MAYOR OF LONDON

Care Home Overheating Audit Pilot Project

Recommendations

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1. Introduction

1.1 Background

This report highlights the main recommendations formulated based on the in-depth audit carried out as part of the Greater London Authority's (GLA) Care Home Overheating Audit Pilot Project. The implementation and results are presented in the Methodology Report, the first of the three outputs of the pilot study, which identifies the sources and causes of overheating in the pilot care home.

This report, the second of the three outputs, is primarily addressed to the pilot care home, including the management team, staff, carers and residents. The dissemination of the third output, the Overheating Checklist, is designed to offer care homes for older residents a list of actions that can be implemented to reduce the indoor overheating exposure of elderly residents, based on the care home audit pilot.

The selected case study, Victoria Care Centre, is a care home that accommodates 115 predominantly older residents. Most occupants are not independently mobile and some residents are under the age of 65 living with dementia and other learning disabilities.

1.2 Aims and objectives

The overall aim of the pilot study was to develop a standardised audit process that will assist the overheating risk mitigation for older people residing in care home settings, using the selected care facility as a testing basis. The specific objectives were to:

- identify possible sources of indoor overheating;
- identify technical measures and heat management solutions to mitigate the heat exposure of the 'at risk' care home residents;
- examine the feasibility of the solutions identified, both in terms of cost and practicality of implementation in the care home setting;
- raise awareness about short- and long- term overheating consequences on the health and well-being of older care home residents through the formulation of an audit process and the identification of behaviour change solutions and mitigation measures that could be taken up by care home managers;
- utilise project findings to develop evidence-based guidance, by producing a best practice Overheating Checklist (in consultation with Public Health England, PHE) suitable for dissemination within the London care home stock.

2. Overheating in care home settings

2.1 Evidence from literature

During the 2003 heatwave, among all age groups, the highest increase in excess mortality was observed for those over 75 years old. Mortality rates appeared to be higher for those residing in care settings throughout England [1–3] and since atypically warm summers are projected to increase significantly, a raised risk of heat mortality and morbidity in the care sector is also anticipated [4–6]. Globally, the World Health Organisation (WHO) has projected that 15% of the 250,000 annual additional deaths due to climate change in the 2030s and 2040s will be due to heat related stress among the elderly [7].

Heat vulnerability is a function of heat exposure, the individual's sensitivity and the given adaptive capacity [8]. Heat sensitivity increases with age, largely due to limitations associated with the human thermoregulatory system [9]. People over 65 years old are among the most heat-vulnerable and especially those suffering from asthma, cardiovascular, respiratory and mental health conditions, socially isolated individuals and people with limited mobility [2,9,10,11]. The presence of health conditions can limit the body's ability to respond to environmental stressors, as well as the individual's capacity to adapt their environment to the changing climatic conditions or move away from an uncomfortable environment, all of which are likely to be aggravated with age. For this purpose, it is important to ensure that residents take the medication they need and keep in mind that certain medication can also exacerbate heat related illnesses, thus putting specific residents at higher risk [11]. In addition, it is important for medication not to be exposed in high temperatures.

As explained in Section 1.1. of the Methodology Report, there is currently some indication of summertime overheating being experienced in both poorly and highly insulated care settings in the UK, as well as a lack of recognition of the summertime heat-related risks [12–14]. Epidemiological studies on older people, both in the UK and France, have shown an increased susceptibility to heat exposure associated with the lack of air-conditioning (A/C) and sleeping on top floors [2,15,16], as well as inadequate building insulation and the presence of higher temperatures around the building [16]. Other generic domestic building characteristics that have been reported as contributing to increased summertime internal temperatures include restricted window opening, single-aspect ventilation, extended glazing areas, especially if facing west or east, inadequate solar shading, low floor to ceiling height, high insulation and air-tightness and high internal heat gains from household equipment, hot water distribution pipes and mechanical ventilation with heat recovery (MVHR), where the summer bypass is not utilised [11,17–19].

Overall, overheating and building age in domestic buildings seem to be correlated, owing to parameters including the typology, size, wall/glazing ratio, insulation level and air tightness of the building. For example, 1960s domestic buildings and top-floor purpose built flats appear to be more prone to overheating due to their poorly insulated building fabric, whereas concrete-built ground floors present the lowest temperatures[20–23]. Highly insulated newbuilds are also prone to overheating due to their low heat loss capacity[24–26] and overheating is often more pronounced in their corridors, due to the presence of hot water pipework distribution systems, such as district heating[19].

Clearly, the placement of the most vulnerable people in buildings that are highly likely to overheat should be avoided. Several studies have indicated an urgent need to address overheating in the care sector [2,9,13,14] and the Committee on Climate Change and its Adaptation Subcommittee (CCC ASC) has recently acknowledged the need to include heatwave climate resilience in the inspection of care settings [27]. However, there are currently no safeguards in place addressing heat risk and ensuring care homes maintain comfortable internal temperatures during hot weather periods. Overheating is not included in the NHS's Emergency Preparedness, Resilience and Response (EPRR) plan and there are no established criteria for assessing the care sector's preparedness against hot weather, both under the current and changing climate.

2.2 Relevant schemes and initiatives

Following the Environmental Audit Committee's (EAC) report [27], the Care Quality Commission (CQC) launched the #TempAware campaign to raise awareness of the overheating risks in care homes, highlighting the need for monitoring people with physical and mental conditions that make them particularly vulnerable [28]. This includes references to Public Health England's (PHE) *Heatwave Plan for England* [11], and the Care Provider Alliance (CPA) advice on the development of contingency plans in adult social care [29]. The former aims to raise awareness, particularly for the vulnerable, and provides straightforward advice to increase the population's resilience under hot weather. It also provides specific advice to care home managers and staff in the NHS *Heatwave plan for England: Supporting vulnerable people before and during a heatwave* [30] and the accompanying *Beat the heat: staying safe in hot weather* leaflet [31], including considerations for indoor temperature monitoring, cooling down measures and the provision of cool rooms. PHE has also published a *Beat the heat: keep cool at home checklist* [32] that highlights the domestic building features that are most likely to lead to overheating, as well as some measures that can be taken to mitigate the risks. The CPA provides more generic advice on the creation of contingency plans in the care sector, considering heatwaves among other circumstances likely to cause disruption to the care services.

The NHS *Heatwave Plan for England* [11] also describes the PHE's heat-health watch system that includes five levels of heatwave alerts running on different periods and/or based on certain triggers, as shown in Table 1. Level 0 refers to long term measures that can be implemented all year round to reduce the impact of climate change and heatwave risks, including urban and building interventions. This is in accordance to UK's National Adaptation Programme [33], setting out the actions that need to be taken to address the risks, as identified in the UK's Climate Change Risk Assessment [34]. Level 2, running between the start of June and mid-September, marks a period of increased awareness and background preparedness for social and healthcare services through the implementation of the measures described in the heatwave plan. Level 3 requires actions targeted towards high risk groups of people and the most severe, Level 4, requires a good coordination between different sectors to respond to heatwave effects that put the integrity of the health and social care system at risk and/or where they extend to other sectors.

