Thermal and indoor air quality in dwellings in Europe during summer
A literature review on findings from empirical studies

Eijkelenboom, A.M.; Tenpierik, M.J.; Ottele, M.; Vogt, M.R.; Isabella, O.; Cavallo, R.; Bluyssen, P.M.

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INVESTING IN WELL-BEING IN A CHALLENGING FUTURE

Thermal and indoor air quality in dwellings in Europe during summer; a literature review on findings from empirical studies.

[1]*Eijkelenboom, A., [1]Tenpierik, M., [1]Ottelé, M., [1]Vogt, M., [1]Isabella, O., [1]Cavallo, R., [1]Bluyssen, P.M.
*lead presenter
[1] a.m.eijkelenboom@tudelft.nl, Delft University of Technology, The Netherlands

Abstract

Changing outdoor conditions, i.e. higher outdoor air temperature, higher occurrence of heatwaves and outdoor air pollution, increase the risk of overheating and accumulation of air pollution in homes. Previous studies showed that high indoor air temperatures and air pollution affect occupants' health, resulting in cardio-vascular and respiratory diseases, eyes and skin symptoms, and mortality. Measures to increase energy efficiency of renovated and newly built homes can further increase health risks during extreme weather events and can increase the outdoor temperature. Moreover, the rise of the outdoor air temperature in Europe is higher than the global average.
Therefore, understanding of the extent of current overheating and indoor air pollution and of the contributing factors is necessary to identify the required adaptability of dwellings in Europe to changing outdoor conditions. The objective of this study is to systematically review consequences of changing outdoor conditions, building characteristics, and technology on the indoor environment and occupants' health in homes in European countries during summer.
This review focuses on empirical studies, as these enable to capture real world interactions of occupants and buildings in relation to outdoor conditions. Varying outdoor conditions, building-, and occupant-related aspects in different European climate zones are discussed. Main findings are that overheating already occurs in normal summers in temperate and northern European countries, while variation in overheating is related to occupants' adaptative behaviour and building-related aspects. Based on the review, it is suggested to investigate adaptability of dwellings to changing occupants' needs, new energy efficient technologies, and changing outdoor conditions.

Keywords

Dwellings; overheating; indoor air pollution; health; adaptability

1.Introduction

Due to rising temperatures, air pollution, and more intensive heatwaves, as a consequence of climate change (De Sario et al., 2013; IPCC, 2023), the risk of overheating and indoor air pollution in buildings increases (Attia et al., 2021). Overheating and air pollution can affect health negatively, e.g. increase prevalence of cardiovascular diseases (Analitis et al., 2014; Khraishah et al., 2022), respiratory, eyes and skin complaints (Grigorieva et al., 2021; Ortiz et al., 2020; WHO, 2021) and mortality (Ballester et al., 2023). The current and predicted rise of temperatures are higher in Europe than globally (European Environment Agency, 2023). While heat-related mortality is higher in a Mediterranean and continental climate, an increase is expected also in northern European countries (Baccini et al., 2011), where symptoms related to heat already occur during a normal summer (Näyhä et al., 2014).

In Europe, occupants spend 56% to 66% of their time at home (Schweizer et al., 2007), where about 80% of the energy is used for heating, cooling and hot water (European Comission, 2024). Moreover, buildings (including dwellings) cause 36% of the energy related greenhouse gas emissions in Europe (European Union, 2021). One of the main measures to lower greenhouse gas emissions is improving the energy efficiency of dwellings, i.e. to reduce fossil energy use and use renewable energy for heating, cooling and ventilation (European Union, 2021). However, measures to increase energy efficiency can have adverse effects. For example, high air tightness of façades can affect occupants' health negatively (Ortiz et al., 2020); technologies for renewable energy, such as building integrated photovoltaic panels, increase the outdoor temperature (T_{out}) locally through infra red radiation (Sheik et al., 2022). Therefore, an integrative approach is required to enhance energy efficiency and support occupants' health in dwellings, which are adaptable to continuously changing climate, technology, and health.

According to the New European Bauhaus (NEB, 2020) the quality of the built environment can be improved by dwellings that are adaptable to changing and future needs. However, insight into the adaptability of dwellings is limited through a lack of empirical evidence (Heidrich et al., 2017). As a first step, an overview of occupants' comfort and health in dwellings during summer can contribute to understanding required adaptability of dwellings in relation to recent technologies, changing occupants' behaviour, and rising temperatures. The objective of this study is to systematically review consequences of outdoor conditions on comfort and health in European countries during summer (non-heating season). This review focuses on empirical studies, as these enable to capture real world interactions of occupants in relation to the built environment (Bluyssen, 2020).

