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Review

The Intersection between Heatwaves, High-Rise Living and the Aged: A Narrative Review of the Literature

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Abstract: High-density living and heatwaves are increasing, at the same time as the population is ageing. The aim of this literature review was to examine the intersection between older and/or vulnerable people, who live in high-density/high-rise situations, and their health during heatwaves. Using electronic databases, the literature was examined. Articles were included if they were: (1) published in English, (2) examined the relationship between building, health, and extreme heat, and (3) included older or vulnerable populations. A total of 241 articles were identified of which 15 were duplicates and 209 did not meet the inclusion criteria. Of the 17 studies included in the review, 4 were conducted following heatwaves in Chicago and Europe. These identified a relationship between age, vulnerability, and floor of residence, in people who died because of the heatwave. High-rise living is increasing globally, and residents are getting older. This, in combination with increased heatwave intensity and frequency, highlights the risk of morbidity and mortality in this group, particularly where there is no access to air-conditioning because of power grid overload in the heat. This research benefits older and vulnerable people who live in high-rise buildings, the health professionals who care for them, architects, urban planners, and policy makers.

Keywords: high-rise; health; ageing; vulnerable populations; climate change; urban bioclimate; vertical paradigm

Citation: Wilson, L.A.; Black, D.A. The Intersection between Heatwaves, High-Rise Living and the Aged: A Narrative Review of the Literature. *Atmosphere* **2022**, *13*, 1461. https://doi.org/10.3390/atmos13091461

Academic Editor: Andreas Matzarakis

Received: 1 August 2022
Accepted: 1 September 2022
Published: 9 September 2022

1. Introduction

Adequate housing plays a crucial role in maintaining health and wellbeing in the human population. Evidence suggests there is a relationship between housing or building type and health of the occupants [1–3]. Residential housing design is known to be influenced by function, culture, available land, product availability, geographical factors, resources, and more recently, building codes and standards [4,5]. Traditionally in Australia, homes were built on a quarter acre block of land, and home ownership was a widely held aspiration, as it provided security and long-term benefits [6]. However, over the last twenty years, because of higher land prices and rapid urban growth, high-rise, high density housing estates have increased. This, along with recent decreases in housing affordability in major Australian cities, has forced many to accept cheaper, older, and poorer quality accommodation that does not meet current standards [7]. For a house to meet an 'adequate' standard for habitation, it should be in a reasonable state of repair, safe, secure, have reasonably modern facilities, have adequate ventilation and thermal comfort, and be easily accessible [8]. This is particularly important for older adults and/or people with a disability, who are likely to spend more time in their home [9].

Increasingly, cities are becoming more urbanised, relying on high-rise living to accommodate the increasing demand for housing [10,11]. In 2009, the number of inhabitants of urban areas outnumbered those of rural areas, thus transitioning from a more rural to more urban society [12]. High-rise developments began to emerge in the 20th Century in South-East Asia, the United States, South America, and China, where it was necessary to house booming populations because of migration [13]. Since the early 1990s when a construction boom in high-rise dwellings became more widespread, urban populations have increased from around 30% in the 1950s to 55% in 2018 [11]. It is anticipated that by the year 2050 around 68% of the worlds' population will live in urban areas [11]. This 'vertical paradigm' in building design has been shown to have both positive and negative effects on the health of residents who live in high-rise dwellings [14–25]. In parallel to the changing urban landscape are two distinct phenomena: an ageing population and changes to the global climate.

Globally, the population is ageing. It is estimated that by the year 2050 around 2.1 billion people will be aged over 65 years: twice the number of this group in 2017 [26]. As a result, older people are increasingly likely to be living in high-rise developments either by choice or because they are forced into high-rise social housing as they age. In Australia, older adults are encouraged to age in place for as long as possible; however, many choose to downsize to apartment living for safety, security, proximity to available services, and less maintenance [27].

At the same time as the population is ageing, the climate is changing, with heatwaves increasing in frequency, duration, and intensity [28]. There is no universal definition of a heatwave, however they are generally considered to be periods of excessively hot weather, often with increased humidity in oceanic countries. Heatwaves are defined relative to the usual/expected temperature of the local area at a given time [29]. In Australia, a heatwave is defined as "three or more days in a row when both daytime and night-time temperatures are unusually high—in relation to the local long-term climate and the recent past". There is no single temperature threshold for a heatwave in Australia [30]. Heatwaves cause an increase in mortality and morbidity, but these outcomes are often overlooked because of the insidious nature of heatwaves. More than 70,000 people died in Europe during the extreme heatwave in 2003, and it is estimated that globally, around 166,000 people have died from heatwaves over the past 20 years [30]. In Australia, there were at least 473 heat-related deaths reported to the coroner in the years from July 2000 to June 2018. Of these, 354 occurred during heatwave conditions and 244 occurred either within or near buildings [31]. In a 2019 study investigating mortality following heatwaves in Australia, Pham and colleagues highlighted the increased risk of mortality and morbidity in older and vulnerable people during heatwaves [32].

