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Investigating effective building fabric as a passive cooling technique to combat overheating in UK residential buildings

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Abstract: The Intergovernmental Panel on Climate Change has predicted that the earth's temperature is increasing by 1.5°. Research indicates that 9 out of 10 homes within the United Kingdom may experience overheating. The growing concern of overheating within residential homes should be resolved before occupants turn to the use of mechanical means. Passive cooling strategies need to be implemented into residential homes as a contribution to the current aim of the United Kingdom government to reduce carbon emission by 77% by 2035 compared to 1990 levels. This research investigates the most appropriate building construction fabric as a passive cooling strategy that can be implemented into residential homes to mitigate the impact of climate change. Computational fluid dynamic simulation of different building fabric scenarios of EcoBIM construction, Passivhaus construction and Standard construction are performed using EDSL Tas thermal modelling software. The simulations incorporate Chartered Institution of Building Services Engineering (CIBSE) weather data files for Glasgow, Belfast, Manchester, and London for 2020s, 2050s and 2080s climatic projections. The results from this investigation show that the standard construction overall did present the most effective solution against the number of hours experiencing overheating. The research provides evidence to suggest that the current 2021 Building Regulations in place are not at risk of experiencing overheating in Manchester, Belfast, and Glasgow across the 2020, 2050 and 2080 simulations, as well as for the 2020 and 2050 London simulation. This proposes that within these locations the current 2021 Building Regulations regarding the U values in document Part-L shall be deemed as having an acceptable tolerance to overheating, and further adaptations are not necessary, as there is no concern regarding the encountering of overheating within these regions and weather periods. Furthermore, the utilization of the EcoBIM construction on average did cause significant increased risk of overheating. The only exception to this was the 2080 simulation for London in which the EcoBIM construction obtained 71.10% less overheating compared to the Standard construction. The outcome of this research suggests that London is at extreme risk of enduring overheating by 2080, as all the constructions during this simulation process were perceived as exceeding the CIBSE TM59 requirement.

Keywords: Overheating, Climate Change, Passive cooling strategies, Weather data, Building Regulations, Standard Construction, Passivhaus Construction, EcoBIM Construction, CIBSETM59

1.Introduction

Research Background

The intergovernmental Panel on Climate Change, formerly known as the IPCC, reports that the planet temperature is increasing by 1.5 degrees due to greenhouse gas emissions (Valerie Masson-Delmotte, 2019). One of the associated challenges faced due to global warming is elevated temperatures, which has a direct effect on overheating in infrastructure. Since, the need to reduce carbon emissions by 50% should be met by 2030, (HS2, 2022) to prevent further increase in the planet temperature, the use of mechanically cooling equipment is not permitted to overcome this indoor overheating crisis.

Overheating within homes is defined as the indoor temperature being extremely elevated, which as a consequence causes the occupants to experience extreme discomfort due to the severity of the internal temperatures. This is often experienced due to poor architecture of the infrastructure, or alternatively due to poor management of deficient services (CIBSE, The limits of thermal comfort: avoiding overheating in Eurpoean buildings , 2013). The CIBSE Journal states that Arup have found evidence suggesting that “9 out of 10 homes will be at risk of overheating if worldwide temperatures rise to 2° above pre-industrial levels” (CIBSE, Nine out of 10 UK homes will overheat at 2 warning, 2022). Adaptations therefore need to be mitigated into the construction industry before global warming increases further.

Overheating in homes directly influences the resident’s well-being. It is predicted that by 2080, there will be an increase of 5,000 deaths due to the rise of thermal discomfort within homes (Goverment D. f., 2012). As a result, occupants may turn to air condition as a short-lived solution to alleviate the internal elevated temperatures they are experiencing within their homes. However, 15% of the world’s total energy is consumed by air conditioning alongside refrigeration (Alejandro Prietoa, 2018) and it predicted that 2.2 billion of the population will acquire cooling devices (Gamero-Salinas, et al., 2021), to improve this thermal discomfort. Energy from homes already dissipates 37% of carbon dioxide emissions which further contributes to global warming (Prof. Ian Hamilton, 2021). If no adaptations are made to the infrastructure design within the residential sector, to improve the indoor thermal temperatures promptly, the effects will have devastating consequences both to lives and to the planet. Therefore, a long-term solution to reduce overheating indoors needs to be provided to reduce the effects for the future, and improve the indoor living quality. The Built Environment requires a strategy that needs to be implemented to prevent the use of air conditioning, or other environmentally damaging techniques.

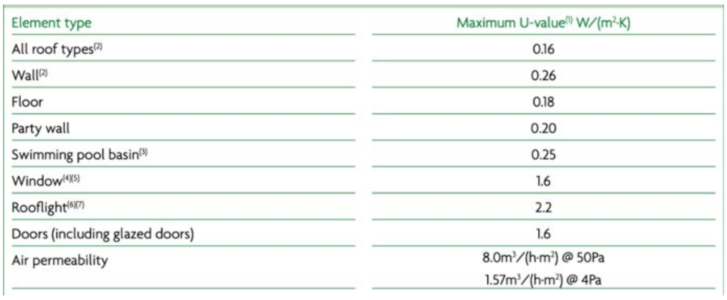
Passive cooling technologies have been administered to residential buildings to
assist in maintaining the indoor thermal comfort, alongside improving the indoor air quality. Passive cooling refers to strategies implemented into the design of the buildings, examples include; green roofing, double or triple glazing, solar shading, and insulation (Talebn, 2014). These strategies are used to decrease the indoor thermal temperature, making the environment more comfortable for the occupants, whilst using minimal energy and not contributing to global warming.

Building standards part L:

In the Built Environment, infrastructure and materials must meet specific standards, whereby engineers must comply by in order for the building to be deemed as in compliance with the sustainability injunction.

The Building Standards Part-L refers to the conservation of fuel and power (Goverment H. , The Building Regulations 2010: Conservation of fuel and power, 2021). This standard refers the restriction of indoor thermal gains and losses, in order to make building more energy efficient (Goverment H. , The Building Regulations 2010: Conservation of fuel and power, 2021). Testing of appliances have to be conducted and commissioned to ensure they are within the current regulations of operation.