2. Methodology

A systematic literature search was performed between February and July 2024. The following three databases were used; Scopus, Web of Science and PubMed. Combinations of five groups of keywords and synonyms were used to find studies on the indoor environment (1) in dwellings (2) during hot weather (3) including health (4) of occupants (5). See Table 1 for all keywords. Papers were selected after reading consecutively titles, abstracts, and full texts. Subsequently, references and citations of the selected papers were examined (snowball).

Table 1: Keywords used in Boolean search.

Indoor (1)	Dwelling (2)	Hot weather (3)	Health (4)	Occupant (5)
Ambient	Home	Overheating	Comfort	Person
	Housing	Heat wave	Wellbeing	User
	Residential housing	Extreme weather event		Human
	Residential building	Smog		People
	Single-family houses	Air pollution		Resident
	Single-family homes			
	Multifamily house			

The selection of papers was based on the following criteria:

- Peer reviewed and original journal papers written in English.
- Data collected in occupied dwellings or from occupants at home.
- Data collected in European countries during summer (non-heating season).

- Studies on relations between outdoor conditions and building characteristics, occupants' health, or comfort.
- Quantitative, qualitative, and mixed methods studies.

Characteristics of methods, analyses, criteria for overheating and for indoor air pollution, occupants, dwellings, region, and study period, were extracted and categorized.

3. Results

Search in the three databases generated initially 1493 titles. After screening of titles, abstracts, and full text reading, thirty-six papers were selected; after examination of references and citations this added up to sixty-eight. The studies were performed in twenty countries, including temperate oceanic (Cfb), humid mild (Dfb), dry warm (Dsa), warm Mediterranean (Csb), hot Mediterranean (Csa) and dry hot (Bsk) summers (Peel et al., 2007). One third of the studies was performed in the United Kingdom, for other countries the number of studies varied from one to eight. Synthesis of the studies is explained according to three main factors, i.e. outdoor conditions (dose-related), building-related and occupant-related.

3.1 Outdoor conditions and indoor thermal and air quality

Overheating in old, renovated, and new dwellings occurs during typical summers throughout Europe (Colclough et al., 2024; Costa-Carrapiço et al., 2022a; Dartevelle et al., 2021; Farahani et al., 2024b; Glad et al., 2024; Mavrogianni et al., 2015; Morgan et al., 2017; Ortiz et al., 2023; Ozarisoy et al., 2021; Pathan et al., 2017; Tabatabaei Sameni et al., 2015; Zuurbier et al., 2021). However, more dwellings are likely to overheat during atypical (hot) summers than typical summers (Hughes et al., 2019; Zahiri et al., 2023), and during heatwaves (Beckmann et al., 2021; Sakka et al., 2012). The relation between average indoor temperatures (T_{in}) and both average solar radiation and outdoor temperature (T_{out}) is weaker during heatwaves than typical summer days (Farahani et al., 2024a). Furthermore, T_{in} varies more than T_{out} during heatwaves (Alonso et al., 2024; Wright et al., 2005; Zuurbier et al., 2021).

During summer the ingress of outdoor air pollutants (fungi, O_3, NO_x) is higher than during the heating season because of higher outdoor concentrations and increased window opening (Derbez et al., 2018; Langer et al., 2015; Szabados et al., 2023; Vu et al., 2022). However, concentrations of O_3 and NO_x tend to be lower than concentrations of other indoor air pollutants, such as formaldehyde and $PM_{2.5}$, because of chemical reactions (Szabados et al., 2023; Vu et al., 2022). Thresholds for indoor air pollutants are exceeded during summer (Coggins et al., 2022; Kaunelienė et al., 2016; Szabados et al., 2023; Vu et al., 2022), while exceedance of indoor CO_2 concentrations varies strongly (Alonso et al., 2024; Coggins et al., 2022; Derbez et al., 2014; Fernández-Agüera et al., 2019; Gupta et al., 2020; Kaunelienė et al., 2016; Langer et al., 2015; McGill et al., 2015; Wang et al., 2022).

3.2 Building-related aspects

Apartments are more likely to overheat than detached dwellings (Beizaee et al., 2013; Colclough et al., 2024; Lomas et al., 2013; Pathan et al., 2017; Tabatabaei Sameni et al., 2015), especially small apartments adjacent to only one façade (Thomson et al., 2019). Some studies did not determine differences in overheating between apartments and semi-detached or terraced dwellings (Colclough et al., 2024; Lomas et al., 2013; McGill et al., 2017; Morey et al., 2020), while other studies did (Beizaee et al., 2013; Pathan et al., 2017; Zuurbier et al., 2021). Furthermore, overheating (Arriazu-Ramos et al., 2023; Beizaee et al., 2013; Desogus et al., 2015; Gupta et al., 2020; Lomas et al., 2024; Morey et al., 2020; Zahiri et al., 2023) and dissatisfaction (Ozarisoy et al., 2021) tend to be higher on top floors than at lower levels during summer. Also, the risk for overheating (Dartevelle et al., 2021; Gupta et al., 2020;