Climate extremes have been reported in the South-East Asia and Pacific region, resulting in periods of drought, [33–35], excessive rainfall [36,37], severe heatwaves [38,39], and subsequent changes to pasture, productivity, and infectious disease patterns [40–42]. Global warming has been increasing across the Asia Pacific Region over the last two centuries because of the burning of fossil fuels and an increase in greenhouse gas into the atmosphere. Average daily temperatures have increased by approximately 0.8 °C since 1880, the global sea-level is rising, and Earth is already committed to additional global warming and climate change in the years ahead [43]. This is having a continued influence on parts of Africa, Asia, and the Pacific, with the possibility of catastrophic results because of increasing sea levels and higher population exposure to extreme heat (particularly in parts of Africa) [44,45]. Recent research undertaken in South Asia (SA) highlights the significant drying trend in some areas of SA, and the relationship between the Indian Ocean Dipole (IOD), El Nino Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO) and warming sea temperatures [46,47].

This has been the case in Australia, a country known for its harsh climate and propensity for periods of drought, flood, and extreme heat [48]. There is a large body of evidence to suggest that extreme heat impacts adversely on health, and historically, the most vulnerable to heatwaves have been of low socio-economic status, aged, or living with a disability [31,49–54].

Although there is a strong body of evidence highlighting the health impact of high-rise living on physical and psychological aspects of health, limited research has investigated the implications of the increasing effects of extreme heat on older people who live in high-rise buildings and may be particularly vulnerable to these effects. Research suggests that older people feel most thermally comfortable when indoor temperature approximates 26 °C [55]. There is a considerable body of research investigating the thermal comfort of buildings (both low and high-rise) and how indoor thermal comfort impacts upon health [56–59]. Research conducted in Taipei, Taiwan, investigated the changes in temperature by floor in the skyscraper Taipei 101. This research highlighted that in vertical buildings temperatures do increase in levels over 150 metres, in line with the urban heat island during summer periods [60]. There is also a burgeoning literature on the impact of bioclimate and the vertical paradigm [59,60]. This area of research clearly describes the impact of the vertical construction of buildings on thermal comfort in the outdoor environment, including on the Urban Heat Island (UHI) effect, and on urban microclimates in cities including London and Belo Horizonte in Brazil [61,62]. Although this literature is increasing and focuses on the importance of ensuring the external microclimate is kept cool, there is limited research focusing on indoor thermal comfort inside skyscraper buildings that are used for residential purposes.

Although most high-rise buildings have air-conditioning to mitigate the impact of extreme heat, this is rendered ineffective if extreme heat causes power grid overload and supply is interrupted [63,64]. There is evidence to suggest that high-rise buildings contribute to the urban heat island (UHI) effect, a phenomena whereby urban environments comprised of large concrete and glass buildings retain heat throughout the day and release this heat at night [65,66]. First described in 1968 by Bornstein, when studying the heat profile of New York City [67], this phenomenon is increasing in areas of high urbanisation across the globe.

Defining a High-Density Environment and High-Rise Buildings

Connon et al. [68] state there is no clear consensus on the definition of a high-density environment; however, they suggest that "the term can be used as a quantitative or qualitative measurement of space and is most commonly used to refer to a heavily populated area or area characterised by high-rise apartments that stand in contrast to the low-rise dwellings that characterise low-density environments". High-rise buildings are variously labelled as 'skyscrapers', 'apartments', 'towers or tower blocks', or 'tall' structures. Countries differ on the height at which they classify a building as 'tall'. For example, the Jeddah Tower in Saudi Arabia, when complete, will be almost one kilometre tall. The tallest building in Hong Kong (the city with the most high-rise buildings in the world) stands at 484 m whereas in Sydney, Australia, the allowable maximum height of a building is 235 m. In Australia, the inclusion of an elevator to provide access to upper levels of a building is not required in apartments or buildings less than three storeys, where the floor area of each storey other than the entrance storey does not exceed 200 m^2; [69]. Buildings that are over three stories high are required to have an elevator, and all buildings open to the public are required to have an elevator under the Australian Disability Discrimination Act [70]. For the purposes of this review, a high-rise building was defined as one with a height greater than four storeys.