The Building Standards Part-L utilises the use of U-values, which is used to describe the thermal performance of the materials (Kaye Hardyman, 2018). If a material mislays heat rapidly then this will acquire a high U value, whereas a low U value indicates gradual heat loss. Therefore, the lower the U values the better the performance of the material as less heat gain or loss is experienced (Kaye Hardyman, 2018). Materials implemented into buildings are required to meet a specific standard in order to meet the current regulations for sustainability perspectives. Therefore, the U-values for the construction elements for new buildings, obtained from the Approved Government Document has been displayed below in figure 1 (Goverment H. , Conservation of fuel and power, 2021):



Element type	Maximum U-value(1) $W/(m^2 \cdot K)$
All roof types(2)	0.16
Wall(2)	0.26
Floor	0.18
Party wall	0.20
Swimming pool basin(3)	0.25
Window(4)(5)	1.6
Rooflight(6)(7)	2.2
Doors (including glazed doors)	1.6
Air permeability	$8.0m^3/(h \cdot m^2)$ @ 50Pa $1.57m^3/(h \cdot m^2)$ @ 4Pa

Figure 1-U-values for construction elements in new dwellings (Goverment,2021)

The U values obtained above will be utilized throughout the EDSL TAS modelling process, to ensure the materials selected meet the current standards to demonstrate the performance of the current building requirements with regard to overheating.

Building standards Part 0:

The Building Standards Part-O refers to the requirements regarding the overheating analysis, which is aimed to reduce the number of solar gains encountered during the summer months, as a consequence this limits the amount of overheating experienced within the building (Goverment H. , Overheating, 2021). Furthermore, this document provides standards which infrastructure and dwellings must be in compliance with for the safety of the occupants to ensure that heat is removed from within the homes with sufficient methods, and mechanical cooling methods such as air-conditioning must only be used in the exception that the indoor thermal comfort cannot be reduced without such strategies (Goverment H. , Overheating, 2021). When the global temperatures inevitably rise further, residential construction will not be able to control the indoor temperatures, and therefore as a result will be inclined to utilize mechanical cooling as a proposition to resolve the extreme thermal discomfort that the occupants are experiencing. Consequently, if the residential building construction does not employ strategies to mitigate this overheating risk for the future, homeowners will be forced to use mechanical cooling as the only solution to combat this thermal discomfort.

CIBSE TM59/TM52:

The CIBSE TM59 was created to provide a set of requirements that dwellings should fulfil in order to reduce the overheating risk. Furthermore, the CIBSE TM59 enables engineers and designers to predict the occurrence of overheating within residential dwellings through the use of dynamic thermal modelling (CIBSE, TM59 Design methodology for the assessment of overheating risk in homes, 2017), whereas the CIBSE TM52 document refers to the overheating analysis within European Buildings. The CIBSE TM59 is the latest version of the overheating analysis, therefore this will be utilised throughout this research, this document does also refer to the CIBSE TM52.

The CIBSE document states that infrastructure must satisfy two precise CIBSE TM59 benchmarks to be deemed as having an acceptable risk of overheating occurring within the home (CIBSE, Design methodology for the assessment of overheating risk in homes, 2017). The requirements are as follows:

1. The first criteria applies to living rooms, kitchens, and bedrooms only, and states that “the internal temperature shall not exceed a define comfort temperature by 1° or more for more than 3% of occupied hours over the summer period (1st May to 30th September)” (CIBSE, Design methodology for the assessment of overheating risk in homes, 2017) (Ministry of Housing, 2019).
2. The second criteria applies to primarily bedroom only and requires “that the internal temperature between 10pm and 7am shall not exceed 26° for more than 1% of annual hours” (CIBSE, Design methodology for the assessment of overheating risk in homes, 2017) (Ministry of Housing, 2019).

The NHBC Foundation who provides guidance to the construction industry have stated that “most people begin to feel warm at 25° and hot at 28°” (Foundation, Understanding overheating- where to start: an introduction for house builders and designers , 2012). This emphasizes the CIBSE TM59 requirement of not exceeding 26°, as in excess of this value, occupants will feel thermal discomfort. In addition, it is already estimated that 55% of buildings within the United Kingdom do fail to meet to CIBSE TM59 criteria (TM59, 2022). This emphasizes the need for passive cooling strategies to be implemented into dwellings to ensure that construction within the residential sector meet this CIBSE TM59 requirement, because if the 26° requirement is exceeded for more than 1% of the annual hours, and further increases to 28° the occupants will experience discomfort, and will need to mitigate strategies to resolve this issue, in which they may approach the use of mechanical cooling techniques, which consequently further contributes to global warming. This is therefore a recurrent cycle that will become persistent if no adjustments are made to the Built Environment.

Standard Construction:

The CIBSE Journal states that Arup have found evidence suggesting that “9 out of 10 homes will be at risk of overheating if worldwide temperatures rise to 2° above pre-industrial levels” (Journal, 2022). This emphasizes the need to employ adaptations into the residential construction industry before this escalates further and every house experience thermal discomfort. 9 out of 10 homes is the majority of the residential sector that is predicted to experience overheating, which concerningly implies that 9 out of 10 homes maybe at risk of using mechanical cooling means to alleviate the pressures of overheating.

It is suggested from the NHBC foundation that a “well insulated fabric will prevent heat gains and losses between the internal environment of homes and outside” (Foundation, 2012). A well-insulated fabric refers to the employment of better U value construction elements, as previously stated in figure 1. In 2014 BRE carried out a report to investigate the U value of the walls within English housing, and from this report it can be concluded that the average U value for the standard solid wall was 1.57

W/m^2K (Doran, 2014). Since this investigation was published, the 2021 updated Building Regulations Approved Document Part-L states that the maxiumum U values for walls should be $0.26 W/m^2K$, which can be seen from figure 1 in section 2.2. This implies that as global warming has progressed the performanace and standards of the construction elements within the residential sector has tremediously improved, in order to meet the 2030 target of reducing the carbon emissions.

Passivhaus Construction:

A Passive house building, also formerly known as a Passivhaus, is defined as dwelling that uses minimal energy consumption to create an improved indoor thermal comfort level (Institute, 2023) , which therefore classifies this building as low energy structure (Moreno-Rangel, 2020). This implies that the passivhaus construction doesn't consume energy to mitigate the effects of overheating, and instead implements superior performing materials.

The aim of the Passivhaus construction is enhance the thermal performance of the building, with regard to the U values of the construction fabrics (Moreno-Rangel, 2020). In addition, another objective of Passivhaus construction is to diminish the amount of energy consumed to heat and cool the building without using mechanical systems (Moreno-Rangel, 2020). To accomplish this the passivhaus construction comprises of having well insulated external walls, ceiling, and flooring (Moreno-Rangel, 2020), by using enhanced materials that have lower U values compared to the current 2021 Building Regulation Part-L U value requirements.

The Passivhaus Trust Document suggests that the choice of superior performance building fabric, which refers to materials compromising of lower U values, as well as employing enhanced strategies to decline the amount of thermal solar gain through glazing, does have a direct effect on the internal temperatures within dwellings. The implementation of such strategies, results in the interior climate being at a more stable level (Jonathan Hines, 2015). The BRE designers guide for Passivhaus states that the recommended limits for walls, floors and roofs should between $0.10 - 0.15\, W/m^2K$ (Moreno-Rangel, 2020) . The Passivhaus construction therefore has a lower U value compared to the Standard construction requirement of $0.26\, W/m^2K$ for the wall construction elements, which implies that the utilization of the Passivhaus construction method should improve the overheating problem of standardized construction.

