The rapid progress of climate change requires effective concepts for protecting people indoors

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Abstract

According to the latest forecasts from the United Nations, it is highly likely that we will miss by a wide margin the 1.5 °C climate target set in the Paris Agreement in 2015. Rather, this planet has to prepare for a global temperature increase of 2.6 - 3.1 °C by 2100 and associated frequently occurring extreme weather events. It is therefore high time to design and technically equip the buildings, in which a large part of everyday life takes place, for future requirements to avoid endangering the health of the population in the short or long-term. Generally, occupied indoor spaces not only serve as living and working environments, but are also needed to protect people, particularly vulnerable population groups (e.g., those residing in hospitals and retirement homes) against heat stress, microbial contamination, air pollutants, and other threats. However, this aspect of climate change has not yet been adequately addressed at either government or municipal level. Many existing buildings do not meet the requirements that can be expected in the future, and disaster protection is not sufficiently taken into account in current planning.

Keywords

Indoor environment; heat stress, humidity; air pollutants; mold; decision making.

Conflict of Interest

The authors declare no conflicts of interest.

Graphical Abstract

As climate change progresses, society is increasingly exposed to extreme weather events. It is therefore high time to adapt our buildings, housing infrastructure, and logistics to protect people and provide them with an appropriate living environment.

1. INTRODUCTION

The effects of climate change on the landscape and society are already clearly noticeable and are being extensively investigated. For example, a book published by Brasseur et al. (2017) offers a comprehensive and careful analysis of the situation in Germany, with the exception that indoor spaces, where people spend most of their day, are not addressed. Indoor-related topics are also rarely represented in terms of the total number of publications on climate change. The first comprehensive indoor-related review was published in 2011 in the United States by the Institute of Medicine of the National Academies (2011). In his review on climate change adaptation through personal indoor and outdoor thermal comfort management, Hitchings (2011) pointed out that aspects other than temperature should also be considered. In the following years, publications occasionally appeared addressing the possible effects of climate change on indoor air quality (Fisk 2015; Gherasim et al. 2024; Mansouri et al. 2022; Nazaroff 2013; Spengler 2012; Tham 2016; Vardoulakis et al. 2015). These reports clearly identified the potential future hazards to human health if no mitigation and adaptation measures are taken.

The slow progress in preparing buildings for future requirements is surprising, as the adverse impacts of extreme weather events have long been known, in Europe at least since the heatwave of 2003 (Fischer et al. 2004; Schär and Jendritzky 2004; Steul et al. 2018). As a consequence of these events, the World Health Organization (2021a) has published recommendations for the prevention of heat stress. Extreme weather events with heat, heavy rain, sandstorms, wildfires, and smog events are no longer unexpected (Merdji et al. 2023; Morawska et al. 2021; Wasko et al. 2021). The only question is when and where the next event will occur. There are numerous publications on the negative health effects of climate change, but mostly with reference to heat and air pollution (Alahmad et al. 2023; Ebi et al. 2021). The influence of humidity is less frequently reported (Papanastasiou et al. 2015), and exposure to allergens related to mold and dampness has also received little attention (Eguiluz-Gracia et al. 2020). However, today it is scientifically accepted that the overall system of outdoor environment – building envelope – indoor environment must be considered in order to describe the living conditions indoors (Pallubinsky et al. 2023). This aspect is taken into account for example by a holistic model, which combines building physics, climatic parameters, indoor emissions, indoor chemistry, and mold growth for long-term predictions of thermal comfort and exposure to pollutants indoors (Salthammer et al. 2022; Zhao et al. 2024).

Singh et al. (2024) also see an urgent need to strengthen heat risk management efforts, and argue that such measures can benefit from advances in knowledge about vulnerability to and adaptation to climate change. There is now sufficient scientific expertise to realistically assess the current and future consequences of climate change for human society in the indoor environment. As a result, action plans must be implemented to communicate the negative health impacts of climate change directly, to enable personal responsibility on building protection that is adapted to the situation, and to establish preventive measures. Although it seems logical that indoor spaces are an important part of such concepts, the significance of this fact is not yet sufficiently understood.

2. THE EXPECTED PROGRESSION OF CLIMATE CHANGE UNTIL 2100

On the occasion of the 21st UN Climate Change Conference in 2015 (COP21), the Paris Agreement was signed, which calls for global efforts to achieve the 1.5 degree target (United Nations 2016). This corresponds to the optimistic shared economic pathway SSP1-1.9 of the Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change 2021) which assumes a sustainable path and radiative forcing of 1.9 W/m^2 or lower in the year 2100. However, it is unlikely that this goal can still be achieved. According to a recent United Nations report (United Nations Environment Programme 2024), global greenhouse gas emissions reached a new record in 2023 with 57.1 Gt CO_2 equivalents, 1.3% higher than 2022 levels. The energy market is showing two opposing trends: on the one hand, the expansion of sustainable energies is progressing rapidly, while on the other hand, global energy demand is growing, which is being met by fossil fuels. The two trends are more or less balancing each other out, so that we are currently heading towards a SSP2-4.5 scenario with intermediate greenhouse gas emissions, which means a global temperature increase of 2.7 °C or higher by 2100. Given the current facts, it seems naive and unrealistic to focus on the 1.5 °C target. It can even be assumed that extreme heat in several regions of the world will increase significantly and faster than predicted by climate models (Kornhuber et al. 2024). The increase in global mean sea surface temperature is also likely to occur faster than expected from linear extrapolation models (Merchant et al. 2025). It is therefore imperative to prepare society for the unavoidable consequences. This applies to both the economic impact and the need for better protection of people from extreme weather events (Semieniuk et al. 2022).