2. Hypothesis/Aim

The aim of this review is to examine the literature investigating the implications of heatwaves on health in older and/or vulnerable people living in high density/high-rise dwellings.

3. Method

3.1. Literature Search Strategy

A literature search was conducted using electronic databases including: PubMed (January 1976–August 2022), (MEDLINE (1950–August 2022), SCOPUS, and Google Scholar. Terms included in the initial search were: 'building', 'high-rise', 'high rise' 'tall structure' 'apartment' 'skyscraper', 'urban climate', 'bioclimate', 'vertical', and 'tower'. Results were then combined with the terms 'health', 'heatwave' 'heat* and subsequently with age* and vulnerability. (*At the end of the search term ensures all words commencing with this word are included in the search).Specific health conditions (such as cardiovascular disease and respiratory diseases) known to be exacerbated by heatwaves were not included in the search strategy, as the focus of this review was to examine the intersection of high-rise living, heatwaves, and vulnerability. Secondary searches were conducted of bibliographies of identified articles and previous systematic reviews. Grey literature was also searched to include relevant articles, commentary, and reviews.

3.2. Inclusion Criteria

To be eligible for inclusion in the review studies needed to be:

- Published in English between 1980–2022;
- Peer-reviewed articles investigating the health impacts of heatwaves on older or vulnerable people, and where this is associated with housing type;
- Reports, reviews, articles relevant to high-rise buildings and heatwaves and older people.

4. Results

Two hundred and thirty-six (236) articles were identified in electronic databases and following a review of secondary sources, an additional five reports were identified (n = 241). Articles were reviewed by the authors and those that did not meet the inclusion criteria or were duplicated were excluded. Sixteen articles were selected for analysis and inclusion in the review (Figure 1). The Critical Appraisal Skills Program (CASP) appraisal tool was used to synthesise findings [71].

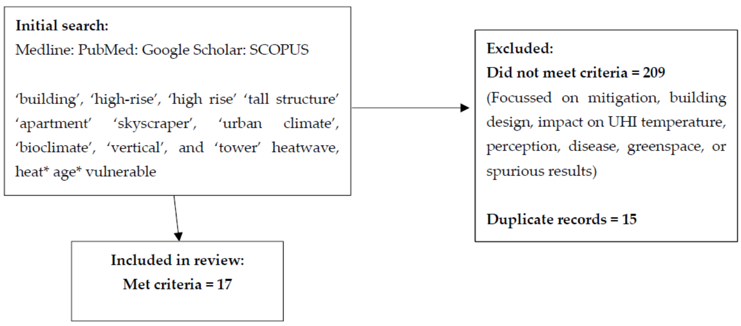

Figure 1. Literature Search Strategy.

Literature investigating the intersection between extreme heat and adverse health impacts in older people who live in modern high-rise structures is limited. However, research conducted following the catastrophic heatwaves in Chicago, (1995) [49,50] and Europe, (2003) [51,52,72], New York, [73–75], Boston and Phoenix [76], the UK, [77] and Canada [78] highlighted the increasing risk of heat-related mortality or morbidity dependent on the level of residence, i.e., the higher the level the greater the risk. Recent research in South-East Asia has also highlighted the increased risk of heatwave illness in ageing and vulnerable populations living in high-rise buildings, and how they can access heatwave refuges [54,79–81]. Recent research investigating heatwave deaths in Australia also highlights the importance of building type, when considering mortality because of extreme heat [31].

The papers identified for this review (Table 1) focused on the intersection of extreme heat, building type, and age or vulnerability, as compounding factors contributing to health, and were all published in English. Due to the limited number of papers that focused on these three factors combined, papers that focused on building type and heat, and older people as part of a population study were also included in the review. Studies on heatwave perception, building design, and mitigation strategies were not included in the review but will be included in the discussion.

Table 1. Literature included in the narrative review.

