DIGEST | CITIES & BUILDINGS • CLIMATE

Cooling People, Not Spaces: Surmounting the Risks of Air-Conditioning Over-Reliance

JANUARY 2025

Multiple authors

Kleinman Center for Energy Policy

Cooling People, Not Spaces: Surmounting the Risks of Air-Conditioning Over-Reliance

JANUARY 2025

Multiple authors*

Introduction

On June 30, 2021, a nascent wildfire swept through Lytton, British Columbia, Canada, destroying 90% of the village of 249 residences (Isai 2021). Days earlier, the community recorded the highest outdoor temperature in Canada, 49.6°C (121.3°F), observed in one of the most unprecedented heat waves in North American history.

Between March and May 2022, heatwaves spanning northwest India and Pakistan resulted in outdoor air temperatures exceeding 50°C (Patel and Masih 2022), deadly heat events that reoccurred in neighboring regions the following year (The Guardian 2023a). In May 2023, regions of Vietnam recorded outdoor temperatures exceeding 44°C, the highest outdoor air temperatures ever recorded in the country (The Guardian 2023c). The southern United States and southern Europe faced similar historic temperatures in July 2023 (The Guardian 2023b). A recent study found that one year prior, Europe registered over 61,000 heat-related deaths (Ballester et al. 2023), the second-highest year ever recorded. Heat stress, implying a lack of human access to cooling, was the major contributor.

With warnings of increased warming and extreme heat abound, the International Energy Agency (IEA) predicts the world will see a threefold increase in energy demand for space cooling if our reliance on current air-conditioning technology continues (Birol 2018). Other experts have made similar predictions, with the view that in addition to climate change, global economic development, and population growth in tropical climates will drive this increase (Frank 2005; Moazami et al. 2019; Olonscheck, Holsten, and Kropp 2011).

The global cooling industry is also aware of this and the challenges these forecasts imply. In 2018, *RMI* (Basalt, CO, U.S.) and the Department of Science and Technology of the Government of India launched the Global Cooling Prize (Kalanki, Winslow, and Campbell 2021), a moonshot technology prize that sought to accelerate critical innovations in highly energy-efficient space cooling technologies.

The mission was simple: if we rely on traditional air-conditioning systems to deliver cooling in the future, we will exacerbate the source of our overheating problem, global greenhouse gas (GHG) emissions. Recently, major research initiatives have sought to identify and discuss the barriers affecting sustainable, resilient building cooling solutions for a warming world (Holzer 2022; Lizana et al. 2022; Levinson et al. 2023).

This policy brief expands on these efforts by conducting a research review and expert engagement process to identify the critical steps policymakers need to address and mitigate the most critical barriers. This work combines expertise in building energy, cooling, and ventilation, and the paper's authors work in academia and the private and public sectors. The outcome of a research review and expert engagement process that began in 2021 follows.

*The full list of authors is provided at the end of the article.

Cooling, Air Conditioning, and Future Challenges

Cooling people in a warming world is essential to human health. While there is diversity in how extreme heat is managed globally, there is little dispute that mechanical air conditioning (AC) is today's most common means of cooling buildings worldwide (Kovats and Hajat 2008). Modern AC systems use fans, ductwork, and vapor-compression refrigeration to cool indoor air by circulating it over coils filled with cooled refrigerant or water. This technology, first introduced in the early 20th century, has revolutionized architecture, urban design, and humanity's thermal comfort expectations (Kovats and Hajat 2008).

AC has also significantly reduced heat-related mortality, particularly in the U.S., where AC adoption has been linked to a 75% decline in heat-related deaths during the 20th century (Barreca et al. 2016). AC in hospitals has further reduced infant mortality and prolonged the lives of patients with heart and respiratory diseases (Bobb et al. 2014; O'Neill, Zanobetti, and Schwartz 2005; Song, Yu, and Lu 2021).

Yet, for all its benefits, the future and expanded use of AC as a single global solution for building cooling is considerably more contested today. Specifically, our continued reliance on conventional AC systems faces three pressing challenges:

1. GHG Emissions from Energy Use and Refrigerants

The building sector accounts for nearly 40% of global energy consumption and GHG emissions (de la Rue du Can and Price 2008). From 1970 to 2010, energy-related CO2 emissions in this sector more than doubled and are expected to double again by 2050 (Berardi 2017). Cooling alone contributes nearly 20% of electricity use in buildings globally (The Guardian 2023a). Second, vapor-compression AC systems commonly use hydrofluorocarbons (HFC), which have a global warming potential thousands of times higher than CO2. Approximately 47% of global HFC use is attributed to building AC, with 60% due to leakage during refills (Sand, Fischer, and Baxter 1997).

