Chapter 5. Reductions in indoor heat exposure: types of intervention and evidence of effectiveness

Summary

Most Europeans spend most of their time indoors, where exposure to overheating tends to occur. A substantial proportion of the housing stock throughout the WHO European Region may be susceptible to overheating. Understanding of the thermal comfort needs of those most vulnerable to heat is still poor, and data on the real-time correlation between outdoor and indoor temperatures in residential settings are lacking. This is of concern for vulnerable population subgroups, for whom combinations of housing characteristics, occupancy profiles, behaviours, lack of access to cooling options and other factors severely increase their risk of heat-related health impacts.

Several technical solutions exist for passive cooling, in both new constructions and retrofitting, but these are often not feasible or affordable for vulnerable groups. For many within those groups, access to adequate cooling can be considered a potentially life-saving medical necessity; yet access to the protection afforded by air-conditioning – the most prevalent cooling technology – remains unequal and hindered by summertime energy poverty. Balancing its many society-level drawbacks against its protective benefits requires a nuanced policy approach towards air-conditioning.

Key messages

- A significant share of hazardous exposure to heat happens indoors.
- Much is still unknown about the relationships between outdoor and indoor temperatures, and between indoor temperatures and the thermal comfort of vulnerable individuals.
- Indoor exposure to overheating occurs through a combination of building and dwelling characteristics, occupancy profiles and behavioural factors.
- While some of the characteristics of a building that can lead to overheating cannot be modified (such as location) or are cumbersome (like building envelope changes), others may only require minimal retrofitting, and could even be installed by dwellers.
- Passive cooling interventions can afford health protection from heat while minimizing energy consumption.
- A wide range of active cooling technologies are available, but air-conditioning is becoming

the de facto technology for protection from overheating.
- Air-conditioning has a number of drawbacks, including equity of access and environmental and social impacts, and may be a clear example of maladaptation to climate change.
- While other options become available, the protective benefits for vulnerable groups of air-conditioning systems need to be ensured, while increasingly sustainable technologies are promoted.

5.1 Introduction

Reduction of indoor heat exposure ought to be a central factor to consider in any effective HHAPs in the WHO European Region. By some estimates, the population of the EU spends 90% of their time indoors on average (Sarigiannis, 2013). Moreover, time spent at home in Europe increases with age, with people aged over 65 years spending around 20 hours a day at home on average – fully six more hours per day than people in their twenties (Eurostat, 2020a). Thus, the individuals most vulnerable to heat spend more time at home, including the hottest hours of the day (Taylor et al., 2016). Unsurprisingly, heat-related mortality tends to happen disproportionately at home (Joe et al., 2016).

Against this background, however, most HHAPs (and their related heat–health warning systems as discussed in Chapter 3) are organized around outdoor temperatures. Whenever indoor heat indices are taken into account, these are typically developed for healthy working populations, and are thus barely applicable to most groups vulnerable to heat.

At the time of publication of the WHO Regional Office for Europe's guidance on heat–health action planning (Matthies et al., 2008), data on how housing quality and characteristics modify the relationship between outdoor and indoor temperatures were limited. Even less evidence was available on the links between indoor heat and health. The guidance thus listed a summary of tentative recommendations for the short, medium and long terms. These were not based on a formal assessment of the evidence, and could be grouped into four main categories:

1. behavioural advice;
2. access to cooling technologies, services or spaces;
3. modifications of housing characteristics and buildings, with an emphasis on passive cooling;
4. urban landscape management.

Categories 1 and 4 are considered elsewhere in this report: behavioural advice for protection from heat is covered in Chapters 4 and 6, and urban landscape management is explored comprehensively in Chapter 8.

Lacking sound evidence in the European context for categories 2 and 3, the 2008 WHO guidance explored passive cooling as a key element to exploit within possible modifications of housing to protect health from heat. A decade on, this chapter explores three main areas of relevance for the reduction of indoor heat exposure in the light of the latest evidence. First, it examines the relationship between outdoor and indoor temperatures and health, including the acceptability and suitability of different ranges of indoor temperatures for various population groups. Second, it considers the possibilities of housing and dwelling modification for passive cooling. Finally, it investigates the effect that the accessibility and affordability of different cooling services and technologies may have on protecting the public and vulnerable groups from hazardous heat.

5.2 Indoor temperatures and health

Leaving aside occupational exposures (see Chapter 6 for more information), the evidence on associations between temperatures experienced at home and health impacts is scarce. So scarce, in fact, that the recommendation of the WHO housing and health guidelines (WHO, 2018) regarding maximum indoor temperatures is a conditional one. While the guidelines recommend developing and implementing strategies to protect populations from excess indoor temperatures, they do so based on the proven association of outdoor temperatures with morbidity and mortality; and on the correlation between outdoor and indoor temperatures.

Because of the scarcity of research directly linking indoor temperatures and health impacts, the guidelines assessed the certainty of the evidence that reducing high indoor temperatures would reduce morbidity and mortality as "low to very low". Although the evidence base is still not comprehensive, a variety of studies and large projects have allowed a corpus of knowledge to be built, with implications for health protection from heat.

5.2.1 The correlation between outdoor and indoor temperatures, and the risks of indoor overheating

While there is a general correlation between outdoor temperatures and indoor temperatures in buildings, this includes very wide variability, greatly influenced by the shape and materials of the building; its orientation, ventilation and shading; and the orientation of the apartments and apartment locations within the building, among others (Mavrogianni et al., 2010; White-Newsome et al., 2012; ZCH, 2015). Some evidence suggests that the relationship between indoor and outdoor temperature is linear at both moderate and high levels of heat (Smargiassi et al., 2008), and that this is especially true in naturally ventilated buildings (Kenny et al., 2019). On the other hand, a study of occupied urban houses in the United Kingdom during a heat-wave demonstrated that indoor temperatures can vary considerably across homes, as well as across rooms within homes, resulting in different peak temperatures and levels of discomfort (Wright, Young & Natarajan, 2005).

