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Review

Bedrooms and the Vulnerability of Sleepers to Extreme Heat Events

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Abstract: Insufficient sleep is known to have an impact on health, wellbeing, and productivity. Sleep has been explored extensively in the medical literature but has received scant attention in the built environment journals. With the climate becoming unpredictable, combined with the climate emergency and concerns over energy poverty, questions need to be asked about the suitability of the housing stock and, especially, bedrooms. This is pertinent for vulnerable individuals (e.g., very young, elder members of society, and those with medical conditions) who may be unable to adapt their sleep environment in extreme and prolonged heat events. The aim of this narrative review is to raise awareness of the complex inter-relationship between the sleeper and the bedroom in domestic properties. It highlights the vulnerability of sleepers and the need for adaptation strategies to cope with extreme heat events without resorting to mechanical air conditioning. It emphasises the need for interdisciplinary research to better inform stakeholders of the risks posed to sleep quality by climate change, and contributes positively to the promotion of health.

Keywords: adaptability; bedrooms; extreme heat impacts; human health; sleep quality; thermal comfort; vulnerability

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1. Introduction

The climate emergency has highlighted the urgent need to reduce carbon emissions from buildings. It has also emphasized the vulnerability of communities to extreme weather, especially extreme heat events, as noted by the Intergovernmental Panel on Climate Change [1]. This needs to be viewed alongside an ageing population, with older members of society particularly sensitive and vulnerable to prolonged heat events [2]. Extreme heat events have been associated with increased mortality. For example, the record temperatures in Europe in the summer of 2003 resulted in approximately 35,000 heat related deaths [3,4]. This, and more recent extreme heat events, highlight the importance of bedrooms and the sleeper's ability to adequately ventilate and cool them to maintain thermal comfort [5]. Climate change is leading to higher temperatures inside properties, with studies suggesting that night-time temperatures are higher in bedrooms compared to the daytime [6]. Furthermore, it is anticipated that the internal night-time temperatures will increase more than the daytime temperatures [7].

Individuals are at their most vulnerable when sleeping [2,8,9]. The challenge of maintaining thermal comfort and regulating heat exchange while sleeping [10] is especially relevant to domestic properties located in climate zones that do not use mechanical cooling in bedrooms, and which rely on windows to facilitate ventilation and cooling. This applies to people sleeping alone, with a partner, or in separate beds in the same room. While the scale of the challenge is difficult to quantify, research has indicated that a significant number of domestic properties are affected in many countries, with a wide range of climate conditions and housing typologies [11]. Even when properties do have air conditioning units, it does not necessarily result in good sleep quality [12]. This is compounded by overcrowding in small residential units, which may negatively affect the health of building residents [13].

2. Method

The research aim was to raise awareness of the complex interactions between individuals and their bedroom environment. A narrative review was employed to explore a broad knowledge base relating to sleep quality and bedrooms in residential properties. Narrative reviews are an established method for developing a critical and informative overview of a multi-faceted subject [14–17]. This review draws on international peer reviewed journal articles written in English. Articles relating to domestic housing and specialist elderly facilities that share characteristics of domestic housing (e.g., care homes) were included. Articles relating to medical facilities, such as hospital wards, were excluded. The exception was a small amount of research into the adaptability behaviour of hospital patients on wards, which has parallels to this research. The primary focus is on bedrooms that do not have mechanical air conditioning, and bedrooms where the users are reluctant to use air conditioning due to concerns over the climate and energy costs. The resulting narrative curates and discusses research findings from different knowledge sets under three discrete headings: sleep, bedrooms, and adaptability. Conclusions relate to research and practice.