Table 1. Heatwave alert levels and triggers for London

Level	Description	Run period or trigger
0	Long-term planning	All year
1	Heatwave and summer preparedness programme	1st June – 15th September
2	Heatwave is forecast, alert and readiness	Whenever a 60% risk of the London specific 32 °C day- and 18 °C night- time external temperature thresholds is projected in the following 2-3 days
3	Heatwave Action	Whenever the London specific 32 °C day- and 18 °C night- time external temperature thresholds are reached
4	Major incident	Whenever severe or prolonged heatwave affects sectors other than health

As part of *London's response to Climate Change*[35], the draft new London Plan sets out the mitigation of climate change effects in terms of overheating. Policy 5.9 on the overheating and cooling of buildings seeks to reduce both overheating and the potential reliance on mechanical cooling through a 'cooling hierarchy' that prioritises the implementation of passive measures over-active. Listed in ascending order, these are: (a) minimising internal heat generation through energy efficiency design, (b) keeping the heat out by orientation, shading, albedo, fenestration, insulation and the application of green roofs/walls, (c) managing the building's heat through exposed thermal mass and high ceilings, (d) employing passive ventilation, (e) using mechanical ventilation and (f) deploying the lowest carbon options of active cooling.

3. Audit findings: Current & future state of overheating and exposure

3.1 Factors contributing to heat exposure in the pilot care home

Victoria Care Centre is a purpose-built, modern building with a flat roof, situated in the industrial area of Park Royal, a heavily built up area of west London. It has a 5-storey, block and beam structure that was built per the 2010 Building Regulations. The U-shaped design features a central courtyard with a main entrance façade facing south east. Its south-west façade is overshaded in the summer by the 9-storey neighbouring building from around noon time onwards. The building is naturally ventilated and is equipped with automatic operation extract fans in all bathrooms and a constantly running in-line duct extract system in utility rooms (kitchen, laundry, plant room etc.). A/C units are only present in the plant room, the medication rooms and the kitchen storage room, where indoor temperatures need to be maintained below certain thresholds for safety reasons. During the site visit, the building was fully operational and all 115 ensuite rooms were occupied. The manager identified two areas of noticeable overhearing, the top floor and the plant room.

The analysis of the data obtained through the physical survey, monitoring, social survey and interviews and building thermal modelling led to the identification of several possible overheating sources in Victoria Care Centre. These relate to one or more of the three following areas:

- High internal heat gains from machinery/heating equipment and their circulation pipework;
- excessive solar gains, mainly due to the unshaded glazing present and,
- inadequate methods for heat management and dissipation.

Internal heat gains

The internal heat gains of the building are a function of the occupancy and equipment schedule and type. The building's occupancy density and the metabolic rates of the occupants are considered low, with residents mostly in a sedentary or recumbent position. The energy efficient lighting utilised is also associated with low heat gains. Perhaps the single most intensive and, at the same time unnecessary, summertime internal heat source is the gas-fired space heating circulation system. Together with the domestic hot water circulation system, they form a year-round source of indoor heat gain. The bypass that is normally in place during the summertime period, so that hot water is not circulated unnecessarily through the space heating pipework, is not utilised due to multiple joint leakages around the system. On a positive note, both the space heating and domestic hot water flow and return pipework seem to be well insulated.

Solar gains
Solar radiation can cause a significant increase in the building's internal temperature. The building's insulated roof and walls appear to be offering sufficient solar thermal protection to the building envelope but the same cannot be said for the glazing elements. Even though double glazed, they are neither shaded, nor do they incorporate a solar protection filter. Some of the windows are partially shaded from other parts of the building itself (i.e. those facing the inner courtyard) or the neighbouring high-rise building but most of them are not adequately protected from solar gains.

Heat management and dissipation
The lack of appropriate methods of heat management and dissipation in modern, highly insulated and airtight buildings, such as Victoria Care Centre, can lead to high levels of indoor overheating due to the unwanted summertime solar gains being trapped within the building envelope. As it stands, the building does not incorporate any solar protection measures and has a limited heat management capacity that stems primarily from the ventilation regime.

In terms of ventilation, the restricted window opening due to potential conflict with safety issues, constrains air flow, which is most effective during the night and especially when coupled with adequate thermal mass. The presence of thermal mass can moderate maximum internal temperatures by storing excess heat during the day and releasing it during the night when the outside temperature is lower. In this case, the heat transfer between thermal mass and air is blocked to some extend due to the finishing materials and the false ceilings present in all floors.

Other features that may hinder the building's heat management and dissipation potential include its low effective floor to ceiling height, in all floors except the ground level that brings the higher stratified air temperatures closer to the occupants' level and its location, in a densely-built area within London's Urban Heat Island.

3.2 Current level of overheating awareness and management

Residents were mostly aware of the cold-related risks, however staff members appeared to be more aware than residents of the negative effects of overheating in the summer. The latter perceived this to be more of a concern for themselves but would put the needs of the residents before their own. Their main method of keeping cool during hot weather was to drink more water. They were aware that residents were not always able to communicate their thermal comfort, and would often check hands/feet/foreheads to confirm thermal needs. Staff members were also aware of the increased health risks of residents getting too cold, but felt that these were rare occurrences in the building. Providing fluids during periods of hot weather is the most common solution to keep the residents cool.

Overheating in the building is managed through opening windows, albeit restricted, the provision of fans and moving residents to the cooler ground floor common areas during heatwaves. Cross ventilation is facilitated through the internal doors remaining open. The ground floor common area and the first floor ensuite rooms overlooking the patio benefit from a daytime-only higher ventilation rate during the hot weather, since their doors can remain fully open and a higher openable area is allowed for ground floor windows.

3.3 Addressing the current & future state of indoor overheating

The social data collection, indoor temperature monitoring and the dynamic thermal modelling analysis all revealed the presence of overheating to some extent, even during the heating season. The monitored resident area temperatures during spring 2019 were found to range predominantly between 26 °C and 28 °C. The two areas that the manager identified as being overheated the most, are the mechanically cooled plant room and the top floor. The latter was also confirmed through the thermal modelling analysis. Considering all lounges in the building, the thermal modelling analysis also showed that the lowest temperatures can be found on the ground floor.

On average internal temperatures are projected to increase by approximately two and four degrees in 2050s and 2080s, respectively, when the measures that are currently used to address overheating will no longer suffice. Currently, adequate night ventilation may be able to maintain internal temperatures close or below the 26 °C overheating threshold in some areas of the building. However, in 2080s, night ventilation, nor a combination of passive measures alone appear to be able to achieve the same effect, with average night-time temperatures lying well above the 26 °C threshold.