3. IMPACT OF EXTREME WEATHER CONDITIONS ON INDOOR AIR QUALITY

It is time for human society to face the facts: we are currently not only failing to reduce greenhouse gas emissions, but are also largely ignoring the necessary measures to protect people from the negative health impacts of climate change. Extreme weather events pose many major challenges to our society and inevitably, depending on interactions via the building envelope, also affect human safety and comfort in the indoor environment. The threats and consequences resulting from delayed action are convincingly demonstrated by Romanello et al. (2024). However, their publication does not explicitly address the impacts of climate change on indoor spaces, so the indoor-related aspects that need to be discussed are summarized in a general way in Figure 1.

It can be clearly seen from Figure 1 that indoor climate and indoor air quality are determined by a complex interaction of various influencing factors inside and outside. In reality, however, the relationships are much more complicated. For example, the emission rates of volatile organic compounds from building materials, consumer products, and furniture increase with temperature (Salthammer and Morrison 2022). Additionally, the bimolecular reaction rates between unsaturated hydrocarbons and ozone, which essentially determine indoor chemistry (Abbatt and Wang 2020), are also temperature-dependent (Atkinson and Arey 2003). If the temperature is lowered indoors, attention must also be paid to the humidity to avoid dew point effects and mold growth. Reasonable indoor air quality can therefore only be achieved by taking several control variables into account.

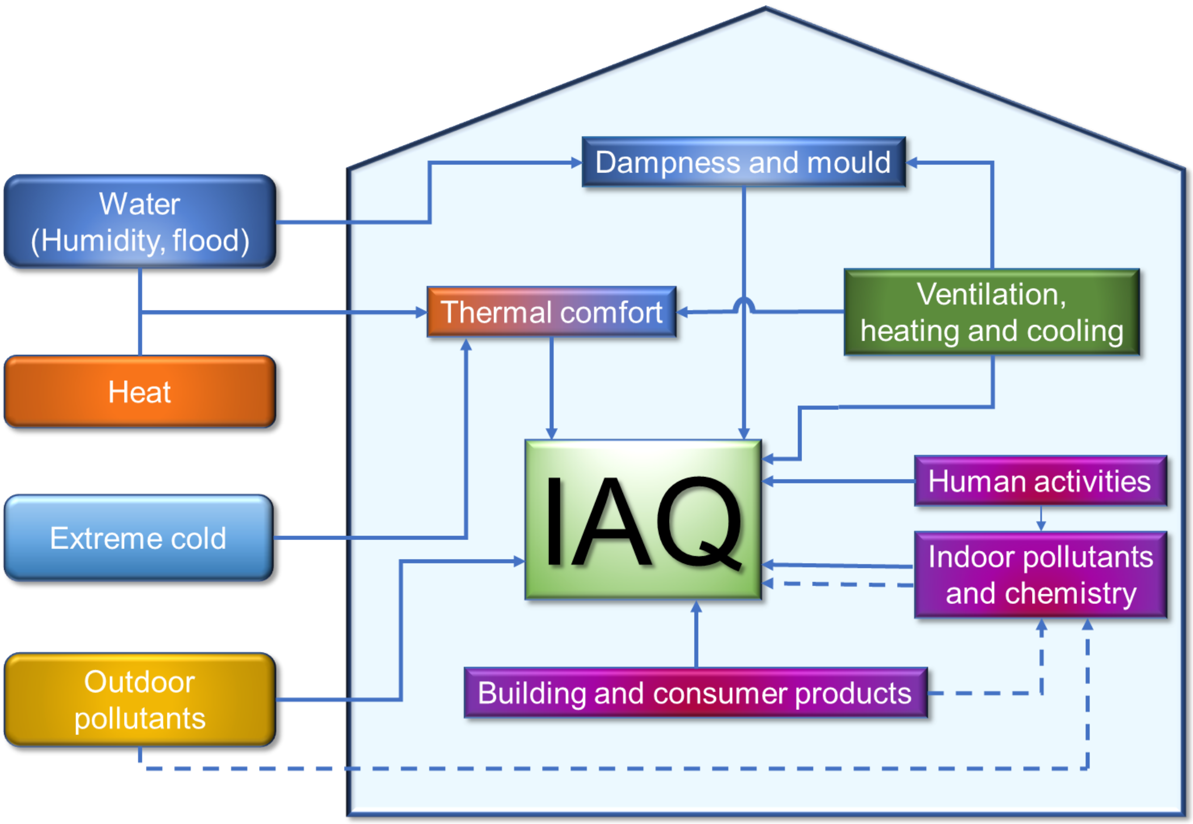

Figure 1. How the interaction of indoor- and outdoor-related factors influences indoor air quality (IAQ). The dashed lines indicate exposure to secondary pollutants from indoor chemistry.