3. Sleep Quality

Sleep is fundamental to an individual's physical and mental wellbeing, with individuals spending around eight hours a day sleeping. Sleep studies have identified factors that affect the amount of time individuals spend asleep (sleep efficiency) and an individual's perception of sleep (sleep quality). Age, mental health, physical health, diet, alcohol consumption, and drug dependency influence sleep efficiency and sleep quality [18,19]. Understanding individual characteristics informs health interventions, such as sleep management for people with long term health conditions, e.g., Parkinson's [20], and the promotion of good sleep health [21]. When individuals experience poor sleep efficiency and/or poor sleep quality, it will negatively impact health [22], cognitive function [23], and productivity [24]. Poor sleep quality is also known to be affected by a sleep partner, although this remains under-researched in domestic settings [25]. The likelihood of people experiencing poor sleep is exacerbated by climate change and higher night-time temperatures in bedrooms [26]. People are more susceptible to temperature change when young, pregnant, older and when suffering from ill health [27–29]. Therefore, the impact of climate change and extreme heat events is likely to have a greater impact on the more vulnerable members of society, especially when they are sleeping. This may add to health inequalities and further the burden on healthcare professionals and facilities.

Sleep quality encompasses all aspects of an individual's sleep experience [30]. Although definitions vary, the aim is to, in essence, understand an individual's sleep behaviour, usually in relation to illness, with the data informing intervention measures. Sleep quality has been measured in controlled environments, such as a sleep lab, where individuals can be closely monitored using polysomnography [31]. While this does provide important data for assessing and understanding sleep physiology, it is an artificial and unfamiliar environment, and is not necessarily representative of an individual's bedroom. To measure sleep quality in the home, it is common to use a self-reported questionnaire, such as the Pittsburgh Sleep Quality Index (PSQI), sometimes combined with a sleep diary [32], and/or an accelerometer worn on the wrist to measure sleep over a long time (known as actigraphy) [31]. More recently, with advances in sensor technologies, it has become possible to remotely monitor sleeper activity using smart sensors on the bed (for example, under the mattress) and in the bedroom [33]. With all these interventions, there is no intrusion into private spaces by researchers; however, there are challenges relating to the acceptance of sensor/smart technologies in the home, which need to be seen to have benefits for the residents [34]. Questionnaires and sleep diaries are prone to the limitations of participant recall and remembering to complete the survey/diary every day. Similarly, the data collected through actigraphy is prone to inaccurate data measurements [31].

Data from self-reported survey tools and actigraphy are used by medical practitioners to identify the reasons that affect sleep quality, from which an intervention package can be designed to promote better sleep health [21]. The sleep questionnaires and sleep diaries do not ask questions about the bedroom. A few researchers in the built environment have designed questions about the bedroom environment to be used alongside the PSQI, for example, to canvas the perceptions of healthy residents in Shanghai, China. Like previous research, the findings demonstrated that temperature, ventilation, and external noise penetration affected sleep quality [35].

Sleep hygiene is a term used to encompass the sleeper's bedroom environment, such as furniture layout, colour, scent, light, sound, and air quality. The intention is to create an interior environment that is calming and promotes sleep. Some of the sleep hygiene research relates to indoor environmental quality (IEQ), and some to bedroom design and use. Sleep is influenced by factors, such as bedroom decorations and house plants [35]. Research has found that bedrooms are used for many functions, such as studying, working from home, and watching TV. This means that the bed position and room decor may be affected by the multi-functionality of the space, as found in an Australian study [36]. This may have a bearing on sleep quality because of the multi-functionality of the bedroom.

4. Bedrooms

In a warming climate that is increasingly prone to extreme heat events, questions need to be asked about the suitability of bedrooms. Are they fit for purpose? A recent review of research suggests that they are not [37]. Designers and engineers require evidence-based guidance to inform their design decision making. Some of this can be found in country specific guidance and regulations that aim to limit excessive night-time temperatures in bedrooms [11], and some in guidance documents for the assessment of overheating [38] via dynamic thermal modelling. Simulation and modelling are important design tools; however, there often remains a performance gap between what was designed and what was realised, with buildings and rooms in buildings not performing as intended [39]. Similarly, it is challenging to anticipate and model individual behaviour, bed occupancy, bedroom use, and the physical and mental health of the sleepers. This has led to the European Insomnia Network providing advice on sleeping during heatwaves [7]. They set out a series of measures that mainly relate to individual behaviours. They note that the bedroom should be kept to around 19 °C, or between 20 and 25 °C if this is not possible. Indoor bedroom temperatures above 25 °C should be avoided. Many countries have building codes that aim to limit the hours that the temperature is above 26 or 27 °C, and some set a maximum temperature of around 30 °C as building performance criteria [11]. This may be difficult to achieve without the use of air conditioning units in extreme heat events when the external air temperature remains high, especially at night. Furthermore, it would be unrealistic not to expect occupants to experience some discomfort in a heatwave [40], especially when temperatures exceed the thermal comfort zone at night [41].

