria.

Table 4 Overheating risk ratings for healthcare buildings

Overheating risk ratings for healthcare buildings			
Fixed temperature threshold % hours above 28°C	Overheating risk rating	Risk description	Number of days assessed as overheating
0-<1%	1	Low risk	0-2 days
=>1-<3%	2	Medium risk	3-4 days
=>3-<5%	3	High risk	4-5 days
=>5-<7%	4	Very high risk	5-6 days
>7%	5	Extreme risk	6 days +

3.5 Offices

All offices other than new builds will be assessed as CIBSE TM52 category 3. All new build offices are assessed as category 2.

The table below shows the overheating risk rating we have set for schools in terms of the number of days exceeding the adaptive and fixed temperature overheating criteria. Thus, the risk rating is 'extreme' when there is a high number of days exceeding the overheating criteria.

Table 5 Overheating risk ratings for offices

Overheating risk ratings for offices			
Fixed temperature threshold % hours above 28°C	Overheating risk rating	Risk description	Number of days assessed as overheating
0-<1%	1	Low risk	0-3 days
=>1-<3%	2	Medium risk	3-6 days
=>3-<5%	3	High risk	6-9 days
=>5-<7%	4	Very high risk	9-12 days
>7%	5	Extreme risk	12 days +

3.6 Schools

We have taken the assessment of schools to be equivalent to primary schools, as these are the most vulnerable. Primary schools are assessed as CIBSE TM52 category 1, i.e. occupants are young/infirm; this covers all types of schools including special educational needs (SEN) and Nursery settings within a school.

The table below shows the overheating risk rating we have set for schools in terms of the number of days exceeding the adaptive and fixed temperature overheating criteria. Thus, the risk rating is 'extreme' when there is a high number of days exceeding the overheating criteria.

Table 6 Overheating risk ratings for schools

Overheating risk ratings for schools			
Fixed temperature threshold % hours above 28°C	Overheating risk rating	Risk description	Number of days assessed as overheating
0-<1%	1	Low risk	0-2 days
=>1-<3%	2	Medium risk	2-4 days
=>3-<5%	3	High risk	4-7 days
=>5-<7%	4	Very high risk	7-9 days
>7%	5	Extreme risk	9 days +

3.7 Categorising buildings

The thermal models are based on the assessment of overheating risks for buildings that have multiple rooms. For example, a house will have different rooms with different overheating responses and a school can have many classrooms, sometimes of different shapes and sizes, with different exposures to solar radiation. To rate the whole building overheating risk a weighting factor is applied to each risk assessment and a greater weight is given to the high, medium and extreme risk ratings. The tables below show the weighting factors applied to determine the overall overheating risk.

Table 7 Overall building risk criteria weighting factors

Overall building risk	Risk condition	Risk weighting factor
1	Low risk	1
2	Medium risk	2
3	High risk	3
4	Very high risk	4
5	Extreme risk	8

Table 8 Overall risk rating bands

Overall Building Risk	Risk Rating
1-<1.25	Low
=>1.25-<2	Low/medium
=>2-<2.5	Medium
=>2.5-<3	Medium/high
=>3-<3.5	High
=>3.5-<4	High/very high
=>4-<4.5	Very high
=>4.5-<5	Very high/extreme
>=5	Extreme

3.8 Worked example

Examples using this categorising method are shown below for a low and extreme risk rating.

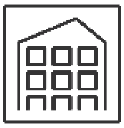
Table 9 Low risk example

Overall building risk	Number of rooms	Risk matrix	Risk weighting factor	Risk weighting results
1	90	Low risk	1	90
2	10	Medium risk	2	20
3	0	High risk	3	0
4	0	Very high risk	4	0
5	0	Extreme risk	8	0
Overall risk	100	Low risk		1.10

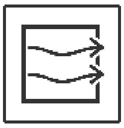
Table 10 Extreme risk example

Overall building risk	Number of rooms	Risk matrix	Risk weighting factor	Risk weighting results
1	0	Low risk	1	0
2	0	Medium risk	2	0
3	0	High risk	3	0
4	50	Very high risk	4	200
5	50	Extreme risk	8	400
Overall risk	100	Extreme Risk		6.00

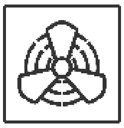
4. Adaptation measures



Our baseline overheating analysis shows the overheating risk for the current building stock, when assessed for future climate projections. The baseline analysis therefore shows the impact of global warming on the existing building stock if we do nothing. In practice there are measures that can be taken to reduce overheating risk, although the practical implications will be building specific.



Passive adaptation measures aim to reduce overheating risk without the requirement for additional equipment that uses energy. Passive interventions include increasing the area of openable windows, adding solar shading or replacing clear glazing with solar control glazing. Passive measures also include behavioural interventions such getting occupants to manage nighttime ventilation to cool building structures that reduce daytime overheating risk.



Active adaptation measures are interventions, such as the addition of mechanical cooling or increasing mechanical ventilation rates which will result in additional consumption of operational energy.

4.1 Implications of overheating for buildings with highly glazed façades

Buildings with large areas of glazing that face south, east and west are generally at greater risk of overheating than similar buildings with lower areas of glazing because of the higher amounts of solar radiation that transmit into occupied rooms.

It is noted that many contemporary building designs have higher proportions of glazing compared to older designs, and this can cause higher overheating risk and discomfort. This can be exacerbated if there are also insufficient window openings to allow purge ventilation.

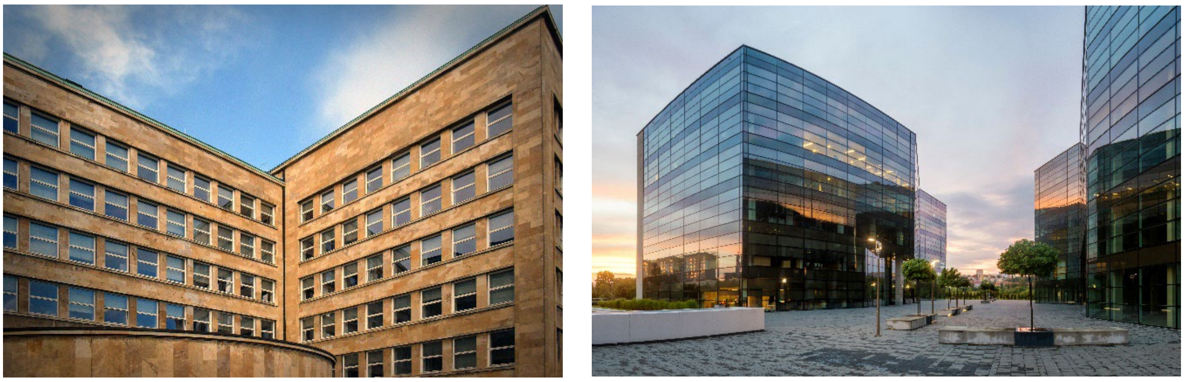


Figure 4 Comparison of office building with low areas of glazing and a typical modern office building with higher areas of glazing

4.2 Options for solar shading

Solar shading can significantly reduce overheating risk by reducing solar radiation transmission into buildings. Examples of shading devices are shown below taken from a useful guidance document published by the Good Homes Alliance.

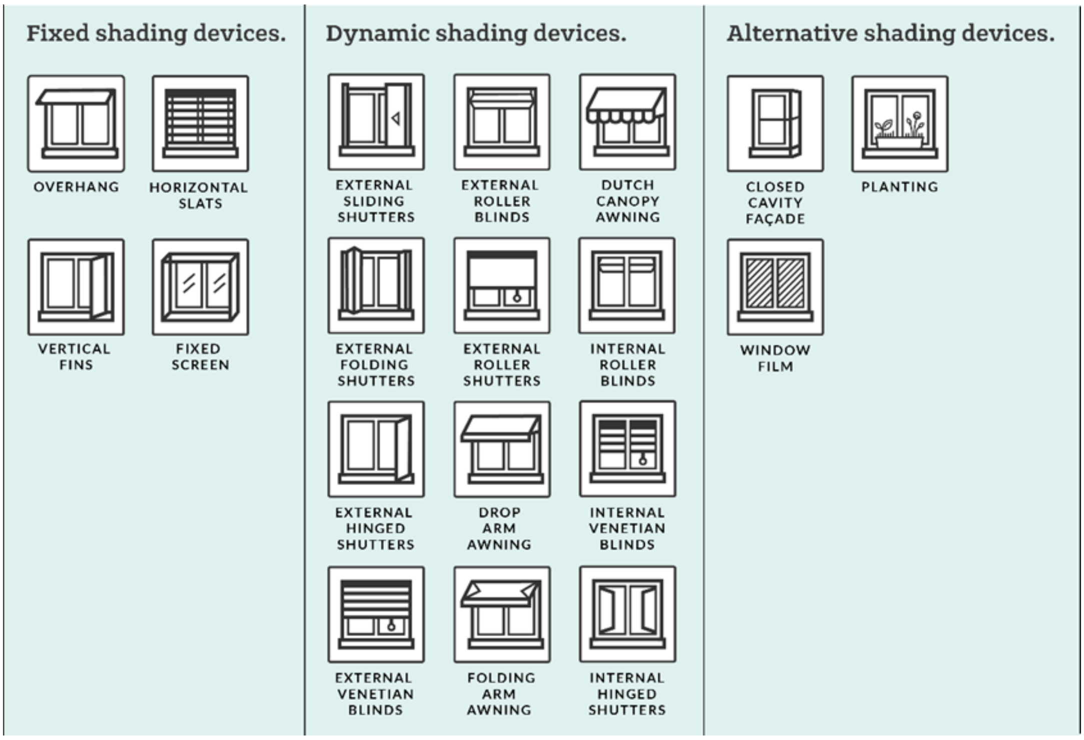


Figure 5 Options for solar shading (source: Good Homes Alliance).[9]

Figure 6 Examples of different solar shading systems

[9] Shading-for-housing-Design-guide_FINAL.pdf

4.3 Implications for buildings with restricted window openings

Figure 7 Window restrictor limiting the opening

Window opening restrictions are applied to many building types in the UK and this can increase the risk of overheating because reduced natural ventilation reduces the ability to purge the building of the high internal temperatures. This will lead to an increasing problem in many buildings that have restrictors, sometimes installed for safety reasons, without consideration of the overheating impacts. These building types are normally hospitals, schools, care homes and public buildings. The guidance is given by the Health and Safety Executive (HSE). It recommends that in health and social care premises windows that are large enough to allow people to fall out should be restrained sufficiently to prevent falls by implementing windows restrictors to no more than 100 mm and that these restrictions should only be able to be disengaged using a special tool or key[10]. From an occupant perspective this adds to increased overheating risk and higher heat related deaths, projected to reach 4,000/year in the UK by the mid-1930s and rise to 10,000/year by 2050[11]. In many cases restrictors provide a gap that is much less than this. It's not uncommon to see restrictors only allowing openings of 80mm with detrimental impacts on ventilation. Furthermore, windows are typically recessed in external walls so that the bottom or sides of the opening window are constrained by the structure, so fee air movement of air is only going through gaps of 50mm or less.

Building owners and designers should consider options for increasing ventilation rates including the provision of more high-level opening windows (1.5 metres above the floor) that can fully and safely open.

Figure 8 Examples of window designs with safe high level openings.
(Image credits Unsplash Bri Mathias, Mint Nisara, Richard Stachmann and Tai S)

[10] Avoiding falls from windows or balconies in health and social care premises, HSE. Avoiding falls from windows or balconies in health and social care premises - HSE

[11] Health Effects of Climate Change in the UK (HECC): 2023 Report, UK Health Security Agency. Health Effects of Climate Change in the UK: state of the evidence 2023

4.4 The influence of the urban heat island effect

The urban heat island effect is the term used to describe the higher air and surface temperatures that are typically found in towns and cities. It occurs when buildings are relatively close together, with rooftops, walls and streets having dark colours which exacerbates solar radiation absorption during the day, often with a lack of green space and insufficient ability for heat to be rejected to the sky at night. This effect exacerbates overheating risk in towns and cities by maintaining relatively higher temperatures overnight.

Our thermal modelling has not considered the influence of the urban heat island (UHI) effect on overheating risk, as this is not easily possible using readily available modelling techniques, and not normally included in standard industry methodologies for assessing overheating risks. This is a shortcoming in how the industry assesses overheating risk in buildings and professional institutions should advancing methodologies to take this into account.

The impact of the urban heat island effect can increase average air and surface temperatures in urban districts by 3-5°C, or more, compared to suburban and rural areas. It should be acknowledged therefore, that in practice, overheating risks for buildings in towns and cities could be higher than modelled, which followed standard industry practice.

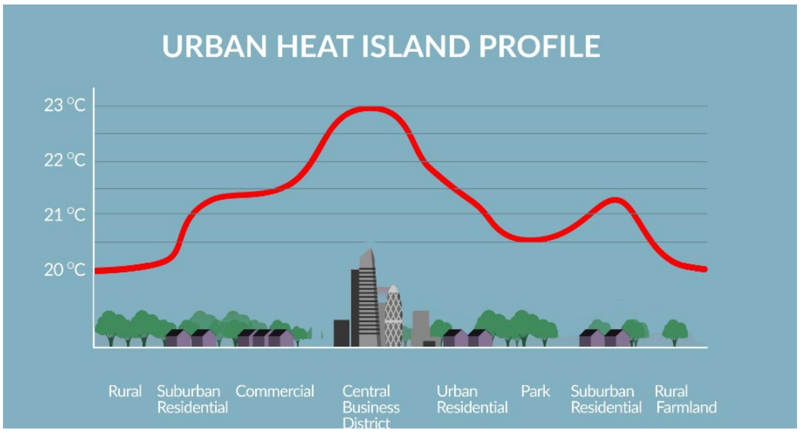


Figure 9 Urban heat island effect

Green landscaping and external water features (also known as green/blue infrastructure) and other nature-based-solutions can be used to reduce urban heat island effects.