Gupta et al., 2019; Jang et al., 2022; Morey et al., 2020) and occupants' dissatisfaction (Mlecnik et al., 2012) in bedrooms are higher than in living rooms, even during cool temperate summers (Mitchell et al., 2019). Particularly, the prevalence and the intensity of overheating (Lomas et al., 2024) and the risk of mortality (Vandentorren et al., 2006) are higher in bedrooms in houses without loft or façade insulation than in insulated rooms. Overall, findings on overheating in relation to higher insulation of façades vary; no difference (Lomas et al., 2024); lower risk in recently built or renovated dwellings (Ahan et al., 2023; Farahani et al., 2024b); higher risk (Arriazu-Ramos et al., 2023; Beizaee et al., 2013; Lomas et al., 2013; Lomas et al., 2021; Maivel et al., 2015; Mitchell et al., 2019; Morey et al., 2020; Pathan et al., 2017; Sarran et al., 2023).

Glazed balconies are likely to result in overheating of adjacent rooms during summer (Fernandes et al., 2015; Grudzińska, 2021). However, double solar shading and sufficient opening for ventilation (more than 25%) reduce overheating indoors (Monge-Barrio et al., 2015). Furthermore, shelter from wind, birds, burglary, and improved thermal comfort during the heating season increase the occupants' acceptability of high temperatures due to glazed balconies during the non-heating season (Grudzińska, 2021). Findings on relations between overheating and orientation vary from none (in retrofitted low-rise dwellings without shading (Vellei et al., 2017)), and weak (dwellings with solar shading (Arriazu-Ramos et al., 2023; Dartevelle et al., 2024; Ortiz et al., 2023)), to strong (in south and south-west facing rooms on top floors (Zahiri et al., 2023; Zuurbier et al., 2021) and west facing rooms at high north latitudes; 58° and 60° (Berge et al., 2016; Glad et al., 2024) without solar shading). Glad et al. (2024) found that occupants even moved from west facing apartments because of overheating.

During summer, indoor air quality, based on CO_2 concentrations, is similar (Wang et al., 2022) or lower (Baborska – Narożny et al., 2022; Gupta et al., 2019) in mechanically ventilated dwellings than in (solely) naturally ventilated dwellings. Overheating occurs both in dwellings with only natural indoor air exchange (Fernández-Agüera et al., 2019; McGill et al., 2017; Sakka et al., 2012; Vellei et al., 2017; Vidal et al., 2020) and in dwellings with mechanical exhaust and supply (Baborska-Narożny et al., 2017; Dartevelle et al., 2024; Farahani et al., 2024b; Gupta et al., 2019; Kaunelienė et al., 2016; McGill et al., 2015; McGill et al., 2017; Sarran et al., 2023; Stamp et al., 2022; Szabados et al., 2023). Automatically opened windows (Psomas et al., 2017), decentralized mechanical ventilation in apartments (Maivel et al., 2015), and low set-point/ switch off of heat recovery (Berge et al., 2016) decrease the risk of overheating.

3.3 Occupant-related aspects

Occupants tend to be more satisfied with indoor air quality during non-heating seasons than during heating seasons (McGill et al., 2015; Sarran et al., 2023). However, no relations were found between satisfaction with indoor air quality and ventilation rates, concentrations of CO_2, or concentrations of indoor air pollutants (Berge et al., 2016; Coggins et al., 2022; McGill et al., 2015).

Relations were found between satisfaction with thermal quality and T_{in} (Beckmann et al., 2021; Dartevelle et al., 2024; van Loenhout et al., 2016). However, occupants are likely to be satisfied with higher T_{in} than estimated by criteria for adaptive comfort (Ozarisoy et al., 2021; Petrou et al., 2019; Vellei et al., 2017; Zahiri et al., 2023), steady-state comfort (Baquero et al., 2022; Ozarisoy et al., 2021) and national standards (Alonso et al., 2024). Acceptability of high T_{in} differs due to habituation, expectations, and previous experiences (Costa-Carrapiço et al., 2022b; Grudzińska, 2021; Hassani et al., 2024; Thomson et al., 2019). Furthermore, elderly and those with chronic diseases prefer higher T_{in} than other occupants (Baquero et al., 2022; Beckmann et al., 2021; Hughes et al., 2019), although they tend to suffer more (Kemen et al., 2021; Thomson et al., 2019) and have a higher mortality risk due to hot weather

(Vandentorren et al., 2006). Also, high T_{in} affects sleep quality negatively (Ahan et al., 2023; van Loenhout et al., 2016; Vidal et al., 2020); while adapted sleeping times might reduce heat exposure during sleep (Hendel et al., 2017).