3.1 Thermal comfort and discomfort

There are many misunderstandings about the term temperature. Thermodynamic temperature is clearly defined and established as an international base unit, but that has little to do with the perceived temperature. It is also important to realize that temperature is not the same as heat. For human thermal comfort, the operative temperature T_{op} is important. T_{op} is calculated for low air velocities (< 0.2 m/s) from the mean value of air temperature T_{air} and the mean radiant temperature T_{mrt} with $T_{op} = (T_{air} + T_{mrt})/2$ (ISO/FDIS 7726 2025). T_{mrt} is determined from the net radiation flux between a person and the environment, with solar radiation making the largest contribution.

The action plans available today mostly deal with protection from high temperatures. But this is an incomplete approach, because the transfer of heat to the human body is crucial. If this happens through convection, the heat content of the air, determined by the enthalpy, is the decisive factor; this essentially depends on the water content. For example, at 30 °C and 40% relative humidity, air has an enthalpy of 57.3 kJ/kg; at 30 °C and 90% relative humidity, the enthalpy is 92.5 kJ/kg (Schmidt 1979). Note that the enthalpy of dry air at 0 °C is by definition 0 kJ/kg. The temperature–humidity range in which people feel comfortable is comparatively small (Salthammer and Morrison 2022). The perception of heat therefore always includes the enthalpy of humid air in addition to the temperature. The importance of humidity for human thermoregulation was emphasized by Oppermann et al. (2017) when they discussed the thermal management system of the Australian continent with its climate zones that range between tropical and temperate.

A quantitative value that takes both humidity and temperature into account is the discomfort index (DI). Various relationships were derived for this purpose (Epstein and Moran 2006). A technically complex principle that is used by many weather stations primarily for outdoor environments is the wet-bulb globe temperature (WBGT). The alternative approach of Giles et al. (1990) (see equation 1) has proven to be pragmatic for indoor environments, where solar radiation can be neglected, as it refers to directly measurable data with the air temperature (T_{air}) in °C and the relative humidity (RH) in %.

$$DI = T_{air} - 0.55 \cdot (1 - 0.01 \cdot RH) \cdot (T_{air} - 14.5) \tag{1}$$

It is therefore advisable to base indoor heat protection measures on both air temperature and humidity. The DI introduced by Giles et al. (1990) defines the following ranges: DI < 21: no heat stress; 21 < DI < 29: increasing thermal discomfort; 29 < DI < 32: severe heat stress; DI > 32:

state of medical emergency. If the body can no longer release heat into the environment but continues to absorb heat from the air, this leads to hyperthermia. The corresponding temperature and humidity ranges are shown in Figure 2.