It should therefore be noted that whilst we have not assessed green infrastructure as a mitigation measure in our thermal modelling it can be used by building owners and planners to improve climate resilience.

Figure 10 Examples of green infrastructure that can reduce the urban heat island effect and reduce overheating risk

Green landscaping near buildings is also shown to provide health and wellbeing benefits in terms of reduced anxiety, better cognitive performance, improved levels of physical activity, improving recovery outcomes and better community interactions and engagement.[12] [13] [14]

[12] The Association of Occupational Health and Wellbeing Professionals: The Role of Biophilia in Workplace Health and Wellbeing

[13] Mental Health Foundation, Nature: How connecting with nature benefits our mental health | Mental Health Foundation

[14] Frontiers in Built Environment, Frontiers | A systematic review of the impact of therapeutical biophilic design on health and wellbeing of patients and care providers in healthcare services settings

5. Overheating analysis

This section of the report summarises the findings of the overheating risk analysis for future climate change scenarios. The results of the analysis are provided for the current building stock, represented by six building types without any additional adaptation measures (i.e. the baseline assessment) and the influence of applying adaptation measures to improve resilience (i.e. passive and active mitigation retrofit measures).

We assessed overheating risk for new development (compliant with current building standards) and older development so that we could compare any differences.

The results of the analysis show that the severity of overheating risk depends on a range of factors.

We found that overheating risk is strongly influenced for the following:

- Climate change scenario – with the greatest severity of overheating risk observed for the highest global warming projection, i.e. 4°C scenario, although overheating risks are also identified for the 2°C and 3°C warming projections
- Building construction characteristics – with the greatest severity of overheating risk observed for buildings that are highly glazed, lightweight, with highly occupied spaces and insufficient ventilation rates (often characterised by lack of adequate window openings)
- Location – with the greatest severity of overheating risk being in Greater London and Southern England, although increased risk of overheating is observed in all regions.

5.1 Houses - overheating analysis

The results for the analysis of overheating risks for houses are shown below. The results present the baseline risks for older houses (pre-1945) and new build, and how overheating risks can be reduced by passive and active adaptation measures. It should be noted that the practicality of taking adaptation interventions will be site specific and depend on feasibility, construction impacts, costs, and planning approval if significant modifications are made to the façade. For houses and high-rise residential buildings (i.e. apartment blocks) the assumptions for occupancy and internal heat gains follow CIBSE TM 59 methodology.

Table 11: Overheating risk analysis for houses

Overheating risk analysis for houses Comparison of baseline overheating risk with improvements for passive and active adaptation measures.							
		Older houses (Pre - 1945)			New build houses		
Location	Climate change projection	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit
Cardiff	Low (2°C)	Low/medium	Low/medium	-	Low/medium	Low/medium	-
	Medium (3°C)	Medium/high	Low/medium	-	Low/medium	Low/medium	-
	High (4°C)	High/very high	Medium	-	Medium	Medium	-
Glasgow	Low (2°C)	Low/medium	Low	-	Low	Low	-
	Medium (3°C)	Low/medium	Low	-	Low/medium	Low	-
	High (4°C)	Low/medium	Low	-	Low/medium	Low/medium	-
Leeds	Low (2°C)	High	Medium	-	Medium/high	Low/medium	-
	Medium (3°C)	Very high	Medium/high	Low	High	High	Low/medium
	High (4°C)	Extreme	Medium/high	Low	V.high/extreme	High	Low/medium
London	Low (2°C)	Extreme	Extreme	V.high/extreme	Extreme	Extreme	Extreme
	Medium (3°C)	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme
	High (4°C)	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme
Nottingham	Low (2°C)	Low/medium	Low/medium	-	Medium	Medium	-
	Medium (3°C)	Medium	Medium	-	Medium/high	Medium/high	Low/medium
	High (4°C)	Medium/high	Medium/high	Low	High	Medium/high	Medium
Swindon	Low (2°C)	High	Medium/high	Low/medium	High	Medium	-
	Medium (3°C)	V.high/extreme	High	Low/medium	V.high/extreme	High	Medium
	High (4°C)	Extreme	V.high/extreme	Medium	Extreme	Extreme	High

The baseline results (i.e. without mitigation measures)

- The results show that all regions experience a certain level of overheating risk under a 2°C, 3°C or 4°C warming scenarios.
- There is regional variation in the level of overheating risk, with the greatest overheating risk observed in the London region.
- There is some difference in overheating risk observed in new and older houses (represented by pre-1945 construction) but this is not significant. Variability in individual designs (such as proportions of glazing, the means of ventilation, size of the home, density of occupation and other characteristics can be more influential than the building standards determined by the age of construction).

Assessment of passive adaptation measures

The passive adaptation analysis assesses the impact of various passive measures to assess the extent to which overheating risk can be reduced without active cooling. The following intervention measures were incorporated:

Occupant behaviour:

- Human behaviour has been incorporated into the modelling profiles, to try and reduce overheating risk by mimicking beneficial human actions.
- The standard internal gain profile for equipment within the kitchens has been adapted so that additional gains from the use of ovens will not come on in periods of high temperatures over the summer months.
- All openable windows have been assigned to the relevant Part O[15] opening profile, which has been adapted to incorporate occupants closing windows in heatwave .

Optimising windows:

- Increased openable window areas have been integrated within the same overall glazing area, as it understood that fixed (non-openable) glazing can be replaced with more openable windows, without structural changes.
- Improved window openings have been modelled, based on best practice. This would take the form of ideally a split window with lower and higher openings, determined by window heights and sill levels. Openings below 1.1m are restricted, whereas openings above 1.5m were assumed to be fully openable.
- Improving the openable window configuration will help increase the benefit of natural ventilation and therefore mitigate overheating risks.

Improved U-values and G-values:

- Current glazing is assumed to be replaced by solar control glazing with a lower G-value. All glazing G-values have been improved from the assumed baseline G-values which vary according to the age of the building to value of 0.33 and the glazing U-values have been improved to 1.4 W/m^2.K, as detailed in Appendix A.
- It is assumed that the glazing specification could be improved alongside optimising the window opening configurations.

Solar shading:

- Solar shading has been incorporated to reduce the impact of solar gain.
- This is assumed to be in the form of interstitial blinds although external louvres, overhangs or shutters could be suitable alternatives.

Thermal mass:

- It assumed that exposed thermal mass, whilst a viable option for non-residential buildings, would not be suitable for most residential buildings and therefore this passive measure has not been tested for housing. If appropriate, this would be most suitable for houses with a higher thermal mass, which tends to be the case for older houses made of brick or stone.

[15] https://www.gov.uk/government/publications/overheating-approved-document-o

Ceiling/stand-alone fans:

- It is assumed that the addition of an internal fan, either ceiling fan or stand-alone floor mounted fan, would be beneficial in helping air circulation and is a well-used passive cooling technique in hot European countries.
- Use of fans will also have an impact on the air speed in the room and will increase evaporative cooling impacts, resulting in occupants feeling cooler.
- Fans have been incorporated by increasing the (elevated) air speed from 0.1 m/s to 0.8 m/s in occupied rooms.

The passive adaptation results show:

- In most locations, passive measures have the capacity to lower overheating risks for most houses.
- In locations where future temperature rises are predicted to be less intensive, notably Cardiff and Glasgow, the impact of passive measures has more of a noticeable impact. Passive measures alone are sufficient to largely reduce the overheating risk to Low, particularly under a 2°C and 3°C warming scenarios.
- In London, overheating risks remain Extreme whereas other locations have a reduced risk rating.
- As anticipated, overheating risks escalate as the climate change projection increases the external temperatures, and follows a similar pattern as identified in the baseline results. The 2°C scenarios maintain Low or Medium risk levels whereas under the 4°C scenario, the risk becomes Extreme. Passive measures reduce risks slightly but are insufficient in the warmest areas.
- Under high warming scenarios and in the locations with the weather files that have the highest external ambient temperatures, additional measures will be required to reduce the risk.

Active adaptation measures

For locations and weather files which demonstrated an overheating risk greater than 'Medium' following the incorporation of passive intervention measures, active measures have been introduced (in addition to passive measures) to test their impact.

Increased flowrates:

In the older homes where, mechanical ventilation is generally not present, a mechanical ventilation heat recovery (MVHR) unit is introduced, with a flow rate capacity of 110 l/s. This relates to a typical system provided in a new home to meet current building regulation requirements.

Tempered air:

An MVHR cooling coil is introduced to cool the supply air temperature in the MVHR unit. This cooling coil output ramps up and down based on the external and internal temperatures.

Analysis of the active adaptation measures show:

- Introducing an MVHR with a cooling coil largely reduces overheating risk, although the London region remains at Very High or Extreme Risk.
- Incorporating a cooling coil within an MVHR is preferable over the installation of a full cooling unit, such as a Variable Refrigerant Flow (VRF) system, due to the costs and additional energy consumption associated with these system types.

5.2 High-rise residential buildings – overheating analysis

The results for the analysis of overheating risks for high-rise residential buildings are shown below. The results present the baseline risks for older buildings (1970-2000) and new build, and how overheating risks can be reduced by passive and active adaptation measures. It should be noted that the practicality of taking adaptation interventions will be site specific and depend on feasibility, construction impacts, costs, and planning approval if significant modifications are made to the façade. Clearly the ownership model for high density residential buildings is also likely to be different than for low density housing, with the units being more likely to have leasehold ownership or be more likely to be rented tenures. This will clearly impact the ability of an individual occupier to undertake some retrofit measures.

The table below quantifies the severity of risk for the occupied spaces tested, in terms of number of hours exceeding 28°C.

Table 12 Number of hours for each overheating risk category

Experienced overheating over summer period			
Overheating criteria Hrs > 28°C		Bedrooms occupied 24/7	Living/Dining Room (9am-10pm)
< 1%	Low	36.7 hours	19.9 hours
1% > 3%	Medium	110.2 hours	59.7 hours
3% > 5%	High	183.6 hours	99.5 hours
5% >7%	Very high	257.0 hours	139.3 hours
7% <	Extreme	Above 258.0 hours	Above 140 hours

Table 13 Overheating risk analysis for high-rise residential buildings

Overheating risk analysis for high-rise residential buildings Comparison of baseline overheating risk with improvements for passive and active adaptation measures.							
		Older high-rise residential buildings (1970-2000)			New build		
Location	Climate change projection	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit
Cardiff	Low (2°C)	Low/medium	Low	-	Low/medium	Low	-
	Medium (3°C)	Medium	Low	-	Low/medium	Low	-
	High (4°C)	High	Low	-	Medium	Low	-
Glasgow	Low (2°C)	Low	Low	-	Low	Low	-
	Medium (3°C)	Low	Low	-	Low	Low	-
	High (4°C)	Low	Low	-	Low/medium	Low	-
Leeds	Low (2°C)	Medium/high	Low	-	Medium	Low	-
	Medium (3°C)	High/V.high	Low	-	Medium	Low	-
	High (4°C)	V.high/extreme	Low/medium	-	High	Low	-
London	Low (2°C)	Extreme	Extreme	Low	Extreme	V.high/extreme	High
	Medium (3°C)	Extreme	Extreme	Low/medium	Extreme	Extreme	V.high/extreme
	High (4°C)	Extreme	Extreme	Low/medium	Extreme	Extreme	Extreme
Nottingham	Low (2°C)	Low/medium	Low	-	Medium	Low	-
	Medium (3°C)	Medium	Low	-	Medium/high	Low	-
	High (4°C)	Medium/high	Low	-	Medium/high	Low	-
Swindon	Low (2°C)	High/V.high	Low/medium	-	Medium/high	Low/medium	-
	Medium (3°C)	Extreme	Low/medium	-	High/V.high	Low/medium	-
	High (4°C)	Extreme	Medium/high	-	V.high/extreme	Medium	-

The baseline results (i.e. without mitigation measures):

- The majority of building types across all locations experience a high level of risk to overheating under a 2°C, 3°C or 4°C warming scenario.
- Overheating risks increase consistently as climate projections move from Low (2°C) to Medium (3°C) and High (4°C). Under High (4°C) projections, most cities experience High, Very High, or Extreme risks across all building eras and types, the exception of Glasgow which identifies a Low risk under all baseline scenarios.
- New builds generally perform better than older typologies, particularly in cooler climates like Glasgow and Cardiff, where risks are mitigated to Low/Medium or Medium.

- Although new builds generally demonstrate a lower overheating risk due to better performing fabric and incorporation of mechanical ventilation, this is not enough to mitigate severe climate projections in regions with higher external ambient temperatures, most notably, the Southeast regions of the UK.
- Southern cities such as London and Swindon consistently show higher overheating risks, with most building types reaching Extreme risk under Medium (3°C) and High (4°C) projections.
- There is consistently an Extreme risk in London, across all ages.
- Across all climate projections for both older and new builds in Glasgow, these maintain a Low overheating risk, due to the cooler climate environment.
- Older building types generally have a higher overheating risk compared to new builds, as these tend to have restricted windows which limit natural ventilation, and no additional mechanical ventilation. These build types also don't have any external shading such as balconies which may help to mitigate excessive solar gains.