While 198 countries signed onto the Kigali Amendment of the Montreal Protocol in 2016, agreeing to reduce global HFC use by 80% before 2050 (United States Environmental Protection Agency 2021), global compliance with the Kigali Amendment has yet to be observed. Additionally, due to the growing demand for air conditioning, refrigerant gas leakage is projected to alone be responsible for 0.5 °C of global warming by 2100 (Shah et al. 2015).

2. Fragility of Single-Solution Dependency

Dependence on AC raises concerns about energy grid resiliency. A 1995 Chicago heatwave resulted in at least 739 deaths, highlighting the risks when power outages occurred during extreme heat (Klinenberg 2015). Similar risks persist today, as seen in Texas in July of 2022 when residents were urged to reduce power use due to high AC demand and low renewable energy generation (Ferman 2022). In 2024, Canadian heatwaves led to outages in completely different climate regions, each outage endangering vulnerable populations (Diego 2024).

Expanding peak electricity generation to cope with extreme heat in the U.S. could cost between $180 billion and $1.2 trillion by 2100 (Auffhammer, Baylis, and Hausman 2017; Khan et al. 2021); the projected investment is tied invariably to projected increases in AC under extreme heat (Burillo et al. 2019). Increasing reliance on AC as the only solution to hot weather does not steer an economy toward climate and infrastructure resiliency (Zhang et al. 2021).

3. Indoor Air Quality and AC-Centric Design

While preventing indoor overheating is crucial, reliance on AC can compromise indoor air quality, particularly in sealed buildings designed for energy efficiency. Beginning in the 1970s, many buildings were constructed with minimal ventilation to conserve energy, leading to poor indoor air quality and health issues, now recognized as "sick building syndrome" (Murphy 2006; Wargocki et al. 2000).

One of the most affordable active cooling solutions for retrofitting existing buildings, particularly housing, is installing split AC systems (Abhyankar et al. 2017; Bhandari and Fumo 2022). These systems provide comfort at an air quality cost. Most split AC systems recirculate indoor air without any fresh air supply, reducing ventilation rates to near zero when windows are closed. This can exacerbate indoor air quality risks, affecting occupant health and sleep patterns (Abhyankar et al. 2017; Bhandari and Fumo 2022).

Summary of Alternative Solutions to Conventional Air Conditioning

Alternative approaches to AC are generally organized into three classes of solutions. The first class includes passive design measures that originated in some of civilization's earliest efforts to build shelters in response to local climates and local material availability. The second class of measures refers to engineered or "active" cooling systems, which include conventional air conditioning and some evolved versions of the technology that emerged in the latter half of the 20th century. A third class of measures comprises hybrid solutions that combine elements of passive design and active systems. Many of these solutions are complementary and can be used in tandem.

The prevailing alternative cooling approaches available today are illustrated in Figure 1. The figure illustrates these solutions, categorized by their type:

- Ventilative cooling techniques (Shetabivash 2015; Brager and Baker 2009; Passe and Battaglia 2015; Lal, Kaushik, and Bhargav 2013; Jomehzadeh et al. 2020; Ciampi, Leccese, and Tuoni 2003; Gagliano et al. 2012)
- Active low-energy fans (Morris et al. 2021; Yang et al. 2015); evaporative cooling (Cuce and Riffat 2016; Ford, Schiano-Phan, and Vallejo 2019; Holzer 2022)
- Low energy dehumidification strategies (Jani, Mishra, and Sahoo 2018; Rafique et al. 2015)
- Cooling strategies assisted by the ground as a heat sink (Khabbaz et al. 2016; Anselm 2012; Romanov and Leiss 2022)
- Passive sky radiative cooling (Zhao et al. 2019) and active radiant cooling (Delgado, Ramos, and Domínguez 2020)
- Thermal storage strategies (Reilly and Kinnane 2017; Rim, Sung, and Kim 2018)
- Heat gain prevention strategies (Akbari and Matthews 2012; Levinson et al. 2019)
- Low-energy active cooling solutions for the individual scale (i.e., personal cooling devices (Khovalyg and Ravussin 2022; Schiavon, Melikov, and Sekhar 2010; Luo et al. 2018)) and for the urban scale (i.e., district cooling (Zhen et al. 2007)).