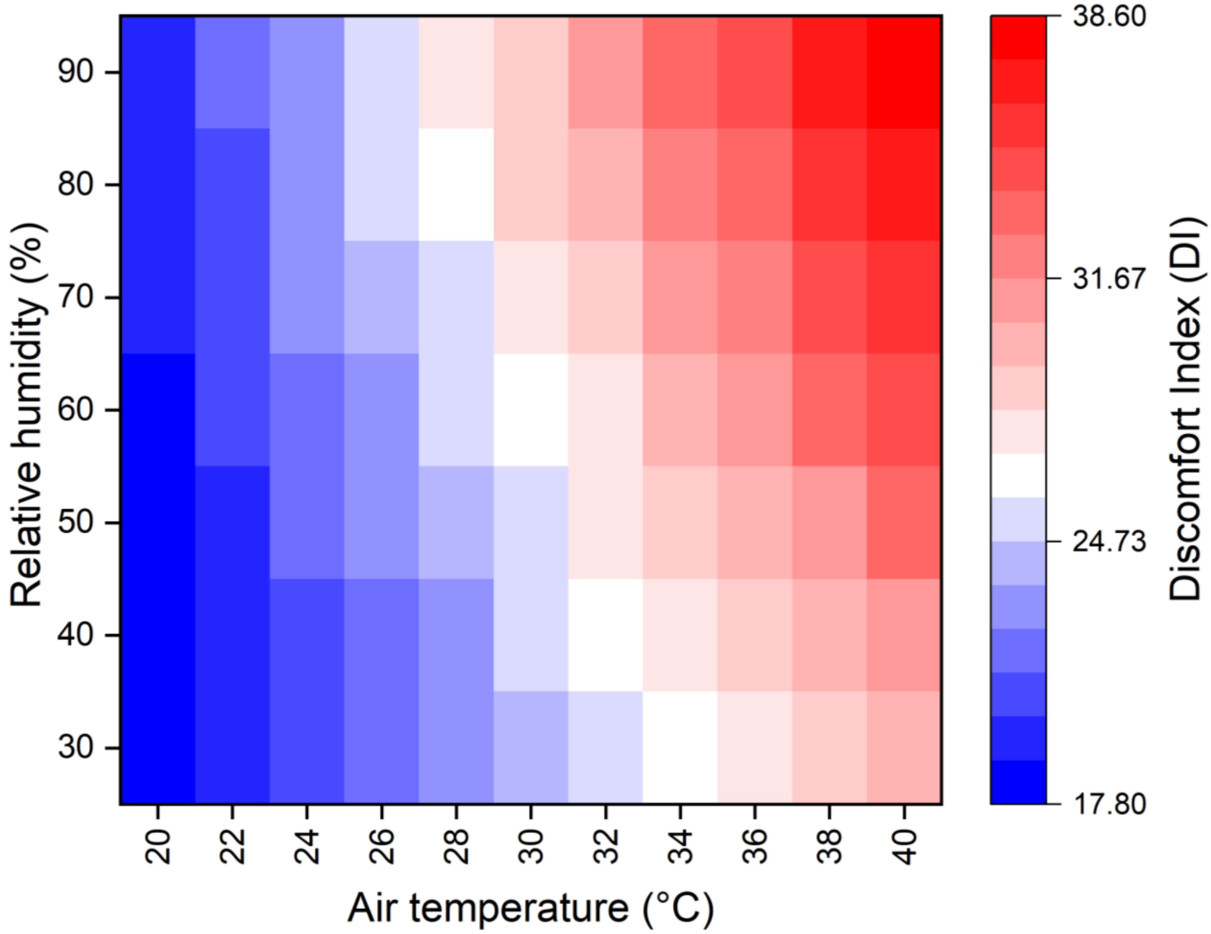

Figure 2. Discomfort index (DI) according to Giles et al. (1990) in dependence of air temperature and relative humidity (see equation 1). DI < 21: no heat stress; 21 < DI < 29: increasing thermal discomfort; 29 < DI < 32: severe heat stress; DI > 32: state of medical emergency.

At high humidity, hyperthermia occurs at approximately 30 °C, and at low humidity from approximately 36 °C. Simulations have shown that with current building structures, hyperthermia in indoor spaces can be expected to increase in the future unless structural or other measures are taken (Zhao et al. 2024). Most buildings worldwide do not have the necessary thermal insulation or are not even equipped for shading (Ghazwani et al. 2025). This creates a vicious cycle. Poorly insulated buildings require more energy for heating and cooling, and more energy, if not generated sustainably, exacerbates climate change.

Another largely neglected point concerns extreme cold. It is undisputed that the Atlantic meridional overturning circulation (AMOC) is weakening further as climate change progresses. According to current simulations, the weakening could be more than 30% by 2040, leading to cold spells in the northern hemisphere and higher temperatures and higher humidity in the southern hemisphere (Pontes and Menviel 2024). However, this is hardly ever taken into account in the energy transition currently underway in Central Europe. Oil and gas heating systems are being replaced by photovoltaics and heat pumps. In cold climates, the air/water heat pumps most commonly installed today face thermodynamic and technical challenges in generating sufficient heat and ensuring the necessary thermal comfort in the indoor environment (Konrad and MacDonald 2023).

3.2 Particulate matter ($PM_{2.5}$ and PM_{10})

One of the biggest current and future challenges is to reduce exposure to airborne particulate matter, although it has long been known that high concentrations of airborne particles are responsible for a large number of respiratory and cardiovascular diseases and excess mortality (Schwarz et al. 2024). According to Brauer et al. (2024), particulate matter air pollution was the leading contributor to global disease burden in 2021. Consequently, the WHO (2021b) has provided revised guideline values for $PM_{2.5}$ and PM_{10}, which can be applied to both ambient and indoor air.

Particles can be of natural origin or formed by human activity. Anthropogenically-caused sources of particles include road traffic, power and heating plants, waste incineration plants, furnaces and heaters in homes, construction work, agriculture, and certain industrial processes. Natural sources include emissions from volcanoes and oceans, erosion, forest and bushfires, and certain biogenic processes. Local climate and climate change have a significant impact on the dynamics of particles in the outdoor air, depending on the region. The average outdoor concentrations of $PM_{2.5}$ and PM_{10} are decreasing in Central Europe (Salthammer et al. 2018), but in many parts of the world outdoor particle concentrations are still permanently high due to the local infrastructure (Molina 2021). High indoor concentrations of particulate matter and other air pollutants resulting from the use of biomass and fossil fuels for heating and cooking are still a problem in many parts of the world, although the use of solid fuels in households has decreased (Liu et al. 2023). Other regions are increasingly coming under the influence of desert dust. In the Canary Islands, the phenomenon is known as "Calima" (Cañadillas-Ramallo et al. 2022), but central and northern Europe are also having to deal with such dust episodes (Merdji et al. 2023). Germany came under the influence of such a Sahara dust event around Easter 2024, which led, for example, to unusually high levels of outdoor air pollution in the Leipzig region, with peak values of 100150 μg/m³ $PM_{2.5}$ and PM_{10} (Zhao et al. 2025).

In principle, wildfires are an important factor in the regeneration of ecological systems. The problem, however, is that wildfires are breaking out more frequently and becoming more intense, and that boreal zones are increasingly affected. Even if residential areas are not directly affected by the fire, there is still a risk of exposure to high concentrations of pollutants because the smoke gases can be transported over long distances. Xu et al. (2024) quantified wildfire as an increasing public health concern, causing more than 1.5 million deaths per year, and called for urgent action to address such a substantial health impact in a warming climate. In concrete terms, this means that in regions with an increased risk of forest fires, the building envelope must be largely sealed not only against carbon monoxide, but also against particulate matter and other pollutants. At the same time, effective ventilation and filter systems are required to ensure the supply of breathable air.

3.3 How outdoor atmospheric chemistry influences indoor chemistry

The electromagnetic spectrum of the sun corresponds approximately to a blackbody radiator of 6000 K. With vertical radiation, the maximum power has the value of the solar constant of 1361 W/m². However, the actual power depends on the time of day, season, region, and weather. Longer periods of intense sunlight combined with nitrogen dioxide (the most significant source in urban areas is road traffic) lead to high concentrations of tropospheric ozone and other reactive gases. This in turn leads to numerous atmospheric organic oxidation products (Molina 2021).