Assessment of passive adaptation measures
The passive and natural ventilation scenario combine various intervention measures and openable windows to assess the extent to which overheating risk can be reduced without active cooling. The following intervention measures were incorporated:

Occupant behaviour:

- Human behaviour has been incorporated into the modelling profiles, to try and reduce overheating risk by mimicking beneficial human actions.
- The standard internal gain profile for equipment within the kitchens has been adapted so that additional gains from the use of ovens will not come on in periods of high temperatures over the summer months.
- All openable windows have been assigned to the relevant Part O opening profile, which has been adapted to incorporate occupants closing windows in heatwave conditions.

Optimise Openable Windows:

- Increased openable window areas have been integrated within the same overall glazing area, as it understood that fixed (non-openable) glazing can be replaced with more openable windows, without structural changes.
- Improved window openings have been modelled, based on best practice. This would take the form of ideally a lower and higher opening, determined by window heights and sill levels. Openings below 1.1m were restricted, whereas openings above 1.5m were assumed to be fully openable.
- Improving the openable window configuration will help increase the benefit of natural ventilation and therefore mitigate overheating risk.

Improved U-values and G-values:

- Current glazing is assumed to be replaced by solar control glazing with a lower G-value. All glazing G-values have been improved from the assumed baseline G-values which vary according to the age of the building to value of 0.33 and the glazing U-values have been improved to 1.4 $W/m^2.K$,
- It is assumed that the glazing specification could be improved alongside optimising the window opening configurations.

Solar shade:

- Solar shading has been incorporated in order to reduce the impact of solar gain.
- For the high-rise residential typology, it is assumed that external shading would be most appropriate.

Thermal mass:

- The ceiling voids in the new build high-rise residential models have been removed to allow for exposed thermal mass. It is assumed this is passive measure is most feasible for new builds, rather than older existing building types.

Ceiling/stand-alone fan:

- It is assumed that the addition of an internal fan, either ceiling fan or stand-alone floor mounted fan, would be beneficial in helping air circulation and is a well-used passive cooling technique in hot European countries.
- Use of fans will also have an impact on the air speed in the room and will increase evaporative cooling impacts, resulting in occupants feeling cooler.
- Fans have been incorporated by increasing the (elevated) air speed from 0.1 m/s to 0.8 m/s in occupied rooms.

The passive results show:

- The incorporation of passive measures and natural ventilation have the capacity to largely reduce the risk of overheating across all building types.
- In locations where future temperature rise is predicted to be less intensive, notably Cardiff and Glasgow, passive measures and openable windows are sufficient to reduce the overheating risk to low, particularly under a 2°C and 3°C warming scenario.
- London and Swindon still experience Extreme risks of overheating.
- Overall, it is evident that passive measures and natural ventilation have significant potential to reduce overheating risk and are a key first step to minimising risk as temperatures increase. It is also shown that the approach adopted should be unique to each location around the UK.
- However, under high warming scenarios and in the locations with the hottest weather environment, reflected by the weather files used, additional measures are required to reduce the risk.

Active adaptation measures

For locations and weather files which demonstrated an overheating risk greater than Medium following the incorporation of passive intervention measures, active measures have been introduced (in addition to passive measures) to test their impact.

Increased flowrates:

In the older build types where, mechanical ventilation is not present, an MVHR unit has been introduced, with a flow rate capacity of 80 l/s and 90 l/s for one and two bed dwellings respectively. Where MVHR was already present, flow rates were not increased as it was understood space planning may be an issue.

Tempered air:

An MVHR cooling coil has been introduced to cool the supply air based on an MVHR unit. This profile ramps up and down based on the external and internal temperatures.

Analysis of the cooling results shows that:

- Introducing an MVHR with a cooling coil has largely reduced the risk level in those buildings which had a High to Extreme risk rating after passive measures were introduced, to a Low or Low/Medium risk rating.
- The impact of the MVHR with a cooling coil within the London climate file is particularly effective in the pre-2000 build types. This is likely due to the façade incorporating lower amounts of glazing, compared to new-builds, where floor-ceiling glazing is more common and excessive solar gain is persistent. For the post-2000 and new build types, the risk is reduced slightly for the Low and Medium climate projections, however, remains as Extreme for the 4^{0}C scenario.
- The impact of the MVHR with a cooling coil within the Swindon climate file shows that the risk drops from High/Very High-risk rating to a Low or Low/Medium risk rating.
- Incorporating a cooling coil within an MVHR is preferable over the installation of a full cooling unit, such as a VRF system, due to the costs and additional energy consumption associated with these system types.

The simulation results also show that even in the areas with relatively higher temperatures, specifically London, active measures can reduce the overheating risk to Low. However, where the risk remains High or Extreme, it is likely that a full cooling system, such as a VRF system, will need to be installed to reduce the risk to a low risk for 2000-2020 and new build types.

5.3 Care homes – overheating analysis

The building typology has been assessed using the 28°C maximum acceptable temperature threshold. As with other buildings, the severity of overheating risk is determined by the number of occupied hours during which internal temperatures exceed the respective overheating criterion limits, expressed as a percentage. The table below presents the risk categories, and the corresponding bandings used to assess the level of risk.

The severity of risk is shown to range from Low to Extreme based on how much of the occupied time, in relative terms, the building exceeds the overheating condition. The table below quantifies the severity of risk for the occupied spaces tested, in terms of number of hours exceeded.

Table 14 Overheating extent in care home buildings in relation to the assessment criteria

Experienced overheating over summer period			
Overheating criteria		Bedrooms occupied 24/7	Living/dining room (9am-10pm)
< 1%	Low	37 hours (1.5 days)	20 hours (almost 1 day)
1% > 3%	Medium	110 hours (4.5 days)	60 hours (2.5 days)
3% > 5%	High	184 hours (almost 8 days)	100 hours (almost 4 days)
5% >7%	Very high	257 hours (almost 11 days)	139 hours (Almost 6 days)
7% <	Extreme	Above 258 hours (more than 11 days)	Above 140 hours (more than 6 days)

The majority of pre-2000 care homes are converted residential homes with smaller single rooms and shared bathrooms while post-2000 care homes tend to be purpose built with larger en-suite rooms. Both types of care homes are however at significant risk of overheating as the temperatures in the UK increase due to anticipated climate change and the occupant vulnerability.

To keep operational carbon and cooling costs to a minimum, care home designers and developers are recommended to incorporate several passive intervention measures. However, depending on the location, active measures such as mechanical ventilation with tempered cooling, and active cooling for some locations and space types, such as common rooms, will still be required to mitigate overheating.

The results for the analysis of overheating risks for care home buildings are shown below. The results present the baseline risks for older care homes and new build, and how overheating risks can be reduced by passive and active adaptation measures. It should be noted that the practicality of taking adaptation interventions will be site specific and depend on feasibility, construction impacts, costs, and planning approval if significant modifications are made to the façade.

Table 15 Overheating risk analysis for care homes

Overheating risk analysis for care homes Comparison of baseline overheating risk with improvements for passive and active adaptation measures.							
		Older care homes (1970-2000)			New build		
Location	Climate change projection	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit
Cardiff	Low (2°C)	Extreme	Medium	Medium	Medium	Low	-
	Medium (3°C)	Extreme	Medium	Medium	Medium/high	Low	-
	High (4°C)	Extreme	Medium	Medium	High	Low/medium	Low/medium
Glasgow	Low (2°C)	V.high/extreme	Low/medium	Low/medium	Low/medium	Low	-
	Medium (3°C)	Extreme	Medium	Medium	Low/medium	Low	-
	High (4°C)	Extreme	Medium	Medium	High	Low	-
Leeds	Low (2°C)	Extreme	Medium/high	Medium/high	High/V.high	Low/medium	Low/medium
	Medium (3°C)	Extreme	High	High	V.high/extreme	Low/medium	Low/medium
	High (4°C)	Extreme	Very high	Very high	Extreme	Low/medium	Low/medium
London	Low (2°C)	Extreme	Extreme	Extreme	Extreme	Very high	Very high
	Medium (3°C)	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme
	High (4°C)	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme
Nottingham	Low (2°C)	Extreme	High	High	High/V.high	Low/medium	Low
	Medium (3°C)	Extreme	High/V.high	High/V.high	Extreme	Low/medium	Low/medium
	High (4°C)	Extreme	Extreme	Extreme	Extreme	Medium	Low/medium
Swindon	Low (2°C)	Extreme	High	High	Very high	Low/medium	Low/medium
	Medium (3°C)	Extreme	High/V.high	High/V.high	V.high/extreme	Medium	Low/medium
	High (4°C)	Extreme	Extreme	Extreme	Extreme	Medium/high	Medium

Assessment of passive adaptation measures
The passive measures scenario combines various intervention measures to assess the extent to which overheating risk can be reduced without active cooling. The following intervention measures were incorporated:

Reconfigured windows:

- For all the building types, windows are reconfigured to allow for windows between 1100 mm and 1500 mm to be restricted to 100 mm openings. Above 1500 mm, windows have been modelled as unrestricted.
- Improving the openable window configuration will help increase the benefit of natural ventilation and therefore mitigate overheating risk.

- All openable windows have been assigned to the relevant Part O opening profile, which has been adapted to incorporate occupants closing windows in heatwave conditions.

Improved U-values and G-values:

- Current glazing is assumed to be replaced by solar control glazing with a lower G-value. All glazing G-values have been improved from the assumed baseline G-values which vary according to the age of the building to value of 0.33 and the glazing U-values have been improved to 1.4 W/m^2.K,
- It is assumed that the glazing specification could be improved alongside optimising the window opening configurations.
- U-values were improved to comply with regulatory requirements.

Solar shade:

- External shutters with 50% transmission factor have been introduced on all the windows that shut in the event of a heatwave where external temperatures exceed 28°C.

Thermal mass:

- The ceiling voids in the new build care homes are removed to allow for exposed thermal mass. This intervention is not applicable to older buildings as they do not contain ceiling voids as a typical feature.

The passive results indicate that:

- The incorporation of passive measures has the capacity to significantly reduce the risk of overheating. However, the 1970-2000 building type still has High to Extreme risk in Leeds, Nottingham and Swindon. London still experiences an extreme risk for all building types following incorporation of passive measures albeit closer to the Extreme risk limit boundary.
- In Glasgow and Cardiff, where the future temperatures are projected to be not as high as in other locations, passive measures have been seen to reduce the risk to Low to Medium risk across all building ages and weather scenarios.
- Passive measures represent the first line of defence against overheating. However, measures should be chosen based on location and other design factors such as building orientation, proximity to adjacent buildings whilst taking into account noise and air quality issues although the majority of care homes are usually located in semi-rural or rural location not typified to have external noise or air quality issues.

For some building types and warmer climate change projections, active mitigation measures are required to reduce the risks further.

Active adaptation measures

Active adaptation retrofit measures were taken as follows:

Mechanical ventilation:

Ventilation from MVHRs is introduced with 8l/s/p and 14l/s/p flowrates for bedrooms and common rooms respectively that operates as internal temperature exceeds 23˚C and air is supplied at external air temperature.

Tempered air:

Where this is insufficient, an MVHR cooling coil has been introduced that can reduce supply temperatures down to 14-20˚C.

The active measure scenarios demonstrate that without any active cooling in any of the spaces, risks would not be reduced to the Low category for all the building types, locations and climate change projection scenarios. This is mainly due to the common rooms, dining halls and lounges continue to be at a higher overheating risk resultant from high internal gains.

The active results indicate that:

- The tested active measures are insufficient for care homes to demonstrate a Low risk, with the exception of Cardiff and Glasgow 2000-2020 and new builds for most of the climate change projection scenarios, unless they are accompanied with active cooling for at least some space types. For example, the 1945-1970 care home model results indicate that active cooling needs to be introduced for common rooms even though the bedrooms will not require any active measures.
- Similarly, tempered air cooling will be sufficient for most bedrooms in all the building ages and locations except London, however some south and west facing bedrooms on the upper floors will still require active cooling in locations like Swindon, Nottingham and Leeds to reduce the overall building risk. Common rooms and lounges will need active cooling regardless of the location and building age.
- For all care homes simulated using the London weather files, active cooling was simulated to be required in the majority of spaces, including bedrooms, to reduce overheating risk to Low for all climate change projections.

5.4 Healthcare buildings – overheating analysis

The results for the analysis of overheating risks for healthcare buildings are shown below. The results present the baseline risks for older healthcare buildings (1945-1970) and new build, and how overheating risks can be reduced by passive and active adaptation measures. It should be noted that the practicality of taking adaptation interventions will be site specific and depend on feasibility, construction impacts, costs, and planning approval if significant modifications are made to the façade.

Table 16 Overheating risk analysis for healthcare buildings

Overheating risk analysis for healthcare buildings
Comparison of baseline overheating risk with improvements for passive and active adaptation measures.