3.4 Discussion and validation of the findings

Overall, the environmental monitoring, social data collection and thermal modelling results agree with the findings previously reported in literature. The presence of overheating and the lack of considerable heat risk awareness and preparedness have been highlighted in two other UK studies on care settings[12,14]. The Joseph Rowntree Foundation (JRF) '*Care provision fit for a future climate'* report discussed the disproportionally heightened awareness of cold- in relation to heat- risks that also emerged in this pilot case study. Common themes between Victoria Care Centre and the two studies on care settings were identified in terms of the parameters contributing to overheating, including high solar gains due to the lack of shading features, poor ventilation associated with safety considerations and the presence of unwanted internal heat gains from the heating system.

This pilot project builds on previous work on overheating risk in the UK care homes settings to develop a methodology for the assessment and mitigation of overheating risks in London care homes that are particularly sensitive to heat risk. While it was not possible to validate the dynamic thermal simulation, model using the spring-time environmental monitoring results, as these were obtained during a space heating period, however the findings agreed with the views expressed by the pilot care home manager with regard to the areas being mostly overheated. The findings were validated using the detailed environmental monitoring deployed as part of Natural Environment Research Council

(NERC) funded ‘Climate Resilience of Care Settings’ project. Members of the Project’s Advisory Board have also provided quality assurance for this audit pilot study.

4. Potential overheating adaptation measures and recommendations

The identification of a suitable mitigation strategy for the audit pilot was based on the assessment of a range of overheating reduction measures against selected evaluation criteria, taking into consideration all-round effectiveness. The list of possible overheating mitigation measures was sourced from literature investigating overheating in care settings and domestic environments in general. These include interventions regarding ventilation regimes, insulation levels, the window's solar protection, internal heat gains, thermal mass, external surface albedo, active cooling options and green and blue landscape solutions. All the solutions identified are discussed in detail in Section 4.1. Section 4.2 details the development of a mitigation strategy, including the criteria against which the overheating measures identified in literature are assessed, and its application to the specific case study pilot. The pilot case study recommendations are presented in Section 4.3.

4.1 Identifying potential overheating solutions

There is significant potential for care homes to benefit from adopting an adaptive approach to overheating. This section presents the range of overheating reduction measures as identified in literature, alongside evidence on their all-round effectiveness, including wider benefits and associated constraints. These may relate to site or physical constraints and impacts in relation to aesthetics, view, noise, security and air quality that may challenge the implementation of adaptation measures. Different measures can be implemented at different levels, for example, urban, building, room-by-room, building services and occupant level. Of those, some can be implemented relatively easily while others involve work that would be more sensible to incorporate during a major refurbishment. Table 2 provides indicative costs for selected measures, however these are for guidance only as they are likely to vary significantly in practice. Costs have been obtained from both BEIS[36] and CIBSE (2014)[19], as no single source was available for the measures listed.

The interventions and actions identified in literature are grouped here under internal heat sources and management, insulation, external surface albedo, window solar protection, thermal mass, ventilation, green/blue spaces and mechanical cooling. The measures whose effectiveness is increased when grouped together and those that are most likely to be useful in specific types of buildings are discussed at the end of this section.

Table 2. Indicative costs for overheating adaptation measures (including materials/installation [a])

Adaptation measure	Indicative cost	Comment
LEDs	£2-£20.40/bulb [36]	Price expected to follow a falling trend.
Dedicated LED fitting	£50 [36]	-
Cavity insulation	£5-£6/m^2 [36]	-
Internal wall insulation	£55-£140/m^2 [36]	Includes additional costs for insulation fitting, plasterboard application and redecorating
External wall insulation	£55-£180/m^2 [36]	Includes additional costs for insulation installation and rendering
Loft insulation (joist level)	£10-£20/m^2 [36]	Differences resulting from varying insulation thicknesses, the presence of existing insulation etc.
Loft insulation, (rafters)	£20-£40/m^2 [36]	-
High reflectance paint	Varied [19]	Relatively low cost that varies with application
Increased glazing g-value	approx. £32/m^2 [19]	On the basis of glazing replacement only. Price expected to fall as it becomes and industry standard.
Solar shading	approx. £34/m^2 [19]	Could take the form of louvres, brise-soleil etc.
External shutters	£200/m^2 or higher[19]	Based on two pairs of vertical and one pair of horizontal bi-fold shutters, to allow at least one part of the window to be open while the rest is closed.
Phase-change plasterboard	approx. £52/m^2 [19]	Currently very expensive but price is expected to follow a falling trend in the years to come.
Increased ventilation area	approx. £22/m^2 [19]	On the basis of ironmongery change.
Ceiling fans	approx. £48/m^2 [19]	-

[a] The costings were published in 2014 or 2017, depending on the study they were derived from, and thus some of the estimations might be out of date. Even though the study by Palmer et al. (2017) excludes VAT [36], it is not clear whether CIBSE's TM55 case studies (2014) include VAT in the costs or not [19].

Internal heat sources and management practices
Ensuring all hot water pipework is adequately insulated and none of it is circulating hot water unnecessarily is significant for the elimination of unwanted internal heat gains. With the same goal in mind, good practice dictates turning off the heat recovery of mechanical ventilation (MVHR) units during summer, switching off any unused lights and non-essential equipment, especially those without an external heat discharge, and ensuring heat generating equipment are discharging heat externally, where possible [18]. While testing several case study buildings under different overheating reduction scenarios, the CIBSE TM55 [19] came to the conclusion that upgrading the lighting and equipment to energy efficient equivalents can in some cases, depending on the incoming solar radiation and effectiveness of ventilation strategy, could be more efficient in the elimination of heat gains in comparison to building fabric and services interventions.

The use of smart controls, such as automatic dimming of lights, and the use of occupancy sensors, and/or training occupants on how to operate the building in order to make the best use of its passive cooling capacity could make an impact comparable to that of a building fabric upgrade at a minimal cost [19]. Other behaviours and management techniques in order to keep the internal environment and occupants cool include regulating the density of room occupation, managing services such as food preparation, ensuring the availability of cool internal and external spaces (for example, cool rooms, usually on the ground floor/north side and shady/green courtyards), maintaining a heatwave plan, being up-to-date in terms of heatwave weather forecasts, monitoring internal temperatures/vulnerable people and avoiding placing them on top floors. Direct actions that can be taken in case of a heatwave involve the reduction of clothing insulation levels, staying hydrated, consuming cool water and food, taking cool showers and maintaining a low metabolic rate by reducing activity levels and avoiding stressful situations [18,19].

Building fabric insulation level
Well insulated walls and roofs are important in the prevention of overheating, providing that solar and internal heat gains are minimised and that appropriate heat dissipation methods are in place [37]. Should this not be the case, the heat trapped inside the insulated building envelope is likely to lead the opposite effect. Between internal and external insulation, the latter has been found to be very effective, especially with higher external wall areas, while internal insulation is likely to lead higher levels of overheating, especially in west- and east- facing rooms [37,38]. However, it may be effective if combined with adequate solar protection [38].

