UWL REPOSITORY

repository.uwl.ac.uk

Investigating the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village adapted to the nZEB standards

Bahadori-Jahromi, Ali ORCID logoORCID: https://orcid.org/0000-0003-0405-7146, Salem, Radwa and Mylona, Anastasia (2019) Investigating the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village adapted to the nZEB standards. Building Services Engineering Research and Technology, 40 (4). pp. 470-491. ISSN 0143-6244

http://dx.doi.org/10.1177/0143624419844753

This is the Accepted Version of the final output.

UWL repository link: https://repository.uwl.ac.uk/id/eprint/5889/

Alternative formats: If you require this document in an alternative format, please contact: open.research@uwl.ac.uk

Copyright:

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy: If you believe that this document breaches copyright, please contact us at open.research@uwl.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Rights Retention Statement:

Building Services Engineering Research and Technology

Investigating the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village adapted to the nZEB standards.

Journal:	*Building Services Engineering Research and Technology*
Manuscript ID	BSE-C-19-003.R1
Manuscript Type:	Research Paper
Date Submitted by the Author:	13-Mar-2019
Complete List of Authors:	Salem, Radwa Jahromi, Ali; University of West London Mylona, Anastasia; CIBSE, Publications/Technical; Oxford University Centre for the Environment, UK CLimate Impacts Programme
Keywords:	Building energy consumption, Building energy efficiency, Building energy retrofit measures, Building energy simulation
Abstract:	The death toll of the 2003 heat wave in Europe exceeded 35 000 heat-related deaths. The elderly population were the most affected. The current paradigm within the construction industry in cold-dominant countries is to design/retrofit buildings with high levels of insulation. Whilst thermal comfort may be reached during colder months with this approach, the risk of overheating can be increased during hotter months. This paper aims to examine the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village. For this study the buildings within the retirement village will be designed to reach the nearly zero energy building (nZEB) standard. Consequently, the risk of overheating of the buildings within the retirement village as they currently stand and as nZEBs will be investigated under current and future climatic conditions. The analysis is carried out using Thermal Analysis Simulation software (Tas, Edsl). Combined heat and power (CHP) and combined cooling, heat and power (CCHP) will be investigated as mitigating strategies with regards to overheating. The results of this study do not undermine the importance of continuing to improve the energy efficiency of existing buildings but rather highlight that the approach undertaken should be reconsidered.

SCHOLARONE™
Manuscripts

Radwa Salem[1], Ali Bahadori-Jahromi [1*], and Anastasia Mylona[2]

[1] Department of Civil Engineering and Built Environment, School of Computing and Engineering, University of West London, London W5 5RF, UK; Radwa.Salem@uwl.ac.uk

[2]Research Department, The Chartered Institution of Building Services Engineers (CIBSE), London SW12 9BS, UK; AMylona@cibse.org

* Correspondence: ali.jahromi@uwl.ac.uk

Conflict of interest: the authors declare that they have no conflict of interest.

For Peer Review

Investigating the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village adapted to the nZEB standards.

Abstract:
The death toll of the 2003 heat wave in Europe exceeded 35 000 heat-related deaths. The elderly population were the most affected. The current paradigm within the construction industry in cold-dominant countries is to design/retrofit buildings with high levels of insulation. Whilst thermal comfort may be reached during colder months with this approach, the risk of overheating can be increased during hotter months. This paper aims to examine the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village. For this study the buildings within the retirement village will be designed to reach the nearly zero energy building (nZEB) standard. Consequently, the risk of overheating and energy performance of the buildings within the retirement village as they currently stand and as nZEBs will be investigated under current and future climatic conditions. The analysis is carried out using Thermal Analysis Simulation software (Tas, Edsl). Once retrofitted to the nZEB standard the building failed to pass the overheating criteria for all weather files. The results of this study however do not undermine the importance of continuing to improve the energy efficiency of existing buildings but rather highlight that the approach undertaken should be reconsidered.

Keywords: nearly-zero energy buildings, thermal analysis simulation, overheating, retirement homes

For Peer Review

1.0 Introduction

Various definitions of overheating exist in the literature; as part of the Cibse TM59 methodology overheating is defined as bedroom temperature that exceeds 26ºC in bedrooms from 10pm-7am for more than 1% of occupied hours per year [1]. The UK is known for its relatively mild winter and temperate summer climatic conditions. During the past 30 years London has exceeded 26.1ºC for less than 1% of the time [2]. Consequently, the use of non-passive cooling techniques is uncommon, meaning buildings are not designed or equipped to cope with any rise in temperatures.

The effects of this is seen when weather abnormalities such as heatwaves occur during the summer months. The death toll of the 2003, 2006, and most recently the 15-day peak of the heatwave in June and July 2018 was 2000+, 680, and 650+, respectively [3, 4, 5]. Each year it is concluded that "the people most at risk in a heatwave are the frail elderly" [6]. A report published in July 2017 also corroborated the fact that the UK is "woefully unprepared" for heatwaves and it is predicted that unless action is taken the death toll will rise to 7000 a year by 2040s for heat-related deaths [5, 7]. The population of over 75s has also been projected to nearly double in the next 30 years meaning there will be an increase in the vulnerable population who are unable to acclimatise due to various physiological and cognitive impairments prevalent within this population demographic [8-11]. This is particularly applicable for residents in retirement homes such as the case study being used for this work [12].

Despite this, because the general existing UK residential building stock tends to be poorly insulated, overheating at the moment is typically not an issue and currently the death toll due to low indoor winter temperature in England and Wales exceeds the heat-related death toll by 98% [13]. Nonetheless, as mentioned previously by 2040 it is estimated that the temperatures experienced in the UK during the summer of 2003 will be the norm and it is expected that this will cause a drastic shift in those percentages.

This paper therefore aims to examine the impacts of a changing climate on the risk of overheating and energy performance for an existing UK retirement village. Homes within the retirement village share common characteristics, and therefore issues. As discussed earlier behavioural changes are not always an applicable solution with this type of housing due to the prototypical demographic of occupants who are classed as part of the susceptible population to overheating. In tandem with this, the risk of overheating as a potential threat is exacerbated as it can lead to preventable loss of life.

2.0 Literature Review

Pathan et al. [14] investigated the risk of overheating in London by monitoring 122 properties during the summers of 2009 and 2010. It was concluded that “London dwellings face a significant risk of overheating under the current climate.” In their review of overheating in new UK homes Dengel and Swainson [15] found that there is growing evidence that high energy efficiency standards (i.e. high levels of insulation without appropriate ventilation) lead to overheating and can also negatively affect the health of occupants. Several studies have concluded that new-build care and retirement homes are already at risk of overheating [16-20].

A UK study investigated summer temperatures in 224 dwellings found that pre-1919 dwellings were least likely to overheat; meanwhile post-1990 dwellings were most likely to experience overheating. It was suggested that this is largely due to the difference in construction, mainly, the levels of insulation and airtightness [21]. A similar notion was established by a 2013 study which found that pre-1919 dwellings were significantly cooler whereas post-1990 dwellings were significantly warmer. Bedrooms in particular seemed to experience overheating even during cooler summer temperatures [22]. Once again Hulme et al. [23] confirmed that modern (1975-80) properties with an energy efficient SAP rating of 70+ and post-1990 dwellings were warmer whilst pre-1919 dwellings were cooler.

The introduction of ‘Nearly-Zero Energy Buildings’ (nZEBs) by the Energy Performance Building Directive (EPBD) [recast] in 2010 and the 2050 carbon budget which led to a shift in the design paradigms within the construction industry across Europe means that new and existing buildings are expected to be energy efficient [24, 25].

New homes are therefore being designed to satisfy the demanding requirements of new regulations whereby high levels of insulation is incorporated amongst other measures to ensure the energy demand of the building is lowered. Furthermore, the EPBD did not only set out a requirement for all new buildings to be nZEBs by 2020 but also for buildings that will undergo refurbishment. As a result, existing buildings are also being retrofitted to catch up to the energy efficiency standard of new homes. The basic concept behind the nZEB standard exacerbates the risk for overheating in homes under hotter weather conditions [26, 27]. Despite this there is very little research and investigation regarding the issue and the potential of the widespread implementation of the nZEB standard across Europe to compound the risk of overheating in buildings.

Increasing population has meant that the proportion of apartment type buildings being developed has increased by at least 50% across the UK and 80% in London. Although this practice allows efficient use of land by increasing the number of dwellings which can be built per unit area, research has shown that flats have a higher risk of overheating [28, 29]. This is largely because typically the level of ventilation that can be achieved with this type of dwelling is smaller in comparison to houses for example.

The average number of Cooling Degree Days (CDD) has more than doubled in London alone between 1961 and 2006. Meaning that the amount of energy required for cooling has increased and is continiuing to increase as temperatures rise. Despite this summertime heat gains are still neglected in both nZEB studies and real-life applications for new and existing buildings being retrofitted [26].

Peacock et al. [30] investigated internal temperatures of dwellings using dynamic thermal simulation and predicted based on findings that by 2030 18% of homeowners will install air conditioning in response to increasing temperatures. Meaning that in London alone more than 500,000 homes will have air conditioning. This would not only lead to difficulties in meeting the 2050 carbon target but would directly hinder any progress being made towards reaching the nZEB standard.

Roaf et al. [31] explored the advantages of utilising passive ways of reducing the risk of overheating in homes built to a high energy efficiency standard and concluded that this is an effective way to mitigate the risk of overheating. However, as previously mentioned, for flats, there is limited opportunities for the incorporation of natural ventilation due to the physical characteristics of such buildings. Another physical building characteristic which seems to have an effect on overheating is the orientation of the building as established by Pana [32]. The orientation of the building is an interesting factor to influence whether or not a building experiences overheating but is limited in terms of applicability as altering the orientation of existing buildings is not possible [28, 29, 33]. Nonetheless some studies suggest that incorporating external shading can help maintain summer thermal comfort [28, 33]. Flats located at higher floor levels were also found to be more likely to experience overheating

For Peer Review

[34, 35]. Carrilho et al. [28] used dynamic thermal simulation to investigate the technical and economic feasibility of the nZEB standard in a mild southern European climate zone, Lisbon on two houses with different levels of glazing (moderately glazed and highly glazed). It was found that high levels of glazing contribute to an increase in the risk of overheating; for example, the living room temperature in the highly glazed house exceeded 28^{o}C for more than 46% of the summer season.

The above signifies that to maintain thermal comfort applied energy efficient measures (EEMs) should ideally achieve a balance between the heating and cooling demand throughout the year. Therefore, whilst the application of high levels of insulation remains necessary during the heating season, consideration must be given to the building performance during the non-heating season through the application of adequate cooling strategies.

For this study the buildings within the retirement village will be designed to reach the nZEB standard with the currently recommended overheating mitigating strategies as obtained from the literature. Furthermore, because in overheating studies there is currently limited research regarding whether combined cooling/ heat and power (C/CHP) systems have the potential to act as mitigating strategies to reduce the risk of overheating they will be investigated. CHP or cogeneration is an alternative method that utilises, by-product heat, which can amount up to 80% of total primary energy during electricity generation; meanwhile CCHP or trigeneration further utilises by-product heat to provide cooling [36]. Consequently, the risk of overheating and energy performance of the various blocks within the retirement village as they currently stand and as nZEBs will be investigated under current and future climatic conditions. The analysis will be carried out using Thermal Analysis Simulation software (Tas, Edsl). The overheating criteria selected for this case study is the CIBSE TM59 Design methodology for the assessment of overheating risk in homes.

3.0 Methodology

3.1 Case-study and modelling details

The selected case study is Hughenden Gardens, located in High Wycombe. It is made up of 7 blocks (A-H) as shown in figure 1a. Figure 1b shows the outcome of the 3D modelling and table 1 is showing a summary of the building characteristics details and outcome of the modelling process. Flats within the village have an average of 2 occupants per dwelling. Flat occupancy type is split into 70% residential occupancy and 30% nursing occupancy.

Building modelling and simulation software TAS is used to predict energy performance, baseline and mitigated CO_2 emissions, thermal performance and therefore occupant comfort [37]. Initially, the model created on TAS will be a replica of the existing state of the building. Thus, the initially generated energy model will act as the reference point for improvements and will be defined as the 'baseline model.' The total primary energy consumption (PEC) is the amount of primary energy consumed in order to meet the building's energy demand (heating, cooling, DHW, lighting, and auxiliaries) and is also the net of any electrical energy displaced by C/CHP generators, if applicable.

The weather data used in this study are supplied by Cibse, based on UKCP09 climate projections. The weather file is the London Probabilistic Design Summer Year (DSY) [WDD16LON]. This is selected because the DSY weather file is suitable for overheating analysis. Meanwhile, the Test Reference Year (TRY) is suitable for "energy analysis and compliance with the UK Building Regulations (Part L)" [38-41].

The weather file closest in terms of geography to the retirement village is the westernmost of the three London regions: London Heathrow. Cities tend to be warmer than rural districts around them, most noticeably during the night hours, and this difference in temperature is accounted for in the data (40). Known as the urban heat island (UHI) effect, the Cibse data uses a larger number of weather stations within each region to more closely monitor temperature. Future climate change is also taken into consideration.

The four-time periods selected were as follows: the current DSY representative of the present climate, together with the 2020s, 2050s, and 2080s DSY. All three of the future databases selected were the 'High' emissions scenario, 50th percentile DSY 1. DSY 1 is comprised of a moderately warm summer, DSY 2 features short intense warm summer temperatures, whilst DSY 3 features long, intense warm spells. Currently, DSY 1, 50th percentile is recommended by the Cibse TM59 criteria for carrying out the overheating analysis and is therefore selected for this study [See section 3.3 for more detail].

Refer to Amaoko-Attah and B-Jahromi (2014) for detailed description of the modelling process on TAS.

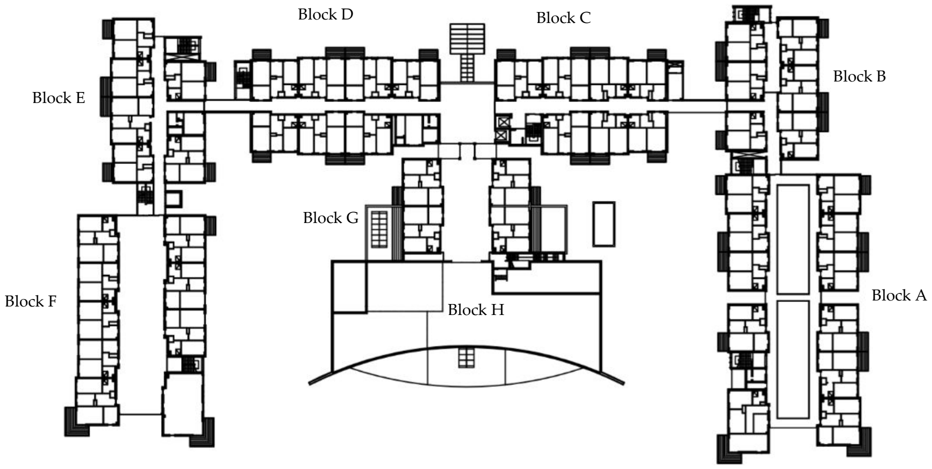

Figure 1a: Typical floor plan of the retirement village

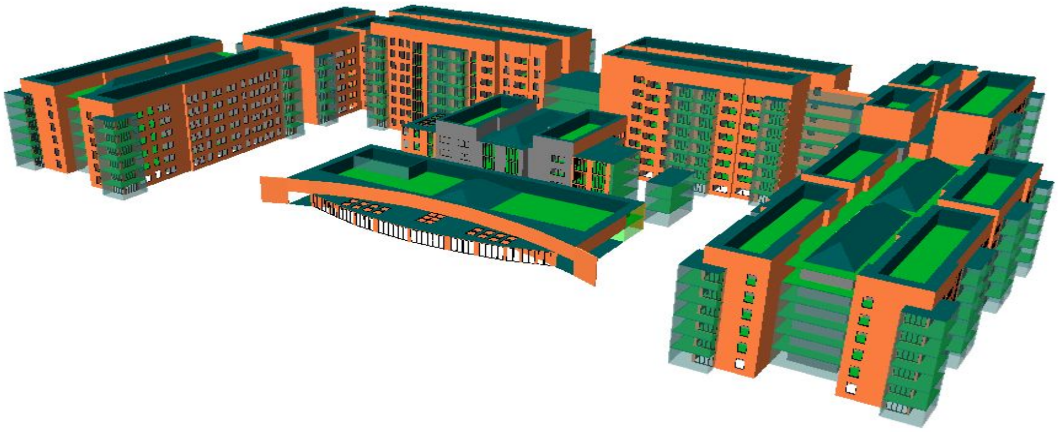

Figure 1b: 3D model of the retirement village

Figure 1: Floor plan and 3D model of the retirement village

Table 1: Summary of case study and modelling process

		Typical block characteristics		
Element/System		**A, F & G**	**B-E**	**H (Village centre)**
Use		Residential & nursing occupancy	Residential & nursing occupancy	Leisure centre, gym, communal area
Building fabric	***Type***	Traditional build[1] including block, bricks, and precast units (stair case and slabs)	Mixture of concrete frames & traditional build	Concrete frame, steel frames (mainly iterance) and blocks and bricks
Total No. of flats		260 [105 one bedroom; 155 two bedrooms]		
Wall (calculated area weighted average u-values)	***u-value (W/m^{2}K)***	0.45		
Roof (calculated area weighted average u-values)	***Type***	Single-Ply Membrane		
	u-value (W/m^{2}K)	0.30		
Floor (calculated area weighted average u-values)	***Type***	Ground & first floor: cast concrete slab Other floors: precast slab		
	u-value (W/m^{2}K)	0.35		
Windows (calculated area weighted average u-values)	***Type***	Double glazing (air-filled) with low emissivity coating		
	u-value (W/m^{2}K)	2.45		
Cooling		No cooling system		
Heating	***Type***	Conventional communal boiler system		
	Fuel	Natural Gas		
	Temperature Set Point	21°C		
	Heating Capacity	3 kW		
	Working temperature	60-80°C		
	Heating distribution	Central heating radiators		
	Schedule	October-April; 10pm-8am		
Domestic Hot Water (DHW)	***Type***	Conventional communal boiler system		
	Temperature	49°C		
	Average daily consumption	140 litres per person per day		
Ventilation	***Type***	Passive/Natural		
	Schedule	8am-10am; 4-6pm		
Zone - occupancy levels, people density, lux level	***NCM constructions database -v5.2.tcd***	Bedroom - 0.094 person/m^2, 100 lux Toilet - 0.1188 person/m^2, 200 lux Reception - 0.105 person/m^2, 200 lux Hall - 0.183 person/m^2, 300 lux Food prep/ kitchen- 0.108 person/m^2, 500 lux Eat/Drink area - 0.2 person/m^2, 150 lux Circulation - 0.115 person/m^2, 100 lux Store- 0.11 person/m^2, 50 lux Laundry - 0.12 person/m^2, 300 lux		
Air permeability		5 m^3/h/m^2 @50Pa		
Infiltration		0.500 ACH		
Lighting Efficiency		5.2 W/m^2 per 100 lux		
Fuel Source		Natural Gas – CO_2 Factor – 0.216 Kg/kWh		

For Peer Review

	Grid Electricity – CO_2 Factor – 0.519 Kg/kWh
Orientation	Latitude: 51.6367/ 51°38’11” N; Longitude -0.753452°W; +0.0 UTC
Weather data	DSY (Cibse) for London. Includes: dry bulb temperature (°C); wet bulb temperature (°C); atmospheric pressure (hPa); global solar irradiation (W·h/m^2); diffuse solar irradiation (W·h/m^2); cloud cover (oktas); wind speed (knots); wind direction (degrees clockwise from North); and Present Weather Code.