		Older healthcare buildings (1945-1970)			New build		
Location	Climate change projection	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit
Cardiff	Low (2°C)	Medium	Low	-	Very high	Low	-
	Medium (3°C)	Medium/high	Low	Low	Very high	Low/ medium	-
	High (4°C)	Medium/high	Medium	Low/medium	High	Low	Low
Glasgow	Low (2°C)	Low/medium	Low	-	High	Low	-
	Medium (3°C)	Medium	Low	Low	High	Low	-
	High (4°C)	Medium	Low	Low	Very high	Low	-
Leeds	Low (2°C)	High/V.high	Medium	Low	Very high	Low	Low
	Medium (3°C)	Very high	Medium	Low	Very high	Low/ medium	Low
	High (4°C)	Extreme	High	Low/medium	Extreme	Medium	Low
London	Low (2°C)	Extreme	Extreme	Medium	Extreme	High/V.high	Low
	Medium (3°C)	Extreme	Extreme	High	Extreme	Very high	Low/medium
	High (4°C)	Extreme	Extreme	Very high	Very high	Low	Low
Nottingham	Low (2°C)	Medium/high	Medium	Low	Very high	Low	-
	Medium (3°C)	High	Medium/high	Low/medium	V.high/extreme	Low/ medium	-
	High (4°C)	Extreme	High	Medium	Very high	Low	Low
Swindon	Low (2°C)	Very high	Medium	Low/medium	V.high/extreme	Low/ medium	-
	Medium (3°C)	Very high	High	Low/medium	V.high/extreme	Medium	Low
	High (4°C)	Extreme	High	Medium	V.high/extreme	Medium	Low/medium

Baseline results

The baseline results (i.e. without mitigation measures) show:

- London is a location of Extreme risk for all UK climate projections.
- The medium and high temperature increase climate change projections have Extreme impact in several other regions, represented by Swindon, Nottingham and Leeds.
- Some designs and periods of construction are more vulnerable than others. This can be due to design characteristics like high proportions of glazing, lightweight construction and inadequate means of ventilation (sometimes due to window opening restrictions and full height window configurations).
- It was also found that occupation density has an influence on overheating risk, i.e. small rooms with high occupation are more at risk, especially if they don't have enough ventilation to allow purging.

Assessment of passive adaptation measures

Analysis shows the following benefits of passive mitigation measures added to the buildings:

- The mitigation measures are sufficient to reduce the severity of risk from Extreme to Medium severity in the London location for some of the age profiles tested.
- The mitigation measures shift the severity of risk from Medium to Low in locations such as Cardiff and Glasgow (representing Wales and Scotland), especially for the low warming projection.

The results shown below incorporate the impact of active mitigation measures (e.g. adding mechanical cooling to temper the supply air temperature in the ventilation system).

Active adaptation measures

Analysis shows the following benefits of active mitigation measures added to the buildings:

- Integrating mechanical cooling coil in the ventilation system significantly reduces the severity of overheating risk, although will increase operational energy.
- The vast majority of locations will show a Low to Low/Medium risk overheating through passive and adoption of mechanical ventilation with a cooling coil, although due to the traditionally high ventilation rates required for healthcare that this almost will act is active cooling through an air system.
- The 3 and 4°C emissions climate change projection still represents an overheating risk in London, even with mechanical cooling added (although further increases to the mechanical cooling system and other active measures could limit the risk).

5.5 Offices – overheating analysis

The results for the analysis of overheating risks for offices are shown below. The results present the baseline risks for older offices (1970-2000) and new builds, and how overheating risks can be reduced by passive and active adaptation measures. It should be noted that the practicality of taking adaptation interventions will be site specific and depend on feasibility, construction impacts, costs, and planning approval if significant modifications are made to the façade.

Table 17: Overheating risk analysis for offices

Overheating risk analysis for offices Comparison of baseline overheating risk with improvements for passive and active adaptation measures.							
		Older Offices (1970-2000)			New Build		
Location	Climate change projection	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit
Cardiff	Low (2°C)	Extreme	Low	-	Extreme	Low	-
	Medium (3°C)	Extreme	Low	-	Extreme	Low	-
	High (4°C)	Extreme	Low/ medium	Low	Extreme	Low/ medium	Low
Glasgow	Low (2°C)	Extreme	Low	-	Extreme	Low	-
	Medium (3°C)	Extreme	Low	-	Extreme	Low	-
	High (4°C)	Extreme	Low	-	Extreme	Low	-
Leeds	Low (2°C)	Extreme	Low/ medium	Low	Extreme	Low/ medium	Low
	Medium (3°C)	Extreme	Medium	Low	Extreme	Medium	Low
	High (4°C)	Extreme	Medium/high	Low	Extreme	Medium/ high	Low
London	Low (2°C)	Extreme	Extreme	Low/ medium	Extreme	Extreme	Low
	Medium (3°C)	Extreme	Extreme	Medium	Extreme	Extreme	Low
	High (4°C)	Extreme	Extreme	Very high	Extreme	Extreme	Low
Nottingham	Low (2°C)	Extreme	Low	-	Extreme	Low	-
	Medium (3°C)	Extreme	Low	-	Extreme	Low/ medium	Low
	High (4°C)	Extreme	Low	-	Extreme	Medium	Low
Swindon	Low (2°C)	Extreme	Low/medium	Low	Extreme	Medium	Low
	Medium (3°C)	Extreme	Medium/high	Low	Extreme	Medium/ high	Low
	High (4°C)	Extreme	Very high	Low	Extreme	V.high/extreme	Low

The baseline results (i.e. without mitigation measures):

- The results show that the majority of building types across all locations will experience an Extreme risk to overheating under a 2°C, 3°C and 4°C warming scenario.
- Offices built after 1970 generally have high ratios of glazing, resulting in high solar gains.
- All windows have been modelled as non-openable. Modern office buildings are often designed to have large non-openable windows and face acoustic and air quality constraints, due to the city centre location, which restrict the potential to utilise openable windows. As such, the buildings rely on mechanical ventilation, supplying external air, to ventilate and cool the internal spaces. As external temperatures increase, the cooling impact reduces and at a point worsens the internal environmental conditions.
- Offices buildings have high internal gains due to the heat generated from office equipment and lighting, and the number of people occupying the spaces.
- The extreme overheating risk experienced across the age ranges and locations can be attributed to a combination of the above design features and building operations.

Assessment of passive adaptation measures

The passive scenario combines various intervention measures and openable windows, creating a mixed mode ventilation strategy, to assess the extent to which overheating risk can be reduced without active cooling. The following intervention measures were incorporated.

Reduced glazing:

- In the 1970-2000 models, the window sizes have been reduced, replacing the glazing up to 1.1m with spandrel panels. This reduces solar gain whilst allowing the original window structural opening to be retained, reducing the extent of intervention work required of any refurbishment.
- The window sizes were also reduced in the new build model, however, as a theoretical building is not yet constructed, there is potential to use external wall construction up to 1.1m, which has a higher fabric performance than spandrel panels.
- The glazing in the pre-1945 and 1945-1970 simulation versions was not reduced as the glazing ratio is not as high and thus there are arguably diminishing returns for this intervention in this age range. There may be heritage constraints to consider in this building of this age.

Openable windows:

- Openable windows have been introduced for all building age ranges. It is understood that when reducing the glazing, as stated above, there is capacity to incorporate openable windows. There may be potential to incorporate opening windows as urban environments become less polluted from an air quality and acoustic perspective in the future and this is expected to facilitate some element of natural or mixed mode ventilation.
- In line with the window opening style present in the building typology, for the pre-1945 and 1945-1970 buildings, hung sash windows at a 50% opening have been introduced.
- In the 1970-2000, and new build models, the windows opening are restricted to 100 mm between 1100 mm and 1500 mm and then fully openable from 1500mm.
- All openable windows have been assigned a suitable opening profile, which has included incorporation of controls whereby occupants can close windows in heatwave conditions.

Improved U-values and G-values

- All glazing G-values, for all building types, have been reduced to 0.25 with a Visible Light Transmission (VLT) of 52% and the glazing U-values have been improved to 1.40 W/m^2.K compared to the baseline performance,
- As the U-values in the older building baseline models are worse than standards in the building regulations (approved Part L), the U-values of all building elements have been improved to match the Part L requirements improvements as part of a refurbishment assumption.

Solar shade:

An external canopy has been introduced above the windows, extending 1 m from the external walls.

Thermal mass

The ceiling voids in the older buildings and new build models have been removed to allow for exposed thermal mass. As discussed, the earlier models do not have ceiling voids.

Daylight dimming

Daylight dimming has been introduced to all models for control of internal lighting. Daylight dimming is already present in the new build baseline.

The passive results show:

- The incorporation of passive measures and mixed mode ventilation have the capacity to significantly reduce the risk of overheating across all building age ranges.
- In locations where future temperature rise is predicted to be less severe, notably Cardiff and Glasgow in those locations tested, passive measures and openable windows are sufficient to reduce the overheating risk to Low, particularly under a 2°C and 3°C warming scenario.
- London and Swindon experience Extreme risk of overheating even following incorporation of passive intervention measures.
- Overall, it is evident that passive measures and mixed mode ventilation have significant potential to reduce overheating risk and are a key first step to minimising risk as external temperatures increase.
- With the 4˚C scenarios and in the locations with the highest external temperatures expressed by the simulation weather files, additional measures are required to reduce the risk.

Active adaptation measures

For locations and weather files which demonstrated an overheating risk greater than Low following the incorporation of passive intervention measures, active cooling has been introduced. The active measures are as follows:

Increased flowrates:

The MVHR flowrates have been increased to 14 l/s/person in line with BCO 2023. The new build baseline already used a flowrate of 14 l/s/person.

Tempered air:

An MVHR cooling coil has been introduced to temper external air to 18˚C if external air temperatures exceed 18˚C. This operates during the core daytime operational hours in line with the NABERS UK HVAC profile (7:00-18:00).

Night and Sunday purge:

Through the night (18:00-07:00) on weekdays and from 12:00 on Sunday, mechanical ventilation will supply external air to the offices, provided internal temperatures exceed external temperatures. This allows the office spaces to be cooled overnight, reducing the initial internal temperatures at the start of the day.

Analysis of the active results shows that:

- Active measures can be used to reduce the overheating risk across all building types for all locations in the UK, outside of London.
- Incorporating a cooling coil and the introducing night and Sunday purge is preferable over the operation of a full cooling system.
- The results also show that even in London, active measures can reduce the overheating risk of new build offices to Low. After the introduction of the passive and natural ventilation measures, the primary difference between the new build and earlier models is the fabric performance.
- The new build model has the lowest U-values and lowest air permeability values which combine to allow the cool air supplied by the mechanical ventilation system to remain inside the building and prevent high external temperatures developing inside.

5.6 Schools - overheating analysis

The results for the analysis of overheating risks for school buildings are shown below. Schools have been assessed using the combined criteria, adaptive criteria with 28°C maximum temperature and adaptive criteria as the overheating threshold. As with other buildings, the severity of overheating risk is determined by the percentage of occupied hours during which internal temperatures exceed the respective overheating criterion limits.

Table 18 Overheating risk analysis for schools

Overheating risk analysis for schools Comparison of baseline overheating risk with improvements for passive and active adaptation measures.							
		Older schools (1970-2000)			New build		
Location	Climate change projection	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit	Baseline	Passive Adaptation Retrofit	Active Adaptation Retrofit
Cardiff	Low (2°C)	Extreme	Medium	Low	Low	Low	Low
	Medium (3°C)	Extreme	Medium/high	Low	Low	Low	Low
	High (4°C)	Extreme	High	Low	Low	Low	Low
Glasgow	Low (2°C)	Extreme	Low	Low	Low	Low	Low
	Medium (3°C)	Extreme	Low	Low	Low/medium	Low/medium	Low
	High (4°C)	Extreme	Low	Low	Low/medium	Low	Low
Leeds	Low (2°C)	Extreme	Medium/high	Low	Medium/high	Low	Low
	Medium (3°C)	Extreme	High	Low	Medium/high	Low	Low
	High (4°C)	Extreme	V.high/extreme	Low	Medium/high	Low	Low
London	Low (2°C)	Extreme	Extreme	Low	V.high/extreme	Very high	Low
	Medium (3°C)	Extreme	Extreme	High	Extreme	Extreme	Low
	High (4°C)	Extreme	Extreme	Medium	Extreme	Extreme	Medium
Nottingham	Low (2°C)	Extreme	Low/medium	Low	Low	Low	Low
	Medium (3°C)	Extreme	Low/medium	Low	Low	Low	Low
	High (4°C)	Extreme	Low/medium	Low	Low	Low	Low
Swindon	Low (2°C)	Extreme	High	Low	Low/medium	Low/medium	Low
	Medium (3°C)	Extreme	V.high/extreme	Low	Low/medium	Low/medium	Low/medium
	High (4°C)	Extreme	Extreme	Low	Low/medium	Low/medium	Low/medium

The baseline results (i.e. without mitigation measures)

The new build school model demonstrates generally good performance against overheating criteria in many regions. Whilst London and Leeds scenarios identify elevated risks, generally performance in other locations is good. It should be noted that whilst the Department for Education's (DfE) criteria related to overheating provides a resilient building, particular features often are required to be included dependant on weather file scenario and location. A building designed for a Newcastle location, as an example, will not be likely to achieve compliance with the DfE criteria in London.