EcoBIM Construction:

BIM which is referred to as Building Information Modelling (Engineers, 2021), is widely used within the construction industry to create a digital representation of structures and buildings. Furthermore, it can be utilized to create a virtual and realistic representation of structures, which can reduce the amount of waste generated from designs and materials that have not been successful during the construction process (Engineers, 2021). The software compromises of implementing data to create a real-life example of the intended product to be constructed. This provides engineers with a realistic perspective of the intended model, which can aid the use of sustainable materials, as well as overviewing how the building is expected to perform once built, which can help aid changes to the design to enhance its sustainability (AutoDesk, 2023).

EcoBIM Construction uses the same concept of BIM; however, it is a set of construction elements within the EDSL TAS construction data base. EcoBIM construction consists of outlining the features within a BIM model, also referred to as Building Information Modelling, which can be used to initiate and develop sustainable future designs of structures (Carmen Antuna, 2014). EcoBIM has the potential to enable engineers within the Built Environment to generate structures that are more sustainable and capable of experiencing more extreme weather conditions as a consequence of global warming. EcoBIM construction can enable engineers to simulate various building components on structures to determine the most sustainable design for the current climatic conditions (Ibrahim, 2016). EcoBIM construction was created to generate and define a set of guidelines that can enhance the sustainability of buildings. Furthermore, the intention of EcoBIM is to employ the set of guidelines and tools provided to change construction models to more "sustainable eco-innovate" residential building models (Pekka Huovilla, 2013). If the tools provided by the EcoBIM construction do prove to be beneficial, then in hindsight this will provide applicable information for policy makers (Pekka Huovilla, 2013).

Passive cooling techniques:

Passive cooling techniques can be classified as heat protection (for example glazing), heat modulation (for example thermal mass or phase change material to store excess heat) or heat dissipation (for example convective natural ventilation cooling) (Bhamare, Rathod, & Banerjee, 2019)

Glazing:

Glazing is a necessity within structures, as it enables natural light to enter into rooms, which can decrease the need for electrical lighting in some instances. However, glazing has properties such as an excessive heat transfer mechanisms (Haiying Wang, 2019), which increases the amount of overheating that is experienced within the home. Sunlight and solar gain enter buildings via windows, and is then absorbed by the furniture, which then emits this as heat inside the house. This cycle is often referred to as the "greenhouse effect" (Foundation, Understanding overheating-where to start: an introduction for house builders and designers, 2012). As a consequence, this increases the temperature within the home, and therefore increases the need for mechanical cooling to prolong the effects of this thermal discomfort.

Single glazing was very common in the construction industry. The utilization of single glazing within structures is thought to cause up to 40% of heat loss in buildings (Dewanta Harjunowibowo, 2019). A single glazing base window is thought to have a U value of approximately $6.9W/m^2K$ (Dewanta Harjunowibowo, 2019), which is a considerable increase considering the 2021 Building Regulations maximum threshold is 1.6 W/m^2K. This indicates that choosing the most suitable glazing for dwellings is crucial with regard to both the overheating risk, and energy consumption to overcome the elevated temperatures.

A type of glazing that can be implemented into infrastructure is silica aerogel glazing, which uses silica aerogel to fill the cavities between the glazing (Tao Gao, 2014). From a recent study it is thought silica aerogel has the ability to reduce the amount of heat losses by 58% compared to common double glazing that is currently used in the industry (Tao Gao, 2014). Aerogel has a U value of approximately 1.05 W/(m^2K) (Tao Gao, 2014), with larger silica aerogel particles having a U value of 1.19 W/(m^2K) (Tao Gao, 2014), these values have a much lower U value than the standard from the Building Regulations Part L which has an estimated U have of 1.6 W/(m^2K). The Building Standards Part L demonstrates that the lower the U value obtained from a material the better the performance regarding thermal comfort, therefore using this method the use of silica aerogel glazing should theoretically improve the performance of the windows and as a result decreases the amount of thermal discomfort experienced within homes. Since sunlight entering glazing can cause the greenhouse effect within the indoor environment of dwellings, which as a result increases the overheating risk, silica aerogel glazing can also decrease the light transmittance by 38% (Tao Gao, 2014) compared to typical double glazing used in homes. This suggests that silica aerogel glazing can also decrease the amount of solar gain experienced within the home, which consequently decreases the amount of indoor thermal discomfort experienced.

An alternative to silica aerogel is triple glazing which compromises of three panels of glass, and two cavities between each layer of glass (Jinbo Wang, 2017) . These cavities can then be filled with gas dependent on the required use and specification of the glazing that is needed. It is thought that the use of triple glazing instead of double glazing can be up to 40% more thermally efficient (group, 2016), which as a result alleviates the pressures of the overheating risk experienced within the home. Triple glazed windows have an estimated U value of 0.68 W/(m^2K) (Ltd, 2016), with the 2021 Building Regulation U value being 1.6 W/(m^2K), therefore this will have an enhanced improvement on the indoor thermal comfort of dwellings.

Within the cavities of triple glazing, gases can be used to enhance the performance of the windows dependent on its intended purpose. An example of the type of gas that can be used includes argon. Argon is primarily a gas that consists of approximately 1% of the Earth's atmosphere (Pessoa, 2013), however the use of argon is ever expanding, as it can now be implemented into double and triple glazed windows to help reduce the amount of heat that can be transferred through glass, to decrease the overheating risk within dwellings, by improving the U value of the glazing (Graham Finch, 2008).

Insulation:

Insulation enables homeowners to run more energy efficient homes, with a reduced need for cooling or heating, and can save homeowners approximately 20% on heating and cooling costs (Energy, 2010). From a Government Document it is suggested that the performance of insulation is quantified through R values, with larger R values indicating a better insulation performance (Energy.gov, 2022). The intention of this research is to improve the thermal comfort experienced within homes for the occupants, therefore the use of different insulation types with larger R values may alleviate some of the pressures experienced from overheating.