[1] refers to brickwork and blockwork constructions (walling is of masonry construction and tied with stainless steel ties to an outer leaf of block/brick)

For Peer Review

3.2 The nZEB retrofit

The aim of this paper is to assess how the case study building performs under current and future climatic conditions as it currently is and once it is retrofitted to the nZEB standard. The strategy undertaken to set the nZEB standard for this paper was derived from the current UK target for residential nZEBs which currently has the target for the annual primary energy consumption (PEC) as 44 kWh/m^2. Although the retirement village has communal areas it still carries a residential classification because the energy consumption, water consumption, occupancy profiles etc. are considering per dwelling. Table 2 is showing a summary of the selected energy efficient measures (EEMs) that make up the nZEB retrofit scenario. From the currently available literature it could be predicted that nZEBs and energy efficient buildings are more likely to experience overheating. Findings from this literature suggests that the incorporation of shading devices, double glazing as opposed to triple glazing, and utilising natural ventilation are currently some of the most effective ways to mitigate the risk of overheating [28, 31, 33, 42].

Table 2: Summary of final selected EEMs for nZEB retrofit

EEMs	Design Measure
Insulation	180mm mineral wool insulation batts
Lighting	LED [+ Auto presence detection in communal areas]
HVAC & DHW	Automatic Thermostat controlled direct gas fired Boiler
	Mechanical Ventilation with heat recovery in communal areas
Microgeneration	100kWp Solar panel system + solar thermal collectors
Overheating mitigating strategies	Internal shading
	Natural ventilation in residential areas
	Double Glazing, 36 mm Argon filled, Low-e

3.3 Overheating Criteria

In the design of non-air-conditioned spaces there have been no detailed guidance on defining and monitoring the risk of overheating within the UK. In previous years the Cibse guide A and Cibse TM52 criteria were utilised to assess the risk of overheating in buildings. Currently, the “TM59: 2017 Design methodology for the assessment of overheating risk in homes” [1] has been specifically developed and tailored by Cibse to assess the risk of overheating in homes. To summarise, the two overheating criteria set out by TM59 are:

1. Criterion 1 for living rooms, kitchens, bedrooms: the number of hours during which DT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 percent of occupied hours.
2. Criterion 2 for bedrooms: during the sleeping hours the operative temperature in the bedroom from 10pm to 7am shall not exceed 26°C for more than 1% of annual hours (33 hours).

Bedrooms must pass both requirements.

Although the TM59 criteria recommends that future weather data files such as 2050s/2080s are run it is not a set requirement that the building passes. On the other hand, it is necessary that the building passes under the ‘current’ and 2020s High emissions, 50th percentile DSY 1.

The equation for comfort temperature T_{comf} is shown by Eq. 1, where, T_{rm} is the exponentially weighted running mean daily mean outside air temperature. The running mean daily mean outside air temperature is calculated using Eq. 1.2 where α is a constant (0.8) and $T_{od\ldots}$are the daily mean outdoor temperatures for the day of interest followed by the previous day(s) [Eq. 1.3].

The criteria are based upon three sets of thresholds known as category I, II, and III. These categories assign a maximum acceptable temperature of varying degrees above the comfort temperature for naturally ventilated buildings as show by Eq. 2-4. The category I threshold applies to spaces that are occupied by very sensitive and

For Peer Review

fragile persons with special requirements, such as the disabled, sick, very young, and the elderly. Category II threshold applies to new buildings and renovations and category III applies to existing buildings. Category I is generally considered the stricter of the three categories and is applied to this particular case study.

$$\Delta T = T_{op} - T_{comf} \qquad [1]$$

$$T_{comf} = 0.33T_{rm} + 18.8 \qquad [1.2]$$

$$T_{rm} = (1-\alpha)(T_{od-1} + \alpha T_{od-2} + \alpha^2 T_{od-3}\ldots) \qquad [1.3]$$

$$Catergoy\ I: T_{comf} = 0.33T_{rm} + 18.8 + 2 \qquad [2]$$

$$Categroy\ II: T_{comf} = 0.33T_{rm} + 18.8 + 3 \qquad [3]$$

$$Category\ III: T_{comf} = 0.33T_{rm} + 18.8 + 4 \qquad [4]$$

4.0 Results and Discussion

To evaluate the impact of the measures to be incorporated on the case-study building, the initial simulation is conducted to reflect the actual current state of the building without any alterations. The simulation model was thoroughly populated to reproduce all the characteristics and systems of the building as built. Once this was completed, the retrofitting measures outlined in the methodology were then incorporated and the simulations were run again with the building performing as a nZEB.

Figure 2 is showing the Primary Energy Consumption (PEC) for the building as it currently is and once it has been retrofitted to the nZEB standard. From figure 2 it can be seen that the space heating PEC decreases for both the baseline scenario and even more so for the nZEB retrofit. However, as the nZEB retrofit incorporates mechanical ventilation in communal areas the total PEC is increased as the cooling demand substantially increases. The simulated annual PEC per dwelling is 97.48 kWh/m^2. Although the total PEC for the nZEB scenario under the future weather projections remains lower than the baseline scenario it can still be said that the nZEB scenario underperforms in comparison to the base case. This is because the baseline scenario experienced a decrease in the total PEC, meanwhile the nZEB scenario experience an increase in the total PEC. This suggests that if the 90th percentile/DSY 3 weather file (worst case projection) had been used for the simulations the nZEB scenario would have an even further increase in the total PEC. Considering the typically high investment costs associated with nZEB retrofits an increase in energy usage in the future this would lead to an increase in the occupants' fuel/energy costs. Generally, with energy efficient retrofit projects the main economic appeal is the drastic lowering in energy costs; meaning that if this were to be reversed under hotter weather conditions the overall financial benefits and economic viability of this option would be drastically lowered.

The TM59 overheating criterion 1 and 2 results for the baseline scenario and the nZEB scenario are shown in figure 3. The results are in consonance with the projected temperature changes. The projections showed a constant increase in temperature over stipulated timelines. Once the building was simulated under the 2050s and 2080s weather overheating hours increase significantly. The general trend observed for both the baseline scenario and nZEB retrofit across every block of the village was that kitchen and bedroom were more prone to experience severe overheating.

Although overheating occurred for both the base case and the nZEB retrofit scenario, severe overheating was experienced under the 2050s and 2080s weather projections for the nZEB scenario in comparison to the base case. For the bedroom and the kitchen, the building failed to pass the criteria under the current, 2020s-2080s weather files for the nZEB scenario. As discussed previously, several studies have confirmed that certain retrofit measures such as the implementation of shading devices, double glazing, and utilising natural/passive ventilation can act as 'mitigating' measures to significantly reduce the occurrence of overheating within buildings. Furthermore, because previous research highlights that overnight natural ventilation in particular is supposedly one of the simplest and most effective methods to combat overheating, the openable window hours were set for 20:00pm-7am during the non-heating season. Therefore, it is of concern that despite foreseeing the potential increased risk in overheating with the nZEB retrofit and therefore including such measures, overheating was severe under future weather projections and much more prominent in comparison to the baseline scenario. In addition, flats within the village are typically dual aspect which is not always possible or

For Peer Review

common with flat type buildings. They are typically single aspect meaning they don't allow for adequate ventilation. Within the UK it is generally recommended that opening windows for approximately 15 minutes every day is enough to ventilate. However studies have found that most properites only open winodws once or twice a week which explains widespread issues of dampness across UK properties [43]. Other studies (simulation and real-life) have examined daytime versus nighttime ventilation and it is always concluded that night time ventilation is the more effective option [44-46]. Meaning that relying on passive ventilation as a mitigating strategy is not an effective solution. Furthermore, behavioural changes such as this cannot be guaranteed in real-life applications and may not be fully adhered even if residents were advised to do so and because of the particularly vulnerable population demographic this cannot be relied on as an effective or suitable method of reducing the risk of overheating for this particular case study.

External shading has been proven by the literature to be more effective than internal shading at reducing solar gains [28, 33, 46]. However there are issues of applicability with this particular case study. Mainly, it will be technically challenging to retrofit the façade as there may be a lack of sufficient fixing points to allow installation. This is a common challenge for existing buildings looking to incorporate external shading as part of their retrofit project. It would also greatly reduce the amount of natural light entering the space thereby affecting occupant comfort. Furthermore, the cost of running, cleaning and maintaining the external façade would incur higher maintenance costs for occupants which will not be well received by all occupants. Due to this, it was not considered a suitable mitigating strategy to be investigated.

It was interesting to note that blocks B-E outperformed blocks A, F-G under the present, 2020s, 2050s and 2080s simulations. The reason for this is due to the differences in building material between the blocks. Materials with a higher thermal mass such as the precast concrete panels used in those blocks have been proven to reduce the risk of overheating. However, the majority of existing UK buildings are traditionally built (as blocks A, F, and G) meaning that the risk of uncomfortable dwellings for occupants during hotter spells will be prevalent. The fifth UK carbon budget called for solid wall dwellings to be insulated to meet the carbon reduction targets set out in the 2008 Climate Change Act [44, 49]. Increasing the insulation will exacerbate the risk of overheating within those dwellings. It has been predicted that approximately 2 million dwellings could be affected [49].

For Peer Review

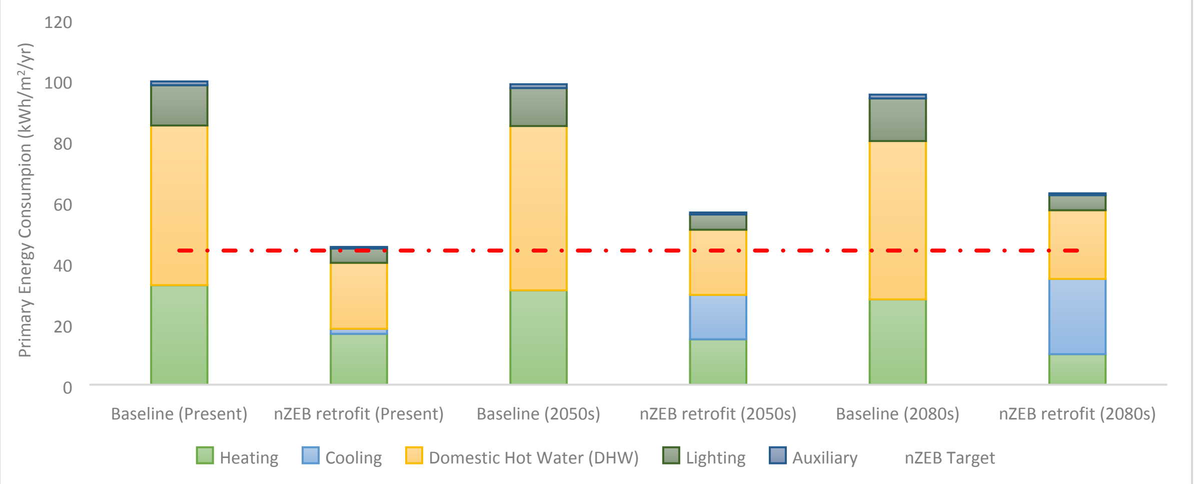

Figure 2: Comparison of the primary energy consumption of the retirement village as built and after nZEB retrofit under current and future climate conditions

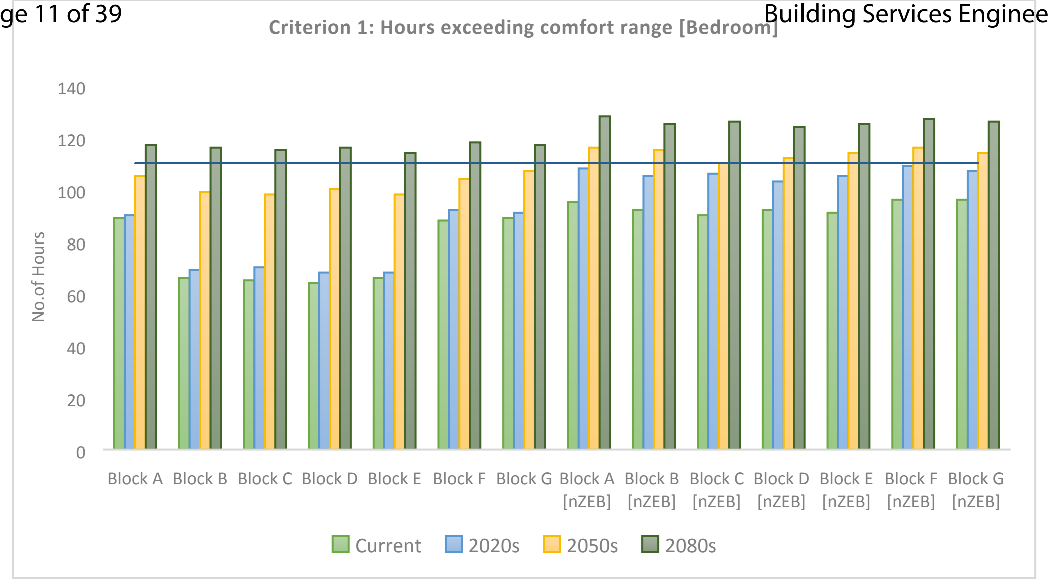

Figure 3a: Cibse TM59 overheating criterion 1 results for bedroom (average) within the village as built and after nZEB retrofit under current and future climatic conditions

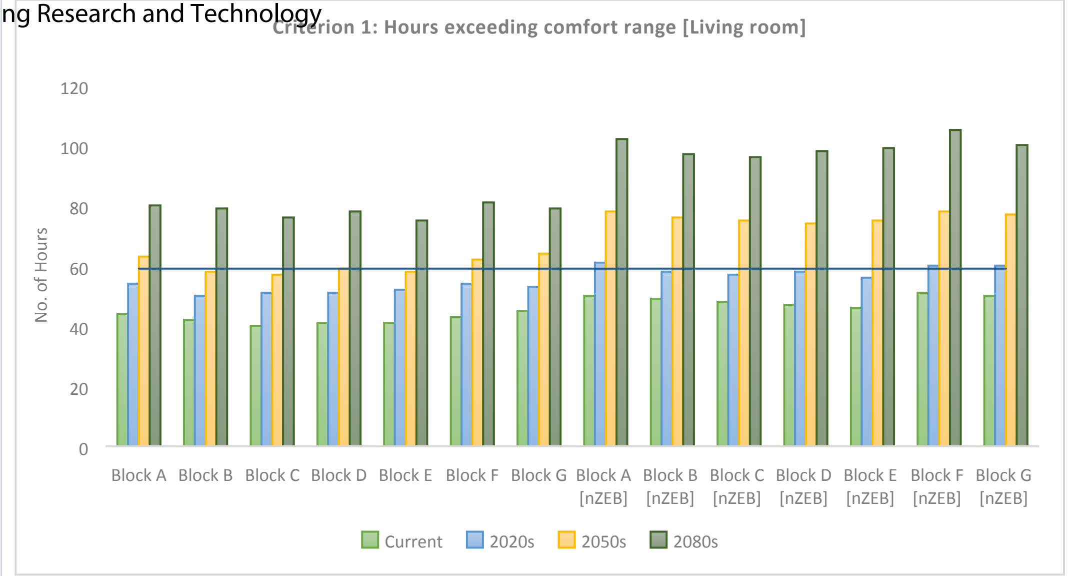

Figure 3b: Cibse TM59 overheating criterion 1 results for living room (average) within the village as built and after nZEB retrofit under current and future climatic conditions