More significant overheating risks are identified in the older building variants, with Extreme risk environments being identified in all baseline scenarios in the comparison tables above. In particular, reasons for overheating in 1970-2000 schools include:

- Restricted window openings of 100 mm
- High internal gains from pupils and staff
- High G-values with no external shading
- No mechanical ventilation

Assessment of passive adaptation measures

The passive scenario combines various measures including increasing openable window area to assess the extent to which overheating risk can be reduced without mechanical ventilation (unless present in the baseline, as is the case with new builds). The following intervention measures were incorporated:

- Window reconfiguration with windows between 1100 mm and 1500 mm to be restricted to 180 mm openings in line with DfE guidance (Annex 2F). Above 1500 mm in line with DfE guidance windows can be unrestricted. Windows are proposed to be controlled by a traffic light system that informs staff members to close and open windows in response to external temperatures.
- A reduced glazing G-value compared to the baseline parameters of 0.33 when the windows are replaced.
- External canopy extending 1 m directly above windows on all south, west and east elevations.
- Introduction of internal fans or ceiling fans.
- Thermal mass exposed by removal of the false ceiling (modelled in the 1945-2000 schools, but not pre-1945 and new builds which already typically have no false ceilings).
- Daylight dimming lighting control to lower lighting heat gains.

The results in Table 18 show a large reduction in the risk to overheating to all building types with only London location scenarios still staying as an Extreme risk. The risks in these locations have been significantly reduced to be closer to the Extreme risk threshold as a result of interventions. Passive interventions have shown Glasgow scenarios have reduced to a Low or Low/Medium risk across all building ages for all climate change projections showing the beneficial impact of passive and natural ventilation to schools.

There is still a large risk of overheating across a significant number of the schools building stock shown, so active measures including mechanical ventilation with heat recovery (MVHR) to introduce beneficial daytime ventilation and allowing night ventilation will be tested the locations and climate change projections currently not in the Low risk category.

Assessment of active adaptation measures

For all buildings ages and locations, the following active measures have been tested.

- Where an overheating risk still is shown after passive measures. Increased mechanical ventilation of 12 l/s/p to classrooms and 14 l/s/p to offices with nighttime ventilation introduced. Where this remains insufficient, an MVHR cooling coil has been introduced capable of reducing supply temperatures down to 14-20°C depending on the internal and external temperatures.
- Where mechanical ventilation is now present (in all building ages except new build), mechanical ventilation of 12 l/s/p has been introduced, without cooling coil systems, including nighttime and weekend ventilation when internal temperatures exceed 18°C, as long as the external temperature is lower than the internal temperature.

- Where an overheating risk still is present from adaption measures listed above, an MVHR cooling coil has been introduced capable of reducing supply temperatures down to 14 to 20°C depending on the internal and external temperatures.

The results show that all schools in London will require an MVHR with a cooling coil to reduce the temperature of the space to below 28˚C. Other locations that will require this solution are Swindon, Leeds and Cardiff but simulated to be required for the 4˚C climate change projection only. Glasgow and Nottingham will require nighttime mechanical ventilation at 12 l/s/p but without a cooling coil for schools built between pre-1945-2000 period. For schools built between 2000-2022, Glasgow and Nottingham for the 2˚C projection will show a low risk with overheating, otherwise, all other locations and climate change projections will require an MVHR with a cooling coil in order to achieve the lower overheating risk levels.

6. Conclusions

Climate change will increase the risk of overheating in all building types in the UK. It is expected that the frequency and severity of overheating risk will increase into the future.

Our analysis shows the severity of overheating risk in buildings depends on the global warming scenario, location, building design, window configuration and method of construction. Other factors, such as the proximity of trees and nature that can reduce the urban heat island effect may also have an impact.

Many areas and building types demonstrate an Extreme overheating risk and adaption interventions will be required to reduce the level of overheating risk

Overheating risk can be reduced by passive and adaptive mitigation measures.

The most effective passive mitigation measures are:

- Reducing solar heat gains (the key options are adding external shading, reducing areas of glazing and replacing clear glass with solar control glass).
- Increasing natural ventilation rates, e.g. increasing window opening areas or converting more windows to be openable including allowing windows above 1500 mm to open unrestricted in healthcare and social care settings.

Other passive mitigation measures include:

- Reducing internal heat loads from equipment, e.g. switching off heat generating equipment when not required.
- Shifting behaviours to reduce internal gains during periods of high temperatures, such as adjusting cooking patterns to reduce internal gains.
- Use of devices to create air movement is expected to have a significant impact on operative temperature.
- Exposing thermal mass, where feasible, to enable night cooling with natural ventilation.
- Incorporating blue/green landscaping features to reduce the urban heat island effect.
- Operational and behavioural influences such as closing blinds to reduce solar gains during summer days and opening windows at night.

Although the benefits of nature-based solutions were not incorporated in the thermal modelling there is significant evidence that green landscaping improves the microclimate, as well as providing mental health benefits. Trees can be used, for example, to provide external solar shading for schools and healthcare buildings.

The most effective active mitigation measures, which entail mechanical interventions, are:

- Using mechanical ventilation for night cooling, i.e. operating the mechanical ventilation at night to cool down the building spaces and structure with cooler night air.
- Using mechanical ventilation with the ability to temper/reduce the supply air temperature without the need for active cooling.
- Nighttime and weekend pre-cooling with ventilation systems operating in 'free cooling' mode.
- In typical open plan offices, where sealed façades and active cooling is commonplace, typically activated at 24˚C internal temperature, the analysis shows that active cooling is not necessarily required and mechanical ventilation with limited cooling capacity (leap lopping) is seen to be sufficient.

Active cooling is expected to be required in many instances as temperatures increase across the UK. Active cooling is expected to be expensive from both a capital installation cost as well as an operational, ongoing running cost and therefore is ideally avoided. The passive mitigation measures identified by the analysis above should be considered prior to incorporation of active mitigation measures or use of full active cooling as these measures will limit the requirement for active measures and thus reduce installed capacity required and reduce ongoing costs for occupants, whom may be organisations in the healthcare sector or in the education sector, with potentially constrained budgets.

The measures recommended in this report will require substantial retrofit across the UK building stock which will clearly come at considerable cost. Some of these measures could occur when windows or façades need to be replaced and could be part of a phased retrofit programme, supported by government in the most pressing cases.

A significant proportion of the buildings in the medium and higher climate change scenarios show that only active cooling will achieve a Low risk of overheating. To avoid the mass adoption of active cooling either by portable air conditioning units or fixed mechanical cooling, every building type will need substantial intervention measures to both reduce the risk of overheating and to avoid active cooling. Building asset owners should consider the ability of that asset to be effectively used as climate change projections become reality. Policy makers, regulators and planners should start considering now how new buildings and existing buildings can be made more adaptable to climate change, otherwise we could experience 10,000[16] heat-related deaths by 2050 and significant discomfort in schools, hospitals, public buildings and offices, resulting in reduced productivity, increased sleep deprivation and a range of negative health and wellbeing outcomes.

[16] Health Effects of Climate Change in the UK (HECC): 2023 Report, UK Health Security Agency. Health Effects of Climate Change in the UK: state of the evidence 2023

7. Recommendations

Recommendations for building developers and designers

- New building designs and refurbishment projects should assess the impact of future climate projections on overheating risk and these future risk assessments be used to inform climate resilient or adaptable development.
- Appropriate configurations of glazing, adequate ventilation and provision of solar shading should be important considerations in design.

Recommendations for planners, regulators and policy makers

- Planning policies and future building regulations should require buildings to be designed and constructed to be climate resilient. Inadequate consideration of climate change in new developments could result in more buildings suffering from overheating risk.
- Planning authorities should promote and facilitate the inclusion of green infrastructure to reduce urban heat island effects and improve local microclimates. This will reduce overheating risks in towns and cities.
- Regulating authorities and policy makers should review and clarify guidance on safe windows openings. The guidance on 100mm window opening restrictions that are standard modern practice in schools, healthcare buildings, care homes and many public buildings severely restrict natural ventilation and increase the risk of overheating, which can have significant health impacts. The current guidance is often poorly implemented with restrictions often being much less than 100mm. Advocating fully openable windows at safe heights (above 1.5m) will improve health and wellbeing outcomes and reduce heat-related deaths.
- Public advice on climate adaptation should be provided.
- The Met Office, and related public organisations, should advance clarity and availability of heatwave advice with timely warnings.
- Consider the system level impacts resultant from extreme temperatures. There is a significant risk that essential services such as healthcare or education facilities will be compromised in high temperatures with significant adverse impacts. For instance, closure of schools due to extreme heat is highly likely to impact significant numbers of pupils and parents, thus also affecting the workforce and economy. Policies should consider these impacts carefully and direct resources to maximise benefit.

Recommendations for building owners and occupants

- Building owners and occupants should assess how they can improve building resilience and reduce the risk of overheating. This may require collaboration between landlords and tenants when the mitigation measures include changes to glazing, shading or means of ventilation in tenanted buildings.
- Provide suitable maintenance to features that are important for mitigating overheating risk, such as the servicing and inspection of ventilation and controls.
- Passive measures which don't increase operational costs should be prioritised before active measures (e.g. mechanical ventilation or cooling) so that increases in energy consumption can be minimised.

Recommendations for insurance providers

- Insurance providers should consider the positive impact they can have on creating a resilient built environment by requiring designers and builders to include resilience measures as a condition of insurance. This will drive the construction and development sector to integrate climate resilience.
- Insurance providers should require that climate resilient works should also be undertaken by qualified and competent contractors and installers.

Recommendations for architecture, planning and engineering educators and universities

- School and college curriculums should include resilience education, and the role of nature, in the teaching of climate change, with practical examples of how planning and design can influence resilience.
- University courses in architecture, planning and engineering should incorporate learning on climate change and resilience with practical examples.

Appendix A – Houses baseline modelling inputs

Houses – model inputs
Fabric parameters

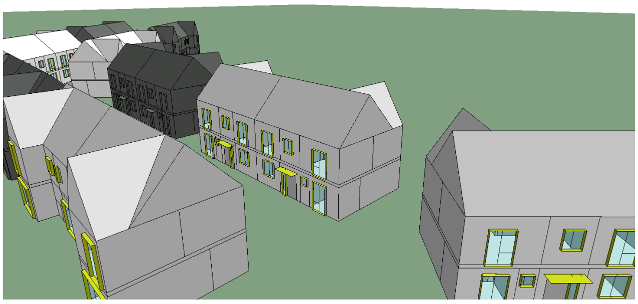
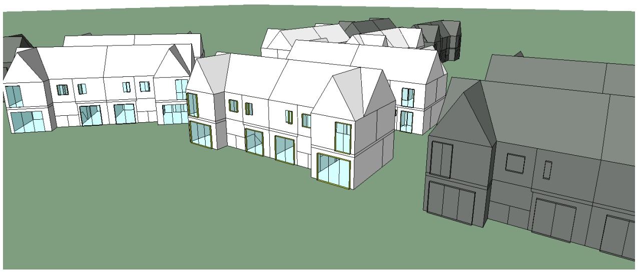
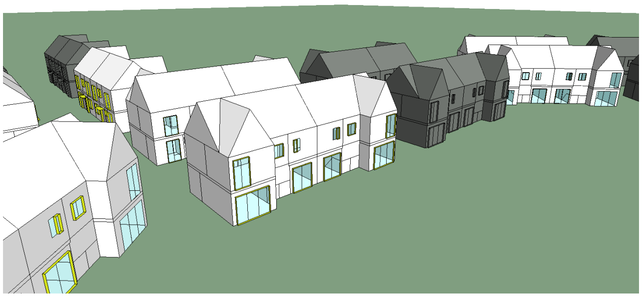
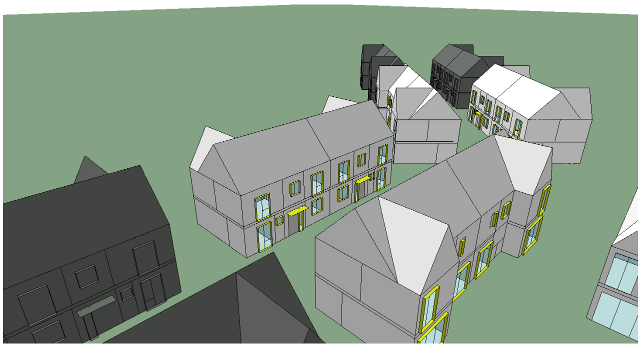
Pre 1945		
Fabric	Baseline (W/m^2.K)	Passive/ Active (W/m^2.K)
External Wall	1.60	0.30
Ground/ Exposed Floor*	1.20	0.25
Roof	0.40	0.16
Window (G-value)	3.10 (0.65)	1.40 (0.33)
Internal Partition: Dwellings / Internal	1.60 / 1.85	1.60 / 1.85
Internal ceiling	2.331	2.331
Air Permeability	0.5 (Loft 3ach)	0.5 (Loft 3ach)
New Build		
Fabric	Baseline (W/m^2.K)	Passive/ Active (W/m^2.K)
External Wall	0.15	0.15
Ground/ Exposed Floor*	0.13	0.13
Roof (insulation assumed at ceiling level)	0.11	0.11
Window (G-value)	1.40 (0.60)	1.40 (0.33)
Internal Partition: Party / Internal	0.20 / 0.68	0.20 / 0.68
Internal ceiling: Floor slab/ Ceiling tile	2.331 / 3.964	2.331 / 3.964
Air Permeability	0.15 (Loft 3ach)	0.15 (Loft 3ach)