Date	Title	Authors	Journal	Population	Study Type	Comments
2022	Heatwave fatalities in Australia, 2001–2018: An analysis of coronial records.	Coates, L., van Leeuwen, J., Browning, S., Gissing, A., Bratchell, J., Avci, A.	*Int. J. Dis. Risk. Red*. **2022**. 67: 102671.	Examination of coronial data of deaths due to extreme heat.	Quantitative analysis of deaths and factors associated with death	Heatwaves are a complex hazard and, as such, any risk management should be collaborative, involving national, state, and local government; health services; community organisations; infrastructure operators and climate practitioners and planners, and should consider the inclusion of a range of integrated treatments.
2021	Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. [Review]	Jay O, Capon A, Berry P, Broderick C, de Dear R, Havenith G, Honda Y, Kovats RS, Ma W, Malik A, Morris NB, Nybo L, Seneviratne SI, Vanos J, Ebi KL	*Lancet*. **2021**. 398(10301):709–724, 08 21.	Focuses on vulnerable populations and housing types	Review article	Describes how a future reliance on air conditioning is unsustainable and further marginalises the communities most vulnerable to the heat. We then show that a more holistic understanding of the thermal environment at the landscape and urban, building, and individual scales supports the identification of numerous sustainable opportunities to keep people cooler.
2020	Future increase in elderly heat-related mortality of a rapidly growing Asian megacity.	Varquez ACG, Darmanto NS, Honda Y, Ihara T, Kanda M	*Sci. Reports*. **2020**. 10(1):930406 09.	In this study, future changes in heat-related mortality of elderly citizens were estimated considering the combined effects of spatially-varying megacity's population growth, urbanization, and climate change.	Spatial heat modelling in Jakarta, Indonesia	The August total number of heat-related elderly deaths in Jakarta will drastically increase by 12~15 times in the 2050s compared to 2010s because of population aging and rising daytime temperatures under "compact city" and "business-as-usual" scenarios.
2020	Housing as a critical determinant of heat vunerability and health.	Samuelson, H., Baniassadi, A., Lin, A., Gonzalez, P.I., Brawley, T., Narula, T.	*Sci. Total. Environ*. **2020**. 720: 137296	Review of heat vulnerability indices and how they relate to housing stock and heat in two vulnerable neighbourhoods in the US		Most HVIs do not include housing characteristics and/or overlook important nuances regarding the impact of building age and AC functionality. Meanwhile, simulations show thatthese characteristics play a substantial role in determining individuals' overall exposure to heat.

Table 1. *Cont.*

Date	Title	Authors	Journal	Population	Study Type	Comments
2020	Physiological factors characterizing heat-vulnerable older adults: A narrative review	Meade, R.D., Akerman, A.P., Notley, S.R., McGinn, R., Poirier, P., Gosselin, P., Kenny, G.P.	*Environ. Int.* **2020**. 144:105909	Review of physiological factors that may impact on health in the aged	Review of physiological factors	Our understanding of the mechanistic links between heatwaves and health are, in many cases, still insufficient. In our view, a move toward an ecological study design is required to better integrate physiological research in public health programs and climate-health models and improveour ability to protect vulnerable sectors of the population.
2018	Effects of neighbourhood building density, height, greenspace, and cleanliness on indoor environment and health of buiding occupants.	Chan, I.Y.Y., Liu, A.M.	*Build. and Environ.* **2018**. 145:213–222	Residents of Hong Kong studying or working in academic buildings of differing heights	Descriptive study	In sum, the study provides empirical support that occupant health is significantly affected by neighborhood building height, neighborhood building density, and neighborhood cleanliness.
2018	Assessing urban population vulnerability and environmental risk across an urban area during heatwaves—Implications for health protection	Macintyre, H.L., Heaviside, C., Taylor, J., Symonds, P., Cai, X-M., Vardoulakis, S.	*Sci. Total Environ*. **2018**. 720: 137296	Review of UHI and how these impact on heatwave vulnerability in cities in the UK	Descriptive modelling study	Interventions such as urban greening or building modifications such as cool roofs may help offset some of the UHI intensity, and reduce the spatial disparity in ambient temperatures, particularly at night. The results from this work could help identify which factors are most strongly correlated with ambient temperatures, and help target resources and interventions, as well as focus health messaging during heatwaves to the greatest effect. Further research is needed to estimate the spatial heterogeneity of factors influencing heat risk in cities.