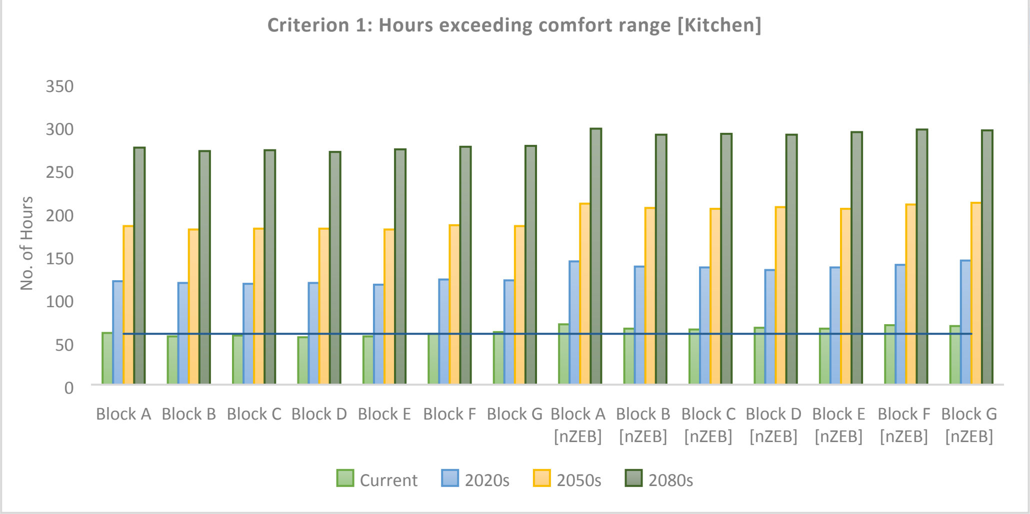

Figure 3c: Cibse TM59 overheating criterion 1 results for living room (average) within the village as built and after nZEB retrofit under current and future climatic conditions

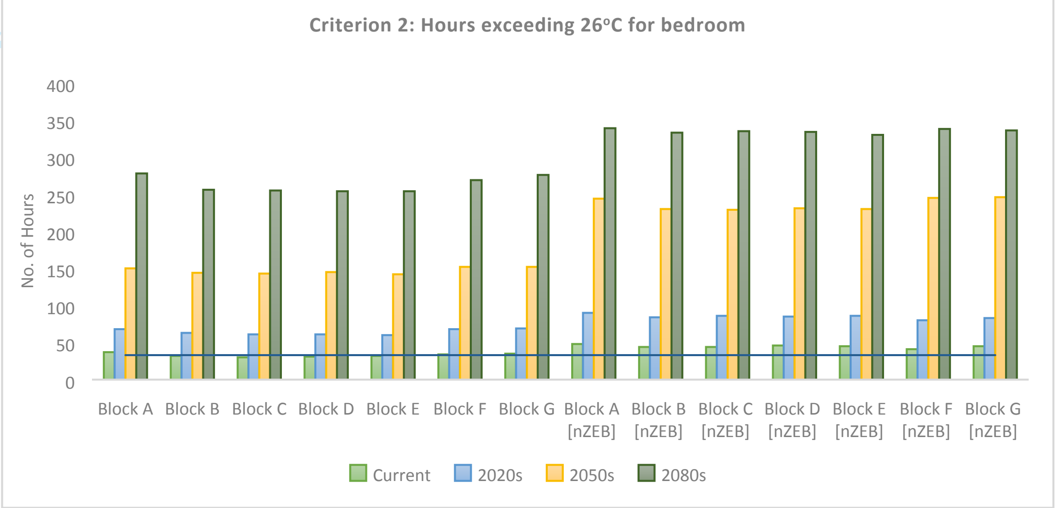

Figure 3d: Cibse TM59 overheating criterion 2 results for bedroom (average) within the village as built and after nZEB retrofit under current and future climatic conditions

Figure 3: Cibse TM59 overheating criterion 1 and 2 results for within the village as built and after nZEB retrofit under current and future climatic conditions

For Peer Review

5.0 Mitigating strategy: C/CHP

The previous figures suggest that the only reliable solution to avoid the risk of overheating would be to utilise some form of cooling measure throughout the entire village. The intrinsic features of existing buildings can be adapted to improve their energy performance, however, as demonstrated opening windows in this case study has not provided the level of ventilation required to avoid overheating. Currently, air conditioning is the most widely used cooling system in both commercial and domestic applications. However, this alternative is incompatible with the nZEB concept that revolves around reducing energy use and CO_2 emissions. Several studies have demonstrated the potential for CHP and CCHP to reduce the PEC of buildings and aid in reaching the nZEB standard [50]. As discussed, in overheating studies there is currently limited research regarding whether C/CHP have the potential to act as a mitigating strategy to reduce the risk of overheating. Consequently, as part of the nZEB retrofit rather than incorporate the PV system and solar thermal collectors the simulation will be run once more with a 100kWe CHP and then CCHP system.

As seen from the above results, within the nZEB building, there is a high summertime demand for cooling and year-round daytime electricity for artificial lighting and equipment throughout the premises. Heating output can therefore be used for cooling through the use of an absorption chiller during the non-heating season. Meanwhile, because the heating demand remains during the colder months this can still be provided by the CCHP unit. By utilising the excess heat for cooling this eliminates the risk of heat being wasted or dumped. Studies have concluded that selection of a C/CHP system will depend on several factors, in particular, the heating and cooling demand of the building. A CHP system will be more appropriate and should be incorporated in a building with considerable heating demand and moderate/no cooling demand. On the other hand, a CCHP system will be more appropriate in applications with equally considerable heating and cooling demands [50, 51].

Comparing the performance of the building with CHP and CCHP against the TM59 overheating criteria it becomes apparent that the CCHP system outperforms the CHP significantly as shown by figure 4 and 5. As expected, with the CHP system in place, the building continues to overheat in exactly the same way as it did whilst the PV system was utilised instead. However, as mentioned the main difference is the fact that the PEC did not increase, thereby making it a better alternative [as shown in figure 6]. The CCHP system on the other hand was able to ensure that the building does not fail the overheating criteria under the current, 2020s, 2050s, and 2080s weather databases. Out of the mitigating strategies that have been examined throughout this study the incorporation of the CCHP system was the only alternative that meant the building passes the criteria. Moreover, the baseline building bedroom [criterion 2] and kitchen [criterion 1] failed to pass the TM59 overheating criteria, meaning that the CCHP alternative was once again the only mitigating strategy that fully passed the overheating criteria whilst ensuring the PEC of the building meets the nZEB standard under current and future climatic conditions.

Looking at figure 6 it is clear that both the CHP and CCHP have reduced the PEC of the building under current weather conditions but more importantly they both maintained the PEC so that it meets the required nZEB standard under future climatic projections. This alone is an improvement from the previous set of results whereby the nZEB target was exceeded under future projections. Despite this significant improvement, it seems that the CCHP system is more compatible with the heating/cooling demands of this building. The PEC increased by less than 3% with CCHP, meanwhile, it increased by more than 5% with the CHP system.

It must be noted that there are problems associated with the use of a CCHP during summer within cities such as London. This is primarily due to the extra firing of boilers and pumping heat into the air to cool the building which exacerbates that urban heat island effect. Nonetheless, if the use of CCHP systems was to become widespread, alternatives to the absorption chiller-based system are available to overcome the heat island effect and attain an even higher seasonal efficiency of the system. The most successful and currently used alternative approach involves the utilisation of an aquifer thermal energy storage (ATES). In an ATES based system excess heat is pumped into aquifers during the non-heating season and extracted once again for heating during the winter. This approach has been successfully applied in the Netherlands and within a social housing scheme in West London [52].

For Peer Review

In terms of applicability to other buildings, CCHP may not be suitable for other residential and commercial buildings such as schools, semi-/detached dwellings, and offices and within dominantly cold or hot climates. The reason for this is because the heating, cooling, and electricity demand must be fairly consistent all year-round to ensure the system is being used to its full efficiency. Furthermore, with a fossil fuel being used as an input source, CCHP cannot be considered an ultimately sustainable solution. Recently, other options such as a solar co-/trigeneration system has been introduced [51]. Certain biomass options can also be utilised instead to ensure the system is energy sustainable. If the use of CCHP as a solution becomes widespread, these alternatives should be considered to aid in the transition towards an energy sustainable future. For these reasons it is understandable that the current available nZEB definitions do not stipulate the use of CCHP as an ultimate solution to reaching the standard.

For Peer Review

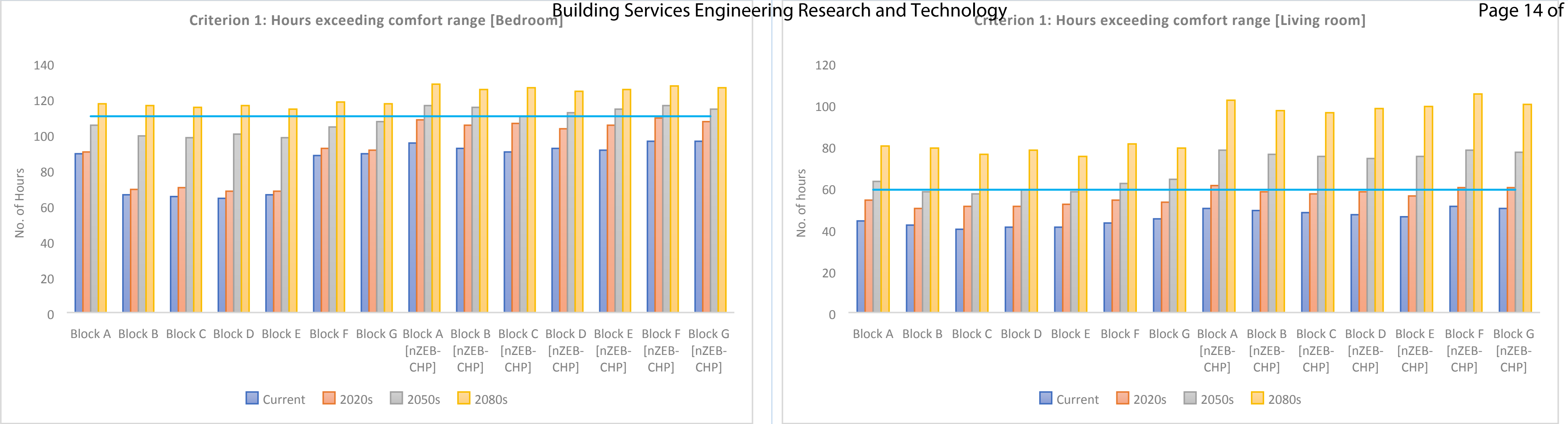

Figure 4a: Cibse TM59 overheating criterion 1 results for bedroom (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 4b: Cibse TM59 overheating criterion 1 results for living room (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

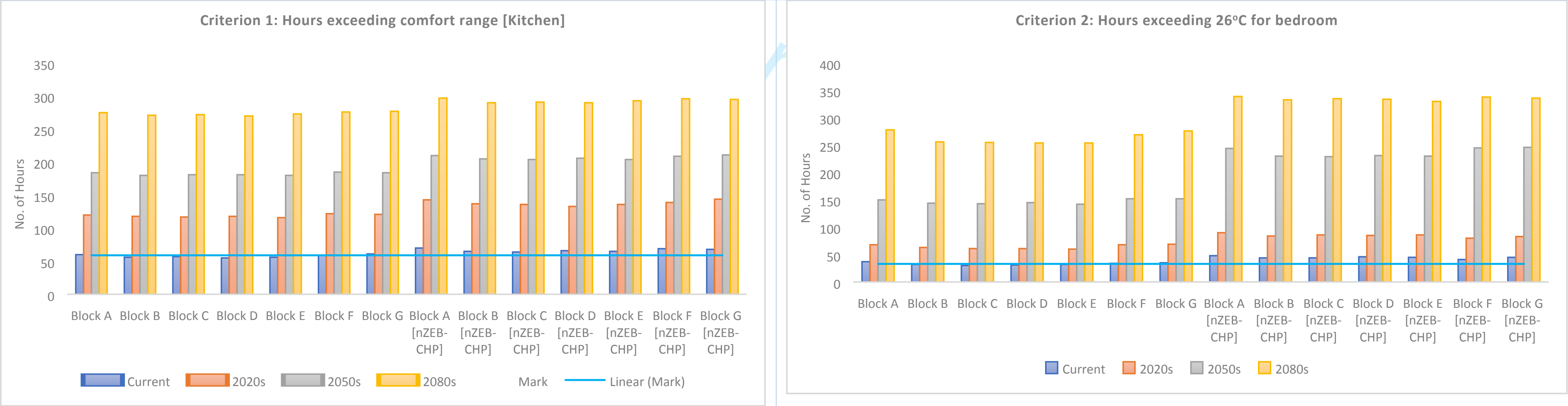

Figure 4c: Cibse TM59 overheating criterion 1 results for kitchen (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 4d: Cibse TM59 overheating criterion 2 results for bedroom (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 4: Cibse TM59 overheating criterion 1 and 2 results within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

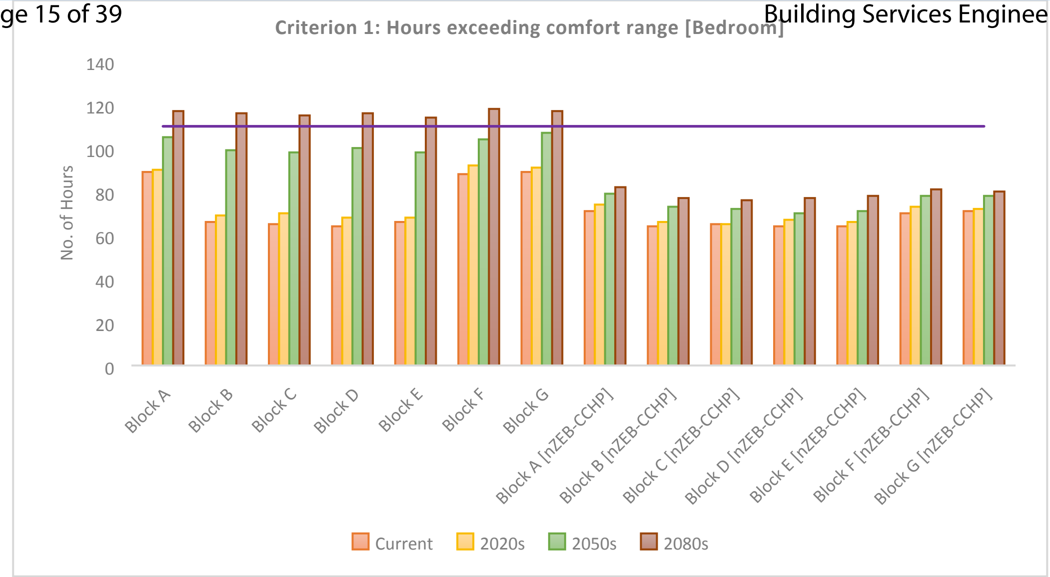
Criterion 1: Hours exceeding comfort range [Bedroom]

Figure 5a: Cibse TM59 overheating criterion 1 results for bedroom (average) within the village as built and after nZEB retrofit with CCHP under current and future climatic conditions

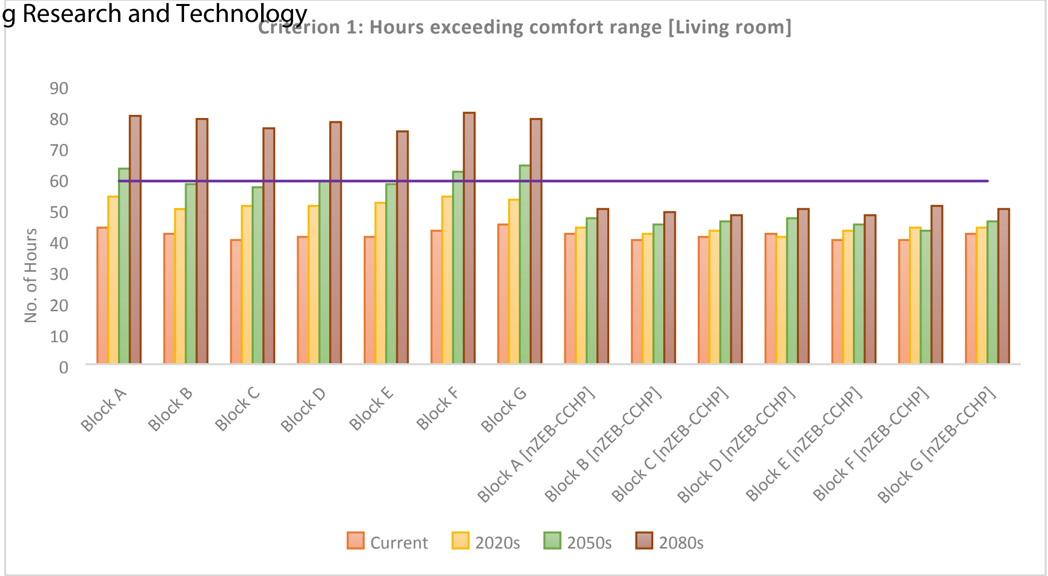
Criterion 1: Hours exceeding comfort range [Living room]

Figure 5b: Cibse TM59 overheating criterion 1 results for living room (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

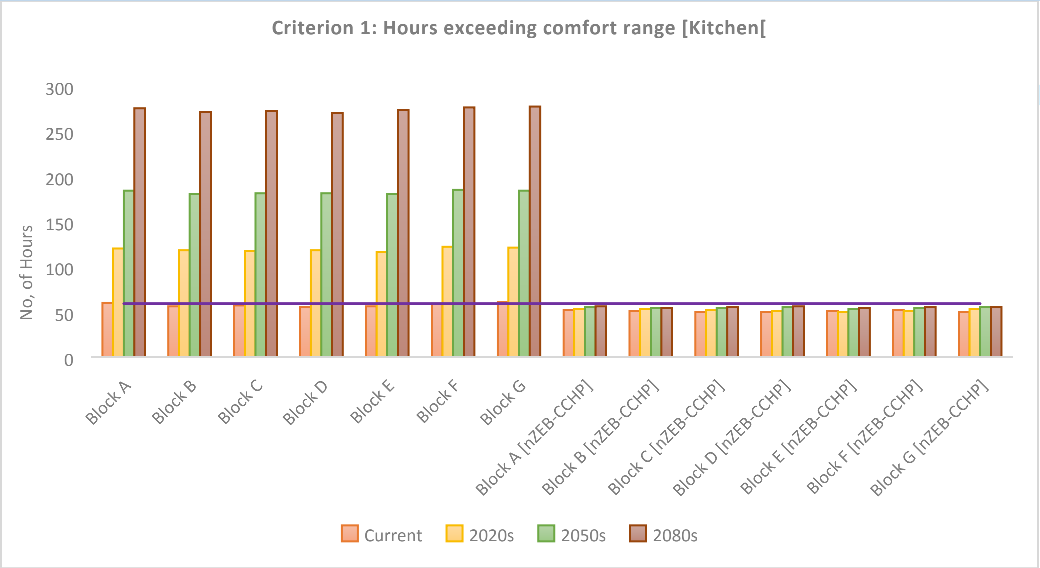
Criterion 1: Hours exceeding comfort range [Kitchen[