Radiant barriers and reflective insulation:

Radiant barriers and reflective insulation enable homeowners to be able to lower their mechanical cooling costs, due to this type of insulation being capable of reducing the amount of thermal gain the house experiences during the summer months (Energy.gov, 2022). Insulation slows and prevents heat transfer around the home which inevitably reduces the thermal discomfort that is experienced within the home (Salih, 2015-2016). The majority of thermal discomfort within homes originates from the roof, as the roof contributes to 70% of the heat gain within home (Karam M. Al-Obaidi, 2014). Therefore, the primary focus to reduce the indoor thermal temperature should come from solving the heat gain through the roof, as this is the prominent issue, with over half of the solar gain originating from the roof of dwellings. The use of reflective insulation within dwellings can ensure that the heat is not absorbed, and is reflected off walls or roofs, therefore no heat is absorbed so overheating is not experienced (SuperFoil, Why is Insulation Important during the summer months, 2021). Reflective insulation typically uses aluminium foils on the surface on the insulation to provide the reflective layer (Energy.gov, 2022). During the summer months, due to the nature of houses the roof often receives the most impact from the heat, the materials used enables this heat to be transferred through the roof, and inherently into the attic, this will then be diffused throughout the house, causing an increase in thermal temperature. However, the use and installation of a radiant barrier limits the transfer of heat from the roof to the attic, which then reduces the amount of heat that is transferred to other parts of the house, and consequently reduces the indoor thermal discomfort preventing the building from overheating (Energy.gov, 2022). This reduces the need for mechanical cooling means during the summer months, and this mechanism has the capability to reduce cooling costs for homeowners by 5-10% (Energy.gov, 2022).

Alternatively, superfoil is another type of insulation that can be employed throughout the construction industry. The superfoil insulation can be provided in array of sizes and material types, therefore they are very robust. The superfoil manufacturers also produce a radiant barrier membrane (SFTV) to improve the performance of insulation (SuperFoil, Experts in Insulation, 2020). In particular, the superfoil radiant membrane is very versatile and can be installed onto the inside of the roof, which helps enable the temperature within the house to be regulated and prevents heat from entering the house via the roof, which reduces the solar gain (Superfoil, Experts in Insulation, 2020). SFTV is thought to excel standard vapour control layers by three times, ensuring that houses remain cool during the summer months by reducing the solar gain, but also ensuring that the heat within the winter months in kept within the house (Superfoil, Reflective membrane radiant barrier , 2021). SFTV has been tested and certified to achieve an R value of 0.95 (Superfoil, Reflective membrane radiant barrier , 2021), when used within the roof. This material can also be used on flat roofs and pitched roof so it is versatile enough to be implemented into current home designs.

2.Methodology

Research methods:

This study will employ quantitative data throughout the research due to the behaviour of modelling and simulation which produces statistical evidence, which will undergo analysis to determine the most appropriate and effective building construction fabric as a passive cooling technique to combat the overheating crisis. Qualitative research is not appropriate for this investigation as this consists of using information not through calculations but in terms of language and speech, for example surveys and interview (Ronald Jackson, 2007) (team, 2021)

Modelling and simulation justification:

This research considers computational fluid dynamics modelling and simulation of three different building fabric construction as passive cooling technologies. Modelling and simulation has been selected as this method is the most effective and will produce realistic in-situ results and data information regarding the current and future climatic conditions. The configuration of the residential building model used within the simulation is 100% of the building, thus the whole residential model is used and analysed throughout the simulation process.

Figures 2 to 4 indicate the 2D floor plans and 3D model of the residential building used throughout this investigation.

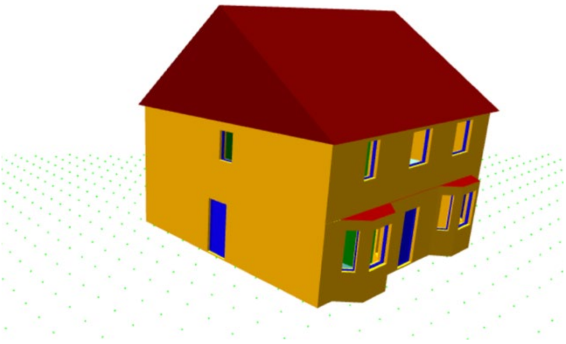


Figure 2-3D Residential model

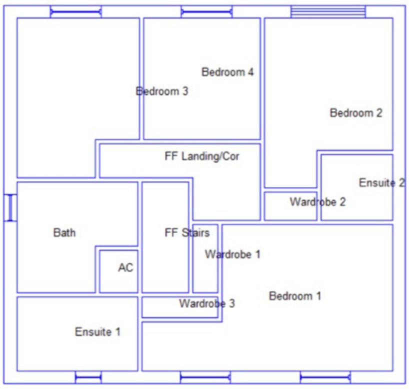


Figure 3-Residential model second floor plan

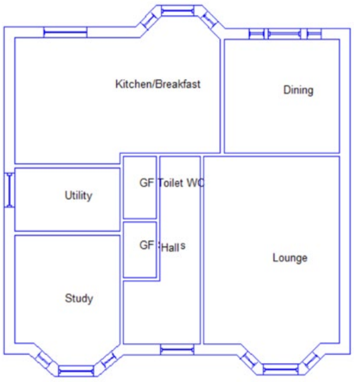


Figure 4-Residential model ground floor plan

EDSL TAS software:

The EDSL TAS software will be used to complete the modelling and simulation process, which is a dynamic thermal modelling software. This is the preferred software as it is an industry-leading software, which enables the CIBSE TM59 assessment to be imported into the software for easy comparison against the modelling (TAS, 2022).

The CIBSE TM59 document does not provide the schedule for which the windows should be opened for during the day, this will be assumed as 9am until 5pm in the EDSL TAS software, as this is the typical working day and therefore this would be the worst-case scenario that the windows are open for 8 hours per day.

A variety of factors will be changed throughout the EDSL TAS software to ensure that the necessary data is simulated for this investigation. The following aspects in the EDSL TAS software model will be altered:

- The weather data from 2020, and predicted weather period for 2050 and 2080 will be implemented.
- The weather data will also change depending on the four locations chosen.
- The schedule for which the windows are open will be 9am-5pm.
- The U values of the construction elements

Building fabric assumptions:

The data used, are the AutoCAD two-storey residential detached buildings drawings of Persimmon South East Ltd Sheppey General Hospital 0712 House Type. (Amoako-Attah & B-Jahromi, Impact of future climate change on UK building performance, 2013). Table 1 below shows thermal simulation parameters and assumptions.