External surface albedo
The use of light coloured/high reflectance paint on external surfaces can reduce building fabric heat gains compared to the use of absorptive materials and is more effective with higher areas of application [37]. The collective increase of roof albedo on an urban scale can contribute towards the reduction of the UHI effect and involves a relatively low cost of application [18]. However, it may also increase the winter heat load, cause some disruption

when retrofitting and may not be appropriate for listed/brick buildings due to the restrictions applied by planning regulations [19].

Window solar protection

There are a variety of options for the control of solar gains through windows, including the use of internal blinds and curtains to protect from direct sunlight, the application of glazing and film technologies, the reduction of extended glass areas and the installation of external shading devices, with the latter usually found to be the most effective measure for the mitigation of overheating, particularly for rooms occupied during the hottest hours of the day [18,37]. External shading could take the form of shutters, louvers, overhangs, side-fins and brise solei[b] fitted on the building exterior but may impact the building's appearance and thus require a planning permission. Once a planning permission is obtained, their installation is fairly simple and suitable for a room-by-room application [19].

Internal and external shading devices can have a visual impact, both in terms of view and natural lighting reduction. This may lead an increased lighting energy consumption that could perhaps be better controlled automatically for movable structures. Since fixed shading cannot be adapted, it may also lead to increased heating energy consumption due to the reduction of winter solar gains [37]. The same applies for glazing and film technologies resulting in low solar energy transmittance. Overall, solar shading has been found to be effective as long as it does not interfere with daylight needs [22,37,39].

In terms of glazing reduction, for example, by replacing glazing panels with opaque insulated panels, this may only be considered where there are large window areas and is also subject to planning permission [19]. Shading devices and solar exclusion technologies are mostly useful on south-, east- and west- oriented glazing. [37]. Shutters and horizontal shading is particularly effective for south-facing glazing, whereas vertical shading structures are more useful for east- and west-oriented windows.

Thermal mass

The presence of thermal mass can be an effective overheating reduction method but only if coupled with night-time purge ventilation and appropriate finishing materials to allow interaction between the thermal mass and the surrounding environment [21,40]. The CIBSE's TM55 [19] suggests optimising the thermal mass of buildings by exposing any existing heavyweight materials, where possible (for example, by removing plaster or wall decorations in concrete-based structures), and using phase-change plasterboard where no thermal mass is available. This can be a disruptive and expensive intervention, especially if existing plaster needs to be removed and phase-change materials are to be utilised. It may also interfere with aesthetic requirements, in case the underlying materials, such as concrete are permanently exposed. However, it can be applied selectively, for example, on selected, high-risk rooms [19].

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[b] A shading device consisting of a perforated screen or louvres.

Ventilation regimes

Natural ventilation for cooling purposes is only useful when the indoor air can be replaced by cooler external air. Keeping windows closed when outdoor temperature is higher than the internal while taking advantage of the cooler night-time ventilation has been found to be an effective cooling practice, particularly for older people who remain at home during the hottest parts of the day [37]. Night-time ventilation can be beneficial both as a passive and mechanical ventilation technique and is crucial for the control of overheating. Night ventilation can maintain lower daytime temperatures, however it can only be effective if the diurnal temperature difference is high enough for the stored heat to be purged [37]. Between cross ventilation and single-sided ventilation, the wind-driven cross ventilation is far more effective as a purge ventilation technique and its cooling effect can be further enhanced using ceiling fans. The buoyancy driven stack ventilation is also more effective than the single-sided ventilation, whose cooling benefits are limited, especially under warm weather [19]. Generally, a higher number of windows with increased openable areas are linked to an increased cooling potential whereas deep floor plans tend to restrict the ventilation potential[18].

A number of practical issues that should be considered when examining natural ventilation options have been identified in literature [18,19]. These include:

- security concerns, particularly for ground and lower floors, including the need to ensure an insect-, bug- and animal- free operation;
- conflicts with the ‘secure by design’ windows and the application of opening restrictors;
- the occupants’ influence on window operation, often involving the habitual opening/closing of openings, an inability to control them optimally due to forgetfulness or the lack of specific advice that could possibly be overcome with automatically controlled windows [37];
- the presence of air and noise pollution and the possible use of sound attenuating baffles with natural/mechanical ventilation that can however reduce airflow;
- fire safety, security and privacy concerns in relation to the operation of internal and/or external doors and windows that may be more pronounced in people with mental health problems;
- wind and precipitation considerations and,
- conflict between the need for winter heat loss reduction and the need for increased natural ventilation in the summer.

While the cost of opening windows is zero or very low, the cost for the provision of an effective ventilation plan can vary significantly depending on the specific circumstances.

This may depend on the need for additional security measures, a change in windows design or hardware, the installation of a whole-building mechanical ventilation system or the implementation of cross-ventilation through large ducts. In addition, some of these interventions can be particularly disruptive [18,19].

Green and blue infrastructure

The use of plants and water features can be an effective way for the reduction of overheating, as they can offer shading and/or evaporative cooling, alongside important psychological benefits [19]. A shaded courtyard featuring such characteristics can be used as a cooler amenity space during the hottest times of the day. The extensive use of green and blue spaces can also be beneficial in reducing the UHI effect [19], with trees being more effective in comparison to low-rise vegetation [18]. Blue features include water bodies and fountains, however their use should be carefully considered in environments where insects can thrive [18].

The application of green spaces includes planting trees, bushes, lawns and green roofs and walls. All of them can provide cooling through evapotranspiration and trees offer the additional benefit of shading. Of all tree types, deciduous trees are the most favoured, as they provide benefits both in the summer and winter due to their varying shading effect, while draught resistant plants provide a weaker evapotranspiration cooling effect [19]. When considering the use of vegetation for cooling purposes, their high maintenance and associated costs need to be taken into account, any physical constraints prohibiting the plantation of trees, as well as the fact that their effectiveness cannot be accurately quantified with the dynamic modelling software tools currently available [19].

Active cooling options

When passive cooling solutions alone are not sufficient for the provision of comfortable conditions, active cooling solutions may be utilised. These range from the use of simple fans, portable mechanical cooling units, cooled supply air provided through mechanical ventilation systems to fully air-conditioned spaces. Standing and ceiling fans cannot lower air temperature but they can assist air circulation and the reduction of perceived temperature by a few degrees through the evaporation of sweat [41]. Ceiling fans are simple to install and may be able to circulate more air than standing fans but they are restricted by a minimum ceiling height requirement of 2.7 m [19]. However, the possible exacerbation of dehydration through the use of fans should be taken into consideration, which is more likely to happen under very hot and dry conditions [41].