Temperatures also tend to increase with elevation (floor number) and proximity to the centre of the urban area (usually a proxy for less green space) (Lundgren-Kownacki et al., 2019). In the United Kingdom a recent study of the housing stock found bungalows and top-floor apartments to be most vulnerable to overheating, along with more modern airtight terraced dwellings (Taylor et al., 2016). It also found that – even without taking into account the urban heat island effect[1] – overheating vulnerability is likely to be higher in urban locations owing to the predominance of apartments and terraced buildings relative to rural areas. Day-to-day variations in outdoor temperatures also play an important role in the evolution of indoor temperatures (Smargiassi et al., 2008). Given the delay (sometimes called inertia) associated with heat storage inside a home, indoor temperature reflects the outdoor temperature during the preceding 24–72 hours much more than the actual (real-time) outdoor temperature (Wright, Young & Natarajan, 2005; Smargiassi et al., 2008).

The risks from indoor overheating result from an interaction between the susceptibility of a dwelling's occupants to heat, their behaviour (including occupancy patterns), the building's location and its characteristics (Bundle et al., 2018). In addition, the combination of time spent indoors and the proportion of time when dwellings experience

[1] An urban heat island happens when a city experiences temperatures that are significantly warmer than nearby rural areas. The phenomenon is explored in more detail in Chapter 8.

overheating are critical factors. A representative study in the United Kingdom found that, among homes that experienced overheating, 39% experienced it 1–4 days per week and 22% every day (BRE, 2013). This suggests fairly constant exposure to overheating during normal summer periods, rather than only during heat-waves. While behavioural factors and advice are covered elsewhere in this report, it is important to keep them in mind when discussing physical and built environment factors. Modifications of the broader urban environment for passive cooling are covered in Chapter 8.

Overheating has been observed even in recently built or refurbished homes in temperate climates (Dengel & Swainson, 2012; Tillson, Oreszczyn & Palmer, 2013; Ji et al., 2014; Morgan et al., 2017). For instance, meta-analytic data in the United Kingdom indicated that 57% of bedrooms and 75% of living rooms in low-energy modern houses are classified as overheated (McGill et al., 2017). Estimates in the United Kingdom suggested that more than 20% of households are affected by overheating (ZCH, 2015), highlighting that these dwellings are vulnerable during times of high heat. A review by Kolokotsa & Santamouris (2015) reported on various studies in the United Kingdom with similar findings, as well as on the results of the Large Analysis and Review of European Housing and Health Status study undertaken by WHO. In this 3373-house sample study in France, Germany, Greece, Hungary, Italy, Lithuania, Portugal, Slovakia and Switzerland, 9% of people reported that their house had a permanent heat-related problem during the summer period, while 13% declared that overheating may happen sometimes. A study of eight buildings in Berlin, Germany, during summer 2013 and 2014 found that indoor heat stress was experienced on 35% of all days (Walikewitz et al., 2018). Kownacki et al. (2019) concluded after a comprehensive review that the characteristics of most buildings in Scandinavia make them likely to experience a strong correlation between outdoor and indoor temperatures. Although mostly drawn from studies in the United States, evidence suggests a higher likelihood of dangerous exposure to heat in areas of lower income and low quality housing (Uejio et al., 2011; 2016; Roberts & Lay, 2013).

The temperature inside buildings rises particularly during heat-waves, when the outdoor temperature remains high for several days and the temperature during the night does not drop enough for buildings to cool down (Morgan et al., 2017). For instance, Sakka et al. (2012) investigated indoor thermal conditions in 50 low-income non-air-conditioned houses in Athens, Greece, during the extremely hot summer of 2007. They found that for almost 85% of the hot period, indoor temperature exceeded 30 °C, and that periods of about 216 continuous hours above 30 °C and six days above 33 °C were recorded in many buildings. Similarly, a study monitoring indoor temperature in homes around London during a heat-wave reported that 33% of bedrooms reached uncomfortable night-time temperatures of 26 °C or greater (Mavrogianni et al., 2010). These high indoor temperatures can continue for several days after the end of a heat-wave (Vant-Hull et al., 2018).

Longer and/or more intense heat events lead to greater increases in indoor temperatures, as well as prolonged duration of peak indoor temperature, and heat-waves occurring towards the end of the summer lead to exaggerated impacts in indoor temperature owing to the natural and progressive build-up of heat in the building over the period (Sakka et al., 2012). This is particularly true in homes lacking air-conditioning (AC), where indoor temperature can be much higher than outdoors (White-Newsome et al., 2012), leading to adverse health outcomes (Vant-Hull et al., 2018). For instance, a study assessing homes of people aged over 65 years in the United States showed that the maximum indoor temperature was 34.8 °C, reaching 35 °C in individual rooms, during a period when the peak outdoor temperature (measured at a nearby airport weather station) was 34.3 °C (White-Newsome et al., 2012).

Despite the acknowledged importance of indoor thermal data for prevention of the health impacts of heat, availability of such information is low globally – even more so when referring to real-time data (ZCH, 2015; Van Loenhout et al., 2016). Existing HHAPs throughout Europe therefore use outdoor environmental parameters to define heat-related health risks (Casanueva et al., 2019). Despite its limitations, the existing knowledge can be applied to heat–health action planning. For example, the German Meteorological Service extended the existing heat–health warning system with a thermal building simulation model to consider heat load indoors (Matzarakis, 2017). The model considers behavioural factors, building factors and weather to predict indoor overheating. While it is limited to the worst-case scenario for indoor conditions and estimated by air temperature only, it constitutes a useful example of practical considerations of indoor temperatures in an HHAP.