Table 1 Modelling and simulation parameters and assumptions

Building Fabric	**Calculated area weighted average U-values (W/m^2K)**	
UK Standard Construction	Wall	0.240
	Floor	0.180
	Roof	0.126
	Windows (pane)	1.220
Passivhaus Equivalent Construction	Wall	0.118
	Floor	0.099
	Roof	0.087
	Windows (pane)	0.813
Ecobim Construction	Wall	0.130
	Floor	0.110
	Roof	0.090
	Windows (pane)	1.360
Construction Database	NCM Construction v5.2.7	
Calendar	NCM Standard	
Weather Data		
Belfast_DSY3_2020High50	London_DSY3_2020High50	
Belfast_DSY3_2050High50	London_DSY3_2050High50	
Belfast_DSY3_2080High50	London_DSY3_2080High50	
Glasgow_DSY3_2020High50	Manchester_DSY3_2020High50	
Glasgow_DSY3_2050High50	Manchester_DSY3_2050High50	
Glasgow_DSY3_2080High50	Manchester_DSY3_2080High50	
Internal Conditions	NCMActivities v5.2.7	
Occupancy levels People Density Lux Level	Bath	0.01873684 pers/m^2. 150 Lux
	Bed	0.02293877 pers/m^2. 100 Lux
	Circulation area	0.01550388 pers/m^2. 100 Lux
	Dining	0.0169163 pers/m^2. 150 Lux
	Kitchen	0.0237037 pers/m^2. 300 Lux
	Lounge	0.0187563 pers/m^2. 150 Lux
	Toilet	0.02431718 pers/m^2. 100 Lux
Openable Windows	6.5% of External Wall Area	
Air Permeability	5 m^3/hm^2@50Pa	
Infiltration	0.250 ACH	
Terrain Type	City	

Weather Data choice and justification

The weather data provided from the CIBSE has been accumulated and authorized from the UK Meteorological Office (MO), across 16 locations in the UK (CIBSE, Weather Data, 2022). They provide easy to access, reliable data sets for a variety of locations over the UK, which also considers different types of weather files (TRY and DSY), a variety of emissions scenarios and specific scenarios of hotness. This therefore makes the CIBSE an impeccable choice for weather data.

The CIBSE have produced two types of weather files include: TRY and DSY (Eames, CIBSE Weather files 2016 release:Technical Briefing and Testing, 2016). The acronym TRY stands for “Test

Reference Year" and is primarily used to discover the mean energy consumption within construction (Eames, CIBSE Weather files 2016 release:Technical Briefing and Testing, 2016). The DSY refers to "Design Summer Year", and refers to the weather period that represents temperatures which are higher than experienced over a typical year (Eames, CIBSE Weather Files 2016 release: Technical Briefing and Testing, 2016), to assess the overheating risk within the building. This research will utilize the application of the Design Summer Year (DSY) provided from the CIBSE, as this is the weather file that can be used to assess the overheating risk within the home. For this investigation, the TRY weather files are not deemed as appropriate due to this investigation not exploring the energy usage within buildings.

The DSY can further be split into three categories, which include: DYS1, DYS2 and DYS3, these are projections for specific scenarios of heat (Eames, CIBSE Weather files 2016 release:Technical Briefing and Testing, 2016). DYS1 weather data refers to a moderately warmer summer period, with a return period of 7 years (Eames, CIBSE Weather files 2016 release:Technical Briefing and Testing, 2016). DYS2 refers to weather data from a short intense warm spell. DYS2 is associated with a moderate summer year, but with a larger intensity (Eames, CIBSE Weather files 2016 release:Technical Briefing and Testing, 2016). DYS3 refers to weather data from a long intense warm spell and is determined from an intense extreme moderate summer year with a longer duration than a moderate summer year (Eames, CIBSE Weather file 2016 release: Technical Briefing and Testing, 2016). The CIBSE TM59 does state that DYS1 is most appropriate (CIBSE, Design methodology for the assessment of overheating risk in homes , TM59), however due to the nature and rapidly increasing effects of global warming the more extreme case of DSY3 will ensure that the passive cooling techniques and models are capable of handling such large overheating exposure, without affecting the indoor environment. The investigation will therefore exclusively employ the DYS3, as this is the worst-case scenario that may occur as a consequence of the increase of global warming.

The projections for the long intense warm spell (DSY3), can be further categorised into percentiles, which represent the carbon emissions. The scope of percentiles include 10th, 50th and 90th (Eames, CIBSE Weather files 2016 release:Technical Briefing and Testing, 2016). This research will implement the 50th percentile throughout the investigation, as the 50th percentile forecasts that there will be a 50% prospect of the outdoor temperature subsiding or a 50% possibility it will exceed the temperature change within the CIBSE DSY weather data (Anna Mavrogianni a, 2011). The percentiles can be further categorised into low, medium, and high scenarios, with low representing low emission scenarios and high referring to high emission scenario's (Guide, 2021). This research will employ the High 50th percentile, which represents the high emission scenarios. The choice of this scenario is due to the increasing effects of global warming as a result of increased emissions; therefore, this scenario is the best representation of the current climatic conditions that we experience.

The CIBSE weather file 2016, provides data regarding 2020, 2050 and 2080. This array of time periods will be applied throughout this research as it provides analysis against previously experienced weather patterns compared to predicted weather periods for the future.

The CIBSE provides weather files for 14 locations throughout the UK. The primary focus is to investigate the overheating in residential buildings throughout the UK, therefore this research will employ 4 of these locations. The following locations shall be utilized throughout this investigation: London, Manchester, Glasgow, and Belfast. The choice of these particular locations is due to enabling a large variety of analysis of weather periods over the UK, which provides a variety of different latitudes for comparisons, instead of confining the research to a small section within the UK.

Chosen strategies for modelling and simulation process.

This research considers three building fabric constructions; the Standard Construction, the EcoBIM Construction, and the Passivhaus Construction. Modelling and simulations are performed on various scenarios on the case study residential building in the EDSL TAS software for the four chosen locations of Belfast, Glasgow, London and Manchester under varying weather conditions. Figure 5 indicate the modelling and simulation process.