Adaptive behaviour varies between occupants due to differences in experiences (Yáñez Serrano et al., 2023), perception (Kemen et al., 2021), vulnerability (Vellei et al., 2017), and knowledge about environmental control (Baborska-Narożny et al., 2017; McGill et al., 2015; Murtagh et al., 2019). Dwellings can become less overheated during hot weather when occupants have become more familiar with their home (Fletcher et al., 2017), e.g., because of increasingly proper use of solar shading (Derbez et al., 2014), or improved control of mechanical ventilation and opening of windows (Berge et al., 2016). The main reason why occupants open windows is cooling (Berge et al., 2016; Mavrogianni et al., 2017; Wang et al., 2022), although it can be insufficient to avoid overheating (Ortiz et al., 2023; Sakka et al., 2012; Zahiri et al., 2023). Furthermore, CO_2 concentrations strongly vary in relation to window opening (Berge et al., 2016; Fernández-Agüera et al., 2019) but are generally lower than when occupants keep their windows closed (Mavrogianni et al., 2017).

4. Discussion

This review provides insights into consequences of outdoor conditions on indoor air quality and thermal quality in dwellings in European countries during summer. Main correlations of thermal and indoor air quality with layout (dwelling type, floor level, room type), building envelope (insulation, orientation, shading, glazing), and technology (mechanical ventilation, automatic windows) are shown. Inconsistencies between studies on correlations between overheating and dwelling types, insulation, and orientation of façades, might be related to differences in the outdoor environment, adaptive behaviour, and interactions of building related aspects with thermal and indoor air quality. Based on these inconsistencies, it can be concluded that overheating is not related to just one single building related aspect; a comprehensive inventory and analysis of building related aspects and local outdoor environmental characteristics might contribute to a better understanding.

No empirical evidence of new technologies that increase the passive cooling capacity, such as green building envelopes (Ottelé et al., 2017; Perini et al., 2011; Stache et al., 2022), or use of phase changing materials (Tenpierik et al., 2018; Tenpierik et al., 2019), was found. Also, the reviewed studies did not include information on new technologies for renewable energy, e.g., photovoltaic panels optimized to reject infrared radiation and improve building integration (Ortiz Lizcano et al., 2020; Ortiz Lizcano et al., 2022). However, as new technologies may evolve and can affect both adaptive behaviour (Hellwig et al., 2022) and required adaptability of buildings (van Ellen et al., 2021), more studies on how new energy efficient technologies contribute to less overheating and indoor air pollution in dwellings are required.

There is ample evidence of discrepancies between overheating criteria and satisfaction with thermal comfort. This can be related to limited consideration in overheating standards of the effects from urban heat islands, heatwaves, climate change (Attia et al., 2023), and variation of psychological and physiological reactions to indoor conditions between individuals (Bluyssen, 2022). Higher tolerance of high temperatures was found for those who are traditionally used to cope with high T_{out}. On the other hand, occupants' preferences can change due to contextual changes (Eijkelenboom et al., 2021) and improve their adaptation strategies to stay comfortable indoors because of changing outdoor conditions (Hellwig et al., 2022). Therefore, it is necessary to increase our understanding of correlations between changing outdoor conditions, acceptability, and evolving adaptive behaviour indoors.

While adaptive behaviour can improve comfort, adaptive behaviour can be insufficient to support health of occupants. For example, the review showed that thermal quality is likely to be a stronger driver for adaptative behaviour (e.g., use of solar shading, opening windows) than indoor air quality. This might have adverse effects, such as deprived sleep quality because of high concentrations of indoor air pollutants when windows are closed and fans are used for cooling (Yan et al., 2022), or, depending on the intensity of traffic and urbanization, too high ingress of outdoor air pollutants when windows are opened for cooling (Belias et al., 2023). Furthermore, while bedrooms seem prone to overheating, possibly due to low thresholds for temperatures in overheating criteria (Beizaee et al., 2013) and high exposure to solar radiation at top floors in houses, behavioural adaptation is limited during sleeping time. Moreover, during working hours, when away from home, the risk for overheating is higher, possibly because of limited opportunities for behavioural adaptation. Furthermore, adaptive behaviour of unhealthy elderly might be insufficient because they are more likely to accept high T_{in}, while they are more vulnerable to heat than others.

5. Conclusions

Overall, this review shows that overheating already occurs in normal summers in European countries with temperate, mild, warm, or hot summers. Indoor air quality is likely to differ during the non-heating season as compared to the heating season due to variation of air exchange and of outdoor air pollutants. The effect of outdoor temperature on indoor temperature highly depends on building- related aspects (such as housing type, floor level, type of ventilation) and occupant-related aspects (health, adaptive behaviour), especially during heatwaves. Because of inconsistent relations between indoor temperatures and housing type, orientation, and insulation, it can be concluded that comprehensive analysis of building-related aspects and the urban environment is required. Furthermore, overheating standards and thresholds for indoor air pollutants do not comply with perceived thermal and indoor air quality. Moreover, adaptive behaviour of occupants can affect health negatively and can change due to changing acceptability, expectations, or familiarity. Therefore, better understanding of occupants' adaptive strategies and their relation to comfort and health is required. Due to the ongoing climate change (including uncertainties on the extent of rising temperatures), changing adaptive behaviour, and evolving energy efficient technologies, study of adaptability of dwellings to these changes is required to contribute to energy efficient, health supporting dwellings.