5.2.2 Indoor thermal comfort

An environment that is comfortable for one person may be too hot or cold for someone else. A number of factors can affect an individual's thermal comfort, including environmental conditions (such as air temperature, humidity, radiant temperature and air velocity) and personal factors (including health status, age, sex, level of acclimatization, hydration status and level of fatigue). For instance, people who live in hot and humid regions are more likely to tolerate these conditions than people who do not (Baccini et al., 2008). Compared to their younger counterparts, older adults are less sensitive to thermal stimuli and have a tendency to feel cooler during exposure to heat. As the body ages, changes in its thermoregulatory and cardiovascular function undermine its ability to dissipate heat when in a hot environment (Kenny et al., 2016). These differences are detectable in adults as young as 40 years old (Larose et al., 2013), and substantial differences become apparent in most individuals after their mid-50s (Flouris et al., 2017). Also, people's perception of and sensitivity to high temperature change with age (Flouris, 2011; Flouris & Schlader, 2015). Hence, older people may deem an environment to be thermally comfortable when, in fact, it may risk their health (Kenny et al., 2015; Flouris et al., 2017; Vellei et al., 2017). The thermal comfort needs of other vulnerable groups, such as children, chronically ill people, those taking certain medications and pregnant women (with elevated core body temperature) are also understudied and poorly understood. Their additional risks and vulnerabilities are explored further in Chapter 6.

The challenge for controlling indoor conditions, particularly during heat-waves, is also linked with the thermoregulatory function of vulnerable populations. Recent evidence from both Europe (Vellei et al., 2017) and the United States (White-Newsome et al., 2012) suggests that overheating occurs frequently in households with vulnerable occupants, even when protective measures (such as AC) are available. It also indicates that availability of an AC system does not appear to affect indoor temperature of homes with vulnerable occupants – one suggested explanation is inability to afford energy expenses. At the same time, vulnerable occupants in overheated households report feeling cooler than their non-vulnerable counterparts (Vellei et al., 2017). The reluctance of elderly people to use cooling measures such as AC may be caused by an age-related reduction in the ability to sense rising body heat (thermal sensation) (Flouris, 2011; Flouris & Schlader, 2015), which places them at high risk of heat-related injury or death as they are less likely to initiate behavioural actions for heat mitigation. This is particularly important because even small elevations above normal summer outdoor temperatures can raise indoor temperatures to levels that can adversely affect elderly people living in temperate climates.

Van Loenhout et al. (2016) found that living room and bedroom temperatures were associated with substantial increases in reported heat annoyance, thirst, sleep disturbance and excessive sweating in a sample of elderly residents in the Netherlands. These self-perceived symptoms increased further with rises in indoor temperature (33% increase in heat annoyance and 24% increase in sleep disturbance) than with similar rises in outdoor temperatures (13% and 11%, respectively), empirically backing the intuitive notion that indoor temperatures are important for reducing heat-related health impacts. Similar studies found a highly complex relationship between outdoor temperatures, indoor temperatures and heat perceptions – again heavily mediated by dwelling characteristics and behavioural adaptations, among other factors (Franck et al., 2013).

With these considerations in mind, Table 6 presents recommendations from various relevant organizations for indoor environmental conditions in homes. While the upper threshold for indoor temperature is typically set at or near 25 °C (95% confidence interval (CI): 24.5–26.3 °C), the lower threshold for indoor temperature was raised from 15 °C in the 1960s to 18 °C in the 1980s, and to ≥19 °C in the last 15 years, with an all-years average of 20 °C (95% CI: 17.7–22.1 °C). The limited recommendations for relative humidity suggest a lower average threshold of 35% (95% CI: 25.2–44.8%) and an upper average threshold of 62% (95% CI: 58.4–64.9%).

Table 6. Recommendations for indoor temperature and relative humidity

Organization	Publication	Recommendation	Note
WHO	*The physiological basis for health standards for dwellings* (Gomorosov, 1968)	15–25 °C	Based on energy expenditure being at the minimum and thermal sensitivity being at the maximum within this range
	The effects of the indoor housing climate on the health of the elderly (WHO Regional Office for Europe, 1984); *Health impact of low indoor temperatures* (WHO Regional Office for Europe, 1987); *Indoor environment: health aspects of air quality, thermal environment, light and noise* (WHO, 1990)	18–24 °C	Based on minimal risk to the health of sedentary people (such as elderly people) in houses at this range
European Commission	*Energy performance of buildings: ventilation for buildings* (CEN, 2019).	22–27 °C	Bedroom temperature during the summer
International Standardization Organization	*ISO 7730:2005 – Ergonomics of the thermal environment* (ISO, 2005)	19–24.5 °C 40–60%	Based on typical levels of body activity and occupant clothing of 0.5 clo (clothing insulation units) in the summer and 1.0 clo in the winter
Passive House Institute	The passive house planning package (Passive House Institute, 2012)	≤25 °C	Home considered overheated if the recommendation is exceeded for >10% of the year
Chartered Institution of Building Services Engineers	*Guide A: environmental design* (CIBSE, 2015)	23–25 °C	Operative summer temperature for living spaces
		>25 °C	Exposure for less than 5% of the occupied time
		>28 °C	Exposure for less than 1% of the occupied time

Table 6 contd

Organization	Publication	Recommendation	Note
United Kingdom Department of Health	*Heating and ventilation of health sector buildings* (Department of Health, 2007)	23–25 °C	Operative summer temperature for living spaces
		>25 °C	Exposure for less than 5% of the occupied time
		>28 °C	Exposure for less than 50 hours of occupied time
American Society of Heating, Refrigeration and Air-conditioning Engineers	*Standard 55-2017: thermal environmental conditions for human occupancy* (ANSI/ASHRAE, 2017)	19.5–27.8 °C	Home indoor temperature
	Standard 62.1-2016: ventilation for acceptable indoor air quality (ANSI/ASHRAE, 2016)	≤65%	Home indoor relative humidity
United States Environmental Protection Agency	*A brief guide to mold, moisture, and your home* (EPA, 2016)	30–60%	Home indoor relative humidity

5.3 Passive cooling at the building scale

Certain characteristics of a building or the dwellings therein can lead to overheating. Some of those (such as location) cannot be modified, or face significant barriers to modification. For example, significant modifications to a building envelope or insulation may be technically complex, expensive or simply unfeasible under building regulations. Others, like shading or shutters, can be achieved through minimal retrofitting, and could even be installed by dwellers.