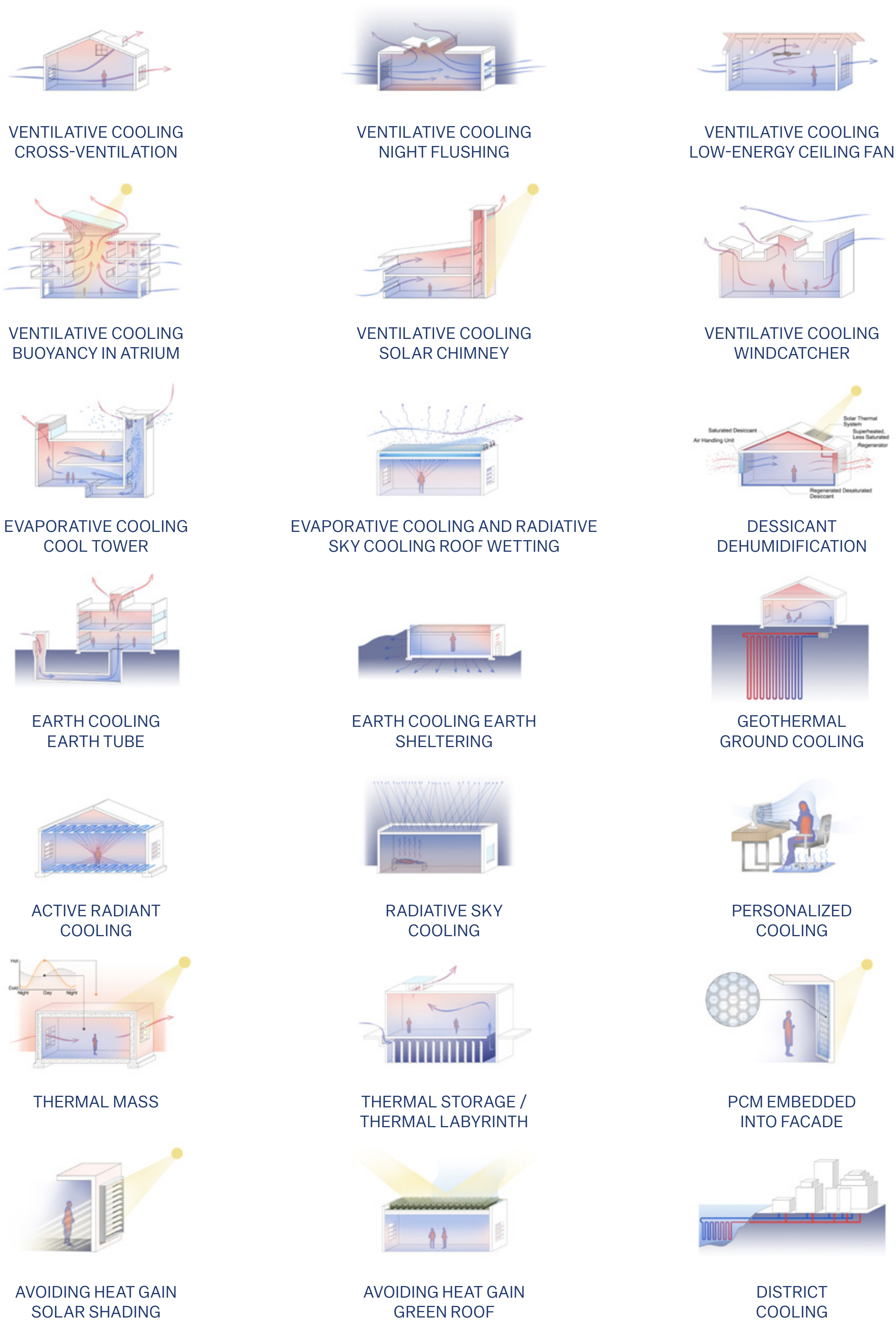
In following best practice, experts recommend a stepwise approach to addressing cooling in building design:

1. Reduce the building's cooling load through passive strategies.
2. Apply suitable low-emissions active cooling systems for the remaining load.
3. Optimize the hybrid control of these systems to minimize reliance on active cooling.