Of those systems that can cool down air temperature, the most energy efficient are those that utilise some sort of renewable technology, including groundwater and earth-coupled cooling. These can be combined into a mechanical ventilation system that should be ideally used when windows are closed and internal temperatures are higher than external [19]. The use of A/C options should be carefully considered as they are likely to significantly increase carbon emissions and exacerbate the UHI effect. An increased use of A/C could lead a higher risk of power outages, which could in turn increase heat risk due to the lack of electricity to power the A/C. Keeping windows closed when A/C is in operation can minimise the energy required for cooling. However, this may be difficult to implement unless the system switches off automatically when a window is opened, since occupants tend to do so for a variety of reasons, including a perceived need for fresh air, the need of odour/condensation removal and habitual window opening behaviours [18]. Even when mechanical cooling shuts down with window opening, there are risks associated with a potential inability of the mechanical system to maintain comfortable internal temperatures due to frequent window opening [18].

Selective application of overheating reduction measures
The effectiveness of overheating reduction interventions and actions in each case depends on the building characteristics, its occupancy profile, as well as the synergistic effect of the selected measures. With the older occupants in mind, who are likely to spend more time indoors and thus are more likely to experience overheating particularly during the hottest hours of the day, those measures that are likely to reduce peak daytime temperatures can be very beneficial. Preventing the warmer external air to enter the building through windows was found to be beneficial in homes occupied by older residents, as well as the provision of night-time ventilation. External shading mechanisms, such as external shutters, overhangs and awnings, have also been found to be very effective, particularly for south-facing rooms [37].

Night-time purge ventilation is useful for both lightweight and heavyweight buildings but when it comes to high thermal mass, it is essential that adequate levels of night-time purge ventilation are provided, for heavyweight buildings to be considered more effective than lightweight buildings [19,20]. The effectiveness of night ventilation can be further enhanced with the use of solar exclusion methods, including wall and roof insulation, high external surface albedo, shading, even if this is in the form of internal blinds and selective glazing filters, and fans to increase air circulation [19,22,37,39]. Overall, interventions on exposed building surfaces, such as light coloured rendering and wall insulation, are more effective with higher wall areas [37]. Even though buildings with external wall insulation perform better in warm weather in comparison to those incorporating internal wall insulation that can even exacerbate overheating, when internal insulation is coupled with other solar control measures and optimum ventilation rules it can still offer significant benefits [37,40].

Despite the beneficial impact of well designed and implemented adaptation solutions, several studies have predicted that passive measures alone may not be adequate for the management of internal temperatures under the future warming climate [42–45]. However, the investment in adaptation measures is expected to allow buildings to remain comfortable for longer and delay the installation of mechanical cooling. The risks associated with buildings that are not designed to passively avoid overheating are highlighted in CIBSE TM55 [19], where highly insulated, heavyweight buildings proved to be better performers than highly-glazed, lightweight buildings, even if the latter were air-conditioned.

4.2 Developing a site-specific mitigation strategy

The overheating mitigation strategy described in this section was developed with a view to inform recommendations for the pilot case study. As a first step, a generic list of measures was compiled through the review of best practice approaches. As shown in Table 3, this list includes measures that can be implemented on different levels, ranging from a larger urban scale down to the building fabric level, the building services and the behavioural level of its residents and stakeholders. The measures concern a range of stakeholders, including local authorities, building designers and inspectors, PHE and the care home providers.

The assessment of possible interventions for the pilot case study was implemented against a 5-point evaluation scale for each assessment criterion. The assessment criteria, concerning a variety of parameters, including overheating reduction potential, implementation cost and feasibility, and their score indicators are presented in Table 4. They were developed to enable the assessment of all-round effectiveness of overheating reduction measures. All measures listed in Table 3 were assigned an indicative rating via expert judgement. Appendix 1 depicts the evaluation matrix utilised for the assessment of the interventions identified in literature against the evaluation criteria, with the pilot care home in mind. Following the assessment, an average overall score was calculated per intervention. The higher the score, the higher the measure’s all-round effectiveness and the reverse.

Table 3. Overview of measures per area of implementation

URBAN LEVEL			
A	Green infrastructure	A1	Evapo-transpirative cooling/shading through tree planting and the presence of parks, woodlands etc.
		A2	Green roofs and walls
B	Blue infrastructure	B1	Evaporative cooling through water bodies and fountains
C	High albedo surfaces	C1	Use heat-reflective, light coloured surfaces on street level (pavements etc.) and building surfaces
BUILDING FABRIC LEVEL			
D	Thermal insulation optimisation	D1	Ensure roofs and walls are adequately insulated
E	Air distribution system optimisation	E1	Allow for increased ventilation rates either through window adaptation and/or the provision of mechanical ventilation
		E2	Enable cross-ventilation through ducts
F	Solar gain control	F1	Solar control window film
		F2	External shading in the form of louvres, side fins etc.
		F3	External shading in the form of movable shutters
G	Thermal mass optimisation	G1	Increase thermal mass, e.g. by exposing existing or using phase-change material
BUILDING SERVICES			
H	Minimise internal heat gains	H1	Turn off unnecessary heat sources, such as lights and electrical equipment not-in-use
		H2	Turn-off unnecessary heat sources, such as heating systems and their circulation network
		H3	Identify and optimise inadequately insulated hot water vessels and pipework
		H4	Ensure all light bulbs are energy efficient
I	Mechanical ventilation and cooling	I1	Utilise standalone fans
		I2	Install ceiling fans
		I3	Increased ventilation through MVHR
		I4	Provide cooled air through a mechanical ventilation system – could be combined with a cooling coil, ground-coupled heat exchanger/earth tubes and RES in general
BEHAVIOURAL LEVEL			
J	Care home occupants	J1	Close curtains when windows exposed to sun
		J2	Keep windows closed when hotter outside than inside
		J3	Keep windows open at night to allow purge ventilation
		J4	Allow cross-ventilation by keeping internal doors open
K	Care home management	K1	Monitor temperatures in all rooms and have an emergency heat response plan
		K2	Educate staff and residents
		K3	Identify cool rooms
		K4	Move residents to cooler rooms and/or cooler external gardens and courtyards if temperatures exceed 26ºC

Table 4. Assessment criteria for the evaluation of overheating reduction measures

Criteria	Definition	Scale
Effectiveness	the measure's potential for overheating reduction	1 – will not affect overheating 3 – may moderately minimize overheating 5 – may significantly minimize overheating
Affordability	the cost associated with the measure's implementation	1 – high cost 3 – medium cost 5 – low cost
Feasibility	the measure's ease of implementation/ deliverability	1 – difficult to implement 3 – neither difficult nor easy to implement, 5 – easy to implement
Disruption-free	the level of disturbance or interruption of the occupants' daily routine	1 – decant required 3 – moderate disruption 5 – stress-free occupant in residence possible
Usability	the degree to which the measure is easy to use and operate	1 – highly demanding to use 3 – moderately easy to use 5 – no usage required
Energy/CO_2 savings	the measure's influence on energy consumption and carbon emissions	1 – energy/carbon intense measure, 3 – no change in energy/carbon 5 – energy/carbon saving measure
Health and safety risk-free	the measure's risk in terms of health and safety	1 - high risk for health and safety 3 – moderate risk for health and safety, 5 – low risk for health and safety
Visual amenity	the measure's effect on the visual perception of the occupant, in terms of view and daylight	1 – negative visual impact 3 – no visual impact 5 – positive visual impact

Table 5 presents the ranked measures in descending order, based on the overall score for each and grouped according to GLA's cooling hierarchy [35]. Thus, of all measures, those that minimise internal heat gains should be addressed first, followed by various passive measures addressing heat protection, heat management and natural ventilation optimisation techniques. Active measures, such as MVHR and mechanical cooling should be considered last. Of all the measures addressed here, some have already been taken up by the pilot case study, at least to some extent. These have been marked with an asterisk in Table 5.