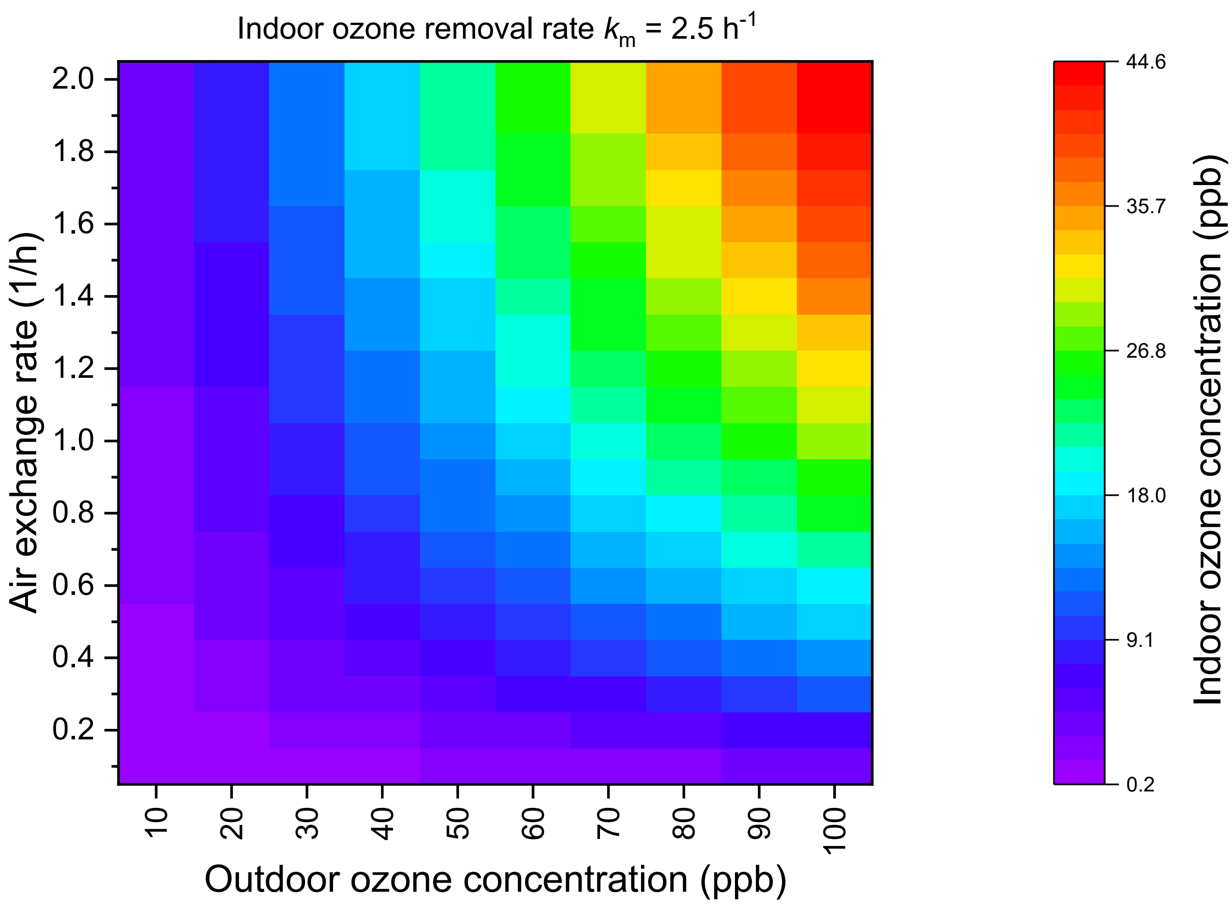

Figure 3. Indoor ozone concentration as a function of outdoor air concentration, air exchange rate, and indoor ozone removal rate; see Salthammer et al. (2018) for details. $[O_3]_{indoor} = [O_3]_{outdoor} \cdot \lambda/(\lambda+k_m)$, where λ (h^{-1}) is the air exchange rate and k_m (h^{-1}) is the ozone removal rate indoors.

Achebak et al. (2024) state that ground level ozone is a is a major source of premature mortality from air pollution in Europe. To protect human health, the environmental agencies of many countries have therefore set information and alert thresholds for ozone concentrations in outdoor areas.

With the manual opening of windows and doors, ozone is then ventilated directly into the indoor environment (Salthammer et al. 2018). As shown in Figure 3, the resulting indoor ozone concentration depends crucially on the outdoor air concentration, the air exchange rate, and the ozone removal rate indoors. Chemically speaking, the indoor environment can be viewed as a reactor vessel, because the ozone reacts quickly with unsaturated hydrocarbon compounds, for example the terpenes released from building and consumer products, to form secondary organic aerosols (SOA) (Toftum et al. 2008). However, this ozone-driven indoor chemistry does not only occur with building products, but is also linked to human activities (Liu et al. 2021) and oxidative reactions on the skin (Zannoni et al. 2022). Weschler and Nazaroff (2023) state that ozone loss could be a metric to investigate health effects resulting from ozone oxidation products in indoor environments. This raises the question of whether natural ventilation is a solution for the future.