Auxiliary Ventilation

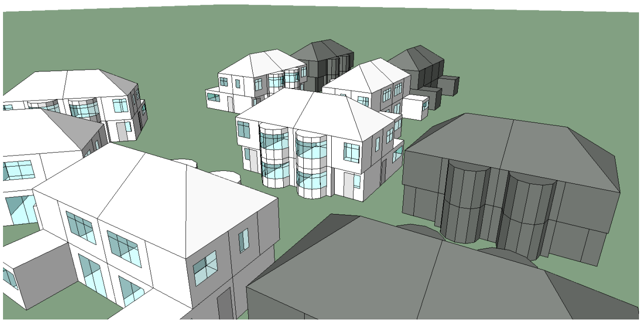
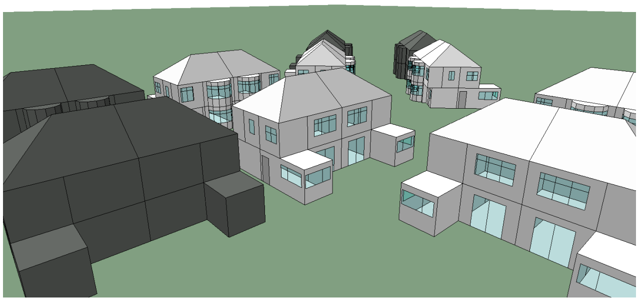
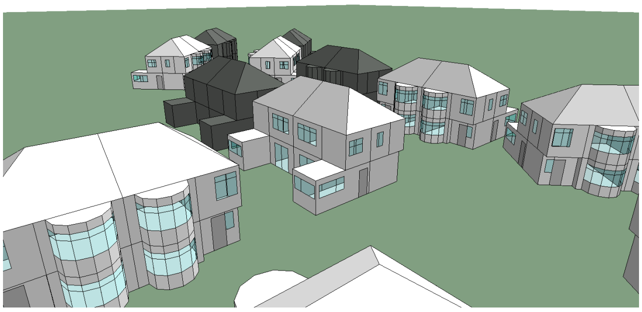
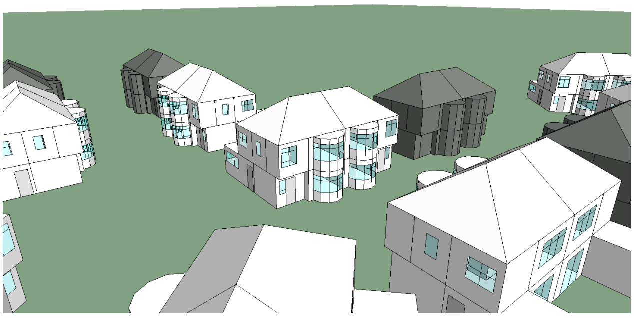
The auxiliary ventilation modelled is detailed below. This is based on total dwelling flow rates. Where appropriate, minimum flow rates have been input separately to boost rates.

Baseline / passive measures			
Building type	Flowrate	Profile	Temperature profile
Pre-1945	None	None	None
New build	80 l/s	Part F minimum - on continuously Boost – when internal temperature exceeds 22 degrees, and external temp is greater than 12 degrees.	Baseline air supply – Bring in external air, if external air is below 16 degrees, heat to 16 degrees.
Active measures			
Building types	Flowrate	Profile	Temperature profile: tempered air
New build	110 l/s	Part F minimum - on continuously Boost – when internal temperature exceeds 22 degrees, and external temp is greater than 12 degrees	Supply air based on MVHR unit with a cooling coil. This profile ramps up and down based on the external and internal temperatures.

Model geometry for new build houses

Model geometry for older houses (pre-1945)

Appendix B – High-rise residential buildings baseline modelling inputs

High rise residential buildings - fabric parameters

1970 - 2000		
Fabric	Baseline (W/m^2.K)	Passive/ active (W/m^2.K)
External wall	0.60	0.60
Ground/ exposed floor	n/a	n/a
Roof	0.40	0.18
Window (G-value)	3.10 (0.65)	1.40 (0.33)
Internal partition: dwellings / internal	2.367/ 1.789	2.367/ 1.789
Internal ceiling	1.124	1.124
Air permeability	0.5	0.4

New build		
Fabric	Baseline (W/m^2.K)	Passive/ active (W/m^2.K)
External wall	0.80 (Curtain Walling)	0.80
Ground/ exposed floor*	n/a	n/a
Roof*	0.15	0.15
Window (G-value)	0.80 (0.45)	1.4 (0.25)
Internal partition: dwellings / internal	0.171 / 1.789	0.171 / 1.789
Internal ceiling: floor slab/ ceiling tile	1.440 / 3.853	1.440 (no plasterboard)
Air permeability	0.15	0.15

* Due to the size of the high-rise residential models, a sample of internal floors were selected for modelling to represent the entire building, as internal floors have higher risk of overheating.

Auxiliary Ventilation

The auxiliary ventilation modelled is detailed below. This is based on total dwelling flow rates. Where appropriate, minimum flow rates have been input separately to boost rates.

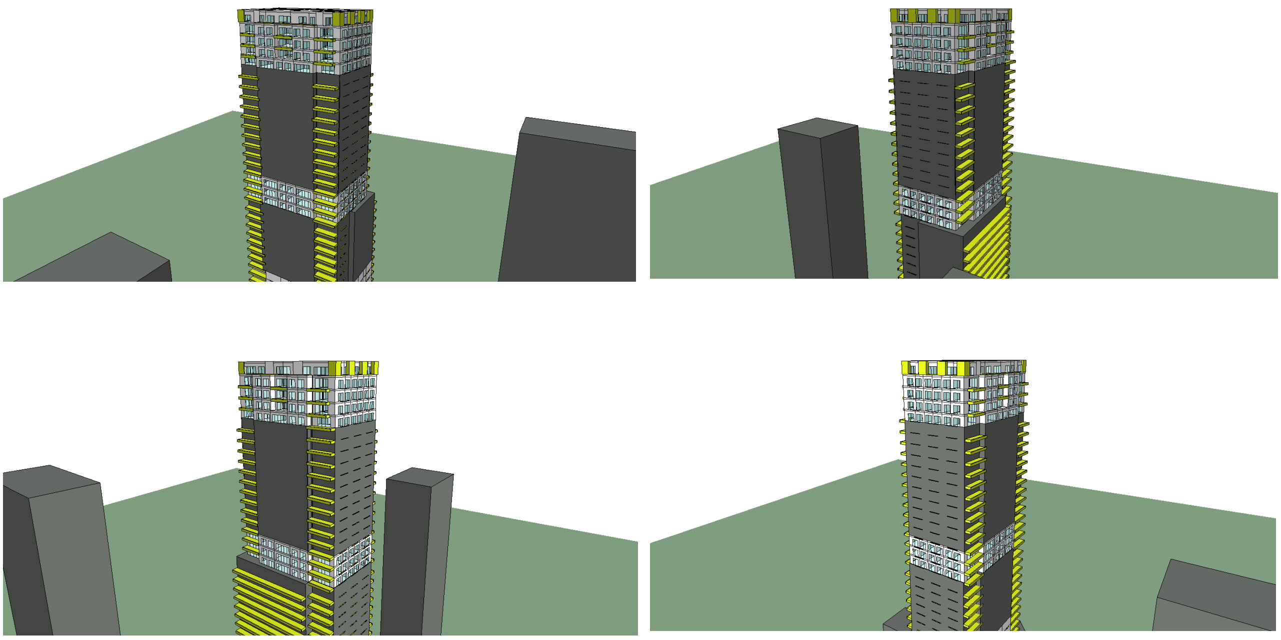
Baseline / passive measures			
Building type	Flowrate	Profile	Temperature profile
1970-2000	None	None	Baseline air supply – Bring in external air, if external air is below 16 degrees, heat to 16 degrees.
New build	1 Bed – 70 l/s 2 Bed – 80 l/s 3 Bed – 90 l/s	Part F minimum - on continuously Boost –	External air

Baseline / passive measures			
		When internal temperature exceeds 22 degrees, and external temp is greater than 12 degrees.	
Active measures			
Building types	Flowrate	Profile	Temperature profile: tempered air
1970-2000	1 bed – 80 l/s 2 bed – 90 l/s	Part F minimum - on continuously Boost – when internal temperature exceeds 22 degrees, and external temp is greater than 12 degrees.	Supply air based on MVHR unit with a cooling coil. This profile ramps up and down based on the external and internal temperatures.
New build	1 bed – 70 l/s 2 bed – 80 l/s 3 bed – 90 l/s		

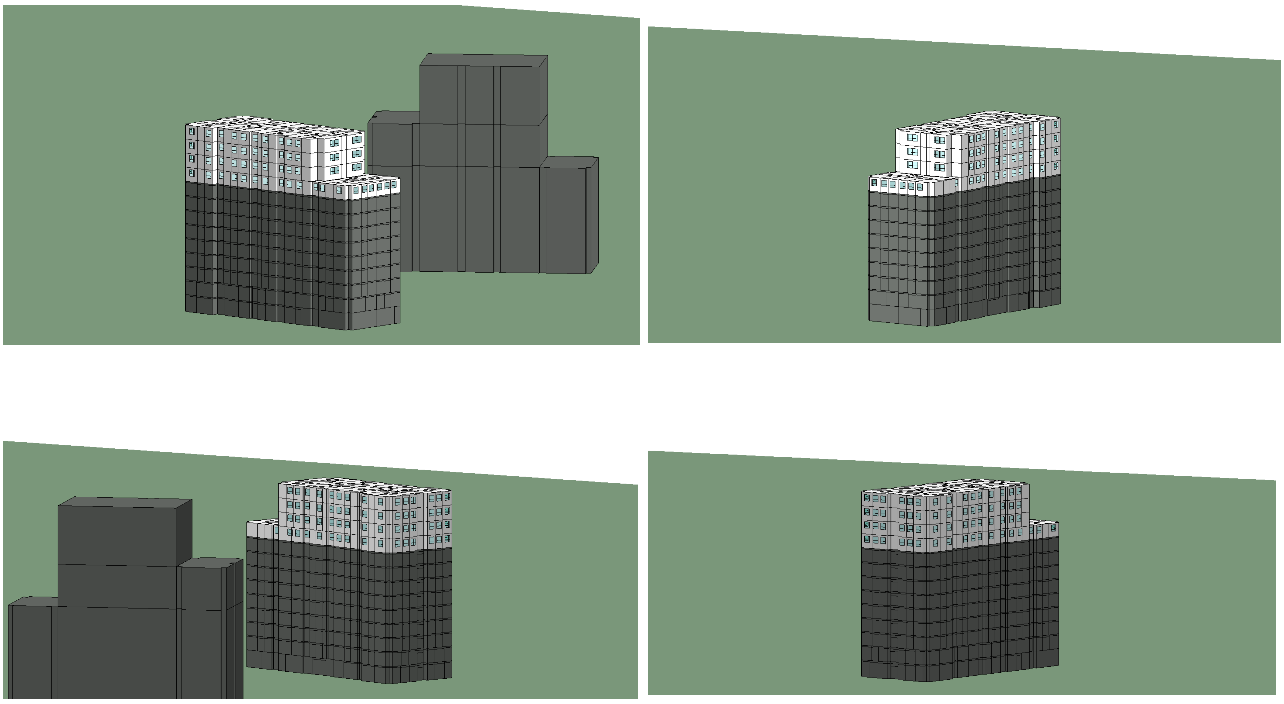
High-rise residential – IES model images

The below images show the integrated environmental solutions (IES) models used for the thermal modelling analysis.

Model geometry for new build high-rise residences



Model geometry for 1970s high-rise residences



Appendix C – Care homes baseline modelling inputs

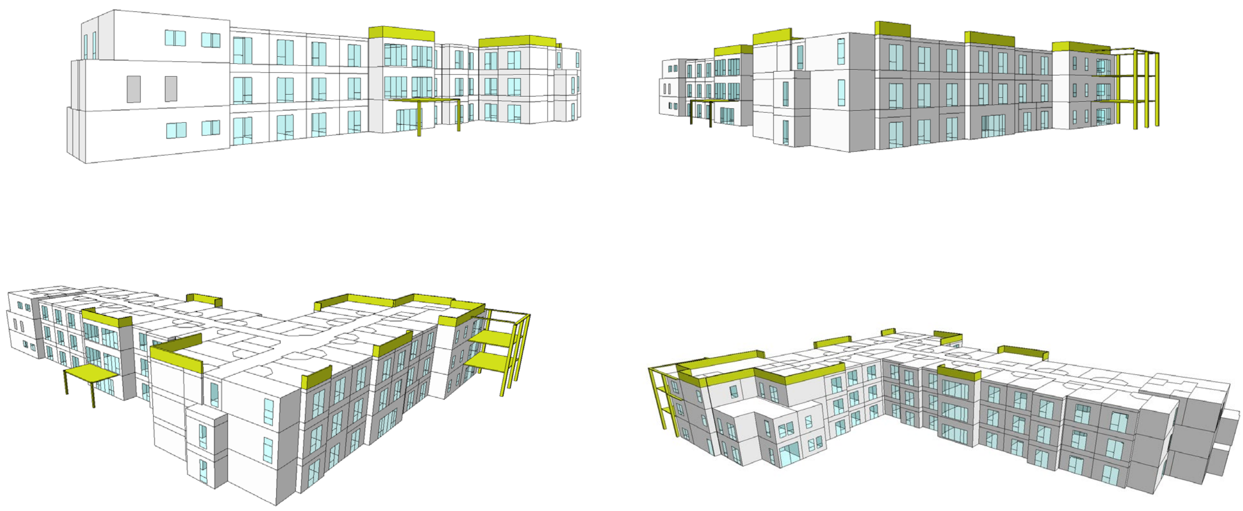
Fabric parameters

1970 - 2000		
Fabric	Baseline (W/m^2.K)	Passive/ active (W/m^2.K)
External wall	0.45	0.45
Ground/ exposed floor	0.45	0.45
Roof	0.25	0.25
Window (G-value)	3.10 (0.65)	1.4 (0.33)
Internal partition (uninsulated)	1.80	1.80
Door	2.20	2.20
Air permeability	10	10
New build		
Fabric	Baseline (W/m^2.K)	Passive/ active (W/m^2.K)
External wall	0.15	0.15
Ground/ exposed floor	0.13	0.13
Roof	0.11	0.11
Window (G-value)	1.20 (0.4)	1.20 (0.33)
Internal partition (uninsulated)	1.80	1.80
Glazed door	1.50	1.50
Air permeability	3	3

Auxiliary ventilation

Baseline/passive measures			
Building type	Flowrate	Profile	Temperature profile
All	No mechanical ventilation	-	-
Active measures			
Building types	Flowrate	Profile	Temperature profile
All	8 l/s (bedrooms) 14 l/s (common rooms)	24/7 if temperature exceeds 23˚C	External air if outside air temperature is lower than the room temperature.
All	8 l/s (bedrooms) 14 l/s (common rooms)	24/7	Supply air based on an MVHR unit with a cooling coil. This profile ramps up and down based on the external and internal temperatures.