Table 5. Ranked measures and their impacts based on individual assessment criteria, grouped according to GLA's cooling hierarchy

ID	Measures	Effectiveness	Affordability	Feasibility	Disruption-free	Usability	Energy/CO^2 savings	Health and safety risk-free	Visual amenity	Overall score
Minimising internal heat gains										
H2	Turn off unnecessary hot water circulation	3	5	4.5	5	5	4.5	5	3	35.0
H1*	Turn off unused lighting/ equipment	3	5	5	5	4	4.5	5	3	34.5
H4*	Energy efficient lighting	3	4.5	4.5	5	5	4	5	3	34.0
H3*	Hot water pipework/ vessel insulation	4	4	4	4.5	5	4.5	5	3	34.0
Keeping the heat out										
A1	Deciduous trees for shading	4	4	3	5	5	3	5	5	34.0
C1	High albedo surfaces	4	3	3.5	4.5	5	3	5	3	31.0
J1	Curtain closed when window exposed to the sun	3	5	5	5	4	3	5	1	31.0
A2	Green roofs/walls	3	2.5	3	4	5	3	5	5	30.5
F1	Solar control window film	3	4	4	4	5	2.5	5	2	29.5
D1*	Roof/wall insulation	4	3	3	3	5	3	5	3	29.0
F2	Louvres and side fins	4.5	3.5	3	3	5	2.5	5	2	28.5
F3	Movable shutters	4.5	2.5	3	3	4	3	5	1	26.0
Managing heat										
J2	Keep windows closed when hotter outside than inside	3	5	5	5	4	3	5	3	33.0
B1	Water bodies, fountains etc.	3	2.5	3	5	5	3	4	5	30.5
G1	Thermal mass	4	3	1	1	5	3	5	3	25.0
Employing passive ventilation										
J3*	Night ventilation	4.5	5	5	5	4	3	4	3	33.5
J4*	Keep internal doors open to enable cross ventilation	4	5	5	5	4	3	4	3	33.0
E1*	Increase window openable area	4	5	5	5	4	3	1	3	30.0
E2	Cross-vent. through ducts	4	3	1	1	4	3	5	3	24.0
Using mechanical ventilation										
I1*	Free standing fans	3	4	5	5	4	2	4	3	30.0
I2	Ceiling fans	3.5	4	4	4	4	2	4	3	29.5
I3	MVHR	4	2	1	1	4	2	4	3	21.0
Deploying the lowest carbon option of active cooling										
I4	Cooled supply air	5	1	1	1	3	1	4	3	19.0

* Measures that have already been taken up by the care home, at least to some extent

Table 6. Beneficial measures that can act synergistically and offer significant overheating reduction benefits when applied to specific building types or uses

Building type	Beneficial measures
Vulnerable occupants	Applying window and curtain rules, adequate solar protection, night-time ventilation
Heavyweight	Adequate solar protection, night-time ventilation (essential)
Lightweight	Adequate solar protection, night-time ventilation
Highly insulated	Adequate solar protection, night-time ventilation
Naturally ventilated	Use of fans to increase air circulation
Mechanically ventilated	Adequate solar protection, night-time ventilation
Mechanically cooled	Adequate solar protection, seal building when A/C in operation

Effectiveness
The overheating reduction effectiveness marking ranged from moderate to high for all the measures evaluated. The cooled air supply was marked the highest as it is the only measure that can lower internal temperatures on demand. However, this may not suffice for buildings that are not passively designed to some extent. Passive design requires a variety of methods to be utilised for their overheating reduction potential to be maximised. The remaining measures have been ranked as having a moderate or moderate-to-high overheating reduction potential. Even though, some would not be able to provide a significant overheating reduction alone, their synergistic effect can be highly beneficial. Table 6 provides some examples of passive measures that can be highly effective when grouped together, based on specific building types or uses.

Affordability
When considering affordability of the suggested measures, the installation of centralised mechanical ventilation and active cooling rank at the least affordable options, however the latter can also be implemented on a room-by-room basis, for example, to ensure that the most overheated areas of the building maintain comfortable temperatures. In general, those measures whose installation require building fabric adaptation or other extensive building work to be accommodated tend to be fairly or moderately expensive, especially if they need to be applied on the whole building. Measures that require a standalone or limited application can incur significantly lower costs while there are also measures that can be implemented at no-cost, particularly if they relate to building features that are already in place, such as windows and curtains, where all is needed is the application of certain rules for their operation.

Feasibility
Of all measures, the most difficult to implement are those involving detailed planning and major building work or reconstruction of the internal space. The installation of a central air-conditioning or mechanical ventilation systems in a building, where provisions for their installation have not previously been made fall under this category. Measures than can be

implemented externally tend to be slightly easier to implement but not necessarily straightforward as they may be, for example, subject to planning permission and may require the presence of scaffolding. External window shading structures fall under this category. Measures, such as the application of solar control window films and ceiling fans are easy to implement as they do not require a highly-specialised design process or skills for their implementation. Most of the no-cost measures are also very easy to implement as they require only simple behavioural changes.

Disruption
The disruption associated with the measures evaluated is higher with major internal building works, where users must be physically removed for them to take place, (exposing thermal mass, applying phase-change materials etc.), and lower with externally installed measures, where the disruption may be mostly associated with noise disturbance, such as the application of external shading. Other measures, such as those working with behavioural changes and small adjustments to existing equipment involve minimal or no disruption at all.

Usability
Following their installation, all measures examined are thought to be easy or very easy to use, perhaps except for air-conditioning due to the confusing, in many cases, user's interface. Many of the measures are easy to use manually, such as closing the windows when external temperatures are higher than internal, but may be subject to human error or handling which may be influenced by habits and subjective judgements. The measures ranked the highest in terms of usability are those that require very little or no manual intervention at all and can just be left alone, such as permanent shading devices, building fabric insulation and high albedo paint.

Energy and carbon savings
Of all measures, the most energy intense is the use of A/C, which is also the most carbon intense unless coupled with renewable energy technologies. Mechanical ventilation systems and fans are also associated with some energy consumption, however this is significantly lower than that of A/C. If the remaining measures are not installed in a mechanically cooled building, they do not have any impact on summertime energy consumption, except for those associated with internal heat gains and those that may increase the need for artificial lighting, and possibly heating in the winter, by blocking the sun. Switching off unnecessary heat sources, insulating hot water pipes/vessels and replacing lighting and equipment with their more energy efficient counterparts, all result in some energy savings. Any structure blocking the sun, particularly if it is a permanent feature, may lead an increase in energy consumption due to the higher need for artificial lighting and heating loads.