Sleepers need to be able to heat, cool, and ventilate their bedroom [42,43]. This applies to new properties and to the existing building stock. In Europe and many other parts of the world, there has been a drive to design buildings that consume no, or very little, energy. This has been achieved by constructing thermally efficient and airtight buildings, which in some cases has created residential properties that are prone to overheating in hot weather [6,11,44], including those designed for older people [45]. This relates to the orientation and thermal mass of the building, ventilation provision via windows and vents, and the ability to limit solar heat gain via passive shading and active interventions by residents (e.g., closing curtains, shutters, and window blinds). Overheating is not only a problem for the newer buildings that are constructed to current building codes and regulations, but also an issue for the existing building stock [12]. Recent studies have shown that retrofitting to conform with national codes can lead to overheating in the summer and uncomfortable internal conditions, because of the complex relationship between thermal insulation, thermal mass, shading, and ventilation [46].

The overheating challenge extends to all property typologies and ages [47]. Housing typologies cover apartments in low-, medium-, and high-rise buildings, row (terraced) houses, and semi-detached and detached houses. These vary in size, orientation, construction methods, and design (internal layout, room orientation and size, and size of windows). Hence, the thermal mass and the ability to naturally ventilate bedrooms will be unique to a building and the bedrooms it contains. Buildings also vary in their location, from densely populated urban areas to semi-urban areas and rural locations. The properties located in densely populated urban areas are prone to higher night-time temperatures compared to rural locations because of the urban heat island effect [48]. It is, however, misleading to generalise about bedroom size, thermal mass, thermal efficiency of the building envelope, or the ability to ventilate the bedroom. In many respects, every bedroom will be unique in terms of context, occupancy, and use. Similarly, every sleeper is unique and, if they can do so, will choose to interact with their bedroom to suit their needs and, where relevant, the needs of their sleep partner.

4.1. Bedroom Size and Psychological Factors

Many bedrooms are small in physical dimensions, and questions have been raised for some time about their functionality [49,50]. There is often only one position that the bed will fit within the room, despite a small amount of research that has demonstrated the psychological importance of bed orientation [51]. Sleeper preference appears to be for a bed that faces the door into the bedroom [52]. A better understanding of how sleepers relate to their bed position and how it affects their sleep is required. This may link to the sleeper's perception of safety. Sleepers need to feel safe in their bedrooms [53], a point that is sometimes overlooked in the design of bedrooms. Chronic overheating has been found in high-density housing [40]. Design faults included external glazed doors to bedrooms that had to be opened for ventilation. These were not opened at night due to security concerns, and exposure to noise, leading to overheating. Safety concerns are also relevant to the opening of windows at night to facilitate cooling, which could allow unwanted entry of people, animals, and insects. This is especially pertinent in many countries where mosquitoes are prevalent [54].

4.2. Indoor Environmental Quality (IEQ)

IEQ is not well explored in relation to bedrooms [42,55], even though the interrelationship between the components of IEQ is known to affect sleep quality [56]. For example, achieving a balance between ventilation and noise pollution through open bedroom windows is challenging, especially in built up areas [35]. The research on IEQ in relation to bedrooms has mainly been on indoor air quality and ventilation [43,53], and the link to cognitive performance [57]; indoor temperature, humidity, and, to a lesser extent, noise pollution also falls under the IEQ umbrella. The relationship between carbon dioxide levels and sleep quality is also relevant to external weather events. Keeping windows closed to retain heat in cold weather can lead to higher levels of carbon dioxide in the bedroom, which has been found to negatively affect sleep quality [58]. The sensory aspects relating to visual and olfactory stimuli are currently under-represented. It has been posited that design guidelines are required to bring about better IEQ in bedrooms [59].