Figure 5c: Cibse TM59 overheating criterion 1 results for kitchen (average) within the village as built and after nZEB

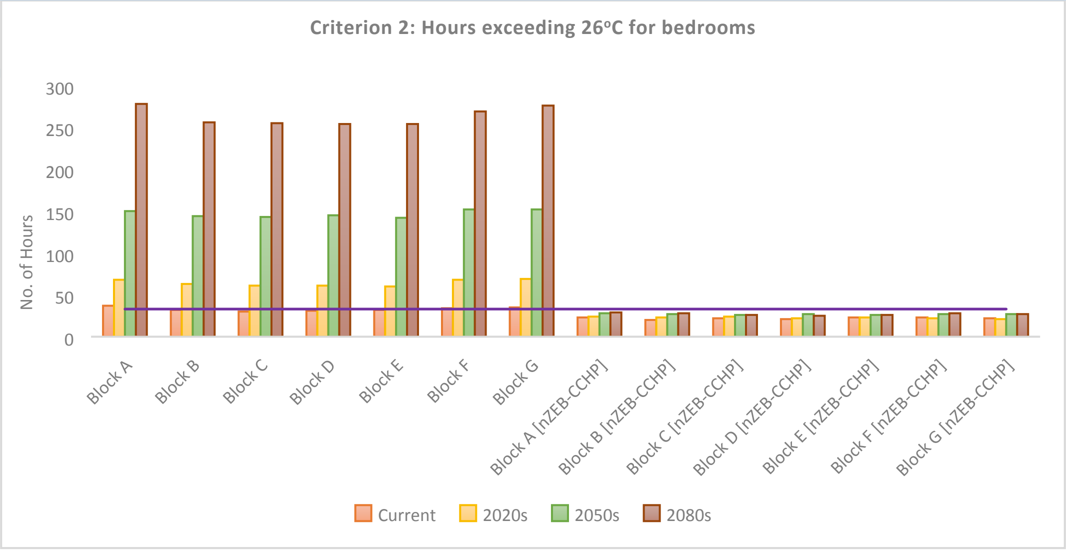
Criterion 2: Hours exceeding 26°C for bedrooms

Figure 5d: Cibse TM59 overheating criterion 1 results for bedroom (average) within the village as built and after nZEB

retrofit with CHP under current and future climatic conditions	retrofit with CHP under current and future climatic conditions

Figure 5: Cibse TM59 overheating criterion 1 and 2 results within the village as built and after nZEB retrofit with CCHP under current and future climatic conditions

For Peer Review

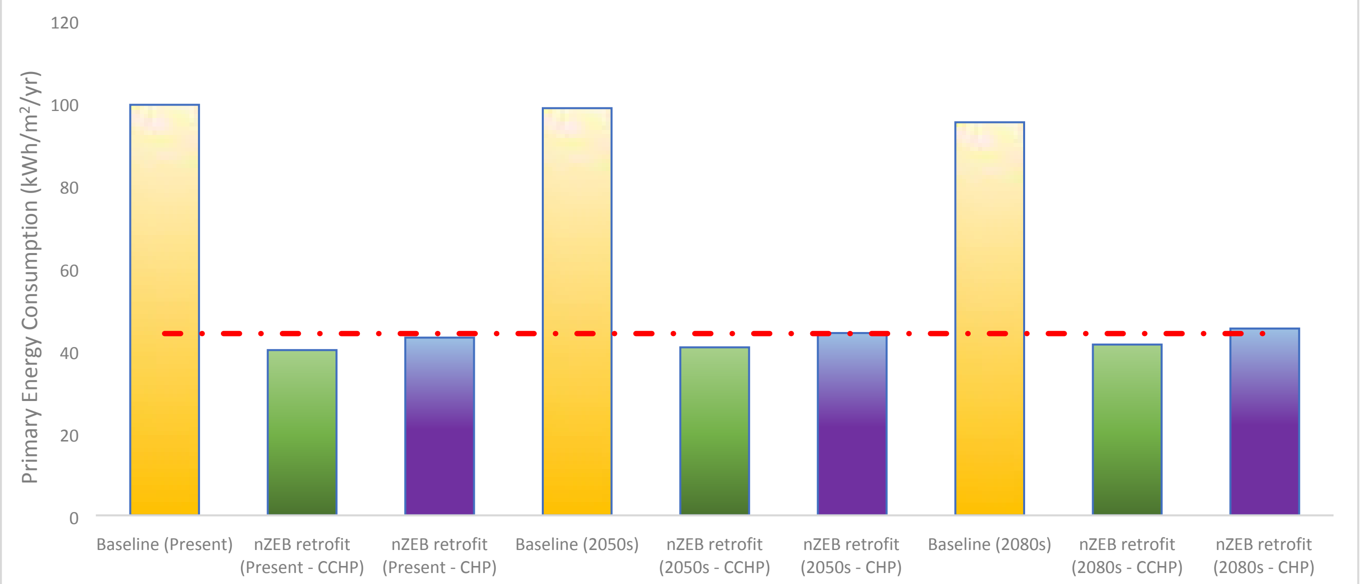

Figure 6: Comparison of the primary energy consumption of the retirement village as built and after nZEB retrofit with CHP and CCHP under current and future climate conditions

6.0 Conclusion

This paper has investigated the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village. Using computational fluid dynamic software Tas Edsl, the energy performance of the village as it currently stands and as a nZEB was examined and compared. Reviewing the current state of the art demonstrated that once retrofitted to the nZEB standard the building would most likely experience severe overheating. The typically recommended mitigating strategies were therefore incorporated as part of the retrofit measures. The overheating criteria utilised was the "CIBSE TM59 Design methodology for the assessment of overheating risk in homes." Once the initial set of results were obtained it was clear that the use of overnight natural ventilation, double glazing, and shading devices was not sufficient to reduce the occurrence and severity of overheating throughout the village.

Overheating occurred for both the base case and the nZEB retrofit scenario. Severe overheating was experienced under the 2050s and 2080s weather projections for the nZEB scenario in comparison to the base case. For the bedroom and the kitchen overheating was experienced under the current, 2020s-2080s weather files for the nZEB scenario. Meaning that after the nZEB retrofit the building completely failed to pass the criteria. It was noted that building material seemed to influence the risk of overheating. The kitchen and bedrooms were more prone to experience severe overheating.

A 100kWe CHP and then CCHP system were then simulated as part of the nZEB retrofit package. Both the CHP and CCHP have proven to work successfully in reducing and maintaining the PEC of the building under future weather files. However, the CCHP was the only mitigating strategy that fully passed the overheating criteria whilst ensuring the PEC of the building meets the nZEB standard under current and future climatic conditions, thereby surpassing the baseline building as well.

Whilst the cooling demand of the building increased substantially under future weather projections the heating demand did not significantly decrease in the same way. This means that carrying out energy efficient retrofits that consider lowering the energy demand of the building first and foremost by improving insulation, glazing etc. is still an important and relevant strategy to ensuring that energy targets are met. This is very apparent by the fact that the baseline building still experienced overheating. If mechanical ventilation or air-conditioning were a part of the baseline model that PEC would have experienced a substantial increase (far more than the nZEB alternative). In real life the majority of buildings do end up incorporating air-conditioning under hotter weather conditions as discussed in the literature review, meaning that the performance of the baseline building would have been significantly worse than the nZEB model.

The results of this study therefore do not undermine the importance of continuing to improve the energy efficiency of existing buildings but rather highlight that the approach undertaken should be reconsidered. Moreover, this does not mean neglecting lowering the energy demand but searching for and selecting mitigating strategies that will work to reduce the risk of overheating.

This study did not consider user behaviour and interaction as a possible mitigating strategy due to the vulnerable population demographic. Further research that collects and examines user behaviour on overheating should be undertaken to assess the significance of occupant behaviour on overheating within buildings. This should then be used in conjunction with data obtained from simulation models to determine a combined approach to mitigating the risk of overheating within buildings. Approaches that include user behaviour will lead to a decrease in costs, and although not applicable to this particular case study, they can be applied within many residential dwellings.

Overall, it can be concluded that in line with the current paradigm that favours energy efficiency, the associated risk of increasing overheating cannot be ignored due to the numerous negative consequences associated with this. It is clear that whilst carrying out energy efficient retrofitting of properties may be necessary to aid in the transition towards an energy sustainable future the design choices and recommendations may need to be reconsidered so that the building continues to perform under variable weather conditions. Thus, integrating mitigation strategies in energy efficient retrofit is necessary. Most importantly, retrofitting with a focus on only adapting to hotter weather conditions is not a viable solution as it may lead to a substantial increase in heating demand during the heating season. Energy efficient retrofit projects should therefore, ideally, find a balance between meeting the heating and cooling demands of the building in an energy efficient way under current and future weather conditions.

References

1. Cibse TM59. Design Methodology for the Assessment of Overheating Risk in Homes, Technical Memorandum TM59. Chartered Institution of Building Services Engineers, London, 2017, ISBN 978-1-912034-17-8
2. CIBSE. Guide A Environmental design (8th ed). London, 2015.
3. Kovats R.S, Johnson H, Griffiths C. Mortality in southern England during the 2003 heat wave by place of death. *Health stat Q*, 2006, p6-8.
4. Health Protection Agency. Evaluation of the 2006 heatwave. Available: https://webarchive.nationalarchives.gov.uk/20140714102514/http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1219130165676. (2007, accessed 28 November 2018).
5. Carrington D and Marsh S. Deaths rose 650 above average during UK heatwave – with older people most at risk. Available: https://www.theguardian.com/society/2018/aug/03/deaths-rose-650-above-average-during-uk-heatwave-with-older-people-most-at-risk. (2018, accessed 25 November 2018).
6. Age UK. Later Life in the United Kingdom. Available: https://www.ageuk.org.uk/globalassets/age-uk/documents/reports-and-publications/later_life_uk_factsheet.pdf. (2015, accessed 26 November 2018).
7. Christidis N, Jones G.S, Stott P.A. Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. *Nat. Clim*. 2014. doi:10.1038/nclimate2468
8. Kenny G.P, Yardley J, Brown C, Sigal R.J, and Jay O. Heat stress in older individuals and patients with common chronic diseases. *Can. Med. Assoc.* 2010; 182: 1053–1060. http://doi.org/10.1503/cmaj.081050
9. Gasparrini A, Armstrong B, Kovats S, and Wilkinson, P. The effect of high temperatures on cause-specific mortality in England and Wales. *Environ. Medic.* 2012; 69: 56–61. doi:10.1136/oem. 2010.059782
10. Office for National Statistics. National population projections, 2012-based projections release. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2013-11-06. (2014, accessed 29 November 2018]
11. Public Health England (PHE). Heatwave plan for England – making the case: The impact of heat on health – now and in the future. 2014, London: Department of Health.
12. NAT. Care Home Benchmarking Report 2016/2017. Available: www.rcpa.org.uk/wp-content/uploads/2016/12/NAT00339_Healthcare_Report_Midres.pdf. (2017, accessed 27 November 2018).

For Peer Review

13. Klenk J, Becker C, and Rapp K. Heat-related mortality in residents of nursing homes. *Age and Ageing*, 2010; 39: 245–252. doi:10.1093/ageing/afp248
14. Pathan A, Mavrogianni A, Summerfield A, Oreszczyn T, Davies M. Monitoring summer indoor overheating in the London housing stock. *Energy and Build. 2017;* 141: 361-378.
15. Dengel A and Swainson M. Overheating in new homes: A review of the evidence. Retrieved from the Zero Carbon Hub: http://www.zerocarbonhub.org/sites/default/files/resources/reports/Overheating_in_New_HomesA_review_of_the_evidence_NF46.pdf. (2012, accessed 1 December 2018).
16. Barnes S, Torrington J, Darton R, Holder J, Lewis A, McKee K, Orrell A. Does the design of extra care housing meet the needs of the residents? A qualitative study. *Ageing and Soc,* 2012; 32: 1193–1214. doi:10.1017/ S0144686X11000791
17. Guerra A, Santin O, and Tweed A.C. Summer post occupancy evaluation of a PassivHaus care home in the UK. In Conference: PLEA Sustainable Architecture for a Renewable Future, 2013.
18. Lewis A. Energy use in an ageing society: The challenges of designing energy-efficient older people's housing. *Manchester Lit. and Philos. Soc.* 2014; 151: 20–32.
19. Kevin J.L and Stephen M. (2017) Overheating in buildings: lessons from research. *Build. Res. and Info.* 2017; 45: 1-18, DOI: 10.1080/09613218.2017.1256136
20. Burns A. POE of colliers' gardens in Bristol. Report for post-occupancy evaluation course. Oxford: Oxford Brookes University, 2008.
21. Firth S and Wright A. Investigating the thermal characteristics of English dwellings: summer temperatures, in: Proceedings of Air Conditioning and the Low Carbon Cooling Challenge, 5th Windsor Conference, 27th-29th July 2008. Windsor, UK: Network for Comfort and Energy use in Buildings (NCEUB), 2008.
22. Beizaee A, Lomas K.J and Firth S.K. (2013). National survey of summertime temperatures and overheating risk in English homes. *Build. and Environ.* 2013; 65: 1–17. doi:10.1016/j. buildenv.2013.03.011
23. Hulme J, Beaumont A and Summers C. Energy Follow-Up survey 2011 Report 7: Thermal Comfort and Overheating. Watford, UK, 2013.
24. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union, 53, 2010.
25. Committee on Climate Change. The fifth carbon budget. Available: https://www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf. (2016, accessed 26 November 2018).
26. Sameni S, Gaterell M, Montazami A, Ahmed A. (2015). Overheating investigation in UK social housing flats built to the Passivhaus standard. *Build. and Environ.* 2015; 92: 222-235.
27. Salem R, Bahadori-Jahromi A, Mylona A, Godfrey P, Cook D. Retrofit of a UK residential property to achieve nearly zero energy building standard. *Adv. in Environ. Res.* 2017; 7: 223-241
28. Carrilho da Graça G, Augusto A, Lerer M. Solar powered net zero energy houses for southern Europe: feasibility study. *Sol. Energy,* 2012; 86: 634-646.
29. Porritt S, Cropper P.M, Shao I, Goodier C. Ranking of interventions to reduce dwelling overheating during heat waves. *Energy and Build.* 2012; 55: 20-42.
30. Peacock A.D, Jenkins D.P and Kane D. Investigating the potential of overheating in UK dwellings as a consequence of extant climate change*. Energy Policy*, 2010; 38: 3277-3288
31. Roaf S, Crichton D and Nicol F. Adapting buildings and cities for climate change. A 21st Century survival guide. *Archit. Press*, 2009; 2: 15-21
32. Pana E. Summertime temperatures and overheating risk: does orientation affect comfort in bedrooms in the UK context? In: Proceedings of 3rd Conference: People and Buildings, 20th September 2013 London, UK: Westminster University, School of Architecture and the Built Environment, 2013.
33. Schnieder J. *Passive Houses in South West Europe: a quantitative investigation of some passive and active space conditioning techniques for highly energy efficient dwellings in the South West European region.* Techn. Uni, 2009, p.210.
34. Baborska-Narożny M, Stevenson F and Chatterton P. Temperature in housing: stratification and contextual factors. *Eng. Sustainability,* 2015; 9: 1-17.
35. Jenkins K, Hall J, Glenis V, Kilsby C, McCarthy M, Goodess C, Smith D, Malleson N, Birkin M. Probabilistic spatial risk assessment of heat impacts and adaptations for London. *Clim. Chang.* 2014; 124: 105–117. doi:10.1007/s10584-014-1105-4
36. ACEEE (American Council for Energy Efficient Economy). (2018). Combined Heat and Power (CHP). Available: https://aceee.org/topics/combined-heat-and-power-chp. (2018, accessed 25th January 2018).
37. Environmental Design Solutions Limited, Tas. Available: http://www.edsl.net/. (2018, accessed on 19th May 2018).

For Peer Review

38. Chartered Institute of Building Services Engineers (CIBSE). TM48: Use of Climate Change Scenarios for Building Simulation: the CIBSE Future Weather Years. Cibse, London, UK, 2009.

39. Eames M.E, Ramallo-Gonzalez A.P, Wood M.J. An update of the UK's test reference year: The implications of a revised climate on building design. Building Services Engineering Research and Technology. *Build. Serv. Eng. Res. Technol*. 2016; 37: 316–333.

40. Mylona, A. (2017). Revision of Design Summer Years and Test Reference Years. Cibse, London, UK. Available: http://www.cibse.org/getmedia/cc7072d9-8e58-42cb-83ce-2316546f0aa0/Introduction-to-CIBSE-Weather-Data-Files.pdf.aspx. (2017, accessed 10 December 2018).

41. Cibse. (2017**).** CIBSE Weather Data Sets. Chartered Institution of Building Services Engineers, London. Available at: https://www.cibse.org/weatherdata. (2017, accessed 29 November 2018).

42. Baborska-Narożny M, Stevenson, and Grudzińska M. (2016) Overheating in retrofitted flats: occupant practices, learning and interventions. *Build. Res. and Info*. 2016; 45: 40-59.

43. Energuide. (2019). How to air your house properly? Available: https://www.energuide.be/en/questions-answers/how-to-air-your-house-properly/1712/. (2019, accessed 3 January 2019).

44. Artmann N, Manz H, Heiselberg P. Climatic potential for passive cooling of buildings by night-time ventilation in Europe. *Appl. Energy,* 2007; 84:187-201.