3.4 Microbiological contamination

It is also largely overlooked in relation to indoor spaces that the capacity of air to absorb water increases with temperature. Microbial contamination has always been a priority problem in indoor environments, and in 2009 the WHO (2009) noted that climate change and its impact on weather are likely to further increase the proportion of buildings with moisture problems. In most cases, high air humidity combined with poorly insulated and poorly ventilated interior spaces is the cause of mold growth. Another aspect concerns the temperature and humidity gradients in the room. With manual ventilation, the dew point also rises with higher temperatures and humidity, which increases the condensation of water and thus the risk of mold formation (Orlik-Kożdoń 2024). In addition, severe flooding is becoming more frequent, with the entire building becoming damp, which inevitably leads to an increased risk of mold growth (Coulburn et al. 2024). Various approaches have been developed to predict mold growth indoors (Vereecken and Roels 2012). Figure 4 shows the temperature/humidity curves for different substrates where mold growth begins according to Sedlbauer's (2002) isopleth model. For typical building products such as wood and wallpaper (blue curve), the humidity range is between 75% and 80%, which is easily reached when warm and humid air cools down.

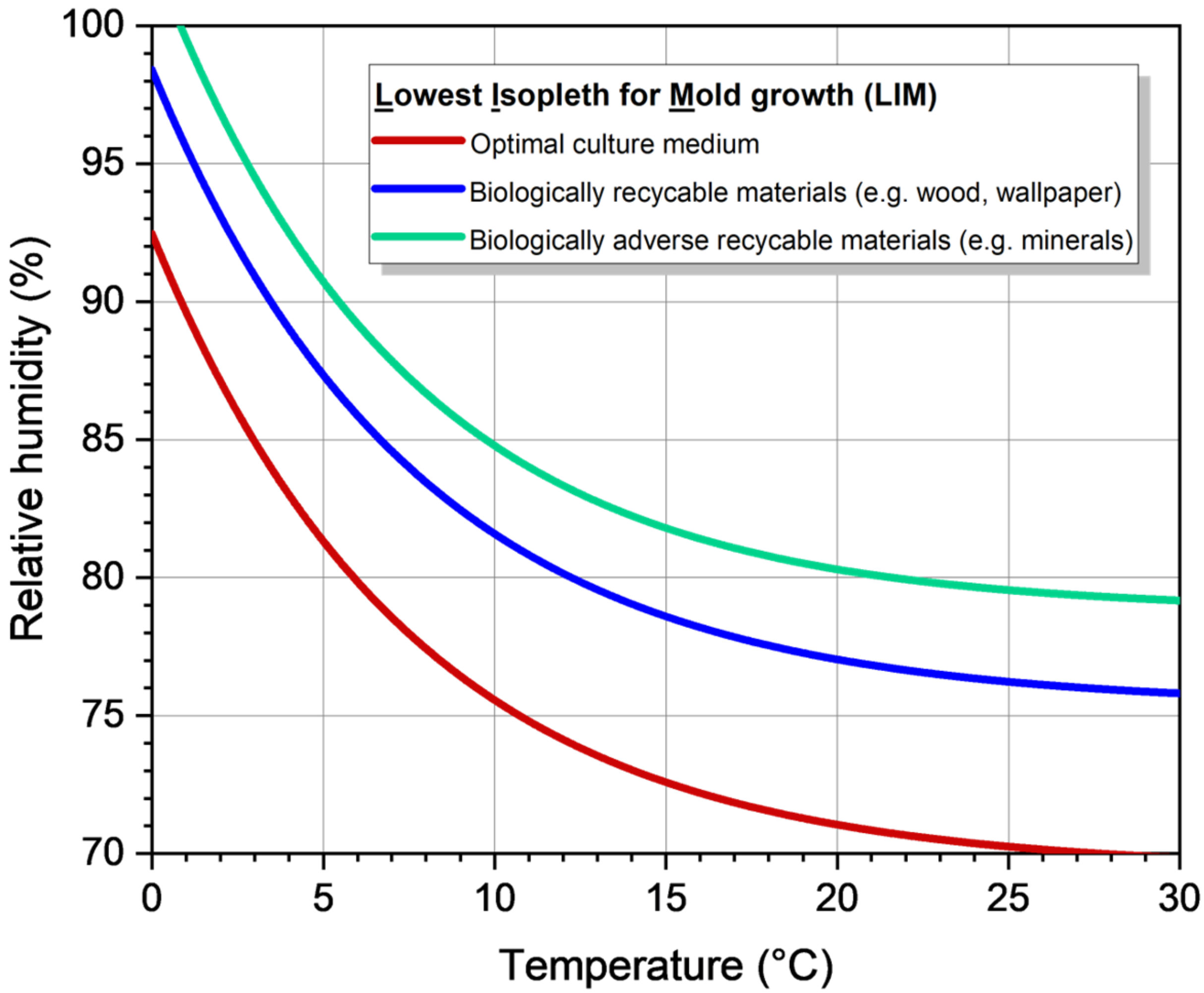

Figure 4. Lowest isopleths for mold growth (LIM), i.e. the conditions under which no spore germination or growth occurs, for different substrates according to the Sedlbauer (2002) model. The design of the figure is based on an illustration in manuals for the hygrothermal software WUFI® (https://wufi.de/en/).