A similar observation can be made of thermal comfort research, which has mainly been focused in office environments rather than the bedroom environment, which is quite different [10]. An individual's metabolism is lower when sleeping compared to when awake. Small changes in temperature can have a big impact on sleep quality [55]. Thermal comfort models relating to sleep and ageing appears to be quite limited and in need of further development [10]. A recent review also highlights the challenges with thermal comfort research in relation to sleep quality, which has mainly been undertaken on healthy, young subjects (often students), usually sleeping alone. The review concludes that there is no direct evidence that thermal comfort relates to good sleep quality [60]. More specifically, the thermal comfort research relating to sleep in extreme heat events is based on indoor and outdoor temperature measurements and simulation. With a few exceptions, it has yet to include the sleeper's perspective [11,47], which is crucial to improving the understanding of the relationship between sleeper and bedroom. Similarly, the duration of the discomfort and disruption to sleep during extreme heat events is currently under-reported in the literature. Without this data, it is not possible to understand how sleepers adapt their sleepwear, bedding, and bedroom environment to cope with periods of extreme cold or extreme heat.

Sleep is affected by light and sound [22]. Natural light can be controlled using blinds, curtains, and/or shutters (interior and exterior). When closed, they will compromise airflow and ventilation rates. When open, they will allow unwanted sound (noise) to enter the bedroom [35]. With a large proportion of people living in densely populated and developed urban and semi-urban areas, usually in multi-storey and row houses, noise pollution while trying to ventilate the bedroom at night is to be expected [61,62]. One solution may be to use portable fan devices that filter indoor air pollutants [63] and keep windows closed to prevent noise pollution. This has been shown to improve sleep quality [64]. Whether this is entirely down to air quality, or the psychological comfort afforded by sleeping with doors and windows closed requires further investigation.

4.3. Sleeper Behaviour and Adaptability

Most residents will live in properties that they have not designed or had any influence over [34], and this extends to the bedroom. During periods of extreme weather, it will be necessary for sleepers to adapt to the situation to try to regulate their body temperature. This may be by changing individual behaviour, such as going to bed later than normal [65] and/or adapting the bedroom to mitigate the effects of high temperatures [66]. In some cases, this may involve the retrofitting of external shading devices and or the installation of mechanical air conditioning units. These interventions have cost implications for the residents and/or building owners [66].

Sleepers can adapt their sleepwear (clothing) and bedding to improve thermal comfort [67], and hence reduce their vulnerability to extreme night-time temperatures. In some situations, sleepers may be able to adjust their bed position, for example, by moving it closer to a source of ventilation (an open window) or away from a hot external wall. This is rarely possible in small bedrooms or bedrooms that include other furniture, such as a study desk and wardrobes. Another possibility is to temporarily move to a cooler room as a haven from the heat [9]. This may not be an adaption option for sleepers living in properties that are occupied to capacity, where there is no spare room, or in properties where all rooms overheat. Nor does it address the practicalities for individuals with a disability or long-term illness, where moving rooms is not a practical option. This also contradicts advice from the European Insomnia Network, which advises sleepers to only sleep in their bed [7]. Thus, in most cases, sleepers remain vulnerable to the effects of extreme weather events because of their relationship with the building in which they reside and sleep.

5. Discussion and Conclusions

The scientific novelty of this research is to raise awareness of the complex interaction between the bedroom environment and the health and wellbeing of sleepers. Intervention measures to improve sleep quality do not yet adequately consider the physical bedroom environment. Similarly, design guidance does not yet adequately consider the physical and psychological characteristics of the people who are going to sleep in bedrooms. These are important findings that relate to everyday sleep quality of healthy individuals just as they do to those with medical conditions and who are more vulnerable to changes in temperature because of their age. The review has also revealed that there is little evidence of how sleepers adapt their bedrooms to regulate their thermal comfort in periods of extreme heat.

It is not clear how the transition of the built environment to a net zero economy will impact sleepers' health and wellbeing. Building better thermally insulated residential developments and retrofitting the existing building stock to improve their thermal performance should enhance sleepers' thermal comfort during the colder months. This will mitigate the impact of extremely cold weather on sleep quality and reduce the vulnerability of residents to extreme cold. However, we still do not have sufficient evidence to understand how thermally efficient buildings will impact sleep quality in hot weather. As noted in this review, the understanding of how buildings perform in very hot weather, the extent to which they overheat, and the ability of residents to cool bedrooms and adapt to the conditions are not sufficiently understood. Research would need to investigate how solar heat gain, the building's thermal mass, and the ability to ventilate bedrooms at night when external temperatures remain high, impacts sleeper behaviour and sleep quality.