45. Campaniço H, Soares P, Hollmuller P, Cardoso R. Climatic cooling potential and building cooling demand savings: High resolution spatiotemporal analysis of direct ventilation and evaporative cooling for the Iberian Peninsula. *Renew. Energy*, 2016; 85: 766-776.

46. Panayiotou G, Koukkouli A, Gelegenis, J and Kalogirou S. Night-time Ventilation for Passive Cooling of Dwellings: A case study for Cyprus, 2010. DOI: 10.13140/2.1.2952.8966.

47. Atzeri A, Cappelletti F, Gasparella A. (2014). Internal Versus External Shading Devices Performance in Office Buildings. *Energy Procedia*, 2014; 45: 463-472.

48. Climate Change Act. https://www.legislation.gov.uk/ukpga/2008/27/contents (2008, accessed 27 November 2018).

49. Committee on Climate Change. Meeting Carbon Budgets: Closing the Policy gap: 2017 Report to Parliament. https://www.theccc.org.uk/wp-content/uploads/2017/06/2017-Report-to-Parliament-Meeting-Carbon-Budgets-Closing-the-policy-gap.pdf, (2017, accessed 5 July 2017).

50. Salem R, Bahadori-Jahromi A, Mylona A, Godfrey P, Cook D. Comparison and Evaluation of the Potential Energy, Carbon Emissions, and Financial Impacts from the Incorporation of CHP and CCHP Systems in Existing UK Hotel Buildings. *Energies,* 2018; 11: 1219.

51. Siegel RP. (2019). Combined Cooling Heat and Power. Available: https://www.triplepundit.com/special/energy-options/combined-cooling-heat-power/. (2019, accessed 4 Jan 2019).

52. Clark P. (2007). Westway Beacon social housing scheme in West London. Available: https://www.westwayha.org.uk/documents//documents/AR1617. (2007, accessed 27 November 2018).

For Peer Review

Investigating the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village adapted to the nZEB standards.

Abstract:
The death toll of the 2003 heat wave in Europe exceeded 35 000 heat-related deaths. The elderly population were the most affected. The current paradigm within the construction industry in cold-dominant countries is to design/retrofit buildings with high levels of insulation. Whilst thermal comfort may be reached during colder months with this approach, the risk of overheating can be increased during hotter months. This paper aims to examine the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village. For this study the buildings within the retirement village will be designed to reach the nearly zero energy building (nZEB) standard. Consequently, the risk of overheating of the buildings within the retirement village as they currently stand and as nZEBs will be investigated under current and future climatic conditions. The analysis is carried out using Thermal Analysis Simulation software (Tas, Edsl). Combined heat and power (CHP) and combined cooling, heat and power (CCHP) will be investigated as mitigating strategies with regards to overheating. The results of this study do not undermine the importance of continuing to improve the energy efficiency of existing buildings but rather highlight that the approach undertaken should be reconsidered.

Keywords: nearly-zero energy buildings, thermal analysis simulation, overheating, retirement homes

For Peer Review

Practical Application:

Currently, there is emphasis placed on retrofitting and designing buildings, with high energy efficiency standards. Whilst this is in line with our vision as a society towards reaching a decarbonised, sustainable future this work highlights that doing so, carries risks with regards to overheating. Nonetheless, the results demonstrate that with the incorporation of suitable mitigation strategies and adequate ventilation strategies, it is possible to achieve an energy efficient building that meets the heating and cooling demand (and thereby thermal comfort of occupants) during the heating and non-heating season.

1.0 Introduction

Various definitions of overheating exist in the literature; as part of the Cibse TM59 methodology overheating is defined as bedroom temperature that exceeds 26°C in bedrooms from 10pm-7am for more than 1% of occupied hours per year [1]. The UK is known for its relatively mild winter and temperate summer climatic conditions. During the past 30 years London has exceeded 26.1°C for less than 1% of the time [2]. Consequently, the use of active cooling techniques is uncommon, meaning buildings are not designed or equipped to cope with any rise in temperatures.

The effects of this is seen when weather abnormalities such as heatwaves occur during the summer months. The death toll of the 2003, 2006, and most recently the 15-day peak of the heatwave in June and July 2018 was 2000+, 680, and 650+, respectively [3, 4, 5]. Each year it is concluded that "the people most at risk in a heatwave are the frail elderly" [6]. A report published in July 2017 also corroborated the fact that the UK is "woefully unprepared" for heatwaves and it is predicted that unless action is taken the death toll will rise to 7000 a year by 2040s for heat-related deaths [5,7]. The population of over 75s has also been projected to nearly double in the next 30 years meaning there will be an increase in the vulnerable population who are unable to acclimatise due to various physiological and cognitive impairments prevalent within this population demographic [8-11]. This is particularly applicable for residents in retirement homes such as the case study being used for this work [12].

Despite this, because the general existing UK residential building stock tends to be poorly insulated, overheating at the moment is typically not an issue and currently the death toll due to low indoor winter temperature in England and Wales exceeds the heat-related death toll by 98% [13]. Nonetheless, as mentioned previously by 2040 it is estimated that the temperatures experienced in the UK during the summer of 2003 will be the norm [5-7, 11] and it is expected that this will cause a drastic shift in those percentages.

This paper therefore aims to examine the impacts of a changing climate on the risk of overheating and energy performance for an existing UK retirement village. Homes within the retirement village share common characteristics, and therefore issues. Behavioural changes such as asking occupants to adhere to opening windows at certain hours are not always an applicable solution with this type of housing due to the prototypical demographic of occupants who are classed as part of the susceptible population to overheating. In tandem with this, the risk of overheating as a potential threat is exacerbated as it can lead to preventable loss of life.

2.0 Literature Review

Pathan et al. [14] investigated the risk of overheating in London by monitoring 122 properties during the summers of 2009 and 2010. It was concluded that “London dwellings face a significant risk of overheating under the current climate.” In their review of overheating in new UK homes Dengel and Swainson [15] found that there is growing evidence that high energy efficiency standards (i.e. high levels of insulation without appropriate ventilation) lead to overheating and can also negatively affect the health of occupants. Several studies have concluded that new-build care and retirement homes are already at risk of overheating [16-20].

A UK study investigated summer temperatures in 224 dwellings found that pre-1919 dwellings were least likely to overheat; meanwhile post-1990 dwellings were most likely to experience overheating. It was suggested that this is largely due to the difference in construction, mainly, the levels of insulation and airtightness [21]. A similar notion was established by a 2013 study which found that pre-1919 dwellings were significantly cooler whereas post-1990 dwellings were significantly warmer. Bedrooms in particular seemed to experience overheating even during cooler summer temperatures [22]. Once again Hulme et al. [23] confirmed that modern (1975-80) properties with an energy efficient SAP rating of 70+ and post-1990 dwellings were warmer whilst pre-1919 dwellings were cooler.

The introduction of ‘Nearly-Zero Energy Buildings’ (nZEBs) by the Energy Performance Building Directive (EPBD) [recast] in 2010 and the 2050 carbon budget which led to a shift in the design paradigms within the construction industry across Europe means that new and existing buildings are expected to be energy efficient [24, 25].

New homes are therefore being designed to satisfy the demanding requirements of new regulations whereby high levels of insulation is incorporated amongst other measures to ensure the energy demand of the building is lowered. Furthermore, the EPBD did not only set out a requirement for all new buildings to be nZEBs by 2020 but also for buildings that will undergo refurbishment [24]. As a result, existing buildings are also being retrofitted to catch up to the energy efficiency standard of new homes. The basic concept behind the nZEB standard exacerbates the risk for overheating in homes under hotter weather conditions [26, 27]. Despite this there is very little research and investigation regarding the issue and the potential of the widespread implementation of the nZEB standard across Europe to compound the risk of overheating in buildings.

Increasing population has meant that the proportion of apartment type buildings being developed has increased by at least 50% across the UK and 80% in London [28]. Although this practice allows efficient use of land by increasing the number of dwellings which can be built per unit area, research has shown that flats have a higher risk of overheating [28, 29]. This is largely because typically the level of ventilation that can be achieved with this type of dwelling is smaller in comparison to houses for example. Flats within London are typically single aspect meaning they don’t allow for adequate ventilation.

The average number of Cooling Degree Days (CDD) has more than doubled in London alone between 1961 and 2006 [30]. Meaning that the amount of energy required for cooling has increased and is continiuing to increase as temperatures rise. Despite this summertime heat gains are still neglected in both nZEB studies and real-life applications for new and existing buildings being retrofitted [17, 23, 26, 31].

Peacock et al. [32] investigated internal temperatures of dwellings using dynamic thermal simulation and predicted based on findings that by 2030 18% of homeowners will install air conditioning in response to increasing temperatures. Meaning that in London alone more than 500,000 homes will have air conditioning. This would not only lead to difficulties in meeting the 2050 carbon target but would directly hinder any progress being made towards reaching the nZEB standard.

Roaf et al. [33] explored the advantages of utilising passive ways of reducing the risk of overheating in homes built to a high energy efficiency standard and concluded that this is an effective way to mitigate the risk of overheating. However, as previously mentioned, for flats, there is limited opportunities for the incorporation of natural ventilation due to the physical characteristics of such buildings. Another physical building characteristic

For Peer Review

which seems to have an effect on overheating is the orientation of the building as established by Pana [34]. The orientation of the building is an interesting factor to influence whether or not a building experiences overheating but is limited in terms of applicability as altering the orientation of existing buildings is not possible [29, 30, 34]. Nonetheless some studies suggest that incorporating external shading can help maintain summer thermal comfort [29, 34]. Flats located at higher floor levels were also found to be more likely to experience overheating [34-37]. Carrilho et al. [29] used dynamic thermal simulation to investigate the technical and economic feasibility of the nZEB standard in a mild southern European climate zone, Lisbon on two houses with different levels of glazing (moderately glazed and highly glazed). It was found that high levels of glazing contribute to an increase in the risk of overheating; for example, the living room temperature in the highly glazed house exceeded 28^{o}C for more than 46% of the summer season.

The above signifies that to maintain thermal comfort applied energy efficient measures (EEMs) should ideally achieve a balance between the heating and cooling demand throughout the year. Therefore, whilst the application of high levels of insulation remains necessary during the heating season, consideration must be given to the building performance during the non-heating season through the application of adequate cooling strategies.

For this study the buildings within the retirement village will be designed to reach the nZEB standard with the currently recommended overheating mitigating strategies as obtained from the literature. Furthermore, because in overheating studies there is currently limited research regarding whether combined cooling/ heat and power (C/CHP) systems have the potential to act as mitigating strategies to maintain the achieved nZEB standard and reduce the risk of overheating they will be investigated. CHP or cogeneration is an alternative method that utilises, by-product heat, which can amount up to 80% of total primary energy during electricity generation; meanwhile CCHP or trigeneration further utilises by-product heat to provide cooling [38]. Consequently, the risk of overheating and energy performance of the various blocks within the retirement village as they currently stand and as nZEBs will be investigated under current and future climatic conditions. The analysis will be carried out using Thermal Analysis Simulation software (Tas, Edsl). The overheating criteria selected for this case study is the CIBSE TM59 Design methodology for the assessment of overheating risk in homes.

For Peer Review

3.0 Methodology

3.1 Case-study and modelling details

The selected case study is Hughenden Gardens, located in High Wycombe. It is made up of 7 blocks (A-H) as shown in figure 1a. Figure 1b shows the outcome of the 3D modelling and table 1 is showing a summary of the building characteristics details and outcome of the modelling process. Flats within the village have an average of 2 occupants per dwelling. Flat occupancy type is split into 70% residential occupancy and 30% nursing occupancy.

Building modelling and simulation software TAS is used to predict energy performance, baseline and mitigated CO_2 emissions, thermal performance and therefore occupant comfort [39]. Initially, the model created on TAS will be a replica of the existing state of the building. Thus, the initially generated energy model will act as the reference point for improvements and will be defined as the 'baseline model.' The total primary energy consumption (PEC) is the amount of primary energy consumed in order to meet the building's energy demand (heating, cooling, DHW, lighting, and auxiliaries) and is also the net of any electrical energy displaced by C/CHP generators, if applicable.

The weather data used in this study are supplied by Cibse, based on UKCP09 climate projections. The weather file is the London Probabilistic Design Summer Year (DSY) [WDD16LON]. This is selected because the DSY weather file is suitable for overheating analysis. Meanwhile, the Test Reference Year (TRY) is suitable for "energy analysis and compliance with the UK Building Regulations (Part L)" [40-43].

The weather file closest in terms of geography to the retirement village is the westernmost of the three London regions: London Heathrow. Cities tend to be warmer than rural districts around them, most noticeably during the night hours, and this difference in temperature is accounted for in the data (40). Known as the urban heat island (UHI) effect, the Cibse data uses a larger number of weather stations within each region to more closely monitor temperature. Future climate change is also taken into consideration.

The four-time periods selected were as follows: the current DSY representative of the present climate, together with the 2020s, 2050s, and 2080s DSY. All three of the future databases selected were the ‘High’ emissions scenario, 50th percentile DSY 1. DSY 1 is comprised of a moderately warm summer, DSY 2 features short intense warm summer temperatures, whilst DSY 3 features long, intense warm spells. Currently, DSY 1, 2020s, high emissions 50th percentile is recommended by the Cibse TM59 criteria for carrying out the overheating analysis and is therefore selected for this study.

Refer to Amaoko-Attah and B-Jahromi (2014) for detailed description of the modelling process on TAS.

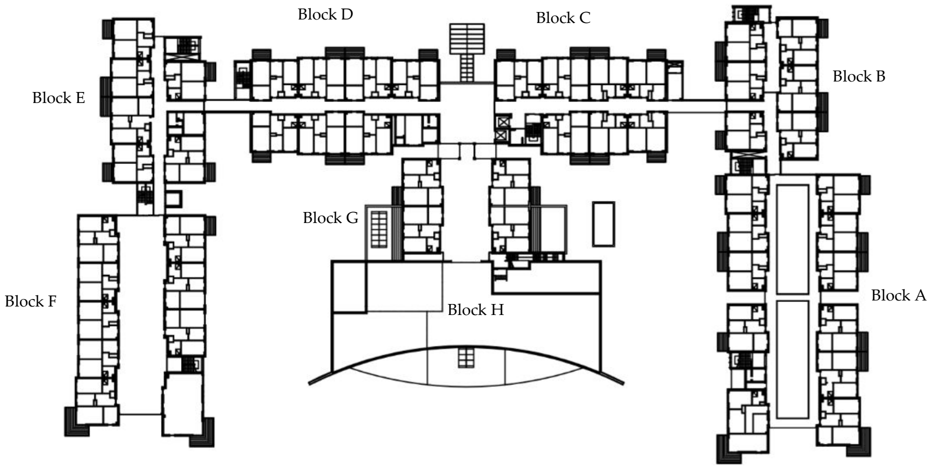

Figure 1a: Typical floor plan of the retirement village

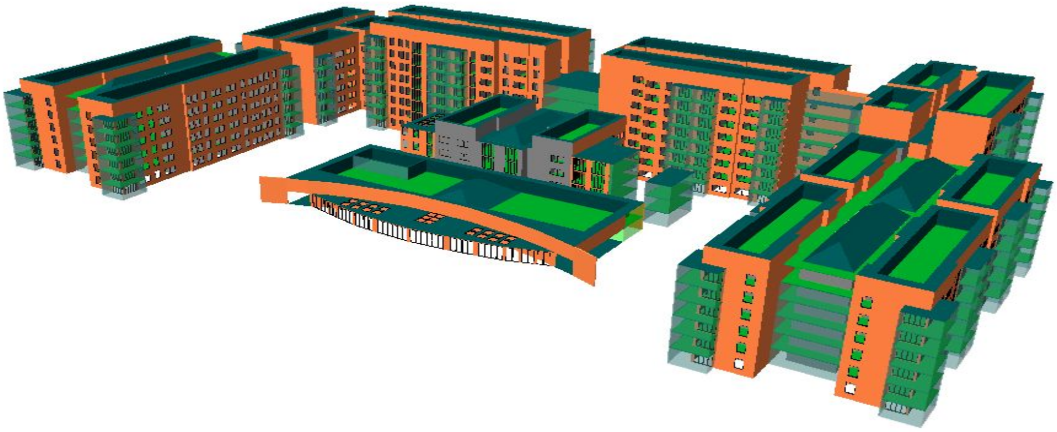

Figure 1b: 3D model of the retirement village

Figure 1: Floor plan and 3D model of the retirement village

Table 1: Summary of case study and modelling process

		Typical block characteristics		
Element/System		**A, F & G**	**B-E**	**H (Village centre)**
Use		Residential & nursing occupancy	Residential & nursing occupancy	Leisure centre, gym, communal area
Building fabric	***Type***	Traditional build[1] including block, bricks, and precast units (stair case and slabs)	Mixture of concrete frames & traditional build	Concrete frame, steel frames (mainly iterance) and blocks and bricks
Total No. of flats		260 [105 one bedroom; 155 two bedrooms]		
Wall (calculated area weighted average u-values)	***u-value (W/m^2K)***	0.45		
Roof (calculated area weighted average u-values)	***Type***	Single-Ply Membrane		
	u-value (W/m^2K)	0.30		
Floor (calculated area weighted average u-values)	***Type***	Ground & first floor: cast concrete slab Other floors: precast slab		
	u-value (W/m^2K)	0.35		
Windows (calculated area weighted average u-values)	***Type***	Double glazing (air-filled) with low emissivity coating		
	u-value (W/m^2K)	2.45		
Cooling		No cooling system		
Heating	***Type***	Conventional communal boiler system		
	Fuel	Natural Gas		
	Temperature Set Point	21°C		
	Heating Capacity	3 kW		
	Working temperature	60-80°C		
	Heating distribution	Central heating radiators		
	Schedule	October-April; 10pm-8am		
Domestic Hot Water (DHW)	***Type***	Conventional communal boiler system		
	Temperature	49°C		
	Average daily consumption	140 litres per person per day		
Ventilation	***Type***	Passive/Natural		
	Schedule	8am-10am; 4-6pm		
Zone - occupancy levels, people density, lux level	***NCM constructions database -v5.2.tcd***	Bedroom - 0.094 person/m^2, 100 lux Toilet - 0.1188 person/m^2, 200 lux Reception - 0.105 person/m^2, 200 lux Hall - 0.183 person/m^2, 300 lux Food prep/ kitchen- 0.108 person/m^2, 500 lux Eat/Drink area - 0.2 person/m^2, 150 lux Circulation - 0.115 person/m^2, 100 lux Store- 0.11 person/m^2, 50 lux Laundry - 0.12 person/m^2, 300 lux		
Air permeability		5 $m^3/h/m^2$ @50Pa		
Infiltration		0.500 ACH		
Lighting Efficiency		5.2 W/m^2 per 100 lux		
Fuel Source		Natural Gas – CO_2 Factor – 0.216 Kg/kWh		

For Peer Review

	Grid Electricity – CO_2 Factor – 0.519 Kg/kWh
Orientation	Latitude: 51.6367/ 51°38’11” N; Longitude -0.753452°W; +0.0 UTC
Weather data	DSY (Cibse) for London. Includes: dry bulb temperature (°C); wet bulb temperature (°C); atmospheric pressure (hPa); global solar irradiation ($W \cdot h/m^2$); diffuse solar irradiation ($W \cdot h/m^2$); cloud cover (oktas); wind speed (knots); wind direction (degrees clockwise from North); and Present Weather Code.