References

Ahan, M.M., Nouri, A.S., et al. (2023). Investigating the Relationship of Outdoor Heat Stress upon Indoor Thermal Comfort and Qualitative Sleep Evaluation: The Case of Ankara. *Atmosphere*, *14*(9), 1407.

Alonso, C., de Frutos, F., et al. (2024). Energy consumption and environmental parameters in Madrid social housing. Performance in the face of extreme weather events. *Building and Environment*, *254*, 111354

Analitis, A., Michelozzi, P., et al. (2014). Effects of Heat Waves on Mortality: Effect Modification and Confounding by Air Pollutants. *Epidemiology*, *25*(1), 15-22

Arriazu-Ramos, A., Bes-Rastrollo, M., et al. (2023). Building parameters that influence overheating of apartment buildings in a temperate climate in Southern Europe. *Building and Environment*, *228*, 109899.

Attia, S., Levinson, R., et al. (2021). Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition. *Energy and Buildings*, *239*, 110869

Attia, S., Benzidane, C., et al. (2023). Overheating calculation methods criteria and indicators in European regulation for residential buildings. *Energy and Buildings*, *113170*, 113170

Baborska-Narożny, M., Stevenson, F., et al. (2017). Overheating in retrofitted flats: occupant practices, learning and interventions. *Building Research & Information*, *45*(1-2), 40-59

Baborska – Narożny, M., & Kostka, M. (2022). Seasonal Air Quality in Bedrooms with Natural, Mechanical or Hybrid Ventilation Systems and Varied Window Opening Behavior-Field Measurement Results. *Energies*, *15*(24), 9328

Baccini, M., Kosatsky, T., et al. (2011). Impact of heat on mortality in 15 European cities: Attributable deaths under different weather scenarios. *Journal of Epidemiology and Community Health*, *65*(1), 64-70
Ballester, J., Quijal-Zamorano, M., et al. (2023). Heat-related mortality in Europe during the summer of 2022. *Nature Medicine*, *29*(7), 1857-1866
Baquero, M.T., & Forcada, N. (2022). Thermal comfort of older people during summer in the continental Mediterranean climate. *Journal of Building Engineering*, *54*, 104680.
Beckmann, S.K., Hiete, M., et al. (2021). Threshold temperatures for subjective heat stress in urban apartments—Analysing nocturnal bedroom temperatures during a heat wave in Germany. *Climate Risk Management*, *32*, 100286
Beizaee, A., Lomas, K.J., et al. (2013). National survey of summertime temperatures and overheating risk in English homes. *Building and Environment*, *65*, 1-17
Belias, E., & Licina, D. (2023). Influence of outdoor air pollution on European residential ventilative cooling potential. *Energy and Buildings*, *289*, 113044
Berge, M., & Mathisen, H.M. (2016). Perceived and measured indoor climate conditions in high-performance residential buildings. *Energy and Buildings*, *127*, 1057-1073
Bluyssen, P.M. (2020). Towards an integrated analysis of the indoor environmental factors and its effects on occupants. *Intelligent Buildings International*, *12*(3), 199-207
Bluyssen, P.M. (2022). All you need to know about the indoor environment, its occupants, interactions and effects. Comfort at the Extremes: Climate Change, COVID and Ventilation, Edinburgh.
Coggins, A.M., Wemken, N., et al. (2022). Indoor air quality, thermal comfort and ventilation in deep energy retrofitted Irish dwellings. *Building and Environment*, *219*, 109236
Colclough, S., & Salaris, C. (2024). Quantifying overheating in nZEB Irish residential buildings. An analysis of recorded interior temperatures of Irish newbuild and retrofit residential buildings against CIBSE, Passive House and WHO overheating criteria and recorded occupant satisfaction. *Energy and Buildings*, *303*, 113571.
Costa-Carrapiço, I., González, J.N., et al. (2022a). Indoor environmental conditions in vernacular dwellings in Alentejo, Portugal. *Science and Technology for the Built Environment*, *28*(10), 1370-1406
Costa-Carrapiço, I., González, J.N., et al. (2022b). Understanding thermal comfort in vernacular dwellings in Alentejo, Portugal: A mixed-methods adaptive comfort approach. *Building and Environment*, *217*, 109084
Dartevelle, O., van Moeseke, G., et al. (2021). Long-term evaluation of residential summer thermal comfort: Measured vs. perceived thermal conditions in nZEB houses in Wallonia. *Building and Environment*, *190*, 107531.
Dartevelle, O., van Moeseke, G., et al. (2024). On the effectiveness of passive controls for summer thermal comfort in highly insulated dwellings. *Building Research and Information*, *52*(3), 311-331
De Sario, M., Katsouyanni, K., et al. (2013). Climate change, extreme weather events, air pollution and respiratory health in Europe. *European Respiratory Journal*, *42*(3), 826-843
Derbez, M., Wyart, G., et al. (2018). Indoor air quality in energy-efficient dwellings: Levels and sources of pollutants. *Indoor air*, *28*(2), 318-338
Derbez, M., Berthineau, B., et al. (2014). A 3-year follow-up of indoor air quality and comfort in two energy-efficient houses. *Building and Environment*, *82*, 288-299
Desogus, G., Di Benedetto, S., et al. (2015). The use of adaptive thermal comfort models to evaluate the summer performance of a Mediterranean earth building. *Energy and Buildings*, *104*, 350-359
Eijkelenboom, A., Ortiz, M.A., et al. (2021). Preferences for Indoor Environmental and Social Comfort of Outpatient Staff during the COVID-19 Pandemic, an Explanatory Study. *International Journal of Environmental Research and Public Health*, *18*(14), 7353
European Comission. (2024). *Energy Performance of Building Directive*.
European Environment Agency. (2023). *Global and European Temperatures*.
European Union. (2021). *Making our homes and buildings fit for a greener future*.