In some cases, passive strategies alone can suffice to meet all cooling needs (Maierhofer et al. 2022; Archdaily 2023; Griffiths 2019), while in others, a balance of active, passive, and hybrid strategies is necessary (Zhang et al. 2021; McLauchlan and Lavan 2010; Transsolar 2009). A relatively large body of literature constructed over several decades details how energy-efficient and sustainable alternative cooling solutions have been implemented across the planet's varying climates, cultures, and economies (Ford, Schiano-Phan, and Vallejo 2019).

There are challenges in extreme climates and urban environments where passive and hybrid cooling solutions may be less effective due to a combination of high air (dry bulb) temperature, and high wet bulb temperature, which is close to or above skin temperature (Engebretsen et al. 2016). This was

Figure 1: A Catalog of Alternative Cooling Strategies



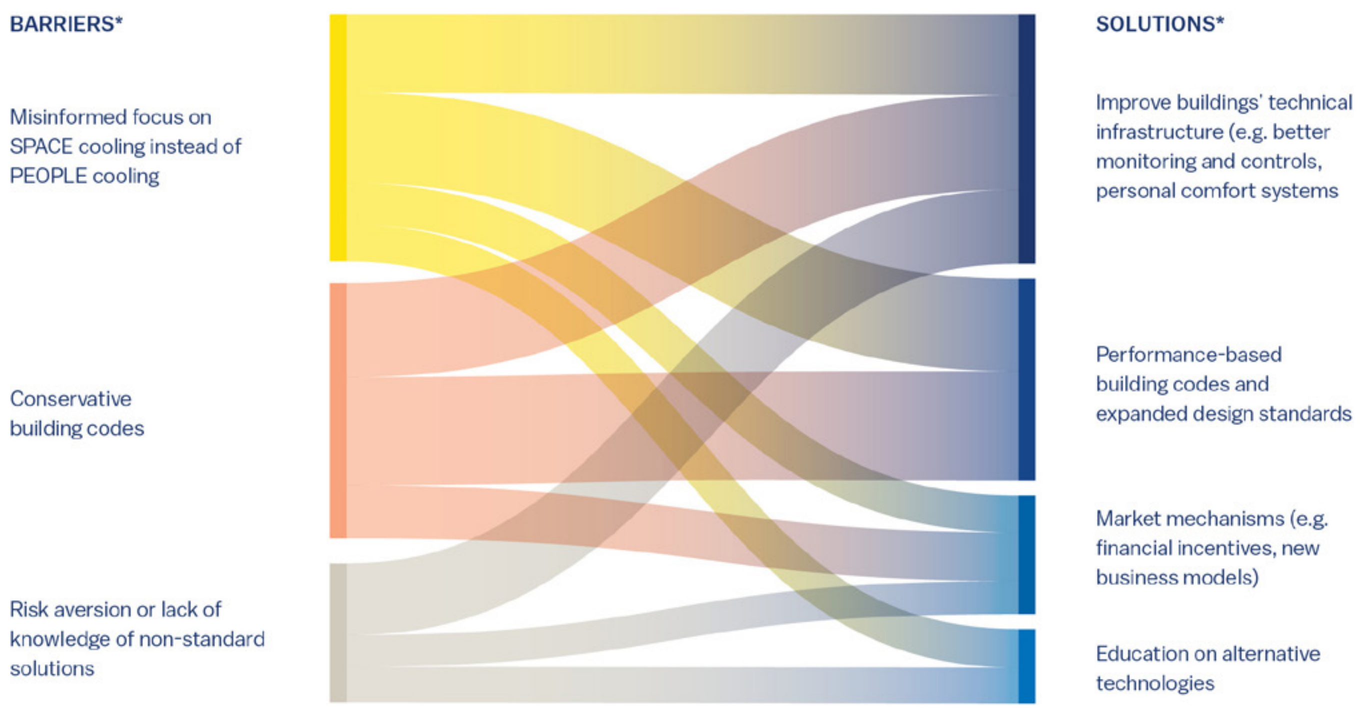
underscored during the June 17, 2023, heatwave in Uttar Pradesh, India, where extreme heat and humidity would have necessitated, at minimum, an active dehumidification system to mitigate such life-threatening conditions (Sherwood and Huber 2010). In such contexts, dependency on current conventional air-conditioning solutions to address cooling may be high without further industry development of alternatives such as desiccant dehumidification. Other environmental factors, such as air and noise pollution and wildfire smoke, may also increase the dependence on mechanical ventilation.