[1] refers to brickwork and blockwork constructions (walling is of masonry construction and tied with stainless steel ties to an outer leaf of block/brick)

For Peer Review

3.2 The nZEB retrofit

The aim of this paper is to assess how the case study building performs under current and future climatic conditions as it currently is and once it is retrofitted to the nZEB standard. The strategy undertaken to set the nZEB standard for this paper was derived from the current UK target for residential nZEBs which currently has the target for the annual primary energy consumption (PEC) as 44 kWh/m^2. Although the retirement village has communal areas it still carries a residential classification because the energy consumption, water consumption, occupancy profiles etc. are considering per dwelling. Table 2 is showing a summary of the selected energy efficient measures (EEMs) that make up the nZEB retrofit scenario. From the currently available literature it could be predicted that nZEBs and energy efficient buildings are more likely to experience overheating. Findings from this literature suggests that the incorporation of shading devices, double glazing as opposed to triple glazing, and utilising natural ventilation are currently some of the most effective ways to mitigate the risk of overheating [29, 32-34, 44]. Table 3 is showing a summary of the schedules used for internal shading, natural ventilation, and mechanical ventilation during the hotter months (May-September] and table 4 is showing the actual typical occupancy profile within the village.

Table 2: Summary of final selected EEMs for nZEB retrofit

EEMs	**Design Measure**
Insulation	180mm mineral wool insulation batts
Lighting	LED [+ Auto presence detection in communal areas]
HVAC & DHW	Automatic Thermostat controlled direct gas fired Boiler
	Mechanical Ventilation with heat recovery in communal areas
Microgeneration	100kWp Solar panel system + solar thermal collectors
Overheating mitigating strategies	Internal shading [Vertical blinds]
	Natural ventilation in residential areas
	Double Glazing, 36 mm Argon filled, Low-e

Table 3: Set schedules for internal shading, natural ventilation, and mechanical ventilation during the non-heating season.

Internal Shading	9am-10am; 12pm-3pm; 7-8pm
Natural Ventilation	8pm-7am
Mechanical Ventilation	8am-9pm

Table 4: Occupancy profile

Room	**Weekday (Mon-Fri)**	**Weekend (Sat-Sun)**
Living rooms	9-10am; 7-10pm	9-10am; 12-3pm; 7-10pm
Bedrooms	10pm-8am	10pm-8am
Kitchen & Dinning	8am-9am; 12-1pm; 6-7pm	8am-9am; 12-1pm; 6-7pm

3.3 Overheating Criteria

In the design of non-air-conditioned spaces there have been no detailed guidance on defining and monitoring the risk of overheating within the UK. In previous years the Cibse guide A and Cibse TM52 criteria were utilised to assess the risk of overheating in buildings. Currently, the "TM59: 2017 Design methodology for the assessment of overheating risk in homes" [1] has been specifically developed and tailored by Cibse to assess the risk of overheating in homes. To summarise, the two overheating criteria set out by TM59 are:

1. Criterion 1 for living rooms, kitchens, bedrooms: the number of hours during which ΔT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 percent of occupied hours.
2. Criterion 2 for bedrooms: during the sleeping hours the operative temperature in the bedroom from 10pm to 7am shall not exceed 26^{o}C for more than 1% of annual hours (33 hours).

Bedrooms must pass both requirements.

Although the TM59 criteria recommends that future weather data files such as 2050s/2080s are run it is not a set requirement that the building passes. On the other hand, it is necessary that the building passes under the 'current' and 2020s High emissions, 50th percentile DSY 1.

The BS EN 15251 [45] equation for comfort temperature T_{comf} is shown by Eq. 1, where, T_{rm} is the exponentially weighted running mean of the daily mean outside air temperature. The running mean daily mean outside air temperature is calculated using Eq. 1.2 where α is a constant (0.8) and $T_{od\ldots}$are the daily mean outdoor temperatures for the day of interest followed by the previous day(s) [Eq. 1.3].

The criteria are based upon three sets of thresholds known as category I, II, and III. These categories assign a maximum acceptable temperature of varying degrees above the comfort temperature for naturally ventilated buildings as show by Eq. 2-4. The category I threshold applies to spaces that are occupied by very sensitive and fragile persons with special requirements, such as the disabled, sick, very young, and the elderly. Category II threshold applies to new buildings and renovations and category III applies to existing buildings. Category I is generally considered the stricter of the three categories and is applied to this particular case study.

$$\Delta T = T_{op} - T_{max} \qquad [1]$$

$$T_{comf} = 0.33T_{rm} + 18.8 \qquad [1.2]$$

$$T_{rm} = (1-\alpha)(T_{od-1} + \alpha T_{od-2} + \alpha^2 T_{od-3}\ldots) \qquad [1.3]$$

$$Category\ I\colon T_{Cat1max} = 0.33T_{rm} + 18.8 + 2 \qquad [2]$$

$$Category\ II\colon T_{Cat2max} = 0.33T_{rm} + 18.8 + 3 \qquad [3]$$

$$Category\ III\colon T_{Cat3max} = 0.33T_{rm} + 18.8 + 4 \qquad [4]$$

For Peer Review

4.0 Results and Discussion

To evaluate the impact of the measures to be incorporated on the case-study building, the initial simulation is conducted to reflect the actual current state of the building without any alterations. The simulation model was thoroughly populated to reproduce all the characteristics and systems of the building as built. Once this was completed, the retrofitting measures outlined in the methodology were then incorporated and the simulations were run again with the building performing as a nZEB.

Figure 2 is showing the Primary Energy Consumption (PEC) for the building as it currently is and once it has been retrofitted to the nZEB standard. From figure 2 it can be seen that the space heating PEC decreases for both the baseline scenario and even more so for the nZEB retrofit as future timeline scenarios are simulated. However, as the nZEB retrofit incorporates mechanical ventilation in communal areas the total PEC is increased as the cooling demand substantially increases. The simulated annual PEC per dwelling is 97.48 kWh/m^2. Although the total PEC for the nZEB scenario under the future weather projections remains lower than the baseline scenario it can still be said that the nZEB scenario underperforms in comparison to the baseline scenario. This is because the baseline scenario experienced a decrease in the total PEC, meanwhile the nZEB scenario experience an increase in the total PEC. This suggests that if the 90th percentile/DSY 3 weather file (worst case projection) had been used for the simulations the nZEB scenario would have an even further increase in the total PEC. Considering the typically high investment costs associated with nZEB retrofits an increase in energy usage in the future this would lead to an increase in the occupants' fuel/energy costs. Generally, with energy efficient retrofit projects the main economic appeal is the drastic lowering in energy costs; meaning that if this were to be reversed under hotter weather conditions the overall financial benefits and economic viability of this option would be drastically lowered. Nonetheless, It can be seen that despite the increase in total PEC after the nZEB retrofit, the nZEB retrofit's PEC is 34% lower than the baseline building's PEC.

The TM59 overheating criterion 1 and 2 results for the baseline scenario and the nZEB scenario are shown in figure 3. The results are in consonance with the projected temperature changes. The projections showed a constant increase in temperature over stipulated timelines. Once the building was simulated under the 2050s and 2080s weather overheating hours increase significantly. The general trend observed for both the baseline scenario and nZEB retrofit across every block of the village was that kitchen and bedroom were more prone to experience severe overheating.

Although overheating occurred for both the baseline scenario and the nZEB retrofit scenario, severe overheating was experienced under the 2050s and 2080s weather projections for the nZEB scenario in comparison to the baseline scenario. For the bedroom and the kitchen, the building failed to pass the criteria under the current, 2020s-2080s weather files for the nZEB scenario. As discussed previously, several studies have confirmed that certain retrofit measures such as the implementation of shading devices, low-e double glazing, and utilising natural/passive ventilation can act as 'mitigating' measures to significantly reduce the occurrence of overheating within buildings. Furthermore, because previous research highlights that overnight natural ventilation in particular is supposedly one of the simplest and most effective methods to combat overheating, the openable window hours were set for 20:00pm-7am during the non-heating season as shown earlier in table 4. Therefore, it is of concern that despite foreseeing the potential increased risk in overheating with the nZEB retrofit and therefore including such measures, overheating was severe under future weather projections and much more prominent in comparison to the baseline scenario.

In addition, flats within the village are typically dual aspect which is not always possible or common with flat type buildings. They are typically single aspect meaning they don't allow for adequate ventilation. Within the UK it is generally recommended that opening windows for approximately 15 minutes every day is enough to ventilate. However studies have found that most properites only open winodws once or twice a week which explains widespread issues of dampness across UK properties [46]. Other studies (simulation and real-life) have examined daytime versus nighttime ventilation and it is always concluded that night time ventilation is the more effective option [47-49]. Meaning that relying on passive ventilation as a mitigating strategy is not an effective solution. Furthermore, behavioural changes such as this cannot be guaranteed in real-life applications and may not be fully adhered even if residents were advised to do so and because of the particularly vulnerable population demographic this cannot be relied on as an effective or suitable method of reducing the risk of overheating for this particular case study.

External shading has been proven by the literature to be more effective than internal shading at reducing solar gains [29, 33, 50]. However there are issues of applicability with this particular case study. Mainly, it will be technically challenging to retrofit the façade as there may be a lack of sufficient fixing points to allow installation. This is a common challenge for existing buildings looking to incorporate external shading as part of their retrofit project. It would also greatly reduce the amount of natural light entering the space thereby affecting occupant comfort. Furthermore, the cost of running, cleaning and maintaining the external façade would incur higher maintenance costs for occupants which will not be well received by all occupants. Due to this, it was not considered a suitable mitigating strategy to be investigated.

A study by Fosas et al. [51] suggested that "insulation plays a minor role in overheating when comparing un-insulated to super insulated buildings." Yet, many energy efficient retrofit projects seem to attribute the cause of overheating to over-insulating the building [15, 21-24]. The results of this study suggest that it is a combination of high levels of insulation without considering appropriate ventilation and mitigating strategies. It must be noted that in certain cases buildings overheat due to a combination of poor design choices [33, 48, 51].

It was interesting to note that blocks B-E outperformed blocks A, F-G under the present, 2020s, 2050s and 2080s simulations. The reason for this is due to the differences in building material between the blocks. Materials with a higher thermal mass such as the precast concrete panels used in those blocks have been proven to reduce the risk of overheating. However, the majority of existing UK buildings are traditionally built (as blocks A, F, and G) meaning that the risk of uncomfortable dwellings for occupants during hotter spells will be prevalent. The fifth UK carbon budget called for solid wall dwellings to be insulated to meet the carbon reduction targets set out in the 2008 Climate Change Act [52, 53]. Increasing the insulation will exacerbate the risk of overheating within those dwellings. It has been predicted that approximately 2 million dwellings could be affected [53]. Furthermore, a study by Aldawoud [54] which examined the thermal performance of various shapes and geometries of atriums in buildings, highlighted that in all climatic models an elongated atrium such as the one utilised within Hughenden Gardens blocks A, F, and G typically has the worst energy performance and leads to higher overall energy consumption within the models examined under cold climates.

For Peer Review

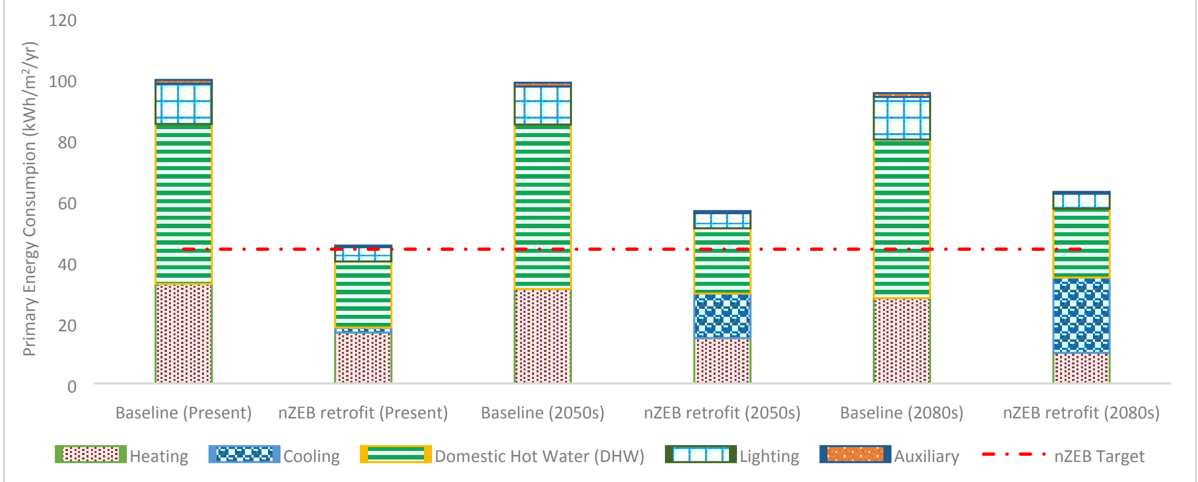

Figure 2: Comparison of the primary energy consumption of the retirement village as built and after nZEB retrofit under current and future climate conditions

For Peer Review

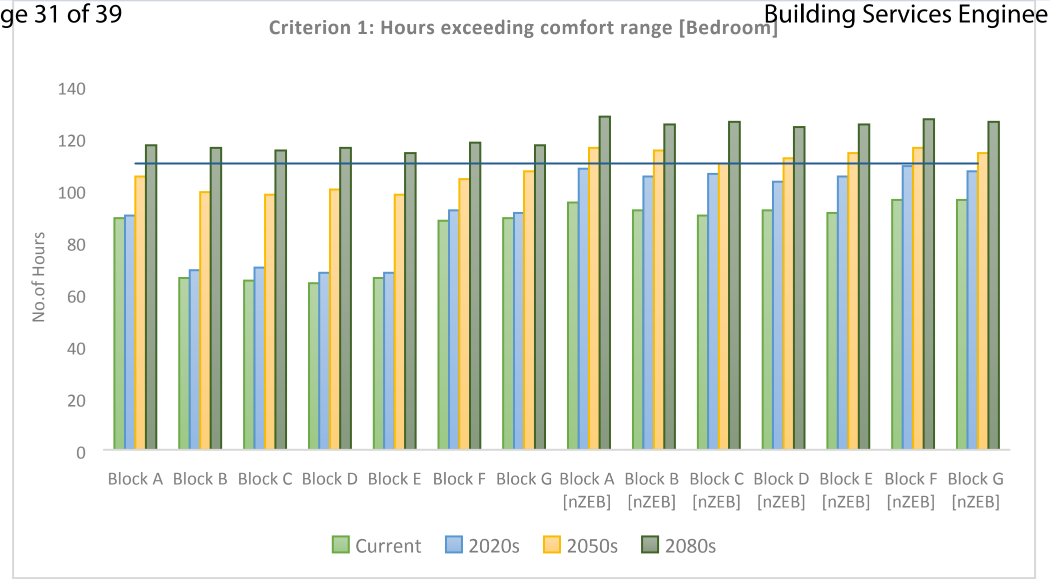

Figure 3a: Cibse TM59 overheating criterion 1 results for bedroom (average) within the village as built and after nZEB retrofit under current and future climatic conditions

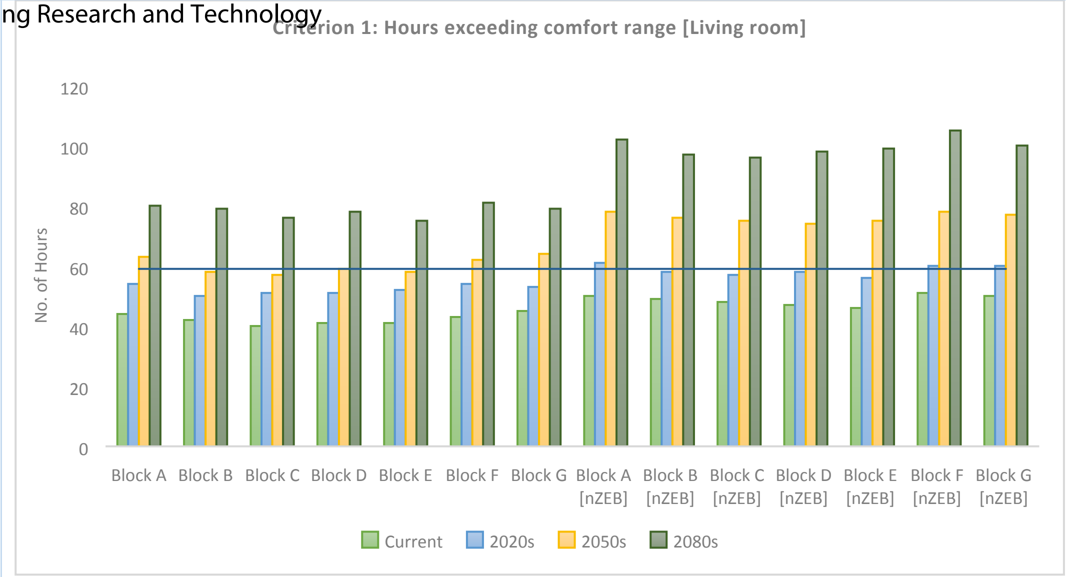

Figure 3b: Cibse TM59 overheating criterion 1 results for living room (average) within the village as built and after nZEB retrofit under current and future climatic conditions