As in the case of other pollutants, exposure to microbial contamination is associated with an increased health risk (Bayram et al. 2023). This leads to a dilemma. On the one hand, excess water, whether in the material or in the air, must be removed from the building, but on the other hand, taking the above arguments into account, providing natural ventilation by opening windows and doors is no longer possible at all times. It is therefore advisable to estimate the risk of mold infestation under the respective building conditions and under certain climate scenarios (Zhao et al. 2024). At the same time, the hygrothermal performance of buildings must be adapted to future requirements (Schroderus et al. 2025).

4. BUILDINGS, SMART MONITORING, AND THE ROLE OF VENTILATION

From a practical point of view, it is now entirely possible to adapt private and public buildings to the acute and long-term requirements of climate change, and technological development is progressing rapidly. The requirements are clear: the building must protect people from natural disasters; the indoor climate and indoor air quality must be healthy; and the energy needs should be covered by sustainable sources (Ahmed et al. 2022; Wu and Skye 2021). Other factors that must be considered when planning a building envelope are sound insulation, fire resistance, and water vapor permeability (Schiavoni et al. 2016). It is often overlooked that good air quality and thermal comfort is also necessary at night, because sleep quality depends on the climatic conditions and the concentration of pollutants in the bedroom (Kang et al. 2024). Since the 19th century it has been known that ventilation plays a key role in the general well-being and health of people in buildings as reviewed by Janssen (1999).

These well-known facts should actually be the basis of all building planning and implementation, but in practice this is rarely the case. It took the COVID-19 pandemic to demonstrate the hygienic necessity of adequate indoor ventilation (Morawska et al. 2024b). The multitude of research results in recent years that have identified clean air supply as an effective measure to reduce the risk of infection indoors can be applied just as well to the indoor air quality problems associated with climate change. However, to achieve a healthy indoor climate and indoor air quality, more technical solutions will have to be used in the future. As pointed out by Morawska et al. (2024b), modern society cannot rely solely on natural ventilation in buildings that are not designed to provide sufficient and effective air supply under all meteorological conditions. This applies to both public and residential buildings, which means that mechanical ventilation must be incorporated into future buildings. Mechanical systems also offer the possibility of various air supply techniques such as mixing, displacement, and personalized ventilation. Moreover, mechanical designs are typically equipped with air purification techniques. Particle filters are standard and a germicidal UV (GUV) air disinfection unit can often be installed. Whether this is generally possible will depend largely on future energy supplies.

One of the main tasks of a smart system is to respond quickly and appropriately to changes in the outdoor climate so that the indoor climate is not negatively affected. This can be done in various ways. For example, if the temperature rises in summer during the day, strategies to address this could include shading, automatically opening and closing the windows, and/or, if available, controlling a heat and ventilation air conditioning system accordingly. Many possible control variables are available to alert people of adverse indoor conditions and to control mechanical ventilation systems (Pourkiaei et al. 2024); in fact, temperature and humidity, clean air supply, carbon monoxide, carbon dioxide, and $PM_{2.5}$ are sufficient for such purposes (Morawska et al. 2024a). These parameters can be measured precisely and with a short response time using sensors and data analysis via intelligent software tools (Kang et al. 2022). The TVOC (total volatile organic compounds) value is not suitable for assessing indoor air quality from a health perspective and should therefore only be used for screening purposes (Salthammer 2022). In most regions of the world, networks of monitoring stations for climatic parameters and air pollutants are established, allowing interpolation for specific geodetic coordinates (Peuch et al. 2022). Combining such data with parameters recorded indoors is the best way to protect people from risks in the indoor environment. This is particularly the case for public buildings with a high density of people and for retirement homes.

5. IMPLEMENTATION OF MEASURES FOR THE BUILDING ENVIRONMENT

After the European heatwave in 2003, the WHO presented a heat action plan for Europe in 2008, which was updated in 2021. The WHO document covers the following main points: governance structure, heat-health warning systems, communicating health risks, types of intervention, care for vulnerable population groups, risks in health and social care settings, urban planning, real-time information, and surveillance and monitoring. Based on the WHO (2021a) recommendation, a heat action plan has been published in Germany (Bund/Länder Ad-hoc Arbeitsgruppe Gesundheitliche Anpassung an die Folgen des Klimawandels 2017) that includes the four major key points shown in Box 1.

Short-term measures:[1)]

- Recommendations for behavior and for simple technical possibilities (curtains, blinds, shutters, moving to cool rooms), etc.

Medium-term measures:[1)]

- Building-relating cooling measures (installing sun protection, cooling technology, etc.).

Long-term measures:

- Urban planning and building design.

[1)] Active cooling indoors is only recommended when other measures have proved unsuccessful.

Box 1. Recommended measures to reduce indoor temperatures in buildings during periods of strong and extreme heat, compiled by the German Federal/States Ad hoc Working Group on adaptation to the impacts of climate change in the health sector (Bund/Länder Ad-hoc Arbeitsgruppe Gesundheitliche Anpassung an die Folgen des Klimawandels 2017) on the basis of the WHO heat and health report (World Health Organization 2021a). Note that the German recommendation refers to the 2008 version of the WHO report.

Preventing and protecting measures can be classified into different categories, depending on whether they are short-term, medium-term, or long-term and whether they concern vulnerable population groups. Depending on the situation, measures with different levels of effort and time horizons may be required. Accompanying measures are equally important. These include in particular the points mentioned in the WHO document regarding information and communication.