Table 1. *Cont.*

Date	Title	Authors	Journal	Population	Study Type	Comments
2017	Health symptoms in relation to temperature, humidity, and self-reported perceptions of climate in New York City residential environments.	Quinn, A., Shaman, J.	*Int J Biometeorol*, **2017**. 61:1209–1220	All population -	Descriptive study	We provide concrete evidence of higher heat levels in top floor apartments and in homes with certain types of AC. High heat levels that persist indoors after outdoor heat has subsided may present an underappreciated public health risk.
2017	Predictors of summertime heat index levels in New York City apartments.	Quinn A, Kinney P, Shaman J	*Indoor Air*. **2017** 27(4):840-851.	Elderly and vulnerable	Monitored indoor temperature and humidity in 36 apartments in New York City during summers 2014 and 2015 and used these values to calculate the indoor heat index (HI).	Apartments on the top floor of a building were significantly hotter during heat advisory periods than other apartments regardless of the presence of AC. High indoor HI levels persisted in some homes for approximately 1 day following the end of the two heat advisory periods. Provides concrete evidence of higher heat levels in top floor apartments and in homes with certain types of AC.
2016	Heat Death Associations with the built environment, social vulnerability, and their interactions with rising temperature.	Eisenman DP, Wilhalme H, Tseng CH, Chester M, English P, Pincetl S, Fraser A, Vangala S, Dhaliwal SK	*Health & Place*. **2016**. 41:89–99.	Elderly and vulnerable,	Comparative study	With heat-related mortality as the outcome the researchers assessed the interaction of increasing temperature with social vulnerability, access to publicly available air conditioned space, home air conditioning, and the thermal properties of residences.

Table 1. *Cont.*

Date	Title	Authors	Journal	Population	Study Type	Comments
2015	The relationship between housing and heatwave resilience in older people.	Loughnan, M., Carroll, M., Tapper, N.J.	*Int J Biometeorol*, **2015**. 59:1291–1298	20 households in rural Victoria, Australia. People aged 55 years and over	Descriptive study	As older people are being increasingly encouraged to 'age in place' and remain in the family home, increasing the risk of heat exposure over summer if those homes are poorly insulated, have flat roofs, are poorly sited, and are not brick veneer. Weatherboard/cement sheeting homes with poor insulation gained more heat during the day and carried this into the evening.
2013	Heat stress in urban areas: Indoor and outdoor temperatures in different urban structure types and subjectively reported well-being during a heat wave in the city of Leipzig.	Franck, U., Kruger, M., Schwartz, N., Grossman, K., Roder, S. Schlink, U.	*Meteorol. Zeit*. **2013**. 22 (2): 167–177.	All population	Observational study	Indoor and outdoor temperatures are not clearly correlated because of several modifying factors.The results of this study underline the importance of conservation and development of building structures and types of urban structures which stay abreast of changes by global warming. In this context, special attention has to be paid to indoor temperatures
2010	A study of intracity variation of temperature-related mortality and socioeconomic status among the Chinese population in Hong Kong.	Chan, E.Y.Y., Goggins, W.B., Kim, J.J., Griffiths, S.M.	*J. Epidemiol. Com. Health.* **2012**, 66: 322–327	Hong Kong residents population data	Retrospective ecological study.	An average of 1.8C increase in daily mean temperature above 28C was associated with an estimated 1.8% increase in mortality. Some population subgroups were more vulnerable to heat-related mortality, including women, men less than 75 years old, people living in low SES districts, those with unknown residence and married people.

Table 1. *Cont.*

Date	Title	Authors	Journal	Population	Study Type	Comments
2006	August 2003 heat wave in France: risk factors for death of elderly people living at home.	Vandentorren S, Bretin P, Zeghnoun A, Mandereau-Bruno, L., Croiser, A., Cochet, C., Riberon, J., Siberan, I., Declercq, B, Ledrans, M.	*Eur. J. Pub. Health*. **2006**. 16:583–591	All population	Descriptive study	Housing characteristics associated with death were lack of thermal insulation and sleeping on the top floor, right under the roof. The temperature around the building was a major risk factor. Behaviour such as dressing lightly and use of cooling techniques and devices were protective factors. These findings suggest people with pre-existing medical conditions were likely to be vulnerable during heat waves and need information on how to adjust daily routines to heat waves.
2006	Excess mortality related to the August 2003 heat wave in France.	Fouillet, A, Rey, G., Laurent, F., Pavillon, G., Bellec, F., Guihenneuc-Jouyaux, C., Clavel, J., Jougla, E., Hemon, D.	*Int. Arch. Occup. Environ. Health*. **2006**. 80: 16–24.	All population		Although the elderly and people living alone are particularly vulnerable to heat waves, no segment of the population may be considered protectedfrom the risks associated with heat waves.
1997	Denaturalizing disaster: A social autopsy of the 1995 Chicago heat wave.	Klinenberg, E	*Theory and Society*. **1997**. 28, 239–295.	All population		
1996	Heat-related deaths during the July 1995 heat wave in Chicago	Semenza JC, Rubin CH, Falter KH, et al.	*N. Engl. J. Med*. **1996**. 335:84–90	Relatives and friends of those who had died of heatwave.	Case-control study	Those at greatest risk of dying from the heat were people with medical illnesses who were socially isolated, aged, and did not have access to air conditioning.