The literature on engineering and architectural solutions for housing modifications against overheating accrued since the publication of the 2008 WHO guidance (Matthies et al., 2008) is extensive. Within it, the corpus of evidence on passive cooling solutions is also enormous, covering every technical aspect from construction to environmental sustainability and economic feasibility. A taxonomy of types of passive cooling interventions in buildings is provided by Chetan et al. (2020).

Analysing the physical effects of all passive cooling interventions on indoor temperatures is beyond the scope of this report, and comprehensive reviews are available in the engineering, architecture and urban management literature. This chapter therefore provides a succinct summary of operationally relevant evidence on selected strategies to modify such characteristics and their potential effects in reducing indoor heat exposure. Where available, evidence on health-protective effects is provided.

5.3.1 External shading and shutters

Shading can be a highly effective option for decreasing internal heat exposure, and it is often possible for occupants at the room level to install it. Shading can be implemented externally through overhangs or shutters, and internally through blinds or curtains. Use of shutters, blinds and curtains is effective in reducing overheating, and external shutters are more effective than internal ones, especially for south-facing living rooms (Porritt et al., 2012).

Hamdy et al. (2017) modelled the impact of climate change on the overheating risk in dwellings in the Netherlands, and concluded that correctly operated solar shading devices can significantly reduce overheating in all scenarios. A study in the United Kingdom (Taylor et al., 2018) estimated that external shutters may reduce heat-related mortality by 30–60%, depending on weather conditions, while shutters in conjunction with energy-efficient retrofitting may reduce risk by up to 52%. This protective effect against heat-related mortality during periods of high summer temperatures may, however, be limited under extreme temperatures. Moreover, the technology has the potential downside of decreasing the quality of natural day lighting. The authors suggest installing shutters in dwellings inhabited by the most heat-vulnerable populations (for example, in nursing homes) as a realistic option, and note that building regulations changes for energy efficiency should require retrofitting to be combined with shading or passive cooling strategies to reduce overheating risk. Technology and materials science are increasing the heat-protective potential of shutters. For example, phase change materials (see section 5.3.2) are already being tested in window shutters to reduce the solar heat gain (Alawadhi, 2012; Silva et al., 2015).

5.3.2 Insulation and reduction of internal heat load

Unlike shading, insulation cannot be assumed to protect against heat in most situations. In fact, while increased insulation can reduce overheating in well designed buildings, it can increase it in poorly designed ones (Pyrgou et al., 2017; Fosas et al., 2018). Porritt et al. (2012) modelled the effect of passive cooling interventions for typical United Kingdom dwellings in different orientations and occupancy profiles, using weather data from the 2003 heat-wave. The results showed that interventions on exposed wall surfaces, such as coating with solar reflective paint and external wall insulation, were very effective, as was controlling ventilation to prevent excess warm outside air entering the dwelling during the hottest parts of the day. Internal wall insulation was less effective, however, even producing an increase in overheating for some scenarios, although it could function and even reduce energy costs when adequately combined with other interventions. Moreover, evidence is increasing that passive houses (a voluntary standard of super-high energy-efficient housing) and other super-insulated dwellings are already at risk of overheating in northern latitudes in Europe. The recently reviewed relevant literature (Morgan et al., 2017) showed such instances of overheating in Denmark, Estonia, Sweden and the United Kingdom (both south and north, in Scotland).

A promising set of technologies for the reduction of heat load are based on the application of phase change materials to buildings. These can change their status (for example, from solid to liquid), absorbing or releasing heat in the process. Incorporated into walls, floors and ceilings they can be used to improve thermal comfort indoors while reducing energy consumption, and specifically for cooling purposes (da Cunha & de Aguiar, 2020).

Another intervention is reducing the heat contribution of appliances and heat sources within buildings, which is substantial within the WHO European Region (Elsland, Peksen & Wietschel, 2014). This is a greater problem in workplaces and offices, where the presence and use of appliances (particularly lighting) and information technology equipment is typically heavier. Moreover, since these non-domestic buildings tend to be air-conditioned, their cooling loads have a highly significant effect on the energy use of urban areas, even causing blackouts during heat-waves (Jenkins, 2009).

5.3.3 Green roofs and walls

Very few studies have looked at the health risk reduction potential associated with heat reduction from green roofs or facades. A complete review of various technologies (Buchin et al., 2016) assessed the indoor heat reduction potential of non-irrigated green roofs and facades as low. Irrigation makes a great difference in the heat mitigation performance of the green roofs by increasing evapotranspiration. Non-irrigated green roofs provide less overall protection than cool roofs combined with insulation (Coutts et al., 2013), and they require much more maintenance.

As with other technologies, however, performance can vary widely with different designs and quality of buildings (Macintyre & Heaviside, 2019). Kolokotsa, Santamouris & Zerefos (2013) examined various configurations of green and cool roofs under the prevalent climatic conditions in London and Crete, and found that both could contribute considerably to improvement of the urban environment while simultaneously decreasing energy demand.
In addition, green roofs may have other health benefits related to the mitigation of air pollution (Rowe, 2011), noise reduction (Van Renterghem & Botteldooren, 2009) and well-being/psychological benefits (Lee et al., 2015; Nurmi et al., 2016; Cinderby & Bagwell, 2018). Conversely, the choice of plants strongly determines their long-term viability, as well as potential health disbenefits such as increased allergenic pollen exposure.

5.3.4 Overall potential of housing modifications against overheating

The literature shows that generalizations about housing modifications to prevent overheating are challenging. There is no one-size-fits-all solution, though some patterns are clear from the last 12 years of published evidence. In general, preventing heat gains is much more efficient than dissipating heat into the environment. In most cases, rather than single interventions, the optimum can be achieved through combinations of interventions for specific settings; these must be designed to take into account not only the dwelling construction details but also the type of occupants and their corresponding occupancy profiles. From the perspective of HHAPs, it is more realistic to promote passive cooling options that can be undertaken by room occupants at no or low cost, such as shading. Adequate ventilation, also an important passive cooling strategy, is explored in section 5.3.5.