So there is no shortage of solutions. The problem lies rather in the costs involved and the fact that far-reaching decisions have to be made both in an emergency and in the medium and long term. However, the economic benefits of preventive protective measures will far exceed the costs of inaction (Romanello et al. 2024). For the safety of people it is crucial to implement emergency plans and be able to react quickly to warnings from meteorological services in cases of impending extreme weather events, but this is often counteracted by the complicated decision-making logistics of countries. Many countries suffer from long and time-consuming administrative processes as shown in Figure 5, using the example of a heat action plan. An international concept, such as the WHO's (2021a) heat and health document, is usually first assessed by the country's federal environment agency and, if necessary, adapted with the help of representatives of the states. It is then transferred to the municipal level and to the health departments of the municipalities. The planning, decision-making, and implementation of specific measures, including information dissemination and training of the executive bodies, is therefore the responsibility of the municipal levels and administrative districts. In Germany, for example, there are around 400 such districts.

It becomes clear that threat prevention does not necessarily fail due to a general lack of information, but rather because existing information is not passed on quickly enough, simply because the administrative processes take too much time and information does not reach the executive bodies in a timely manner. This case occurred, for example, in the German Ahr Valley flood disaster in 2021 with more than 180 fatalities. Although there were early warnings from the Deutscher Wetterdienst (German Meteorological Service), decisions were made far too late, which resulted in the executing bodies being uninformed, overloaded, and only partially functional (Dittmer and Lorenz 2024). This again underlines the need for automated processes, short-term warning devices for heat stress and cold, and sensor-controlled mechanical ventilation systems as well as timely information through early warning systems for approaching risks and hazards caused by weather phenomena.

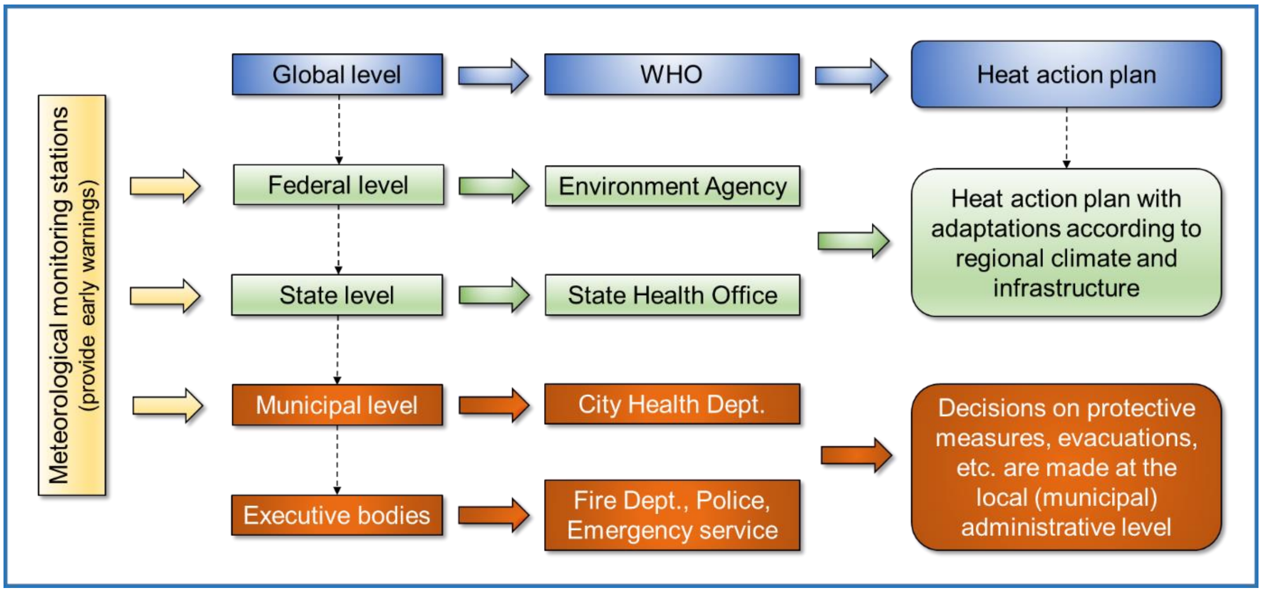

Figure 5. Typical administrative structure and processes of a country using the example of the implementation of a World Health Organization (WHO) heat action plan at the municipal level.

6. CONCLUSION

The main function of buildings is to protect people from the weather and to create a comfortable and healthy thermal environment. As climate change progresses, it is becoming increasingly important for society, governments, and administrative bodies not only to realize this, but also to factor the indoor environment into the concepts for protective measures. Key roles will be played by monitoring of the indoor air quality and advanced ventilation concepts. Any further delay massively increases the health risk with potentially fatal consequences, especially for vulnerable population groups. If appropriate crisis management strategies are not in place, social anxiety may also be a possible consequence (Clayton 2020). Nevertheless, there is still a lack of consistent planning, not to mention implementation. This is due to only partial insights, other priorities, and economic aspects. To make matters worse, the processes in a complex society are also convoluted and therefore time-consuming (Simpson et al. 2021). The attitude of authorities and operators is difficult to understand, because short- and medium-term heat protection measures need resources that are small compared to the overall infrastructure budget. Long-term strategies of course require a holistic understanding of the thermal interaction of the landscape, the building sector, and people; it appears that reliance on air conditioning alone is not sustainable (Jay et al. 2021).

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Data Availability

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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