Two studies [49–51] were matched case-control studies following the severe heatwave events in Chicago (1995) and France (2003). Each of these studies used deaths as 'cases' and compared age, sex, and location of residence-matched live controls to investigate the factors that contributed to an increased risk of death. Chronic illness (particularly cardiovascular illness), disability, age or infirmity and social isolation were all considered risk factors for an increased likelihood of mortality or morbidity. In addition, both studies found an association between floor of residence and likelihood of mortality or morbidity. Residents of higher levels, particularly top floors where thermal insulation was poor, and windows were unable to be opened, were more likely to die in extreme heat. A qualitative study [50] and a descriptive study [52] investigating the extremely high number of deaths following the Chicago and European heatwaves, respectively, also found that social disadvantage, social isolation, and floor of residence were factors contributing to an increased likelihood of heatwave illness or death. Each of these studies highlighted the number of socially disadvantaged people likely to live in poor housing stock that had little if any insulation, or multi-storey apartments that were built to retain heat during cold winter periods (therefore windows did not open or open fully).

Nine cross-sectional studies [55,72–79] have been published investigating the relationship between building infrastructure and extreme heat, and the subsequent impact on health outcomes. These studies have been conducted in Australia [55], Europe [72], USA [73–76], UK [77], Canada [78], and South-East Asia [79]. Franck and colleagues [73] specifically tested the hypothesis that indoor temperature is related to storey height and found that higher floors (described as attic floors) were of higher temperature later in the day than those floors closer to ground level. Eisenmann's 2016 study [73] focused on the availability of cool space for people during periods of extreme heat, but also used a thermal building index to measure thermal comfort in a building. This index can be used to describe "the number of hours it takes for the indoor temperature to reach an unsafe temperature in response to outside air temperature, measured as degrees Celsius per hour" ([64], p. 91). This study also investigated 'census tracts' or building districts that were defined by building type and categorised by access to cool spaces. Although this research did not find a relationship between decreased mortality risk and access to cool space, the researchers did find that buildings that take longer to heat up are associated with a decreased risk of heat-related mortality.

Quinn and colleagues [74,75] have conducted studies in New York City (the city with the second highest number of high-rise buildings in the world) investigating indoor temperature, floor of residence, and adverse health impacts. Quinn found that irrespective of the presence of air-conditioning, the higher floors of a high-rise building are hotter than floors on lower levels and that top floor apartments are significantly hotter [75]. Over two summers, Quinn and colleagues monitored the indoor temperatures in apartments in New York City and found that heat illness was associated (however not significantly so) with higher indoor temperature; however, heat illness was significantly associated with a perceived higher indoor temperature [75].

In 2020, Varquez and colleagues conducted a mapping/modelling study in Jakarta, Indonesia to predict the impact of increasingly warmer weather on the health of older people in an increasingly urbanised city [79]. This research indicated that by the 2050s, the number of summer heatwave deaths in the elderly population, because of extreme heat, will increase by 12–15 times under 'compact city' and 'business as usual' scenarios. Most recently, Jay and colleagues [82] highlight the importance of the intersection between vulnerability, urbanisation, and extreme heat, and outline the limitations and unsustainability of air-conditioning as a cooling strategy. This research describes the cooling strategies that can be implemented in a sustainable way to assist in reducing the adverse impacts of extreme heat. Application of this research can be used to inform practice in several settings and is based on the best current evidence applied to different vulnerable groups including children (Figure 2).