Health and safety
Except for larger window openable areas, the remaining measures have minimal or no impact on health and safety. Care homes usually place restrictors on their windows for

safety reasons, however this significantly restricts the cooling potential of natural ventilation and can only be overcome through an optimised window design or mechanical ventilation, both of which would incur high adaptation costs. Other measures that may pose some health and safety risks, albeit minimal, are cross-ventilation and all types of mechanical ventilation and cooling that may associated with the presence of draughts and the possibility of blue spaces attracting insects.

Visual amenity
The only ways the measures examined can impact visual amenity are either by blocking the residents' view and daylight or by offering them a pleasant scenery using green and blue spaces. The measures that are likely to interfere with the view and lighting conditions are those employed for solar control, especially curtains and shutters that need to be completely closed to be able to effectively block the sun. Whilst curtains and shutters can still offer unobstructed views once opened, permanent shading features and glazing filters obstruct view and daylight permanently but to a lesser extent.

4.3 Pilot case study recommendations

Based on the overheating reduction measures evaluation process described in Section 4.2, the measures that could offer the highest all-round effectiveness for application to Victoria Care Home are listed below in ranked order and grouped according to GLA's cooling hierarchy[35]. A standalone Overheating Checklist that can be used more widely by other care homes was also produced as part of this audit pilot project.

- Minimise internal heat gains by turning off the unnecessary space heating circulation in the summer. This can only be achieved after fixing any leaky joints.

- Keep the heat out by planting deciduous trees for shading on the pavements, (requires collaboration with the local council), painting the roofs and walls with high-reflectivity paint, applying green roofs/walls and employing either of the following window shading methods, listed from the least- to the most- effective:

    - keeping curtains closed when windows are exposed to the sun
    - applying solar control window film
    - installing permanent louvres and side fins
    - installing movable shutters.

- Manage heat by keeping windows closed when hotter outside than inside, utilising water features, such as fountains, and exposing any existing thermal mass, for example by removing carpets and exposing the concrete floor or using vinyl flooring that do not block the concrete's absorptive capacity.

- Optimise passive ventilation by utilising night-time purge ventilation, keeping internal doors open to enable cross ventilation and increasing the window openable area. These natural ventilation measures are already utilised to some extent but would be more effective if combined and applied extensively throughout the building. The extensive application of higher window openable areas would require window redesign to take place.

- Employ fans, providing there is no risk of cross infection [46], and ceiling fans in specific, where ceiling height allows their installation, and install MVHR to increase the ventilative cooling capacity.

- Provide slightly cooled supply air through the mechanical ventilation system, ideally coupled with renewable energy systems.

Table 7. Low cost, easy to implement measures for Victoria Care Centre

Type of measure	Measure description
Manage internal gains	Turn off the unnecessary space heating hot water circulation*
Keep the heat out	Keep curtains closed when windows exposed to the sun*
Manage heat	Keep windows closed when hotter outside than inside*
Passive ventilation	Utilise night-time purge ventilation, keep internal doors open and increase window openable area, where safe to do so*
Mechanical ventilation	Use free-standing and ceiling fans

* Measures considered as part of behaviour change initiatives

Table 8. Measures of moderate cost and installation complexities for Victoria Care Centre

Type of measure	Measure description
Keep the heat out	Plant deciduous trees on pavements
	Apply solar control window film
Manage heat	Expose existing thermal mass
Passive ventilation	Window redesign to allow higher openable areas without compromising safety

Table 9. Higher cost measures that could be implemented in the longer run, as part of a major retrofit of Victoria Care Centre

Type of measure	Measure description
Keep the heat out	Paint roofs/wall with high-reflectivity paint
	Apply green roofs/ walls
	Install permanent or movable window shading
Manage heat	Utilise water features
Mechanical ventilation	Install MVHR to allow higher ventilation rates
Mechanical cooling	Cooled air supply

The curtain, window and door rules included in Tables 7-9 concern behavioural changes that could be part of a wider behaviour change initiative. This can take the form of a care home management plan that aims to (a) educate staff and residents on how to act to prevent overheating and (b) formulate an overheating emergency response that could be adopted in case of an extreme heatwave event. This highly affordable and feasible preventative measure that could significantly minimise overheating health risks, particularly for the higher-risk residents, includes but is not restricted to the measures listed in Table D of the standalone Overheating Checklist document. These concern educating staff and residents to recognise and respond appropriately to heat related stress symptoms, monitoring internal temperatures and identifying and maintaining cool rooms, where residents can be moved to, should the temperatures exceed the overheating threshold.

The measures listed in Table 7 could be implemented instantly, without incurring any additional costs or by incurring minimal costs. Table 9 concerns more expensive measures that can be implemented at a later stage or, possibly during the planned building work for the addition of the 6th floor, and Table 8 presents measures that are in-between. Some measures can be implemented on a room-by-room basis, for example, to minimise costs by treating the most overheated areas first, or as part of a whole building adaptation strategy. Most of the measures can generally be combined, unless they serve the same purpose, as is the case of different external shading devices, or where there is a clash between the purposes served by each, for example, in the form of contradicting window rules. Overall, both adequate solar protection and night-time purge ventilation that can be enhanced by the presence of fans, are critical for the avoidance of overheating. Alongside these measures, the application of window and curtain rules during the hottest times of the day is particularly useful for buildings occupied by older occupants, such as Victoria Care Home.

5. Summary and lessons learnt

The audit pilot case study was based on an interdisciplinary approach for mitigating the risk of overheating in London care homes that are particularly sensitive to heat-related effects. The audit pilot case study provided: (a) a methodology report, which shows the evidence based approach taken to inform the recommendations for indoor and outdoor interventions, activities and initiatives to reduce indoor overheating in one audit pilot case study and mitigate residents' exposure to heat, (b) a recommendations report detailing the factors contributing to heat exposure in the pilot care home, as well as the recommendation identification and prioritisation process and (c) an overheating checklist, produced in consultation with PHE, that could be used more widely to other care homes. It also provided a baseline for the more detailed study of overheating in care settings, that is the Natural Environment Research Council (NERC) funded ClimaCare project. The main findings and recommendations of this audit pilot case study are summarised below:

- The main sources of overheating in Victoria Care Centre were found to be associated with the unnecessary circulation of hot water through the space heating pipework, the lack of solar protection for windows and the limited ventilation due to the restrictors placed for safety reasons.

- Between residents, carers and staff the latter were more aware of the negative effects of overheating while both were very aware of the cold-related risks.

- The most common actions taken to keep cool during hot weather were keeping residents hydrated, opening windows, subject to safety requirements, and moving residents to the cooler ground floor common areas.