Traditional (often called "vernacular") architectural solutions for cooling may hold potential for health protection, although the need for more research is clear. In a case study of the potential of vernacular architecture for passive cooling in Évora, Portugal, researchers found differences of up to 16 °C between indoor temperatures and peak outdoor temperatures, illustrating the potential of such approaches (in this case, high thermal inertia, use of light colours and courtyards) to decrease the energy consumption required by active cooling (Fernandes et al., 2015). A recent case study of traditionally built dwellings in downtown Seville, Spain, found that they could not guarantee thermal comfort conditions without mechanical cooling, however, although the study also found that adequate shading and ventilation could greatly reduce the need for AC in the dwellings (Caro & Sendra, 2020).

The progressive accumulation of evidence and knowledge in this area is setting the basis for a much deeper discussion among researchers and practitioners about the roles of building insulation, building envelopes, building design, ventilation possibilities and shading in general, given the key role these factors play in thermal comfort and heat stress (Loughnan, Carroll & Tapper, 2015; Hatvani-Kovacs et al., 2018, Park et al., 2020). Factors like the degree of home maintenance and housing material quality have been shown to play a crucial role in modulating the effects of heat-waves (López-Bueno, Díaz & Linares, 2019), and should also be part of the discussion.

A range of regulatory and other barriers (for instance, lack of specialized technical knowledge and/or standard operating procedures for inspection against overheating risks) may constrain effective action on preventing building overheating as a public health risk, however (Environmental Audit Committee, 2018). A recent study noted that building policies and regulations have largely focused on sustainability or energy efficiency of buildings without sufficient consideration of health impacts, leading to unintended health consequences and a lack of resilience of the housing stock resilient to future climate change (Carmichael et al., 2020). While much knowledge has been gained about this area in the last decade, empirical evidence of the role these factors play in thermal comfort and heat stress for vulnerable groups is still scarce.

5.3.5 Natural ventilation

Natural ventilation refers to supplying air to and removing air from homes without using mechanical systems. It is a very effective passive cooling strategy – especially for the warmer climates of southern Europe – that can reduce buildings' cooling requirements and improve the thermal comfort of occupants (Schulze & Eicker, 2013). As the flow of external air to an indoor space is driven by environmental pressure differences, natural ventilation in buildings can be achieved by wind-driven and/or buoyancy-driven ventilation. Wind-driven natural ventilation is achieved by forming openings on the perimeter, which permit airflow (caused by differences in pressure created by wind) to pass through the building. Buoyancy-driven natural ventilation is achieved by temperature differences between the interior and exterior of the building, causing directional buoyancy force.

Despite its vast potential for improving thermal comfort and reducing heat-related mortality without the disadvantages of mechanically-driven cooling technologies, natural ventilation can be complex and challenging. A recent study in Germany simulated various natural ventilation strategies and showed that opening the windows when the outside temperature is lower than the inside temperature is the ideal natural ventilation solution and can achieve a comfortable indoor climate (Rosenfelder et al., 2016). The same study reported, however, that natural ventilation strategies should be selected based on practicality and occupant characteristics and lifestyle, and noted that in Germany they can sometimes lead to days with cold stress even in summer months.

The total daily duration of natural ventilation is important for keeping the internal home temperature at a comfortable level. Further, natural ventilation is inappropriate for short-term cooling (such as when a building is occupied only for a few hours in the middle of the day) because the building mass must be cooled when the outside air temperature is still relatively low (Rosenfelder et al., 2016). Another challenge of natural ventilation relates to the complex and turbulent flows inside and around buildings, which can diminish effective ventilation rates, particularly in urban areas (Omrani et al., 2017). Finally, natural ventilation is influenced by a number of other parameters, including facade design (such as window size/shape/location and window opening type/angle), occupant characteristics and the indoor and outdoor environment (for example, indoor air quality, placement of furniture, outside air quality and noise) (Roetzel et al., 2010). With the caveats of the particularities of the locale, buildings and other factors, the best timing for natural ventilation is generally found to be in the morning and during the night (Schulze & Eicker, 2013). For purposes of thermal comfort,[2] daytime ventilation is suitable only when indoor comfort can be experienced at outdoor air temperature. Night-time ventilation is especially suitable for situations when daytime ventilation is not possible (as when outside temperatures are too hot) and it works best when night-time temperatures are substantially lower than daytime temperatures (Guedes, 2013).

[2] Natural ventilation is also important for indoor air quality.

5.4 Access to cooling technologies, services and spaces

While the conversation about cooling has traditionally tended to focus on the use of built-in or portable AC devices, the technical literature is increasingly considering cooling as a service that can be obtained through various means, including on- and offsite services, and different categories of products.

5.4.1 Electric fans and personal cooling systems

Using electric fans against the heat has been widespread practice at both the individual and institutional levels for a long time, but whether it does more good or harm overall is still uncertain. Generally, fans have been found to fit best in hot and dry environments if the air temperature is not much above 40 °C (Jay et al., 2015). A Cochrane review (Gupta et al., 2012) concluded that the current evidence does not resolve uncertainties about the health effects of electric fans during heat-waves. People making decisions about electric fans should therefore consider the current state of the evidence base and local policy or guidelines when deciding whether or not to use or supply them.

Another technological set of possibilities is "personal cooling systems" – a wide range of devices and systems that are receiving increasing attention in research, with recognition of their ability to improve some degree of thermal comfort in a cost-effective way. These may include shade structures, water-based cooling, smart textiles, ventilated clothing, personal ventilation, personal humidifiers, fans, AC and cooling clothes using air or liquids (Lundgren-Kownacki et al., 2019). Several studies have evaluated the most effective body segments for localized cooling to promote thermal comfort and sleep (Wang et al., 2017; Lan et al., 2018).