The Barriers and Solutions to Alternative Cooling

As more information becomes available on designing best practices and sustainably cooled buildings, most new construction projects globally still do not follow these proven strategies. More so, best practices are nearly non-existent in the building retrofit market, which is fundamentally critical for addressing global challenges such as climate change.

Building on the reviewed academic and gray literature, many of this study's authors initially convened as a panel of experts in winter 2021 to deliberate on the barriers to mainstreaming alternative cooling systems and discuss the most promising solutions to these barriers. An initial symposium was held, where the experts who work across academia, policy, and

Figure 2: Top Barriers and Proposed Corresponding Solutions



*Thickness of bands corresponds to scale of importance ranked per survey industry each presented a perspective on barriers and drivers to alternative cooling solutions from their respective domains.

These presentations were subsequently distilled into an expert elicitation survey, which was returned to the experts, who sought to establish a consensus on the perceived top barriers and the desired solutions. The process of arriving at this collaborative statement included iterative rounds of feedback to refine the initial assessments. This collaborative and iterative approach sought to obtain a robust perspective grounded in a broad range of established viewpoints and empirical data. (The findings of this process are detailed in Appendix A.)

The following sections summarize the collaborative view of the authors on these top barriers and solutions. This work comprises the authors' views while acknowledging the significant and growing body of research on barriers to sustainable cooling (Lizana et al. 2022), alternative cooling solutions (Holzer 2022), and cross-government initiatives aimed at improving market conditions for alternative cooling solutions.

Notable examples are the international Venticool project and policy-oriented actions like the Kigali Cooling Efficiency Program (UN Environment Programme 2022). The IEA's *The Future of Cooling* report (Birol 2018), the IEA Research Annex on Resilient Cooling of Buildings (IEA EBC Annex 80 2019), the Asian Development Bank's support for energy-efficient centralized AC systems (Asian Development Bank 2020), and the *Cooling Singapore* project (Ruefenacht and Acero 2017), have each aimed to advance commercial development and deployment of low-carbon cooling solutions. The Global Cooling Prize was a recent international competition to develop highly efficient and affordable residential cooling solutions. Such initiatives have framed the outcome of this work.

Three Barriers to Alternative Cooling Solutions

1. Misinformed focus on space cooling instead of people cooling

Air conditioning, by its very name, has historically entailed conditioning indoor air by cooling the air of entire air spaces within buildings. Whether a room is occupied by only one person or many, it is the room that is typically cooled rather than individual occupants. The belief that the purpose of cooling is to condition entire rooms is so entrenched in industry and policy that "air conditioning" is often used synonymously with "space cooling" (International Energy Agency 2022).

Rarely, if ever, do policy briefs or building codes refer directly to "people cooling" or a similar term, which ironically forms the basis of current thermal comfort standards. For example, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55: Thermal Environmental Conditions for Human Occupancy (Standard 2017, 55–2013) gives higher quality ratings to spaces that provide personalized thermal environments. However, few building codes make it easy for designers to take advantage of these emerging principles. Building codes across North America, at least, explicitly require indoor air spaces to be heated or cooled to specific minimum or maximum air temperatures (California Building Code 2022; British Columbia Codes 2018).

The persistent association of indoor cooling with the conditioning of entire rooms did not descend from established theories of building science but from the very early manifestations of mechanical cooling. Like how the very first internal combustion engines of the 19th century were physically large contraptions producing relatively limited power, the earliest ducted ventilation systems of that time were sized according to the characteristics of the earliest modern electric fans.

Large, inefficient fans necessitated large ducts and their corresponding spatial accommodation in buildings. They provided large volumes of air to cool entire building zones partly because it was not technically practical or feasible to deliver air cooling in any other way. While technology and design methods for cooling systems evolved throughout the 20th century, including the miniaturization of AC system components, the general tendency of architects and engineers to implement central ducted solutions for cooling entire building volumes remained very common due to the accumulation of decades of familiarity and cost optimization.