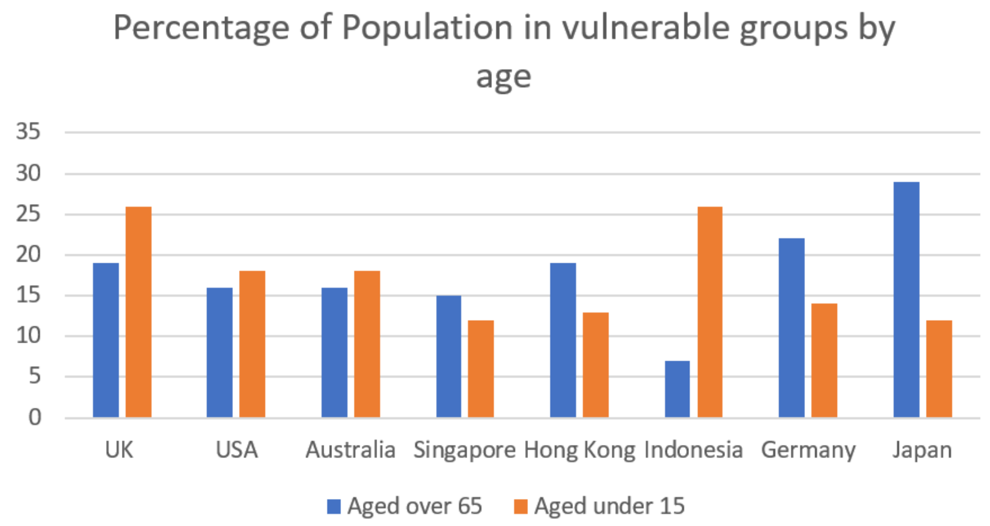

Figure 2. Proportions of children aged <15 years and adults aged >65 years in the countries experiencing heatwaves.

Research in South-East Asia, particularly Hong Kong and Singapore, where there are the most high-rise, high-density cities in the world reflect these findings. Research undertaken in this region highlights the association between high-rise, high-density living and increased morbidity and mortality particularly in vulnerable groups such as the aged, medically compromised, or those who are of low socio-economic status [54,60,79,80]. Of note, heatwaves are occurring in cities in medium latitudes, not just latitudes that experience warmer weather routinely (Figure 3).

Figure 3. Cities experiencing heatwave events referenced in the review.

5. Discussion

Investigation into the intersection between heatwaves, high-rise living, and an increase in mortality and/or morbidity shows there is an emerging literature suggesting there is a relationship between these variables [83–87]. Early studies following heatwave events in the USA and Europe first highlighted the increase in mortality and morbidity in older people who were residents of high-rise, high-density apartments [49–52]. More recently, research in South-East Asia has identified the impact of heatwaves on health, in high-density, high-rise cities where the urban heat island (UHI) effect magnifies the impact of heat [54,60,79,80]. Literature has highlighted the relationship between chronic conditions, such as diabetes, cardiovascular, respiratory, and kidney disorders and increased risk of morbidity and mortality, when exacerbated by extreme heat [88]. Although this review did not investigate the link between chronic conditions and extreme heat specifically, it was noted that people who live in high-rise dwellings and have chronic conditions are at an additional risk of heatwave illness [49–54].

It is evident that the global climate is changing, impacting on the frequency of extreme weather events. This has been well studied in South-East Asia, and research conducted in this region highlights the impact of global climate change on drought, floods, food production, agricultural land, and air temperature [33–48]. These changes have a broader impact on societal health, particularly on those who are aged, have chronic conditions, or are vulnerable. Research by this author and others highlights the impact of extreme weather events on both physical and mental wellbeing, and as these events intensify the adverse effects on health are likely to increase [31,89–91].

Literature suggests that floor level and building type is a predictor of increased mortality and morbidity during periods of extreme heat, particularly in those who are aged, have chronic conditions, mobility constraints, or disability [49–52,84–87]. Recent improvements in technology have mitigated the risk of living on an upper floor, enabling efficient cooling devices such as air-conditioning and fans to be incorporated into high-rise dwellings [92,93]. These devices rely on electricity to function and are therefore unreliable during extended periods of extreme heat, where power grids are likely to overload and malfunction [31,63,64]. It is in this scenario that the adverse impacts on health of the vulnerable are magnified, particularly for those who are unable to exit the building due to mobility constraints. Given the relatively recent safety requirement for all Australian strata buildings with windows at greater than two metres high to have opening limitations to 12.5 cm [93], this also increases the potential for adverse health effects in extreme heat. These considerations underscore the importance of increasing resident awareness of non-electrical, sustainable, strategies to keep cool during periods of extreme heat [82], and empowering GPs and health professionals to monitor vulnerable people during heatwaves [68,94].