Farahani, A.V., Jokisalo, J., et al. (2024a). Hot Summers in Nordic Apartments: Exploring the Correlation between Outdoor Weather Conditions and Indoor Temperature. *Buildings*, *14*(4), 1053

Farahani, A.V., Kravchenko, I., et al. (2024b). Overheating assessment for apartments during average and hot summers in the Nordic climate. *Building Research & Information*, *52*(3), 273-291

Fernandes, J., Pimenta, C., et al. (2015). Contribution of Portuguese Vernacular Building Strategies to Indoor Thermal Comfort and Occupants' Perception. *Buildings*, *5*(4), 1242-1264

Fernández-Agüera, J., Domínguez-Amarillo, S., et al. (2019). Thermal comfort and indoor air quality in low-income housing in Spain: The influence of airtightness and occupant behaviour. *Energy and Buildings*, *199*, 102-114

Fletcher, M.J., Johnston, D.K., et al. (2017). An empirical evaluation of temporal overheating in an assisted living Passivhaus dwelling in the UK. *Building and Environment*, *121*, 106-118

Glad, W., Gramfält, M., et al. (2024). Residents' thermal comfort in Swedish newly built homes: political aesthetics and atmospheric practices. *Housing Studies*, 1-23

Grigorieva, E., & Lukyanets, A. (2021). Combined Effect of Hot Weather and Outdoor Air Pollution on Respiratory Health: Literature Review. *Atmosphere*, *12*(6), 790

Grudzińska, M. (2021). Overheating assessment in flats with glazed balconies in warm-summer humid continental climate. *Building Services Engineering Research and Technology*, *42*(5), 583-602

Gupta, R., & Gregg, M. (2020). Assessing the magnitude and likely causes of summertime overheating in modern flats in UK. *Energies*, *13*(19), 5202.

Gupta, R., Gregg, M., et al. (2019). Meta-analysis of summertime indoor temperatures in new-build, retrofitted, and existing UK dwellings [Article]. *Science and Technology for the Built Environment*, *25*(9), 1212-1225

Hassani, A., Jancewicz, B., et al. (2024). Understanding Thermal Comfort Expectations in Older Adults: The Role of Long-Term Thermal History. *Building and Environment*, 111900

Heidrich, O., Kamara, J., et al. (2017). A critical review of the developments in building adaptability. *International Journal of Building Pathology and Adaptation*, *35*(4), 284-303

Hellwig, R.T., Teli, D., et al. (2022). Design of adaptive opportunities for people in buildings. In *Routledge Handbook of Resilient Thermal Comfort* (pp. 193-209). Routledge.

Hendel, M., Azos-Diaz, K., et al. (2017). Behavioral adaptation to heat-related health risks in cities. *Energy and Buildings*, *152*, 823-829

Hughes, C., & Natarajan, S. (2019). Summer thermal comfort and overheating in the elderly. *Building Services Engineering Research and Technology*, *40*(4), 426-445

IPCC. (2023). *Climate change 2023 Synthesis Report Summary for Policymakers*.