This review has found that research into sleep quality is primarily concentrated in the medical literature, where the focus is on sleep and disease. In this body of knowledge, attention is on the individual and the illness that they are presenting with, not the bedroom environment per se. In the built environment literature, most research related to sleep has been concerned with thermal comfort and indoor air quality. In contrast to the medical literature, the focus has been on healthy, mostly young, individuals. These two bodies of research do not overlap. While this may be linked to disciplinary boundaries and research funding requirements, there is an opportunity for interdisciplinary research to better explore the link between sleepers and how they adapt to or adjust their bedroom. This has recently been recognised with a call for co-operation between sleep researchers to develop interdisciplinary research [7].

The research challenge should not be underestimated. Interdisciplinary research is required that can accommodate the context of the bedroom (orientation, size, function, thermal performance, solar shading, etc.), while simultaneously monitoring the following: air quality; temperature (internal and external); humidity (internal and external); carbon dioxide; light and sound levels; scent; ventilation; occupancy levels; occupant behaviour; sleepwear and bedding; bed comfort and position in the room; perception of sleep; and measurements of sleep. Research would also need to include a wide range of sleeper ages, socio-economic characteristics and also a variety of mental and physical health conditions that are known to affect sleep quality. This presents practical and ethical challenges for research teams. Simulation may be one way of shedding some light on the issues through, for example, the use of a digital twin to examine a range of design interventions and how it may influence the sleep environment. However, simulation would need to be informed by research findings that are currently missing and there is likely to be a difference between the simulation and the actual performance of the bedroom environment due to the performance gap [39].

Poor sleep quality is a public health challenge that is likely to become more acute as the planet warms. With an ageing population that is likely to be more sensitive and vulnerable to extreme weather events, combined with the gravitation of people to densely built-up urban areas, the challenge is particularly pertinent. Bedroom design and new domestic developments require a rethink to mitigate the effects of climate change and provide sleepers with a functional, adaptable, and comfortable sleep environment. This requires a balance between thermal insulation, thermal mass, solar control, and the provision of adequate ventilation and cooling (natural, mechanical or mixed mode). It also requires a better understanding of how the bedroom is used and how the sleepers may choose to adjust their environment to improve sleep quality. Failure to act will leave sleepers vulnerable to extreme heat events, which may compromise sleep quality, health, and performance. This requires better evidence than is currently available to designers.

For the existing building stock, the picture is more complex. The sheer range of residential buildings, construction methods, location, and orientation make it difficult to provide specific guidance on interventions to improve the bedroom environment. Interventions need to be designed to suit the building and sleeper context. This requires significant investment in research before design and retrofitting work is undertaken. It also questions the reliance on existing codes and national regulations, the danger being that the retrofitted buildings then exhibit similar problems to the new building stock.

This review was confined to residential properties that traditionally do not have mechanical air conditioning. It is recognised that the issues discussed in this article are less relevant to climatic zones and buildings where mechanical cooling is commonplace, if not essential, for maintaining a comfortable internal environment. The narrative view draws on a wide range of the literature and there is a risk of introducing author bias in the selection of the articles and overlooking sources. These limitations need to be considered in the context of the strengths of a narrative review, which has highlighted the complex interactions between sleepers and their physical bedroom environment.

To promote better sleep quality [21] requires a better understanding of how sleepers interact with their bedroom and how they adapt their environment in extreme weather to maintain sleep quality. Advances in sensor technologies and remote monitoring will have a role to play in providing robust evidence from which policy and practical interventions will develop. This will enable building designers, policy makers, and urban planners to make better informed decisions. Raised awareness of the vulnerability of sleepers to a changing climate will also help to inform residents of the importance of their bedroom environment. In the meantime, sleepers remain vulnerable to the effects of extreme weather events because of their relationship with the building in which they reside and sleep, and which many residents have little control over.

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