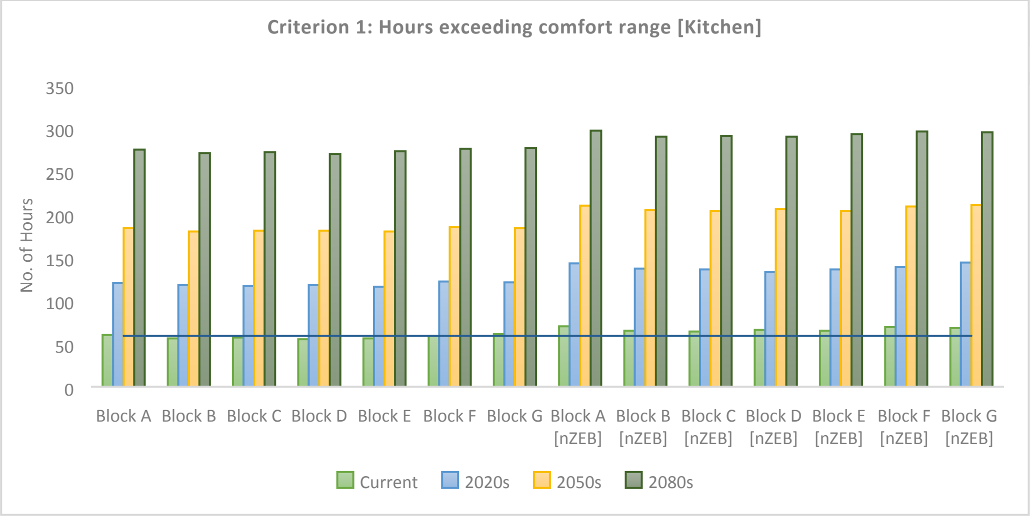

Figure 3c: Cibse TM59 overheating criterion 1 results for Kitchen (average) within the village as built and after nZEB retrofit under current and future climatic conditions

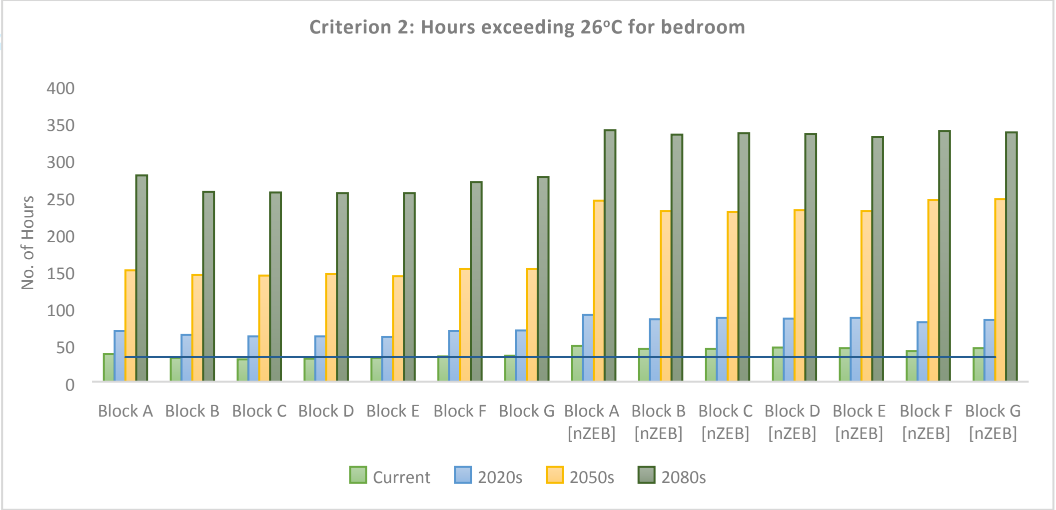

Figure 3d: Cibse TM59 overheating criterion 2 results for bedroom (average) within the village as built and after nZEB retrofit under current and future climatic conditions

Figure 3: Cibse TM59 overheating criterion 1 and 2 results for within the village as built and after nZEB retrofit under current and future climatic conditions

4.1 Mitigating strategy: C/CHP

The previous figures suggest that the only reliable solution to avoid the risk of overheating would be to utilise some form of cooling measure throughout the entire village. The intrinsic features of existing buildings can be adapted to improve their energy performance, however, as demonstrated opening windows in this case study has not provided the level of ventilation required to avoid overheating. Currently, air conditioning is the most widely used cooling system in both commercial and domestic applications. However, this alternative is incompatible with the nZEB concept that revolves around reducing energy use and CO_2 emissions. Several studies have demonstrated the potential for CHP and CCHP to reduce the PEC of buildings and aid in reaching the nZEB standard [55]. As discussed, in overheating studies there is currently limited research regarding whether C/CHP have the potential to act as a mitigating strategy to reduce the risk of overheating. Consequently, as part of the nZEB retrofit rather than incorporate the PV system and solar thermal collectors the simulation will be run once more with a 100kWe CHP and then CCHP system.

As seen from the above results, within the nZEB building, there is a high summertime demand for cooling and year-round daytime electricity for artificial lighting and equipment throughout the premises. Heating output can therefore be used for cooling through the use of an absorption chiller during the non-heating season. Meanwhile, because the heating demand remains during the colder months this can still be provided by the CCHP unit. By utilising the excess heat for cooling this eliminates the risk of heat being wasted or dumped. Studies have concluded that selection of a C/CHP system will depend on several factors, in particular, the heating and cooling demand of the building. A CHP system will be more appropriate and should be incorporated in a building with considerable heating demand and moderate/no cooling demand. On the other hand, a CCHP system will be more appropriate in applications with equally considerable heating and cooling demands [55, 56].

Comparing the performance of the building with CHP and CCHP against the TM59 overheating criteria it becomes apparent that the CCHP system outperforms the CHP significantly as shown by figure 4 and 5. As expected, with the CHP system in place, the building continues to overheat in exactly the same way as it did whilst the PV system was utilised instead. However, as mentioned the main difference is the fact that the PEC did not increase, thereby making it a better alternative [as shown in figure 6]. The CCHP system on the other hand was able to ensure that the building does not fail the overheating criteria under the current, 2020s, 2050s, and 2080s weather databases. Out of the mitigating strategies that have been examined throughout this study the incorporation of the CCHP system was the only alternative that meant the building passes the criteria. Moreover, the baseline building bedroom [criterion 2] and kitchen [criterion 1] failed to pass the TM59 overheating criteria, meaning that the CCHP alternative was once again the only mitigating strategy that fully passed the overheating criteria whilst ensuring the PEC of the building meets the nZEB standard under current and future climatic conditions.

Looking at figure 6 it is clear that both the CHP and CCHP have reduced the PEC of the building under current weather conditions but more importantly they both maintained the PEC so that it meets the required nZEB standard under future climatic projections. This alone is an improvement from the previous set of results whereby the nZEB target was exceeded under future projections. Despite this significant improvement, it seems that the CCHP system is more compatible with the heating/cooling demands of this building. The PEC increased by less than 3% with CCHP, meanwhile, it increased by more than 5% with the CHP system.

It must be noted that there are problems associated with the use of a CCHP during summer within cities such as London. This is primarily due to the extra firing of boilers and pumping heat into the air to cool the building which exacerbates that urban heat island effect. Nonetheless, if the use of CCHP systems was to become widespread, alternatives to the absorption chiller-based system are available to overcome the heat island effect and attain an even higher seasonal efficiency of the system. The most successful and currently used alternative approach involves the utilisation of an aquifer thermal energy storage (ATES). In an ATES based system excess heat is pumped into aquifers during the non-heating season and extracted once again for heating during the winter. This approach has been successfully applied in the Netherlands and within a social housing scheme in West London [57].

For Peer Review

In terms of applicability to other buildings, CCHP may not be suitable for other residential and commercial buildings such as schools, semi-/detached dwellings, and offices and within dominantly cold or hot climates. The reason for this is because the heating, cooling, and electricity demand must be fairly consistent all year-round to ensure the system is being used to its full efficiency. Furthermore, with a fossil fuel being used as an input source, CCHP cannot be considered an ultimately sustainable solution. Recently, other options such as a solar co-/trigeneration system has been introduced [56]. Certain biomass options can also be utilised instead to ensure the system is energy sustainable. If the use of CCHP as a solution becomes widespread, these alternatives should be considered to aid in the transition towards an energy sustainable future. For these reasons it is understandable that the current available nZEB definitions do not stipulate the use of CCHP as an ultimate solution to reaching the standard.

For Peer Review

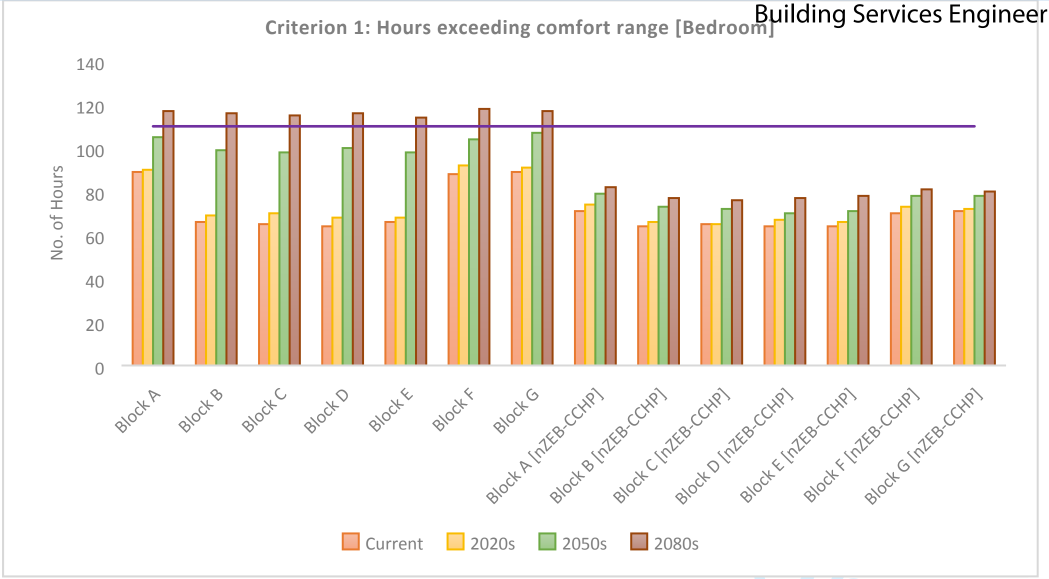

Figure 4a: Cibse TM59 overheating criterion 1 results for bedroom (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 5a: Cibse TM59 overheating criterion 1 results for bedroom (average) within the village as built and after nZEB retrofit with CCHP under current and future climatic conditions

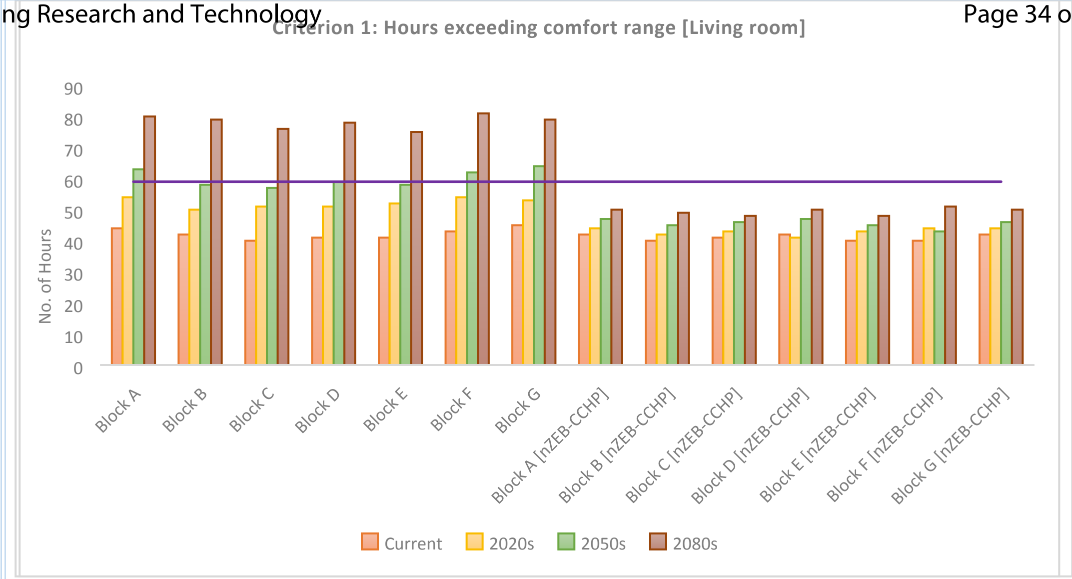

Figure 4b: Cibse TM59 overheating criterion 1 results for living room (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 5b: Cibse TM59 overheating criterion 1 results for living room (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

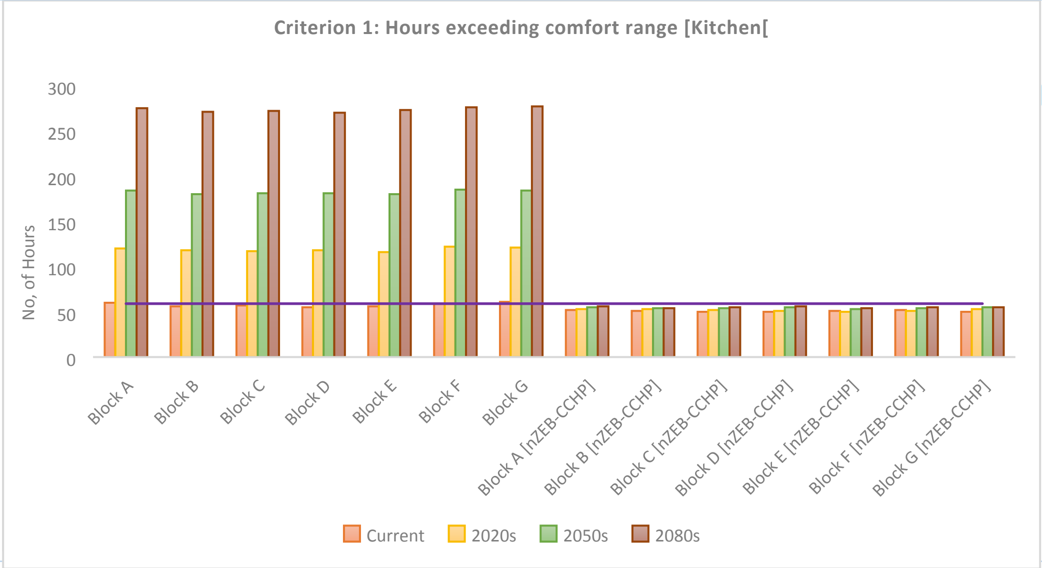

Figure 4c: Cibse TM59 overheating criterion 1 results for kitchen (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 5c: Cibse TM59 overheating criterion 1 results for kitchen (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

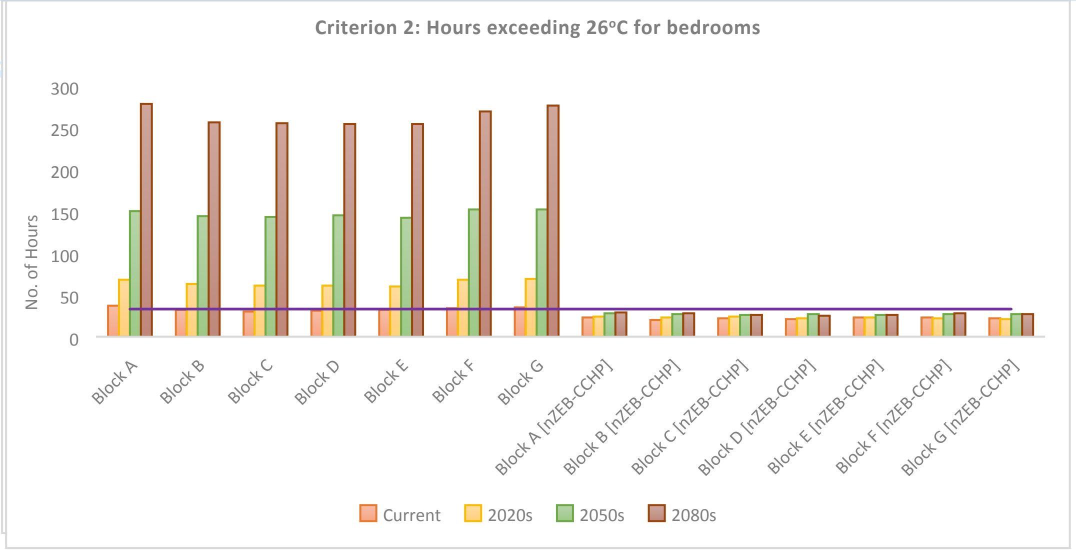

Figure 4d: Cibse TM59 overheating criterion 2 results for bedroom (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 5d: Cibse TM59 overheating criterion 2 results for bedroom (average) within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 4: Cibse TM59 overheating criterion 1 and 2 results within the village as built and after nZEB retrofit with CHP under current and future climatic conditions

Figure 5: Cibse TM59 overheating criterion 1 and 2 results within the village as built and after nZEB retrofit with CCHP under current and future climatic conditions