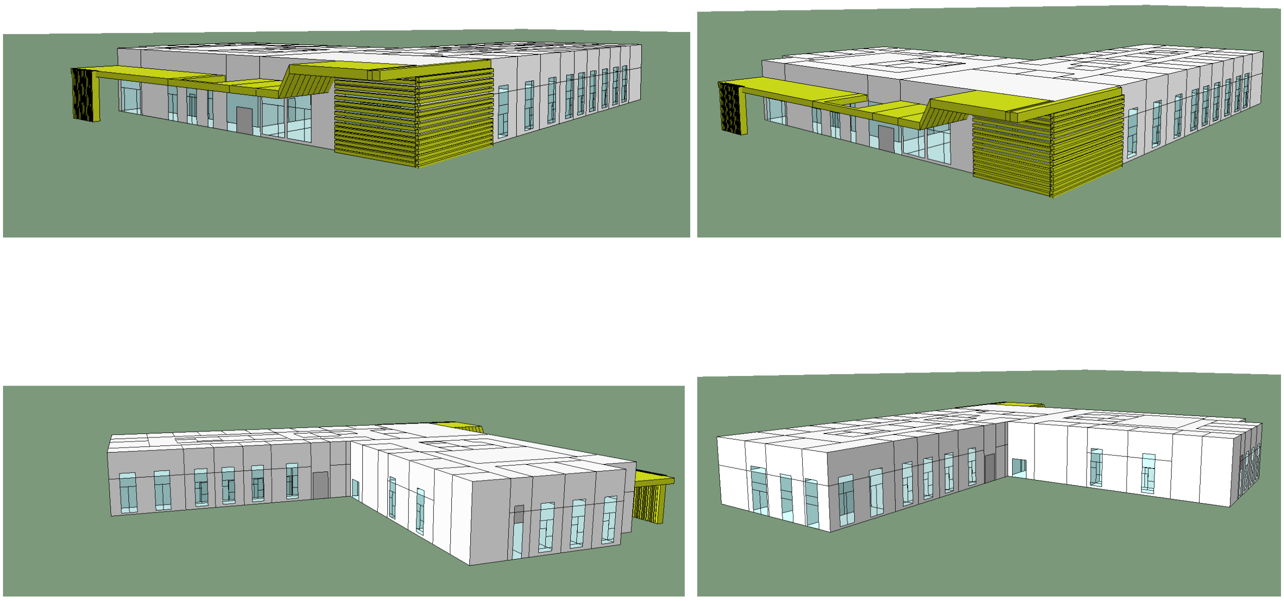
Model geometry for new build care homes



Model geometry for older care homes

Appendix D – Healthcare buildings baseline modelling inputs

Model geometry for new build healthcare building



Fabric

Parameter	Value	
	New builds	2000 – 2020
External wall U-value (W/m^2*K)	0.19	0.26
Roof U-value (W/m^2*K)	0.14	0.25
Exposed floor U-value (W/m^2*K)	0.14	0.25
Ground floor U-value (W/m^2*K)	0.14	0.25
Opaque door U-value (W/m^2*K)	1.00	2.20
High usage entrance doors (glazed) U-value (W/m2*K)	2.0	2.20
Window U-value (non-curtain wall) U-value	1.40	2.20
Spandrel Panel	1.00	1.40
All glazing G-value	0.4	0.6
Perimeter infiltration	3.00	8.00

Natural ventilation details

Windows

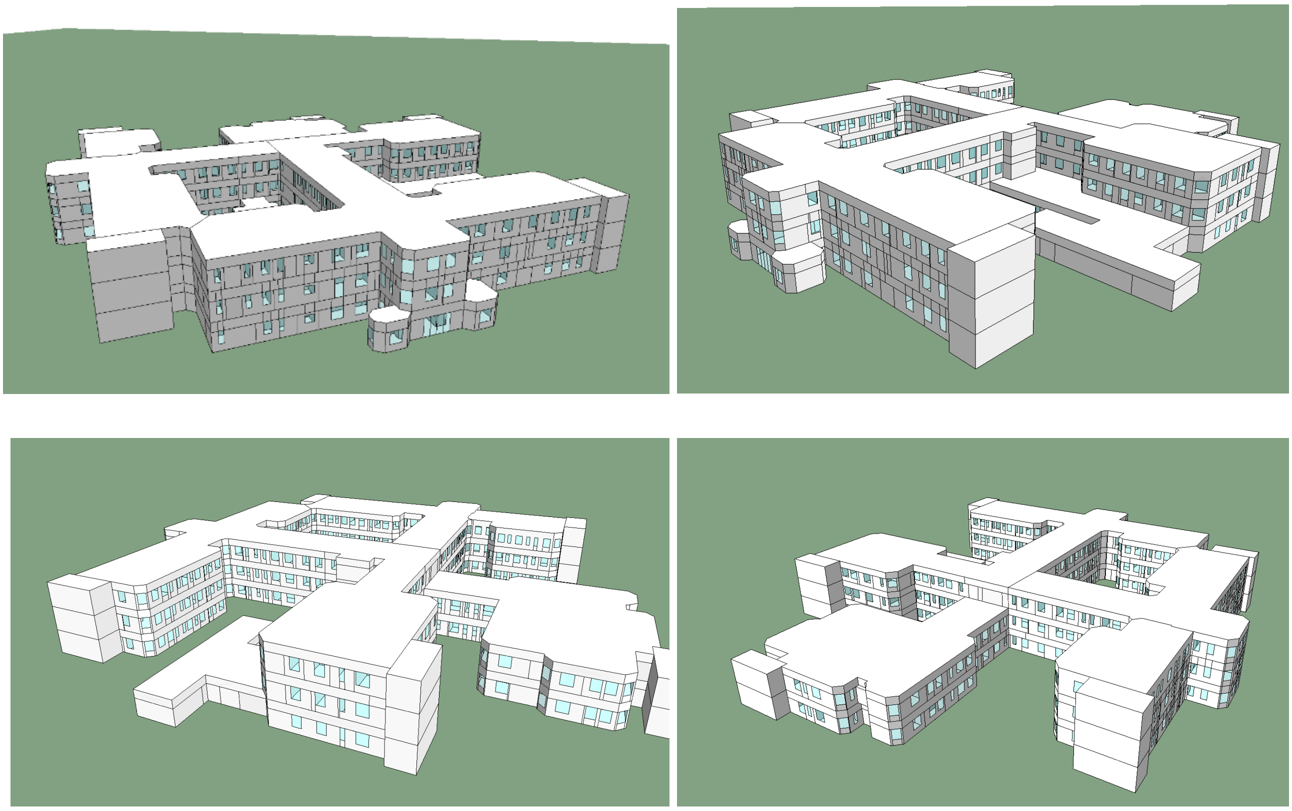
Operating Profile	Conditions	Condition times
Windows / Louvres	If the room temperature exceeds 24 degrees, then window/door is set as open Please note that **no blinds** have been assumed for any windows	Operating during the room occupied hours
Mechanical ventilation	Fixed airflow based on a time control Where allowance for mechanical ventilation has been done,	Operating during the room occupied hours

Mechanical Ventilation Details

Ventilation system	
Central AHU supply and extract	– All remaining spaces.
Extract only	– Dirty utility and WCs
Supply only	– Clean utility

Room	Ventilation rates	Daily profile
Circulation	1.5 ACH	24/7
Consultation	6 ACH	24/7
Store	1.5 ACH	24/7
Office	6 l/s/p	24/7
WC	10 ACH	24/7
Waiting	10 ACH	24/7
Treatment- ED Majors	10 ACH	24/7
Treatment- Resus	15 ACH	24/7
Treatment- Trolley bay	6 ACH	24/7
Clean Utility	6 ACH- Supply only	24/7
Dirty Utility	6 ACH- Extract only	24/7
Viewing room	6 ACH	24/7
Staff base	6 ACH	24/7
Lab	10 ACH	24/7
Pantry	5 ACH	24/7

Model geometry for older health care building (1945 – 1970)



Fabric

Parameter	Value	
	1945 – 1970	1970 – 2000
External wall U-value (W/m²*K)	1.70	0.6
Roof U-value (W/m²*K)	1.40	0.6
Exposed floor U-value (W/m²*K)	1.40	0.6
Ground floor U-value (W/m²*K)	1.40	0.6
Opaque door U-value (W/m²*K)	4.0	4.0
Window U-value U-value	5.57	5.57
All glazing G-value	0.6	0.6

Natural Ventilation Details

Windows

Operating profile	Conditions	Condition times
Windows / louvres	If the room temperature exceeds 24 degrees, then window/door is set as open Please note that **no blinds** have been assumed for any windows Window open area equivalent to 100mm restrictors	Operating during the room occupied hours
Mechanical ventilation	Fixed airflow based on a time control where allowance for mechanical ventilation has been done	Operating during the room occupied hours

Fabric

Parameter	U-value (W/m².K)
External door	1.80
Spandrel panel	0.29
External window	1.60 (G-value: 0.40)
External wall	0.30 or 0.26
Ground floor	0.25
Roof	0.16
Air permeability	5.57 m³/m² per hr @ 50 Pa
External door	1.80

Natural ventilation details

Operating profile	Conditions	Condition times
Windows / Louvres	If the room temperature exceeds 24 degrees, then window/door is set as open Please note that **no blinds** have been assumed for any windows	Operating during the room occupied hours
Mechanical ventilation	Fixed airflow based on a time control where allowance for mechanical ventilation has been done	Operating during the room occupied hours

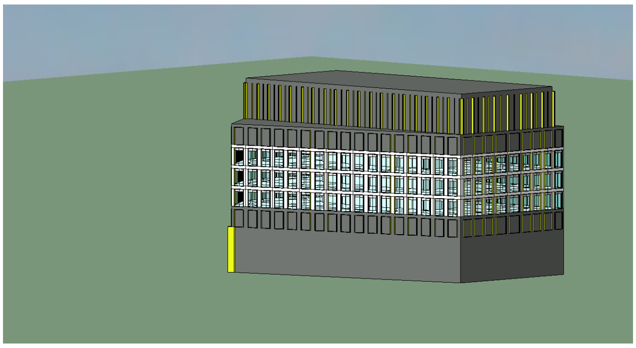
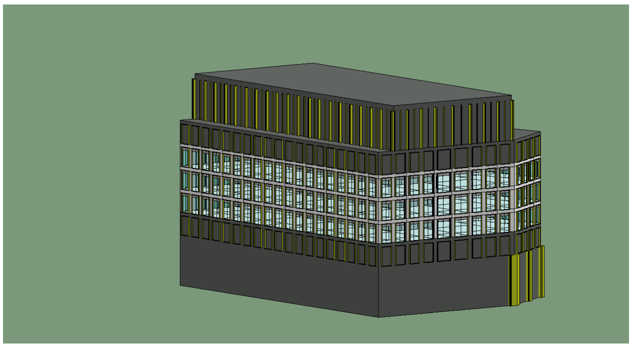
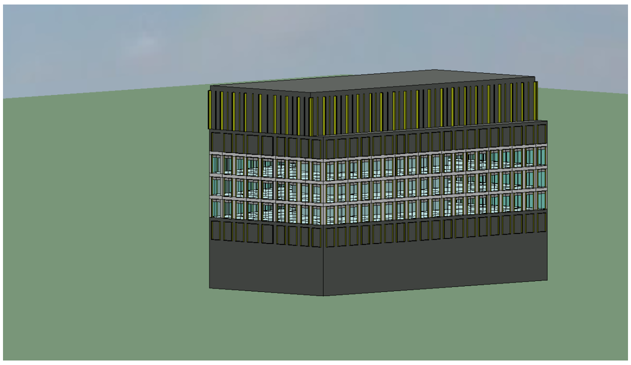
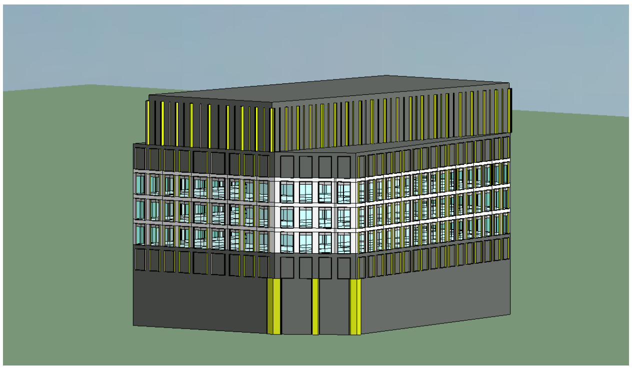
Appendix E – Office buildings baseline modelling inputs