Jang, J., Natarajan, S., et al. (2022). Comparative Analysis of Overheating Risk for Typical Dwellings and Passivhaus in the UK. *Energies*, *15*(10), 3829

Kaunelienė, V., Prasauskas, T., et al. (2016). Indoor air quality in low energy residential buildings in Lithuania. *Building and Environment*, *108*, 63-72

Kemen, J., Schäffer-Gemein, S., et al. (2021). Heat Perception and Coping Strategies: A Structured Interview-Based Study of Elderly People in Cologne, Germany. *International Journal of Environmental Research and Public Health*, *18*(14), 7495

Khraishah, H., Alahmad, B., et al. (2022). Climate change and cardiovascular disease: implications for global health. *Nature Reviews Cardiology*, *19*(12), 798-812

Langer, S., Bekö, G., et al. (2015). Indoor air quality in passive and conventional new houses in Sweden. *Building and Environment*, *93*, 92-100

Lomas, K.J., & Kane, T. (2013). Summertime temperatures and thermal comfort in UK homes. *Building Research & Information*, *41*(3), 259-280

Lomas, K.J., Li, M., et al. (2024). How do energy efficiency measures affect the risk of summertime overheating and cold discomfort? Evidence from English homes [Article]. *Energy Policy*, *188*, 114108.

Lomas, K.J., Watson, S., et al. (2021). Dwelling and household characteristics' influence on reported and measured summertime overheating: A glimpse of a mild climate in the 2050's. *Building and Environment*, *201*, 107986.

Maivel, M., Kurnitski, J., et al. (2015). Field survey of overheating problems in Estonian apartment buildings. *Architectural Science Review*, *58*(1), 1-10

Mavrogianni, A., Taylor, J., et al. (2015). Urban social housing resilience to excess summer heat. *Building Research & Information*, *43*(3), 316-333

Mavrogianni, A., Pathan, A., et al. (2017). Inhabitant actions and summer overheating risk in London dwellings. *Building Research & Information*, *45*(1-2), 119-142

McGill, G., Oyedele, L.O., et al. (2015). An investigation of indoor air quality, thermal comfort and sick building syndrome symptoms in UK energy efficient homes. *Smart and Sustainable Built Environment*, *4*(3), 329-348

McGill, G., Sharpe, T., et al. (2017). Meta-analysis of indoor temperatures in new-build housing. *Building Research & Information*, *45*(1-2), 19-39

Mitchell, R., & Natarajan, S. (2019). Overheating risk in Passivhaus dwellings. *Building Services Engineering Research and Technology*, *40*(4), 446-469

Mlecnik, E., Schütze, T., et al. (2012). End-user experiences in nearly zero-energy houses. *Energy and Buildings*, *49*, 471-478

Monge-Barrio, A., & Sánchez-Ostiz, A. (2015). Energy efficiency and thermal behaviour of attached sunspaces, in the residential architecture in Spain. Summer Conditions. *Energy and Buildings*, *108*, 244-256

Morey, J., Beizaee, A., et al. (2020). An investigation into overheating in social housing dwellings in central England. *Building and Environment*, *176*, 106814

Morgan, C., Foster, J.A., et al. (2017). Overheating in Scotland: contributing factors in occupied homes. *Building Research & Information*, *45*(1-2), 143-156

Murtagh, N., Gatersleben, B., et al. (2019). Occupants' motivation to protect residential building stock from climate-related overheating: A study in southern England. *Journal of Cleaner Production*, *226*, 186-194

Näyhä, S., Rintamäki, H., et al. (2014). Heat-related thermal sensation, comfort and symptoms in a northern population: The National FINRISK 2007 study. *European Journal of Public Health*, *24*(4), 620-626

NEB. (2020). *Common Ground: Making the Renovation Wave a Cultural Project*.

Ortiz, J., Carrere, J., et al. (2023). Energy consumption and indoor environmental quality evaluation of a cooperative housing nZEB in Mediterranean climate. *Building and Environment*, *228*, 109795

Ortiz Lizcano, J.C., Haghighi, Z., et al. (2020). Photovoltaic chimney: Thermal modeling and concept demonstration for integration in buildings. *Progress in Photovoltaics: Research and Applications*, *28*(6), 465-482

Ortiz Lizcano, J.C., Procel, P., et al. (2022). Colored optic filters on c-Si IBC solar cells for building integrated photovoltaic applications. *Progress in Photovoltaics: Research and Applications*, *30*(4), 401-435

Ortiz, M., Itard, L., et al. (2020). Indoor environmental quality related risk factors with energy - efficient retrofitting of housing: A literature review. *Energy and Buildings*, *221*

Ottelé, M., & Perini, K. (2017). Comparative experimental approach to investigate the thermal behaviour of vertical greened façades of buildings. *Ecological Engineering*, *108*, 152-161

Ozarisoy, B., & Altan, H. (2021). Regression forecasting of 'neutral' adaptive thermal comfort: A field study investigation in the south-eastern Mediterranean climate of Cyprus. *Building and Environment*, *202*, 108013

Pathan, A., Mavrogianni, A., et al. (2017). Monitoring summer indoor overheating in the London housing stock. *Energy and Buildings*, *141*, 361-378

Peel, M.C., Finlayson, B.L., et al. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci.*, *11*(5), 1633-1644

Perini, K., Ottelé, M., et al. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment*, *46*(11), 2287-2294