In regions of the world that were relatively late to adopt space cooling systems, including Europe and most of the world's emerging economies, there is greater diversity in how building designers implement and control cooling solutions. Smart building control systems, for example, can now predict occupancy patterns and occupancy movements in buildings with increasing ease and target cooling delivery accordingly (Dong et al. 2019). This can lead to significant energy savings while improving occupant comfort (Kim et al. 2019; Pasut et al. 2015). (Radiant cooling and personalized ventilation systems are other solutions discussed later in this paper.)

2. Conservative Building Codes Entrench Conservative Cooling Solutions

Building codes can create many barriers to alternative cooling solutions, either directly or through the reinforcement of inefficient or ineffective practices. For example, in the New York City Building Code, the words "shading," "thermal mass," "night flush cooling," "radiant cooling," and seemingly any other synonyms referring to alternative cooling solutions cannot be found within any clauses of the code chapters about indoor environmental quality and energy efficiency (NYC Building Code 2014). Only statements regarding minimum thermal performance requirements of air conditioners exist. The prescribed minimum performance requirements do not refer directly to ASHRAE's thermal comfort standard or any established design standard that may provide a richer body of information and instruction on cooling solutions.

It is reasonable to expect that if high-performance building design standards like those from ASHRAE (ASHRAE 2018; 2022) and other international bodies (CEN/ISO 2021, 11855) exist to chart the pathway for future resilient, energy-efficient, and low-carbon buildings. Therefore, at the very least, building codes and regulations must not provide clauses and code requirements that make meeting these standards unnecessarily difficult or useless. It would be even better for building regulators to acknowledge multiple standards bodies and provide parallel pathways to compliance.

3. Low Appetite for Risk Among Stakeholders

Many stakeholders affect the delivery and operation of buildings, including the architects, engineers, facilities managers, building owners, contractors, and subcontractors, who have the most substantial influence in choosing a low-energy solution. Among these stakeholders, there are several distinct facets to the perception of performance and financial risks:

1. **Invisibility of carbon cost:** The total upfront and full-life carbon cost of cooling decisions is not fully appreciated. It is also more difficult to estimate than other financial and performance outcomes. The carbon-related barrier exists because stakeholders might not value the 'triple bottom line' of social, environmental, and financial investments.
2. **Predictability of status quo:** Users of new technologies sometimes have limited experience and ability to predict technical and investment performance. The unpredictability of a technical and financial outcome increases design liability and may affect the operational costs for the most influential stakeholders.
3. **Old solutions are already built-in and costly to replace:** Existing buildings are designed for central ducted air systems, and retrofits of alternative cooling solutions may require significant infrastructural investments. While the higher perceived risk of retrofits

minimizes the attraction of installing alternative cooling technologies in existing buildings, minimizing the future cooling demand of existing buildings remains critical for future climate goals.

Defaulting to the status quo is not unique to engineering in the face of performance or financial risks. A default posture, however, is one of the primary barriers to adopting better cooling strategies.

Three Solutions to Barriers Facing Alternative Cooling Strategies

1. Expand and cross-pollinate design standards for alternative cooling solutions and re-orient regulatory compliance.

A multi-pronged approach is necessary to promote alternative cooling solutions within regulatory frameworks. While ASHRAE's design standards, or sections thereof, are well recognized in circumstances that support air-conditioning design, there is less awareness and availability of ASHRAE standards supporting non-air-based cooling solutions (ANSI/ASHRAE 2020). Beyond ASHRAE, however, regulators may find there exists an ample number of guiding principles established across the international canvas of standards authorities. For example, CEN-ISO 11855 exists for radiant systems in Europe (CEN/ISO 2021, 11855), and the Chartered Institution of Building Services Engineers (CIBSE) *TM40: Health and Wellbeing in Building Services* standard covers natural ventilation (CIBSE 2020).

Beyond governmental standards, there is also the WELL Building Standard (International WELL Building Institute 2016), the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) green building rating scheme (U.S. Green Building Council 2019), and the Living Building Challenge 4.0 (International Living Future Institute 2019) which provide different imperatives on building energy use and air quality that can steer building designers towards alternative heating and cooling solutions.

A multi-pronged approach is necessary to promote alternative cooling solutions within regulatory frameworks.

Some jurisdictions have gone as far as mandating alternative cooling solutions as a matter of building code and regulation. Singapore's Housing Development Board (HDB), which has overseen the historic development of Singapore's renowned public housing stock, lays out explicit design guidelines that require architects to prioritize natural daylighting, shading, and cross-ventilation solutions—effectively ruling out air-conditioning-reliant building design (Housing and Development Board 2012). Switzerland enforces similar passive-first solutions to extreme heat (Swiss Society of Engineers and Architects 2009).