Evaporative cooling has a positive cooling effect, especially in dry conditions, although its effectiveness is highly dependent on the outdoor climate and it can cause problems related to mould. In general, it has been considered a moderately effective strategy for heat exposure reduction, with the advantage that it does not require any special installation (Buchin et al., 2016). Most studies evaluating personal cooling systems, however, have so far focused on laboratory experiments or workplace settings, or even emergency response situations. These are not representative of the bulk of population groups vulnerable to heat, which generally have a different and not well studied sensitivity to heat and thermal comfort. To illustrate how poorly understood the differences are, a comprehensive systematic literature review focusing on the differences in temperature of thermal comfort between younger adults and older people (Baquero Larriva & Higueras García, 2019) found a wide range of estimates, from 0.2 °C to 4 °C. This highlights the heterogeneity of studies and the need for further research before considering a selection of cooling options for elderly people. There is therefore a need for further research on the health-protective potential of these devices for use at home and/or by vulnerable groups.

5.4.2 The role of AC: health-protective effects

Despite its drawbacks (see section 5.4.3), AC remains a crucial technology for protecting vulnerable groups from high temperatures, as well as for refrigerating essential medicines and other health-protecting technologies (such as technology-based health information systems). Centralized or decentralized, in institutions, cooling centres and homes, AC may de facto be providing a significant proportion of the protection from overheating in the built environment across Europe. Buchin et al. (2016) rate AC as the most effective strategy for indoor hazard reduction potential, and several studies have found that for buildings without AC –

the norm in most of central and northern Europe – there is a strong correlation between the outdoor and indoor temperature (Lundgren-Kownacki et al., 2019).

Although no robust estimates have been made of how much AC has reduced heat-related mortality, it can reasonably be assumed to have played a role in the overall decreasing trend of heat-related mortality in recent years in Europe. Several EU countries made AC mandatory in various types of institution, including nursing homes, in the aftermath of the 2003 heat-waves (Klenk, Becker & Rapp, 2010). The Lancet Countdown on health and climate change (Watts et al., 2018) estimated that global AC use in 2016 may have reduced heat-wave-related mortality by 23% compared to a complete absence of AC. There are several caveats to that estimate, however, including the current validity and representativeness of the evidence used for calculation of the relative risk (Bouchama et al., 2007). Even accounting for such caveats, insufficient discussion is taking place on access to and use of AC to afford significant protection from heat-related health effects. How that AC is accessed and used is an important related conversation, framed within its drawbacks and possible solutions.

One way to provide access to AC during episodes of extreme heat is to provide cooling rooms or centres (publicly accessible air-conditioned spaces). Although the use of air-conditioned public facilities as cooling centres is assumed to be relatively widespread in Europe, no significant body of scientific evidence on the matter exists. Moreover, most of the published literature focuses on urban settings in the United States.

There are serious concerns about the accessibility of such spaces for vulnerable populations. Transportation is typically considered to be a barrier for those trying to go to cooler places (Sampson et al., 2013; White-Newsome et al., 2014). Relatively compact urban settings in Europe probably mean that distances to the nearest cooling centre may be less of an issue than in the United States – the average distance in New York State was over 3 km (Nayak et al., 2019). Nevertheless, even average walking distance (typically under 1 km) can be simply unfeasible without aid or transportation for those with impaired mobility, for whom maximum walking distances without a rest are often recommended not to exceed around 100 m (O'Flaherty, 2018). Additional concerns include the availability of staff or volunteers to run these spaces; the extent to which such spaces are welcoming of homeless people or people with a mental illness; and the threat that concentrating people in a single place raises the chance of severe risks if electricity or transport networks fail (Bolitho & Miller, 2017).

Cooling centres are typically part of locally deployed heat–health strategies, along with extended opening hours for swimming pools, parks and homeless shelters; ensuring water to public fountains; and misting machines, among others. Data on the scale of deployment of such cooling spots are difficult to compile nationally or supranationally, but specific local level examples abound. During the heat-waves of summer 2019, Paris city authorities identified 922 cool islands, including 218 accessible at night, which could be found in real time through a mobile phone application called EXTREMA (Ville de Paris, 2019). The use of shopping malls as either officially sanctioned or de facto public cooling centres is not well documented in the scientific literature in Europe, though examples exist in the United States and Japan. Some evidence exists that the deployment of cooling centres reduced heat-related mortality in the United States (Eisenman et al., 2016), but more research is needed on whether and how these cooling efforts provide actual risk reduction.

5.4.3. The drawbacks of AC from a public health perspective

This section details a number of drawbacks to AC, including the risks of inequitable access and energy poverty, societal and individual dependency leading to loss of resilience, increased energy consumption and blackouts, waste heat, local air pollution and greenhouse gas emissions.

Ensuring access to AC in an equitable and effective way for those who may need it most is one of the main pitfalls of this technology, at least from a public health standpoint. Those most vulnerable to heat tend to concentrate within the urban core, in housing that is on average more conducive to overheating. At the same time, they are often less able to afford the costs of AC (purchase, installation, maintenance and running costs). This results in deep income-related inequalities in being able to afford the protective effect of AC against heat (Ito, Lane & Olson, 2018). The running costs of AC may become unaffordable even for households who may have been able to afford the equipment and installation, representing an additional type of fuel poverty to that of unaffordability of heating. There is some indication that those at high risk from heat who have AC at home do not use it systematically during hot spells (Lane et al., 2014).

Summertime energy poverty is an overlooked and poorly understood phenomenon, including in Europe. No region-wide information is currently collected on whether dwellings are equipped with AC facilities or whether they are comfortably cool during summer, although it used to be collected. In data from 2012, people in all EU countries reported difficulties in maintaining comfortable levels of cooling during summer, with wide variation from a low of 3.3% of the population in the United Kingdom to a high of 49.5% of the population in Bulgaria (Thomson et al., 2019). The definition of energy-poor and/or vulnerable households is essential for policy targeting and should be tailored to the local context, in terms of income, climate, housing quality and the structure of energy costs. Country-specific data for the EU are set out in Table 7.