Petrou, G., Symonds, P., et al. (2019). The summer indoor temperatures of the English housing stock: Exploring the influence of dwelling and household characteristics. *Building Services Engineering Research and Technology*, *40*(4), 492-511

Psomas, T., Heiselberg, P., et al. (2017). Automated roof window control system to address overheating on renovated houses: Summertime assessment and intercomparison. *Energy and Buildings*, *138*, 35-46

Sakka, A., Santamouris, M., et al. (2012). On the thermal performance of low income housing during heat waves. *Energy and Buildings*, *49*, 69-77
Sarran, L., Hviid, C.A., et al. (2023). How to ensure occupant comfort and satisfaction through deep building retrofit? Lessons from a Danish case study. *Science and Technology for the Built Environment*, *29*(7), 663-677
Schweizer, C., Edwards, R.D., et al. (2007). Indoor time–microenvironment–activity patterns in seven regions of Europe. *Journal of Exposure Science & Environmental Epidemiology*, *17*(2), 170-181
Sheik, M.S., Kakati, P., et al. (2022). A comprehensive review on various cooling techniques to decrease an operating temperature of solar photovoltaic panels. *Energy Nexus*, *8*, 100161
Stache, E., Schilperoort, B., et al. (2022). Comparative analysis in thermal behaviour of common urban building materials and vegetation and consequences for urban heat island effect. *Building and Environment*, *213*, 108489
Stamp, S., Burman, E., et al. (2022). Seasonal variations and the influence of ventilation rates on IAQ: A case study of five low-energy London apartments. *Indoor and Built Environment*, *31*(3), 607-623
Szabados, M., Magyar, D., et al. (2023). Indoor air quality in Hungarian Passive Houses. *Atmospheric Environment*, *307*, 119857
Tabatabaei Sameni, S.M., Gaterell, M., et al. (2015). Overheating investigation in UK social housing flats built to the Passivhaus standard. *Building and Environment*, *92*, 222-235
Tenpierik, M., Turrin, M., et al. (2018). Double Face 2.0: A lightweight translucent adaptable Trombe wall. *SPOOL*, *5*(2-)
Tenpierik, M., Wattez, Y., et al. (2019). Temperature control in (translucent) phase change materials applied in facades: A numerical study. *Energies*, *12*(17), 3286.
Thomson, H., Simcock, N., et al. (2019). Energy poverty and indoor cooling: An overlooked issue in Europe. *Energy and Buildings*, *196*, 21-29
van Ellen, L.A., Bridgens, B.N., et al. (2021). Rhythmic Buildings, a framework for sustainable adaptable architecture. *Building and Environment*, *203*, 108068
van Loenhout, J.A.F., le Grand, A., et al. (2016). The effect of high indoor temperatures on self-perceived health of elderly persons. *Environmental Research*, *146*, 27-34
Vandentorren, S., Bretin, P., et al. (2006). August 2003 Heat Wave in France: Risk Factors for Death of Elderly People Living at Home. *European Journal of Public Health*, *16*(6), 583-591
Vellei, M., Ramallo-González, A.P., et al. (2017). Overheating in vulnerable and non-vulnerable households. *Building Research & Information*, *45*(1-2), 102-118
Vidal, I.R., Otaegi, J., et al. (2020). Thermal comfort in nzeb collective housing in Northern Spain. *Sustainability (Switzerland)*, *12*(22), 1-30, 9630.
Vu, T.V., Stewart, G.B., et al. (2022). Assessing the contributions of outdoor and indoor sources to air quality in London homes of the SCAMP cohort. *Building and Environment*, *222*, 109359
Wang, Y., Tahmasebi, F., et al. (2022). Exploring the relationship between window operation behavior and thermal and air quality factors: A case study of UK residential buildings. *Journal of Building Engineering*, *48*, 103997.
WHO. (2021). *Ambient (outdoor) air pollution*
Wright, A., Young, A., et al. (2005). Dwelling temperatures and comfort during the August 2003 heat wave. *Building Services Engineering Research and Technology*, *26*(4), 285-300
Yan, Y., Lan, L., et al. (2022). Association of bedroom environment with the sleep quality of elderly subjects in summer: A field measurement in Shanghai, China. *Building and Environment*, *208*, 108572
Yáñez Serrano, P., Torrego Gómez, D., et al. (2023). Energy vulnerability and self-imposed austerity: An ethnographic approach to adaptation strategies to extreme heat among older adults in Madrid. *Energy Research and Social Science*, *103*, 103207.
Zahiri, S., & Gupta, R. (2023). Examining the Risk of Summertime Overheating in UK Social Housing Dwellings Retrofitted with Heat Pumps. *Atmosphere*, *14*(11), 1617.
Zuurbier, M., van Loenhout, J.A.F., et al. (2021). Street temperature and building characteristics as determinants of indoor heat exposure. *Science of the Total Environment*, *766*, 144376.