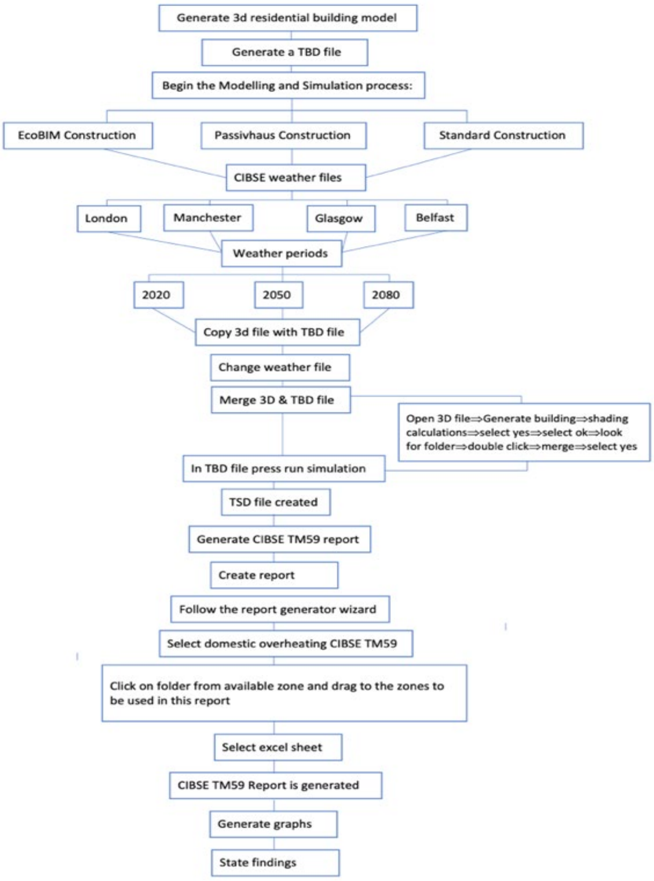


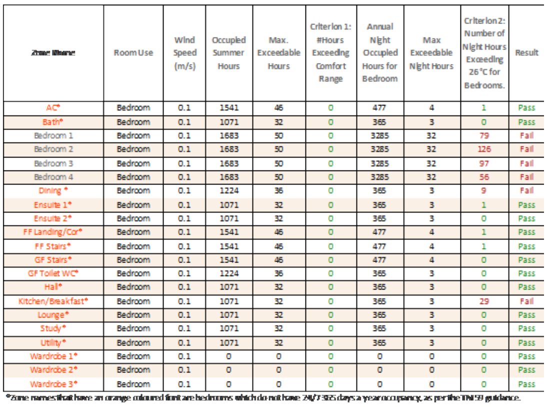
Figure 5-Flow chart for modelling and simulation process

The data used in the modelling and simulation are the AutoCAD two-storey residential detached buildings drawings of Persimmon South East Ltd Sheppey General Hospital. The various construction elements for the three specified scenarios are modelled and simulated. The CIBSE weather files for Manchester, London, Belfast, and Glasgow for the 2020, 2050 and 2080 weather are incorporated in the simulation to reflect the specified locations. The other simulation parameters of Building Summary, Calendar, Weather, Zones, Internal conditions, Schedule, and Aperture Types were populated to simulate the building for it to reflect the construction design criteria specified by the (CIBSE, CIBSE Guide A – Environmental Design, 2016) and as indicated in figure 1. TM59 Design methodology for the assessment of overheating risk in homes in EDSL TAS software is then used to generate overheating reports in excel format. An example is shown in figure 6.

3.Results, Analysis and Discussion

Results from TAS software:

The EDSL TAS software has created a report with regard to the CIBSE TM59 assessment, as illustrated in figure 6. The data presented below is the report for the London Standard construction simulation for the 2080 weather data.



Zone Name	Room Use	Wind Speed (m/s)	Occupied Summer Hours	Max. Exceedable Hours	Criterion 1: #Hours Exceeding Comfort Range	Annual Night Occupied Hours for Bedroom	Max Exceedable Night Hours	Criterion 2: Number of Night Hours Exceeding 26°C for Bedrooms.	Result
AC*	Bedroom	0.1	1541	46	0	477	4	1	Pass
Bath*	Bedroom	0.1	1071	32	0	365	3	0	Pass
Bedroom 1	Bedroom	0.1	1683	50	0	3285	32	79	Fail
Bedroom 2	Bedroom	0.1	1683	50	0	3285	32	126	Fail
Bedroom 3	Bedroom	0.1	1683	50	0	3285	32	97	Fail
Bedroom 4	Bedroom	0.1	1683	50	0	3285	32	56	Fail
Dining *	Bedroom	0.1	1224	36	0	365	3	9	Fail
Ensuite 1*	Bedroom	0.1	1071	32	0	365	3	1	Pass
Ensuite 2*	Bedroom	0.1	1071	32	0	365	3	0	Pass
FF Landing/Cor*	Bedroom	0.1	1541	46	0	477	4	1	Pass
FF Stairs*	Bedroom	0.1	1541	46	0	477	4	1	Pass
GF Stairs*	Bedroom	0.1	1541	46	0	477	4	0	Pass
GF Toilet WC*	Bedroom	0.1	1224	36	0	365	3	0	Pass
Hall*	Bedroom	0.1	1071	32	0	365	3	0	Pass
Kitchen/Breakfast*	Bedroom	0.1	1071	32	0	365	3	29	Fail
Lounge*	Bedroom	0.1	1071	32	0	365	3	0	Pass
Study*	Bedroom	0.1	1071	32	0	365	3	0	Pass
Utility*	Bedroom	0.1	1071	32	0	365	3	0	Pass
Wardrobe 1*	Bedroom	0.1	0	0	0	0	0	0	Pass
Wardrobe 2*	Bedroom	0.1	0	0	0	0	0	0	Pass
Wardrobe 3*	Bedroom	0.1	0	0	0	0	0	0	Pass

*Zone names that have an orange coloured font are bedrooms which do not have 24/7 365 days a year occupancy, as per the TM59 guidance.

Figure 6-Standard construction London 2080 CIBSE TM59 overheating report.

From figure 6 it is evident that this particular simulation is classified as passing this the CIBSE TM59 criteria 1, as it has not gained any hours exceeding this comfort range. This exact relationship occurred throughout all the simulations (which can be seen in the appendix), and therefore due to the constructions passing this criterion consistently throughout the 2020, 2050 and 2080 weather periods, it is apparent that all the simulated constructions strategies (EcoBIM construction, Passivhaus construction and the Standard construction) satisfy the requirements for the CIBSE TM59 criteria 1.

The main concern from the simulations was in accordance with the CIBSE TM59 criteria 2. This criterion refers to the bedroom only areas. Thus critical consideration is primarily given to criteria 2 for the four bedrooms only. It is evident that from figure 6, that London for the 2080 weather data exceeded this threshold on all four bedrooms for the Standard construction simulation, therefore this construction is not within the acceptable tolerance of overheating.