People on low incomes had less comfortably cool homes in 26 of the 28 EU countries across 2007 and 2012, and a substantially lower proportion of homes with AC in 27 countries. As electricity prices (excluding taxes and adjusted for inflation) continue to rise in the EU (Eurostat, 2020b), summertime energy poverty may be further aggravated.

Inequalities may even occur within households (with elderly or chronically ill people overexposed) or in a gender-biased manner, with women in some cases spending more time at home and/or engaged in activities that increase heat exposure, such as cooking (Lundgren-Kownacki et al., 2018). Despite the falling relative prices of AC (as with any other developed technology), there are no solid grounds to believe that affordability of use may improve for vulnerable populations. Further, the poorer segments of society may be less likely to work in air-conditioned places, thus not attaining the workplace protection from heat that others may get.

Another drawback of increasing use of AC for protection from heat is the loss of ability to manage high temperatures without it, at both the individual and societal levels. There is some indication (more evidence is needed) that spending a majority of time in air-conditioned environments may impair people's natural heat acclimatization, and that re-acclimatization may depend on the time unexposed, to some extent (Ashley, Ferron & Bernard, 2015). Moreover, such AC dependency may also become psychological (Santamouris, 2012), leading to systematic over-cooling (Brager, Zhang & Arens, 2015).

At the societal level, building cities dependent on AC for their cooling may leave residents unprotected during grid overloads and blackouts, which are in turn more likely with increasing cooling energy demands. Without regulatory provision, there may be little incentive for promoters to build in a less AC-dependent manner. Traditional urban forms and building designs for dealing with heat – as well as traditional knowledge about dealing with hot conditions – may be lost, thereby reducing resilience to unforeseen eventualities (such as blackouts) during heat-waves.

Extreme weather – including heat-waves – increases unpredictability for power generation

Table 7. Proportions of population for AC and comfortably cool indicators

Country or region	Whole population with AC (2007)	Income-poor population with AC (2007)	Dwelling not comfortably cool during summer			
			Whole population (2007)	Income-poor population (2007)	Whole population (2012)	Income-poor population (2012)
EU average	10.8	8.2	25.8	31.3	19.2	26.3
Austria	1.5	0.8	18.1	25.7	15.0	22.3
Belgium	3.1	1.0	14.3	21.9	12.7	21.0
Bulgaria	8.4	1.1	–	–	49.5	70.7
Croatia	–	–	–	–	24.2	32.0
Cyprus	77.1	52.5	40.9	47.3	29.6	34.4
Czechia	0.9	0.1	39.1	44.4	21.8	27.6
Denmark	5.7	4.0	17.7	22.4	11.6	11.9
Estonia	1.9	0.6	23.3	22.8	23.3	26.3
Finland	19.2	9.9	20.3	20.3	25.2	27.8
France	5.2	4.2	29.0	30.6	18.9	24.8
Germany	1.8	0.7	22.7	30.0	13.6	21.4
Greece	52.8	33.3	29.4	37.3	34.0	48.9
Hungary	4.5	1.5	28.5	27.6	25.8	32.8
Ireland	0.4	0.2	7.8	9.9	4.0	4.4
Italy	25.1	15.1	33.4	43.8	26.3	37.9
Latvia	1.8	1.4	39.4	46.0	29.9	31.7
Lithuania	2.1	0.7	33.1	22.8	24.6	21.4
Luxembourg	5.2	0.9	17.9	30.9	10.2	14.1
Malta	55.7	42.2	16.0	20.1	35.4	40.1
Netherlands	6.4	3.2	18.2	24.5	17.7	22.9
Poland	0.9	0.5	41.2	47.1	25.3	28.2
Portugal	7.2	2.6	42.4	51.2	35.7	41.4
Romania	5.3	0.6	–	–	22.6	21.5
Slovakia	1.0	1.8	37.5	39.1	21.0	23.4
Slovenia	12.0	5.9	21.0	25.1	17.3	21.4
Spain	38.2	32.7	25.9	31.2	25.6	33.1
Sweden	15.2	14.3	11.1	12.5	7.6	9.9
United Kingdom	1.9	1.8	10.8	11.4	3.3	4.3

Source: Eurostat (2012).

and consumption, affecting operations, price volatility and ultimately energy security, including for vulnerable groups (Añel et al., 2017). On hot days in locations where AC is highly prevalent, cooling can use more than half of peak electricity demand (Waite et al., 2017). Thus, increased electricity demand from AC can lead to blackouts, in turn increasing the risk of overheating, in a vicious circle. Moreover, electricity companies may respond by upgrading infrastructure, creating a risk of rising energy costs, thus making it increasingly unaffordable for vulnerable groups.

Beside the risk of blackouts and the associated lack of cooling services and increased heat exposure, increased energy use during heat-waves is known to increase tropospheric ozone, furthering health impacts (Añel, 2016). The predicted effect of climate change on energy consumption is mixed, however. Increased demand of energy for cooling will be somewhat compensated in the WHO European Region by decreased demand for heating. Eskeland & Mideksa (2010) predicted that in countries like Cyprus, Greece, Italy, Malta, Spain and Turkey the net effect of increased cooling will outweigh decreased heating consumption, whereas in most of the EU the opposite is projected.

A further drawback is that most AC devices produce waste heat while cooling indoor air. This is typically expelled to areas surrounding the building, and can significantly affect the microclimate in those areas, as well as more widely in urban settings. The effects of AC waste heat are particularly evident during night-time, when they exacerbate the nocturnal urban heat island effect and increase cooling demands (Salamanca et al., 2014). For a city like Paris, for instance, increases range from 0.5 °C currently to potentially 2 °C under a doubling of AC use in the city (de Munck et al., 2013). AC heat waste is also estimated to be contributing to London's urban heat island (Iamarino, Beevers & Grimmond, 2012; Bohnenstengel et al., 2014). Under some scenarios, and driven by current trends in energy demand, anthropogenic heat flux could increase by 10–12% in Europe (Lindberg et al., 2013).