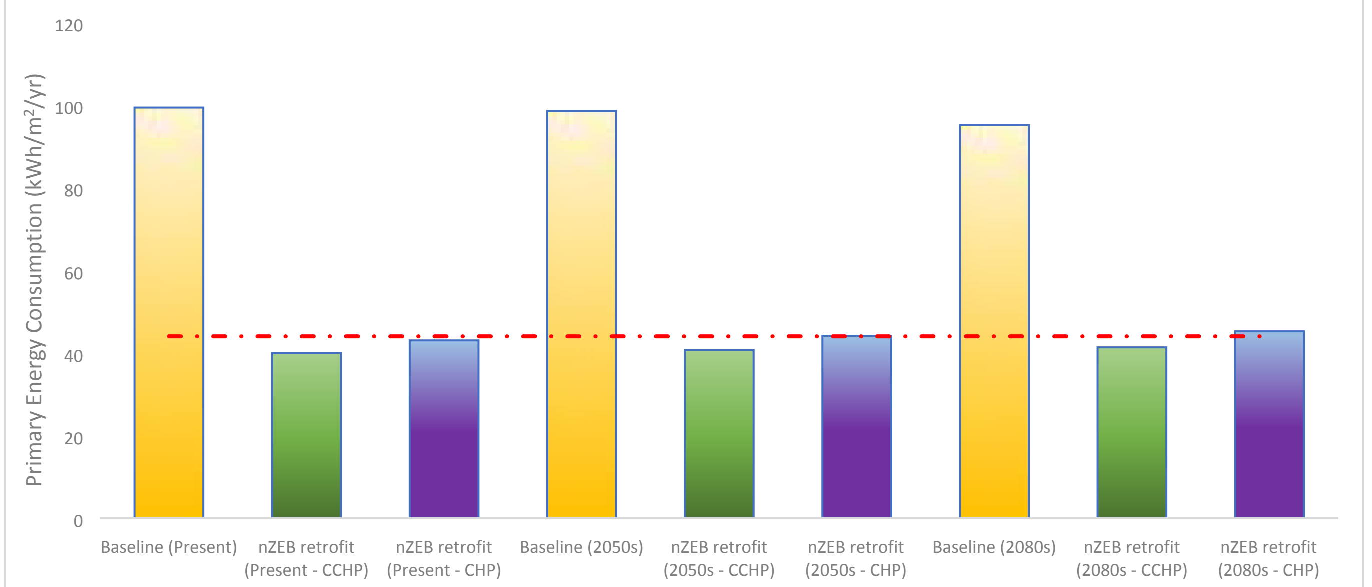

Figure 6: Comparison of the primary energy consumption of the retirement village as built and after nZEB retrofit with CHP and CCHP under current and future climate conditions

5.0 Conclusion

This paper has investigated the impacts of a changing climate on the risk of overheating and energy performance for a UK retirement village. Using dynamic thermal analysis simulation software Tas Edsl, the energy performance of the village as it currently stands and as a nZEB was examined and compared. Reviewing the current state of the art demonstrated that once retrofitted to the nZEB standard the building would most likely experience severe overheating. The typically recommended mitigating strategies were therefore incorporated as part of the retrofit measures. The overheating criteria utilised was the “CIBSE TM59 Design methodology for the assessment of overheating risk in homes.” Once the initial set of results were obtained it was clear that the use of overnight natural ventilation, double glazing (low-e), and shading devices was not sufficient to reduce the occurrence and severity of overheating throughout the village.

Overheating occurred for both the baseline scenario and the nZEB retrofit scenario. Severe overheating was experienced under the 2050s and 2080s weather projections for the nZEB scenario in comparison to the baseline scenario. For the bedroom and the kitchen overheating was experienced under the current, 2020s-2080s weather files for the nZEB scenario. Meaning that after the nZEB retrofit the building completely failed to pass the criteria. It was noted that building material seemed to influence the risk of overheating. The kitchen and bedrooms were more prone to experience severe overheating.

A 100kWe CHP and then CCHP system were then simulated as part of the nZEB retrofit package. Both the CHP and CCHP have proven to work successfully in reducing and maintaining the PEC of the building under future weather files. However, the CCHP was the only mitigating strategy that fully passed the overheating criteria whilst ensuring the PEC of the building meets the nZEB standard under current and future climatic conditions, thereby surpassing the baseline building as well.

Whilst the cooling demand of the building increased substantially under future weather projections the heating demand did not significantly decrease in the same way. This means that carrying out energy efficient retrofits that consider lowering the energy demand of the building first and foremost by improving insulation, glazing etc. is still an important and relevant strategy to ensuring that energy targets are met. This is very apparent by the fact that the baseline building still experienced overheating. If mechanical ventilation or air-conditioning were a part of the baseline model that PEC would have experienced a substantial increase (far more than the nZEB alternative). In real life the majority of buildings do end up incorporating air-conditioning under hotter

For Peer Review

weather conditions as discussed in the literature review, meaning that the performance of the baseline building would have been significantly worse than the nZEB model.

For this particular case study, CCHP proved to be the most suitable solution; however, the type(s) of mitigating strategy will vary depending on the type, location, heating and cooling demand of the building and various other factors. The results of this study therefore do not undermine the importance of continuing to improve the energy efficiency of existing buildings but rather highlight that the approach undertaken should be reconsidered. This does not mean neglecting lowering the energy demand but searching for and selecting suitable and relevant mitigating strategies and adequate ventilation strategies relative to the building being considered that will work to reduce the risk of overheating.

This study did not consider user behaviour and interaction as a possible mitigating strategy due to the vulnerable population demographic. Further research that collects and examines user behaviour on overheating should be undertaken to assess the significance of occupant behaviour on overheating within buildings. This should then be used in conjunction with data obtained from simulation models to determine a combined approach to mitigating the risk of overheating within buildings. Approaches that include user behaviour will lead to a decrease in costs, and although not applicable to this particular case study, they can be applied within many residential dwellings.

Overall, it can be concluded that in line with the current paradigm that favours energy efficiency, the associated risk of increasing overheating cannot be ignored due to the numerous negative consequences associated with this. It is clear that whilst carrying out energy efficient retrofitting of properties may be necessary to aid in the transition towards an energy sustainable future the design choices and recommendations may need to be reconsidered so that the building continues to perform under variable weather conditions. Thus, integrating mitigation strategies in energy efficient retrofit is necessary. Most importantly, retrofitting with a focus on only adapting to hotter weather conditions is not a viable solution as it may lead to a substantial increase in heating demand during the heating season. Energy efficient retrofit projects should therefore, ideally, find a balance between meeting the heating and cooling demands of the building in an energy efficient way under current and future weather conditions.

For Peer Review

References

1. Cibse TM59. Design Methodology for the Assessment of Overheating Risk in Homes, Technical Memorandum TM59. Chartered Institution of Building Services Engineers, London, 2017, ISBN 978-1-912034-17-8
2. CIBSE. Guide A Environmental design (8th ed). London, 2015.
3. Kovats R.S, Johnson H, Griffiths C. Mortality in southern England during the 2003 heat wave by place of death. *Health stat Q*, 2006; 6-8.
4. Health Protection Agency. Evaluation of the 2006 heatwave. Available: https://webarchive.nationalarchives.gov.uk/20140714102514/http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1219130165676. (2007, accessed 28 November 2018).
5. Carrington D and Marsh S. Deaths rose 650 above average during UK heatwave – with older people most at risk. Available: https://www.theguardian.com/society/2018/aug/03/deaths-rose-650-above-average-during-uk-heatwave-with-older-people-most-at-risk. (2018, accessed 25 November 2018).
6. Age UK. Later Life in the United Kingdom. Available: https://www.ageuk.org.uk/globalassets/age-uk/documents/reports-and-publications/later_life_uk_factsheet.pdf. (2015, accessed 26 November 2018).
7. Christidis N, Jones G.S, Stott P.A. Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. *Nat. Clim*. 2014. doi:10.1038/nclimate2468
8. Kenny G.P, Yardley J, Brown C, Sigal R.J, and Jay O. Heat stress in older individuals and patients with common chronic diseases. *Can. Med. Assoc.* 2010; 182: 1053–1060. http://doi.org/10.1503/cmaj.081050
9. Gasparrini A, Armstrong B, Kovats S, and Wilkinson, P. The effect of high temperatures on cause-specific mortality in England and Wales. *Environ. Medic.* 2012; 69: 56–61. doi:10.1136/oem. 2010.059782
10. Office for National Statistics. National population projections, 2012-based projections release. https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2013-11-06. (2014, accessed 29 November 2018]

11. Public Health England (PHE). Heatwave plan for England – making the case: The impact of heat on health – now and in the future. 2014, London: Department of Health.
12. NAT. Care Home Benchmarking Report 2016/2017. Available: www.rcpa.org.uk/wp-content/uploads/2016/12/NAT00339_Healthcare_Report_Midres.pdf. (2017, accessed 27 November 2018).
13. Klenk J, Becker C, and Rapp K. Heat-related mortality in residents of nursing homes. *Age and Ageing*, 2010; 39: 245–252. doi:10.1093/ageing/afp248
14. Pathan A, Mavrogianni A, Summerfield A, Oreszczyn T, Davies M. Monitoring summer indoor overheating in the London housing stock. *Energy and Build. 2017;* 141: 361-378.
15. Dengel A and Swainson M. Overheating in new homes: A review of the evidence. Retrieved from the Zero Carbon Hub: http://www.zerocarbonhub.org/sites/default/files/resources/reports/Overheating_in_New_HomesA_review_of_the_evidence_NF46.pdf. (2012, accessed 1 December 2018).
16. Barnes S, Torrington J, Darton R, Holder J, Lewis A, McKee K, Orrell A. Does the design of extra care housing meet the needs of the residents? A qualitative study. *Ageing and Soc,* 2012; 32: 1193–1214. doi:10.1017/ S0144686X11000791
17. Guerra A, Santin O, and Tweed A.C. Summer post occupancy evaluation of a PassivHaus care home in the UK. In Conference: PLEA Sustainable Architecture for a Renewable Future, 2013.
18. Lewis A. Energy use in an ageing society: The challenges of designing energy-efficient older people's housing. *Manchester Lit. and Philos. Soc.* 2014; 151: 20–32.
19. Kevin J.L and Stephen M. (2017) Overheating in buildings: lessons from research. *Build. Res. and Info.* 2017; 45: 1-18, DOI: 10.1080/09613218.2017.1256136
20. Burns A. POE of colliers' gardens in Bristol. Report for post-occupancy evaluation course. Oxford: Oxford Brookes University, 2008.
21. Firth S and Wright A. Investigating the thermal characteristics of English dwellings: summer temperatures, in: Proceedings of Air Conditioning and the Low Carbon Cooling Challenge, 5th Windsor Conference, 27th-29th July 2008. Windsor, UK: Network for Comfort and Energy use in Buildings (NCEUB), 2008.
22. Beizaee A, Lomas K.J and Firth S.K. (2013). National survey of summertime temperatures and overheating risk in English homes. *Build. and Environ.* 2013; 65: 1–17. doi:10.1016/j. buildenv.2013.03.011
23. Hulme J, Beaumont A and Summers C. Energy Follow-Up survey 2011 Report 7: Thermal Comfort and Overheating. Watford, UK, 2013.
24. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union, 53, 2010.
25. Committee on Climate Change. The fifth carbon budget. Available: https://www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf. (2016, accessed 26 November 2018).
26. Sameni S, Gaterell M, Montazami A, Ahmed A. (2015). Overheating investigation in UK social housing flats built to the Passivhaus standard. *Build. and Environ.* 2015; 92: 222-235.
27. Salem R, Bahadori-Jahromi A, Mylona A, Godfrey P, Cook D. Retrofit of a UK residential property to achieve nearly zero energy building standard. *Adv. in Environ. Res.* 2017; 7: 223-241
28. GOV.UK. Housing in London. Available: https://www.london.gov.uk/sites/default/files/housing_in_london_2017.pdf. (2017, accessed 27 December 2018).
29. Carrilho da Graça G, Augusto A, Lerer M. Solar powered net zero energy houses for southern Europe: feasibility study. *Sol. Energy,* 2012; 86: 634-646.
30. Jenkins G, Perry M, Prior J. The climate of the UK and recent trends. Available: https://ukcip.ouce.ox.ac.uk/wp-content/PDFs/UKCP09_Trends.pdf. (2009, accessed 20 December 2018).
31. Porritt S, Cropper P.M, Shao I, Goodier C. Ranking of interventions to reduce dwelling overheating during heat waves. *Energy and Build.* 2012; 55: 20-42.
32. Peacock A.D, Jenkins D.P and Kane D. Investigating the potential of overheating in UK dwellings as a consequence of extant climate change. *Energy Policy*, 2010; 38: 3277-3288.
33. Roaf S, Crichton D and Nicol F. Adapting buildings and cities for climate change. A 21st Century survival guide. *Archit. Press*, 2009; 2: 15-21
34. Pana E. Summertime temperatures and overheating risk: does orientation affect comfort in bedrooms in the UK context? In: Proceedings of 3rd Conference: People and Buildings, 20th September 2013 London, UK: Westminster University, School of Architecture and the Built Environment, 2013.
35. Schnieder J. Passive Houses in South West Europe: a quantitative investigation of some passive and active space conditioning techniques for highly energy efficient dwellings in the South West European region. *Techn. Uni,* 2009; 210-234.

For Peer Review

36. Baborska-Narożny M, Stevenson F and Chatterton P. Temperature in housing: stratification and contextual factors. *Eng. Sustainability,* 2015; 9: 1-17.
37. Jenkins K, Hall J, Glenis V, Kilsby C, McCarthy M, Goodess C, Smith D, Malleson N, Birkin M. Probabilistic spatial risk assessment of heat impacts and adaptations for London. *Clim. Chang.* 2014; 124: 105–117.
38. ACEEE (American Council for Energy Efficient Economy). (2018). Combined Heat and Power (CHP). Available: https://aceee.org/topics/combined-heat-and-power-chp. (2018, accessed 25th January 2018).
39. Environmental Design Solutions Limited, Tas. Available: http://www.edsl.net/. (2018, accessed on 19th May 2018).
40. Chartered Institute of Building Services Engineers (CIBSE). TM48: Use of Climate Change Scenarios for Building Simulation: the CIBSE Future Weather Years. Cibse, London, UK, 2009.
41. Cibse. (2017). CIBSE Weather Data Sets. Chartered Institution of Building Services Engineers, London. Available at: https://www.cibse.org/weatherdata. (2017, accessed 29 November 2018).
42. Eames M.E, Ramallo-Gonzalez A.P, Wood M.J. An update of the UK's test reference year: The implications of a revised climate on building design. Building Services Engineering Research and Technology. *Build. Serv. Eng. Res. Technol*. 2016; 37: 316–333.
43. Mylona, A. (2017). Revision of Design Summer Years and Test Reference Years. Cibse, London, UK. Available: http://www.cibse.org/getmedia/cc7072d9-8e58-42cb-83ce-2316546f0aa0/Introduction-to-CIBSE-Weather-Data-Files.pdf.aspx. (2017, accessed 10 December 2018).
44. Baborska-Narożny M, Stevenson F and Grudzińska M. Overheating in retrofitted flats: occupant practices, learning and interventions. *Build. Res. and Info*. 2016; 45: 40-59.
45. BSI, BS EN 15251: 2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lightning and acoustics. London: British Standard Institution, 2007.
46. Energuide. (2019). How to air your house properly? Available: https://www.energuide.be/en/questions-answers/how-to-air-your-house-properly/1712/. (2019, accessed 3 January 2019).
47. Artmann N, Manz H, Heiselberg P. Climatic potential for passive cooling of buildings by night-time ventilation in Europe. *Appl. Energy,* 2007; 84:187-201.
48. Campaniço H, Soares P, Hollmuller P, Cardoso R. Climatic cooling potential and building cooling demand savings: High resolution spatiotemporal analysis of direct ventilation and evaporative cooling for the Iberian Peninsula. *Renew. Energy*, 2016; 85: 766-776.
49. Panayiotou G, Koukkouli A, Gelegenis, J and Kalogirou S. Night-time Ventilation for Passive Cooling of Dwellings: A case study for Cyprus, 2010. DOI: 10.13140/2.1.2952.8966.
50. Atzeri A, Cappelletti F, Gasparella A. (2014). Internal Versus External Shading Devices Performance in Office Buildings. *Energy Procedia*, 2014; 45: 463-472.
51. Fosas D, Coley D, Natarajan S, Herrera M, Pando M, Ramallo-Gonzalez A. Mitigation versus adaptation: Does insulating dwellings increase overheating risk? *Build. And Environ,* 2018; 143: 740-759.
52. Climate Change Act. https://www.legislation.gov.uk/ukpga/2008/27/contents (2008, accessed 27 November 2018).
53. Committee on Climate Change. Meeting Carbon Budgets: Closing the Policy gap: 2017 Report to Parliament. https://www.theccc.org.uk/wp-content/uploads/2017/06/2017-Report-to-Parliament-Meeting-Carbon-Budgets-Closing-the-policy-gap.pdf, (2017, accessed 5 July 2017).
54. Aldawoud A. The influence of the atrium geometry on the building energy performance. *Energy and Build.* 2013; 57: 1-5.
55. Salem R, Bahadori-Jahromi A, Mylona A, Godfrey P, Cook D. Comparison and Evaluation of the Potential Energy, Carbon Emissions, and Financial Impacts from the Incorporation of CHP and CCHP Systems in Existing UK Hotel Buildings. *Energies,* 2018; 11: 1219.
56. Siegel RP. (2019). Combined Cooling Heat and Power. Available: https://www.triplepundit.com/special/energy-options/combined-cooling-heat-power/. (2019, accessed 4 Jan 2019).
57. Clark P. (2007). Westway Beacon social housing scheme in West London. Available: https://www.westwayha.org.uk/documents//documents/AR1617. (2007, accessed 27 November 2018).

For Peer Review

LIST OF TABLES

LIST OF FIGURES

For Peer Review