- The data analysis revealed the presence of overheating to some extent, even during the heating season, with summer overheating expected to become worse under the changing climate.

- On average, internal temperatures during heatwaves are projected to increase by approximately two and four degrees in 2050s and 2080s respectively, when the use of passive measures alone will not suffice for the maintenance of internal comfortable conditions.

- Of all passive measures tested, the combination of external window shading with the provision of an increased ventilation rate whenever external temperatures are lower than internal was the most effective, however the only way to ensure that the internal environment remains comfortable at all times, both under the current and future climate (based on the 26 °C overheating criterion utilised in this study), appears to be the provision of mechanical cooling, ideally in a solar shaded and sealed environment.

- The care home could benefit from simple measures incurring minimal or no cost at all, such as switching off unnecessary heat sources and applying window opening and curtain rules, to highly efficient albeit more complex and expensive solutions that could be implemented in the longer term. These include the application of external shading, high albedo finishing materials and green roofs.

- Even though passive solutions alone may not be adequate under the future warming climate, care homes investing in adaptation measures are expected to remain comfortable for longer and rely less on mechanical cooling.

- The results and findings aim to provide consideration by the CQC to include overheating risk due to climate change in their inspection assessment of care homes.

It is beyond the scope of this audit pilot study to report on all possible interventions and their combinations. Instead, this study presents an assessment process that could be utilised to inform overheating adaptation decision-making. The key lessons learnt identified will be used to inform the establishment of a longer-term process that could be replicated in the future. These include:

- The heating season monitored data can provide valuable insights when studying overheating, as heat exposure and heat related mortality can occur all year round, even when external temperatures are low.

- The all-round effectiveness of summertime overheating adaptation measures should always be considered, as improving one area may cause significant unintended consequences in other areas, including possible impacts on annual heating loads.

- Adaptation measures are best implemented at the design stage, however existing buildings can also benefit significantly from a variety of measures that can be implemented under varying timescales, budgets and other requirements.

- Occupant behaviour plays a significant role in overheating reduction and thus training care home residents and staff on how to best operate the building to keep cool is critical.

Further investigation into the conditions leading to overheating in the audit pilot case study and other care homes, particularly during the summer, when longer and more intense heatwave periods are much more likely to occur, is conducted as part of the ClimaCare and the follow-up *Governing the Climate Adaptation of Care Settings* project (a brief description of the projects is included in Appendix 2 of the Executive Summary). The inclusion of both outdoor and indoor environmental monitoring of multiple locations can provide empirical evidence on the internal conditions in different parts of the building (residents' rooms, communal areas and staff areas, such as offices). Future studies could also assess whether the staff/carers/management awareness changed after the audit process, determine whether there has been an increase in awareness due to the raising awareness approach and subsequent changes in heat management practices.

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Appendix 1

Overheating reduction measures evaluation matrix

The following matrix for ranking overheating reduction measures was based on the assessment of each measure suggested for the pilot care setting against the set evaluation criteria.

		Effectiveness	Affordability	Feasilibity	Disruption-free	Usability	Energy demand/ CO2	Health and safety	Visual amenity	
		1 - will not affect overheating	1 - high implementation cost	1 - difficult to implement	1 - decant required	1 - highly demanding to use	1 - energy/ carbon intense measure	1 - high risk for health and safety	1 - negative visual impact	
		5 - could significantly minimise overheating	5 - low implementation cost	5 - easy to implement	5 - stress-free, occupant in residence possible	5 - no usage required	5 - energy/ carbon saving measure	5 - low risk for health and safety	5 - positive visual impact	Overall Score
	NATURAL VENTILATION									
J3	Night ventilation	4.5	5	5	5	4	3	4	3	**33.5**
E1	Increased ventilation through larger window openable areas	4	5	5	5	4	3	1	3	**30.0**
J2	Keep windows closed when hotter outside than inside	3	5	5	5	4	3	5	3	**33.0**
J4	Enabling cross-ventilation by keeping internal doors open	4	5	5	5	4	3	4	3	**33.0**
E2	Enabling cross-ventilation through ducts	4	3	1	1	4	3	5	3	**24.0**
	INSULATION									
D1	Increase roofs/walls insulation, if not adequately insulated	4	3	3	3	5	3	5	3	**29.0**
	WINDOW SHADING									
J1	Curtains closed when window exposed to the sun	3	5	5	5	4	3	5	1	**31.0**
F1	Solar control window film	3	4	4	4	5	2.5	5	2	**29.5**
F2	External solar shading - louvres/side fins	4.5	3.5	3	3	5	2.5	5	2	**28.5**
F3	External solar shading - shutters	4.5	2.5	3	3	4	3	5	1	**26.0**

		Effectiveness	Affordability	Feasibility	Disruption-free	Usability	Energy demand/ CO2	Health and safety	Visual amenity	
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		5 - could significantly minimise overheating	5 - low implementation cost	5 - easy to implement	5 - stress-free, occupant in residence possible	5 - no usage required	5 - energy/ carbon saving measure	5 - low risk for health and safety	5 - positive visual impact	Overall Score
	INTERNAL HEAT GAINS									
H1	Turn-off unecessary heat sources - lights and electrical equipment not-in-use	3	5	5	5	4	4.5	5	3	**34.5**
H2	Turn-off unecessary heat sources - heating systems and their circulation network	3	5	4.5	5	5	4.5	5	3	**35.0**
H3	Insulate hot water pipes/vessels if not adequately insulated	4	4	4	4.5	5	4.5	5	3	**34.0**
H4	Replace any energy intensive lighting and equipment with energy efficient	3	4.5	4.5	5	5	4	5	3	**34.0**
	THERMAL MASS									
G1	Increase thermal mass, e.g. by exposing exisitng or using phase-change material	4	3	1	1	5	3	5	3	**25.0**
	ALBEDO									
C1	Heat-reflective, light coloured paint for walls and roofs	4	3	3.5	4.5	5	3	5	3	**31.0**

		Effectiveness	Affordability	Feasibility	Disruption-free	Usability	Energy demand/ CO2	Health and safety	Visual amenity	
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	MECHANICAL VENTILATION/COOLING									
I1	Free standing fans	3	4	5	5	4	2	4	3	**30.0**
I2	Ceiling fans	3.5	4	4	4	4	2	4	3	**28.5**
I3	Increased ventilation through MVHR	4	2	1	1	4	2	4	3	**21.0**
I4	Provide slightly cooled air through a mechanical ventilation system, e.g. using a cooling coil or ground-coupled heat exchanger/earth tubes	5	1	1	1	3	1	4	3	**19.0**
	GREEN/BLUE LANDSCAPE									
A1	Deciduous trees for shading	4	4	3	5	5	3	5	5	**34.0**
A2	Green roofs and walls	3	2.5	3	4	5	3	5	5	**30.5**
B1	Use water features, such as water bodies and fountains	3	2.5	3	5	5	3	4	5	**30.5**

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