The relationship of AC with air pollution and its health effects is complex, with two main causal pathways in opposite directions. On one hand, there is evidence that the use of AC could lower the short-term effects of PM smaller than about 2.5 μm in diameter ($PM_{2.5}$) by reducing the penetration of outdoor pollutants into homes, compared with homes using open windows for cooling (Bell et al., 2009). On the other hand, AC use in combination with reduced ventilation and/or inadequate maintenance can increase indoor air pollution (Lundgren-Kownacki et al., 2019). In 2016 AC accounted for 10% of global electricity consumption and 18.5% of electricity used in buildings. The number of premature deaths due to $PM_{2.5}$ exposure attributable to AC was 1088 in the EU and 749 in the USA (Watts et al., 2019).

AC also produces a significant amount of greenhouse gas emissions, contributing to global warming in two ways. Many AC devices use hydrofluorocarbons, a type of chemical which, when leaked to the atmosphere, traps several times more heat than CO_2. In a "business as usual" scenario, these emissions may amount to 1–2 gigatons of CO_2 equivalent per year by 2050, resulting in a large climate warming potential (Velders et al., 2015; Purohit & Höglund-Isaksson, 2017).

Moreover, AC often runs on electricity generated by burning fossil fuels, which releases both local air pollutants (such as $PM_{2.5}$ and nitrogen dioxide) and carbon dioxide (CO_2) into the atmosphere. CO_2 emissions from AC use tripled from 1990 to 2016, and the International Energy Agency calculates that the share of cooling in total CO_2 emissions of the power sector worldwide could double from 8% in 2016 to 15% in 2050, even accounting for more efficient AC devices (IEA, 2018). AC devices sold in the EU, for example, are on average more efficient than those sold in the United States or China (the main consumers of AC worldwide). Despite its global warming potential, AC sales and use are increasing rapidly. At current growth rates, 1 billion AC units could be installed globally in the next decade (IEA, 2018). The use of energy for space cooling more than tripled between 1990 and 2016, and is growing faster than for any other end use in buildings. The rising responsibility of AC in global warming represents yet another vicious circle in this technology: as temperatures rise, more AC use will further exacerbate warming rates.

Being a protective mechanism against heat exposures aggravated by climate change, AC can be categorized as an adaptation strategy. It is generally a kind of autonomous (not institutionally planned or directed) kind of adaptation, mainly undertaken and paid for by individuals and families. At the societal level, however, it is also a clear example of potential maladaptation (actions that could result in increased vulnerability or risk from climate change, now or in the future). Without a change of incentives, climatic and socioeconomic factors would usually work in favour of AC rather than other more sustainable and safer solutions, such as thermal insulation (De Cian et al., 2019).

The prospect that AC may de facto become the main means of protection from heat is highly worrying from the perspective of adaptation to climate change. Its various drawbacks, combined with the fact that it is more often than not unavailable to the very groups that it should protect, make it a clear case of potential maladaptation (Farbotko & Waitt, 2011). In general, there are solid arguments for steering away from AC as a main pillar of HHAPs beyond ensuring protection for vulnerable groups.

5.4.4 A nuanced policy approach towards AC

Despite the clarity and importance of the drawbacks set out above, public health authorities have a responsibility to acknowledge that current heat-related mortality can be prevented, and that AC can contribute significantly to that prevention. This discussion must be intrinsically related to the existing inequalities in access to cooling, with wasteful and inefficient AC being the norm rather than the exception. Ito, Lane & Olson (2018) propose various interventions to increase access to AC for those who need it most, including

- facilitating access to, financing of and knowledge about AC for vulnerable populations;
- addressing energy insecurity, including during summer;
- identifying particularly vulnerable individuals for whom AC amounts to life-saving medical equipment;
- addressing inequities in cooling use, discouraging demonstrably excessive AC use in public spaces and work settings, with thermostats and other regulating devices.

If, as it seems, AC growth is likely to continue unabated, a nuanced policy approach may be useful. AC does not necessarily need to be carbon-intensive: AC alternatives with lower greenhouse gas emissions include district cooling and solar-powered AC. If the share of electricity produced through renewable means increases, the carbon intensity of AC will decrease. And increasingly stringent energy efficiency standards will also contribute, as will the progressive substitution of hydrofluorocarbons by other chemicals, as promoted by the global Kigali Amendment to the Montreal Protocol. In such a context, the goal would be to ensure the protective benefits for vulnerable groups of increasingly sustainable AC systems, while promoting increasingly sustainable AC technologies. Moreover, stated plans by several countries to improve building codes in the context of their Nationally Determined Contributions under the Paris Agreement would have multiple benefits in addition to heat risk reduction, including reducing CO_2 and local pollution emissions, decreasing energy poverty and improving energy security (Davide, De Cian & Bernigaud, 2018).

5.5 Conclusions

HHAPs throughout the WHO European Region would benefit from a stronger evidence-based consideration of the factors affecting indoor overheating and possible interventions to address them. Better understanding of the thermal comfort needs of those vulnerable to heat, as well as of the actual correlation between outdoor and indoor temperatures and modulators thereof, is therefore needed. HHAPs include some early examples of modelling and consideration of indoor temperatures, and their transferability should be studied. A wide range of effective passive cooling interventions can afford health protection from heat and should be prioritized on account of their additional benefits for minimizing energy consumption and greenhouse gas emissions.

In addition, ensuring adequate access to indoor cooling is crucial to protect those most vulnerable to heat; yet deep inequalities remain. Addressing those inequalities requires consideration of cooling as a health-protective service and of summertime energy poverty. Given the current increasing trend of residential AC, it must be ensured that those most vulnerable to heat can access the preventive benefits of AC, while minimizing the societal and environmental drawbacks of the technology throughout its life-cycle.

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