Research suggests that the built environment must consider the use of cool space and allow for buildings that provide thermal properties that "heat slower in the sun and maintain cool air within" [95–100]. The use of these thermal efficiencies mitigates the use of devices reliant on electricity [82]. Investigation of source literature for this review revealed the increasing focus on multiple strategies employed by architects, urban planners, and policy makers when designing urban environments in an era of increasing heatwaves [68,95–100]. Strategies that focus on the reduced use of air-conditioning to keep cool in extreme weather are to be encouraged and provide a more sustainable solution to the adverse effects of extreme heat [82]. Similarly, constructing buildings that are thermally efficient by design (green buildings), policy development in urban design and planning, and increasing resident knowledge of how to manage heatwave stress, will contribute to a reduction in adverse health effects attributable to extreme heat [68,95–100]. The importance of building design, and the interaction with heatwaves in the Asia-Pacific region, is highlighted in a recent paper by Coates and colleagues investigating heatwave-related deaths in Australia [31]. In this study the importance of building design is highlighted, as most heatwave deaths occurred in or around buildings, and in buildings that were built prior to 2006. That said, Ren and colleagues suggest that newer designed, thermally efficient buildings are also of concern as increased thermal insulation and 'air tightness' may lead to overheating [100].

Urban density is increasing globally, based on the rising value of urban land and the need to house an increasing population [11–13]. As the population ages, it is reasonable to assume that increasing numbers of older people will live in high-rise apartment blocks.

Given the literature suggesting that the older population [53], those who are socially isolated, the medically compromised, and those with poor mental health [49–53] are at greater risk of heat-related morbidity and mortality anyway, the addition of high-rise living has the potential to increase the risk of heat-related illness or death in these populations.

The percentage of the population who are aged 65 years and older is increasing globally. That said, children are also a vulnerable group in the population. In countries where heatwaves are occurring more frequently in medium latitudes, there are higher proportions of older populations (Figure 3).

Strengths and Limitations of This Study

This study reviewed literature that highlighted an interaction between high-rise living, extreme heat, and adverse health outcomes. The literature that specifically focused on the interaction between these three factors is limited and this was evident in the number of papers identified. Furthermore, this study focused on health risk in vulnerable populations, and it became clear on further investigation that the intersection between health literature and literature on architecture and urban design, has, until recently, been limited because of disciplinary differences. Future research should be undertaken by multidisciplinary teams to examine the intersection of these factors in a more holistic way.

However, a strength of this study is that it highlights the changing climatic conditions in the Asia Pacific region, an area that is currently undergoing massive urbanization. With an ageing global population, it is critical to investigate whether the increasingly frequent and intense heatwaves are a risk factor for vulnerable communities living in high-rise settings. A strength of this study is that it starts to bring together the literature published in the health arena combined with literature in building, science, and climatology. It is evident that more collaborative research focusing on health outcomes is being undertaken, and this will contribute to the broader body of literature in health, sociology, urban planning, architecture, climatology, and science.

6. Conclusions

Urbanisation, global warming, and an ageing population are all increasing in parallel. These phenomena, in combination, have the potential to lead to adverse health outcomes, particularly where residents of high-rise buildings have other co-morbidities. This research identifies research in the field of health, urban planning, and environmental science that suggests a link between housing type (both older style, and newer high-density, thermally efficient) and the potential for an increase in morbidity and mortality during heatwaves in older or vulnerable people.

This research will benefit several sectors of the community including residents of high-rise buildings, architects, urban planners, and workplaces. Mitigation strategies that could be employed include: keeping cool wherever possible, planning ahead for hot weather, use of non-electrical devices for cooling (such as cool cloths or cool baths), taking adequate fluids on very hot days, altering workload, or outdoor work if temperatures exceed 35 °C or 28 °C with 70% humidity, ensuring buildings are well ventilated, and can be cooled naturally, increasing the tree canopy, including awnings or breezeways in buildings, and reducing the amount of concrete in and around buildings [32,99].

Although there has been an increase in awareness of the implications of these factors combined, there remains a need to educate older, or vulnerable, residents of high-rise buildings, about the implications of extreme heat. Architects and urban planners should consider heatwave implications in building and urban design in an in an era where heatwaves are becoming more frequent and more intense, and power failure is a possibility. Heatwave awareness is the responsibility of all health professionals and should be included in routine assessments by GPs, allied health professionals, and carers. Future research should focus on the knowledge of older, vulnerable residents of high-rise buildings regarding sustainable, non-electrical, heatwave health strategies and how they employ these during periods of extreme heat.

Author Contributions: L.A.W. had the conceptual idea for the review. L.A.W. and D.A.B. reviewed the articles and identified those that met the inclusion criteria. L.A.W. wrote the first draft of the paper and L.A.W. and D.A.B. jointly finalised the paper for review. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This literature review did not require ethics approval.

Informed Consent Statement: This study did not require an Informed Consent document.

Conflicts of Interest: The authors declare no conflict of interest.

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