Fabric parameters

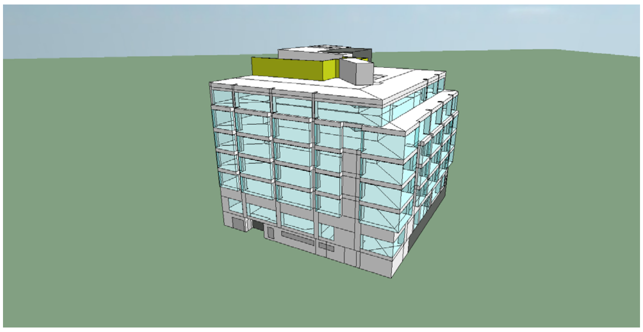
1970 - 2000		
Fabric	Baseline (W/m^2.K)	Passive/ active (W/m^2.K)
External wall	0.6	0.6
Ground/ exposed floor	1.2	1.2
Roof	0.4	0.4
Window (G-value)	3.1 (0.6)	1.4 (0.25)
Internal partition: office/ stair core and lift	1.36/ 1.405	1.36/ 1.405
Internal ceiling: floor slab/ ceiling tile	1.77/ 2.36	1.77
Air permeability	15	15
New build		
Fabric	Baseline (W/m^2.K)	Passive/ active (W/m^2.K)
External wall	0.26	0.26
Ground/ exposed floor*	-	-
Roof*	-	-
Window (G-value)	1.6 (0.4)	1.4 (0.25)
Internal partition: office/ core	1.36/ 2.46	1.36/ 2.46
Internal ceiling: floor slab/ ceiling tile	1.64/ 2.36	1.64
Air permeability	3	3

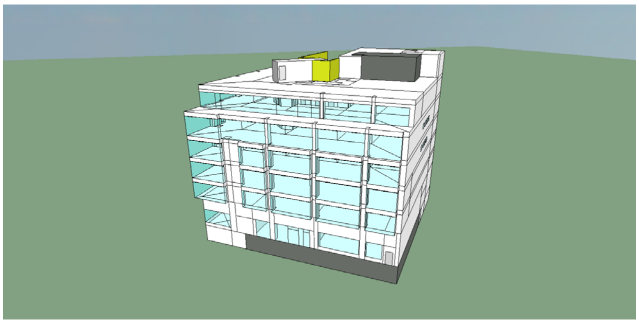
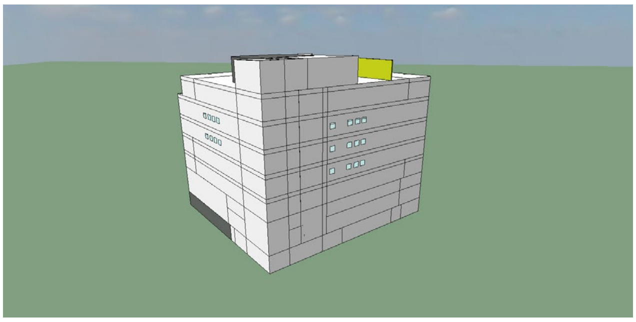
* - Due to the size of the New Build, a sample of three internal floors were selected for modelling to represent the entire building, as internal floors have higher risk of overheating.

Model geometry new build office.

Model geometry older office (1970-2000)



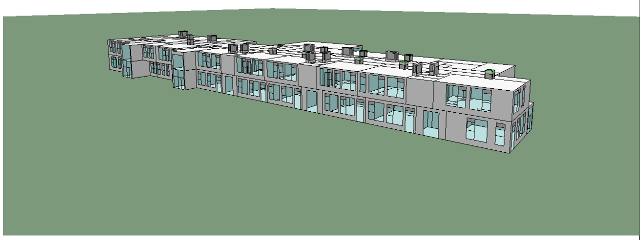



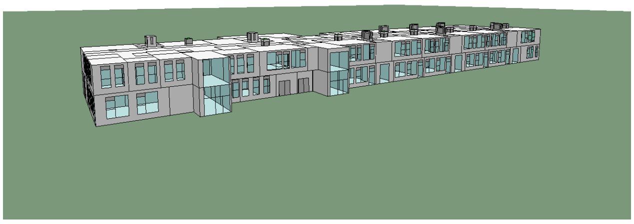
Appendix F – Schools baseline modelling inputs

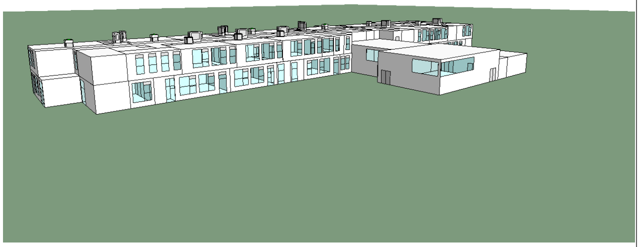
New Build

Two storey primary school with classrooms, nursery and provision for SEN children. Includes studio and dining hall. This school is a DfE compliant school.

IES Model Image







Internal Gains (Occupancy, Lighting, Equipment)

Room Type	Lighting Gains	Pupils (no of people) (60 W/55 W)	Teachers (no of people) (70 W/55 W)	Small Power	Profile
Classroom	5.4 W/m^2	30	3	10 W/m^2	Overnight – 0% 9am-12pm – 100% 12-1pm – 0% 1pm-4pm – 100%
Nursery	5.4 W/m^2	26	3	10 W/m^2	
Dining Hall/Sports Hall	5.7 W/m^2	330	17	10 W/m^2	9am-10am – 100% 10-12pm-40% 12-2pm – 100% 2-4pm – 40%
Office	4.7 W/m^2	0	2	10 W/m^2	7am-5pm – 100 %

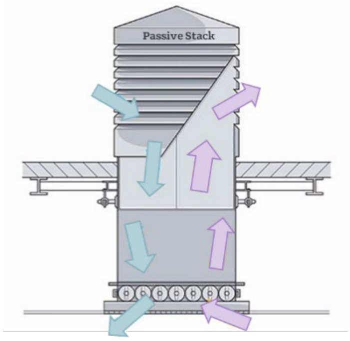
Fabric

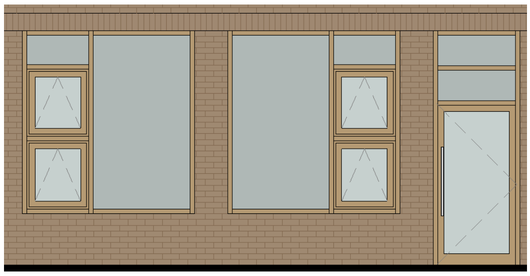
Parameter	U-value (W/m^2.K)
External Wall	0.13
Louvred Panels	1.1
External Glazing – Typical (G-value)	1.1
Frame Factor	30%
G-value	0.4
Roof	0.12
Ground Floor	0.12
Door	1.50
Internal Partition (Insulated/Uninsulated)	0.64/1.33
Partitions Thermal Mass	Low
Ceiling voids included	Yes
Floor Thermal Mass	Medium
Fabric Air Permeability Average (m^3/m^2.h at 50Pa)	3.00 equating to 0.1 ach

Natural Ventilation Details

Windows

Classrooms/Offices - Openable top hung windows restricted to 180 mm. Windows open during occupied hours when the Dry Resultant Temperature exceeds 20°C provided that the Outdoor Temperature does not exceed the Indoor Temperature.





Passive Stack Ventilation

Day Ventilation 06:00 – 24:00: Operational when the Dry Resultant Temperature exceeds 30°C, the outdoor temperature does not exceed the indoor temperature OR CO_2 exceeds 950 ppm +/- 100 ppm.

March 1st until May 14th & September 22nd until November 30th

Day Ventilation 06:00 – 24:00: Operational when the Dry Resultant Temperature exceeds 19°C, the outdoor temperature does not exceed the indoor temperature OR CO2 exceeds 950 ppm +/- 100 ppm.

May 15th until September 21st:

Day Ventilation 06:00 – 24:00: Operational when the Dry Resultant Temperature exceeds 19°C, the outdoor temperature does not exceed the indoor temperature OR CO2 exceeds 950 ppm +/- 100 ppm.

Night Ventilation 24:00 – 06:00: Operational when the Dry Resultant Temperature exceeds 16°C and the outdoor temperature does not exceed the indoor temperature.

Mechanical Ventilation Details

MVHR and NVHR Units in spaces with Openable Windows

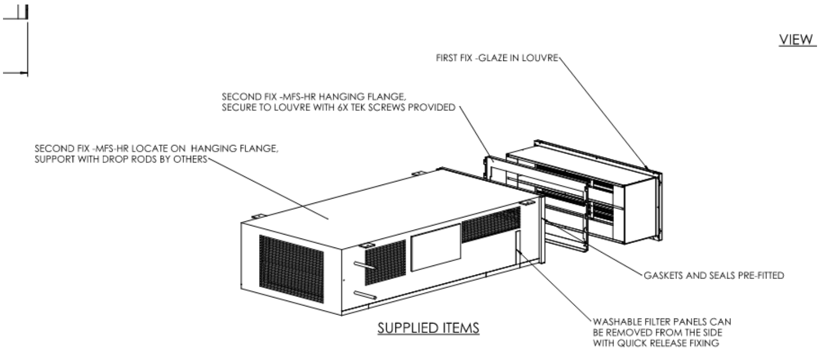
Day Ventilation 07:00 – 17:00: Operational when the Dry Resultant Temperature exceeds 22°C providing the outdoor temperature does not exceed the indoor temperature OR CO_2 exceeds 1250 ppm.

Night Ventilation 17:00 – 07:00: Operational when the Dry Resultant Temperature exceeds 18°C and the outdoor temperature does not exceed the indoor temperature.

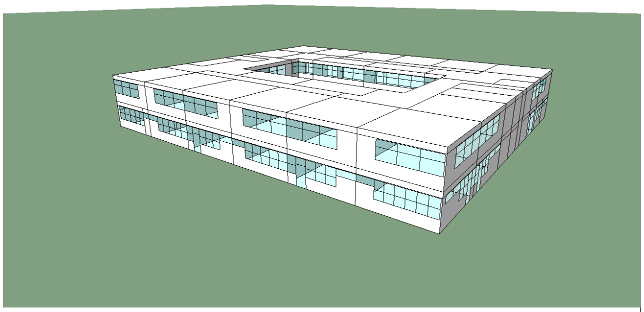
MVHR Units in spaces without Openable Windows

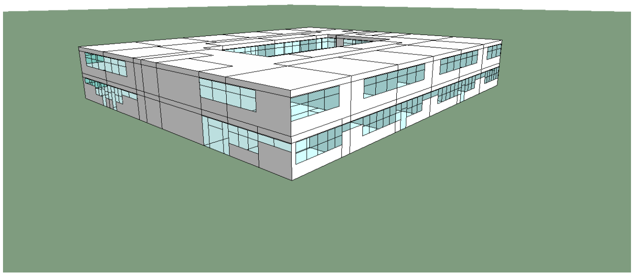
Day Ventilation 07:00 – 17:00: Operational when the Dry Resultant Temperature exceeds 20°C providing the outdoor temperature does not exceed the indoor temperature OR CO_2 exceeds 850 ppm.

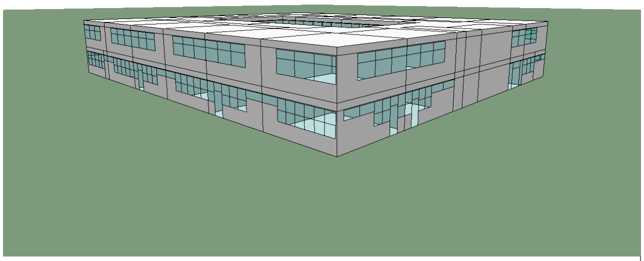
Night Ventilation 17:00 – 07:00: Operational when the Dry Resultant Temperature exceeds 18°C and the outdoor temperature does not exceed the indoor temperature.

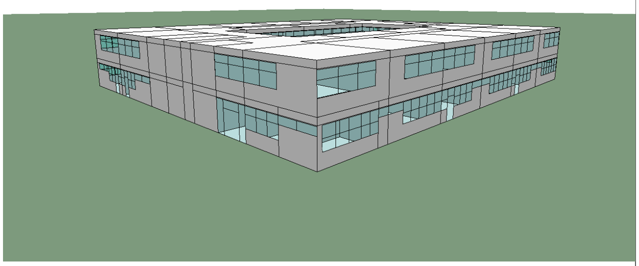


School: 1970 – 2000









Fabric	Natural Ventilation Details

Fabric

Parameter	U-value (W/m^2.K)
External Wall	0.5
External Glazing – Typical	3.1
Frame Factor	10%
G-value	0.7
Roof	0.32
Ground Floor	0.4
Door	2.2
Internal Partition (Insulated/Uninsulated)	0.64/1.33
Partitions Thermal Mass	Low
Ceiling voids included	Yes
Floor Thermal Mass	Low
Fabric Air Permeability Average (m^3/m^2.h at 50Pa)	15 equating to 0.5 ach

Natural Ventilation Details

Classrooms - Openable top hung windows restricted to 100 mm at ground and first floor level. Windows open during occupied hours when the Dry Resultant Temperature exceeds 22°C.

Mechanical Ventilation Details
Extract only to toilets.

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