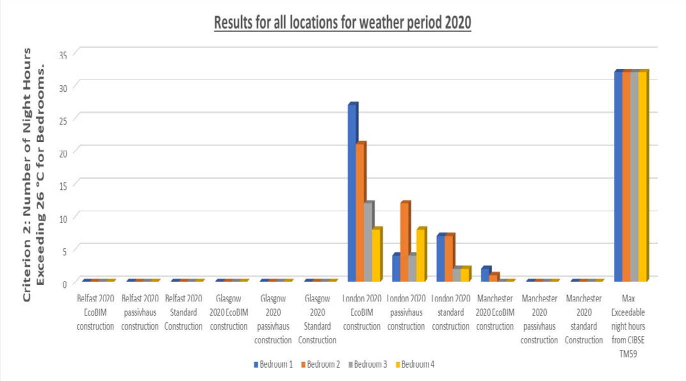


Figure 7-Modelling and simulation results for 2020

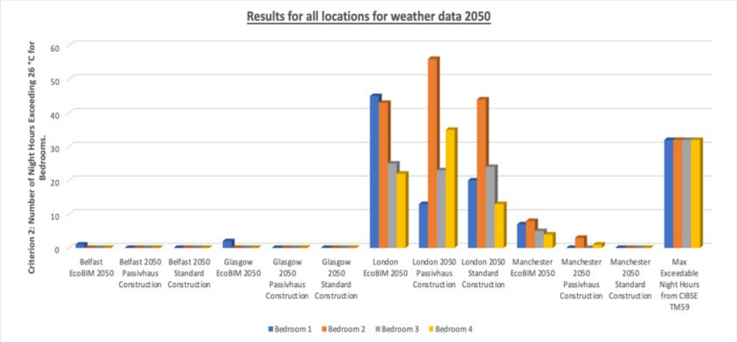


Figure 8-Modelling and simulation results for 2050

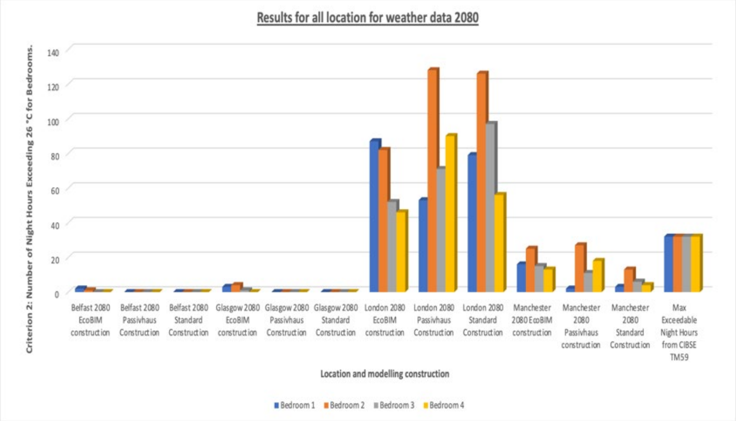


Figure 9-Modelling and simulation results for 2080

The maximum exceedable nights hours for Criteria 2 regarding the 4 bedrooms is 32 hours per room, which cumulatively equals 128-hours for all four bedrooms. The hours from the simulation that are in excess of the 128-hours will be classified as failed for this particular construction, and values below this threshold will pass the CIBSE TM59 criteria. The cumulative number of hours exceeding the 26° for all 4 bedrooms for each location and construction has been displayed below:

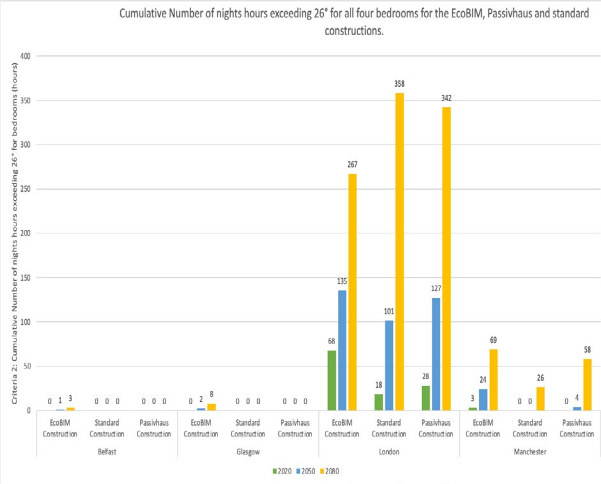


Figure 10-Cumulative number of hours exceeding the 26-degree requirement for each location and construction.

Impact of the Standard construction on the performance of the residential model:

It is evident that from figures 8, 9 and 10, that the Standard construction for the Belfast and Glasgow locations passed the CIBSE TM59 assessment for criteria 2 for all the weather data. This portrays that the locations of Glasgow and Belfast do not require construction adaptations for the predicted future climate to deal with the expected overheating, as the Standard construction that complies with the U values stated in the 2021 Building Regulations Part-L is capable of not being at risk of experiencing significant overheating.

Furthermore, figure 8 and 9 illustrate that for the weather periods of 2020, 2050 and 2080 the Standard Construction for Manchester did not gain any hours in excess of the 26° requirement for criteria 2. From figure 10, it is evident that the Standard Construction simulation for Manchester did experience some overheating over the four bedrooms for the 2080 weather data, which cumulatively was 26 hours across all four bedrooms. Although this is a slight increase from the previous weather data's that were simulated, the construction shall still be deemed as having an acceptable tolerance to overheating, even with the expanding effects of global warming.

Figure 8 displays that London did experience some hours above the 26° requirement for the 2020 weather data, however, it can be deduced from figure 10, that this was cumulatively only 18 hours across all four bedrooms. In addition, figure 9 portrays London did exceed the 26° requirement across one of the bedrooms, and cumulatively collected 101 overheating hours, which is below the cumulative 128-hour limit across all four bedrooms. The Standard construction for London during the 2020, and 2050 weather period simulation shall be deemed as having an acceptable tolerance to overheating. It can be illustrated from figure 10 that for the weather period of 2080, London experienced excessive overheating within the standard construction. It obtained 358 overheating hours, which is 179.69% above the CIBSE TM59 128-hour threshold, and therefore shall be deemed as failing the CIBSE TM59 criteria 2, which clarifies that the Standard construction for the predicted weather period of 2080 shall not be deemed as having an acceptable tolerance to overheating, and is very much at risk of experiencing excessive overheating hours. Earlier similar study on the subject had also indicated that London obtained the highest operative temperatures due to the increasing effects of global warming (Amoako-Attah and B-Jahromi, 2013, 2016)

Impact of the Passivhaus construction on the performance of the residential model:

It is apparent that from figures 7, 8 and 9 that Glasgow and Belfast did not present any overheating hours for the 2020, 2050 and 2080 weather data simulation, and is deemed as having an acceptable risk to overheating for the Passivhaus construction, due to passing both the CIBSE TM59 criteria 1 and 2, for these years.

It can also be identified from figure 7 that Manchester also presented no hours in exceedance of the 26° requirement and is also deemed as having an acceptable tolerance to overheating for the 2020 Passivhaus construction. However, the implementation of the Passivhaus construction did present to steadily increase the number of overheating hours from 2050 to 2080. During the 2050 Manchester simulation the Passivhaus construction exceeded 4 hours of the 26° requirement for all four bedrooms, whilst during 2080 it presented as having 58 hours of overheating, which can be seen from figure 10. Although, the simulation for Manchester is classified as passing the CIBSE TM59 criteria, and is deemed as having an acceptable tolerance to overheating, it also presents that the employment of the Passivhaus construction does cause an increase in the number of hours the experience overheating, with the 2080 weather data presenting as the highest number of overheating hours.

In addition, London throughout all the simulations did present as having some overheating hours. Furthermore, from figure 7 it can be deduced that even though London did gain some overheating hours for the 2020 weather period, it did not obtain enough to exceed the maximum exceedable 32 hours, and is therefore deemed as passing. Figure 10 identifies that cumulatively over the four bedrooms the Passivhaus construction for the 2050 London simulation obtained 127 hours, this was below the cumulative CIBSE TM59 threshold of 128 hours. However, it is clearly identified from figure 10 that for the 2080 simulation the Passivhaus construction was inevitably in exceedance of this threshold, by obtaining 342 overheating hours, which is an increase of 215 hours compared to the 2050 simulation. This identifies that as the effects and temperature of global warming increase the passivhaus modification does not positively influence the residential building model, as an increase in overheating hours is experienced.

Impact of the EcoBIM construction on the performance of the residential model:

Belfast and Glasgow presented similar relationships as previously stated, by obtained zero hours beyond the CIBSE TM59 26° threshold, and therefore did not experience any overheating hours for the weather period of 2020. However, during the simulation of the predicted weather data for 2050, it is apparent, that both of these locations did experience some hours in excess of the 26° threshold in bedroom one, and therefore did experience an increase in the amount of overheating. In addition, from figure 10 it can be identified that amount of overheating experienced for the 2080 simulation in Glasgow and Belfast did increase again. However, Belfast and Glasgow did not exceed the CIBSE TM59 threshold on any of the weather period simulations for the EcoBIM constructions, and therefore is deemed as having an acceptable tolerance to overheating for the 2020, 2050 and 2080 predicted weather periods.

Figure 10 illustrates that during the Manchester simulation, all the weather data's that were implemented did experience some overheating hours, which steadily increased as the weather period progressed. In spite of this, Manchester was still below the CIBSE TM59 requirement, and therefore is classified as having an acceptable tolerance to overheating.

Lastly, it can be deduced that from figure 7, London did pass the CIBSE TM59 criteria 2 threshold and therefore the EcoBIM construction for the weather period of 2020 is deemed as having an acceptable risk to overheating. From figure 7, 8 and 9 it can also be deduced that bedroom 1 experienced the most overheating, whilst bedroom 4 experienced the least amount of overheating. In addition, figure 9 and 10 illustrates that the EcoBIM construction in London did exceed the maximum exceedable night hours. During the 2050 simulation the EcoBIM construction was classified as exceeding the 32-hour requirement on two of the bedrooms, whilst during the 2080 simulation the EcoBIM construction was classified as failing on all four of the residential model bedrooms. This emphasizes that as the decades progress, the amount of overheating that is experienced increases, which is as a result of the expected temperature inflation due to the ever-expanding effects of global warming.

Critical discussion of the EcoBIM construction, Passivhaus construction and Standard construction:

The U values for the three constructions provided from the EDSL TAS software, has been summarised in table 1. The Passivhaus construction has the lowest U values consistently throughout all the construction elements within the residential model. In addition, the EcoBIM construction has obtained the largest U values which are shown to exceed the 2021 building standard U requirements provided through the Standard construction.

It can be deduced that the Standard construction in compliance with the 2021 Building Regulation's Part-L, is classified as having an acceptable tolerance to overheating for Belfast, Glasgow and Manchester for the weather period of 2020, and predicted weather periods of 2050, and 2080. London shall also be deemed as having an acceptable tolerance to overheating for 2020, and 2050. This suggests that the need to implement further strategies into these locations to overcome the expected overheating due to the rise in temperatures, is not necessary as the current Building Standard U values for the construction fabrics currently suffices the CIBSE TM59 overheating analysis.

It is indisputable that the Passivhaus construction incorporated the lowest U values compared to the other constructions. However, despite this the Passivhaus construction did obtain slightly higher overheating hours compared to the Standard construction. It is apparent that only during the London 2080 simulation the Passivhaus construction performed better than the standard construction and presented a similar relationship to the EcoBIM construction, even though the EcoBIM construction did perform better again.

It is evident that the utilization of the EcoBIM construction did cause an increase in the number of hours in excess of the 26° requirement across all the locations, except during the 2080 weather data for London. Only under these circumstances did the employment of the EcoBIM construction appear to improve the overheating performance of the residential model. In this instance, the employment of the EcoBIM construction did significantly reduce the number of overheating hours for the London 2080 simulation. The utilization of the EcoBIM construction during the 2080 weather period for London resulted in a 71.10% decrease in the number of hours exceeding the 26° CIBSE TM59 requirement. Even though the EcoBIM construction did significantly improve the amount of overheating the residential model experienced, all the simulations for the 2080 weather period for London exceeded the CIBSE TM59 128-hour requirement for all four bedrooms, and therefore shall be deemed as not having an acceptable tolerance to overheating. This implies that London requires exceptional adaptation to mitigate the effects of global warming by 2080, in order to decrease the amount of thermal discomfort that is experienced, and as a result pass the CIBSE TM59 criteria 2.

4. Conclusions

Concluding remarks:
To conclude, this research has demonstrated evidence to suggest that Belfast, Glasgow, and Manchester do not experience a significant risk of overheating in the current and future climatic projections, due to the not failing or exceeding the CIBSE TM59 26° threshold throughout all four bedrooms. Adaptations to these regions with regard to infrastructure therefore do not need to be implemented to defuse the rising effects of global warming within the home.

In addition, the Standard construction for London during the 2020 and 2050 weather periods fulfilled the CIBSE TM59 requirement, and is therefore classified as having an acceptable tolerance to overheating. The need for adaptations in these regions with regard to global warming is not necessary, as the 2021 Building Standard Regulations for the current Standard construction are not at significant risk of overheating, as they satisfy both criteria's for CIBSE TM59 overheating analysis. On average it is evident that the Standard construction was the most effective proposition to combat the overheating, which has the median U value across all building fabrics.

The implementation of the EcoBIM construction, which had the largest U values, did negatively impact the overheating in homes, which was demonstrated throughout all the simulations except during the London 2080 simulation. It is evident that during the 2080 weather data simulation for London the utilization of the EcoBIM construction did significantly decrease the amount of overheating experienced by 71.10% compared to that of the Standard construction, even though this construction compromises of the highest U values.

The Passivhaus construction consists of the lowest U values for the residential building construction elements, however during the simulations this construction did not perform any better than the Standard construction, except during the 2080 London simulation. Throughout all the simulations the, Passivhaus construction has not deemed to be significantly effective and has remained on average equidistant regarding the number of hours experiencing overheating between Standard construction and the EcoBIM construction.

Ultimately, this research has demonstrated the London will experience the most overheating compared to Belfast, Glasgow, and Manchester. By 2080 London is expected to experience major overheating and the current 2021 Building Standard construction will not satisfy the CIBSE TM59 requirement, and consequently a considerable amount of thermal discomfort will be encountered in this region. It is therefore proposed that additional adaptations need to be implemented into the residential constructions located in London by 2080 to avoid experiencing extreme overheating within the residential sector.

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