2. Seek and implement new market mechanisms.

Deploying alternative cooling solutions is a market transformation that will necessitate new market incentives and instruments, which is not without precedent, even in the cooling industry. Innovative business models are most compelling when the upfront capital costs of a heating or cooling solution are prohibitive for a single building owner (X. Zhao, Pan, and Lu 2016) but can be financed collectively by pooling customers.

Cooling as a Service (CaaS) framework (IEA 2020; X. Zhao, Pan, and Lu 2016; Clean Cooling Collavorative, n.d.) creates opportunities for businesses to become cooling service providers to buildings by installing, owning, and operating cooling equipment and guaranteeing occupant comfort at a fee rate. The Cooling as a Service Initiative, launched in 2019 by the Basel Agency for Sustainable Energy and the Clean Cooling Collaborative, has successfully implemented CaaS in certain emerging economies (Clean Cooling Collavorative, n.d.) . Financial assistance for CaaS and similar programs through direct government investment or taxation policies could be tied to using site- and climate-appropriate alternative cooling solutions.

3. Improve education.

There is an urgent need to redefine "cooling" beyond "air conditioning." Public perception often equates cooling with conditioning of the air despite the significant role of radiant heat transfer in human comfort (McIntyre and Griffiths 1972). Many people are likely unaware that more than 50% of the heat lost by the human body indoors is attributed solely to radiant heat transfer between the human body and the physical surfaces surrounding it (McIntyre and Griffiths 1972).

An individual must be familiar with the multiple forms of heat transfer that affect human comfort. These include the benefits of using vegetation to shade building envelopes, how thermal mass and night-flush cooling can facilitate maintaining comfortable conditions in hot climates, and why strategies like active radiant cooling or ceiling fans can be so energy-efficient.

Additionally, education campaigns targeting architects, urban designers, and the public should ensure that all building design and construction sector segments, from designers to mechanical contractors to building inhabitants, understand the importance of radiant heat transfer and air movement and their relation to thermal comfort. Organizations such as ASHRAE and aligned governmental, non-governmental, and regulatory bodies should help shift the discourse away from AC-centric solutions, stressing that cooling should focus on people, not buildings.

Conclusions

We must shift towards building methods and technologies that minimize the carbon footprint of cooling. While global initiatives aim to expedite the research, development, and implementation of energy-efficient and alternative cooling solutions, more effort is required to mainstream these alternatives.

This paper has outlined that the most significant obstacles to alternative cooling solutions are not that alternatives are underdeveloped or necessarily unaffordable. Instead, a cultural perception of cooling, supported by the language of present-day building codes and regulations, has ensured that functional, important alternative solutions are marginalized and trivialized in building design and renovation.

Ultimately, this work translates our expertise into a consensus on the most critical actions to mitigate existing barriers. Accelerated adoption of alternative cooling strategies will require:

1. **Standards:** Establish design criteria and regulatory compliance procedures that stop prohibiting "alternative" cooling strategies and promote these more sustainable approaches through regulatory criteria that explicitly identify and advocate for alternative solutions.
2. **Market incentives:** Financial penalties, rewards, and regulations are needed to encourage new business models and better financing options; performance-based financial incentives for alternative cooling solutions are feasible.
3. **Awareness:** Spreading knowledge about cooling best practices through creating courses for architects, engineers, and building operators, as well as public education campaigns.

Bibliography

Abhyankar, Nikit, Nihar Shah, Won Young Park, and Amol A Phadke. 2017. "Accelerating Energy Efficiency Improvements in Room Air Conditioners in India: Potential, Costs-Benefits, and Policies." https://escholarship.org/uc/item/8710154k.

Akbari, Hashem, and H Damon Matthews. 2012. "Global Cooling Updates: Reflective Roofs and Pavements." *Energy and Buildings* 55:2–6.

Anselm, Akubue Jideofor. 2012. "Earth Shelters; A Review of Energy Conservation Properties in Earth Sheltered Housing." *Energy Conservation* 31:125–48. https://doi.org/DOI: 10.5772/51873.

ANSI/ASHRAE. 2020. "ANSI/ASHRAE 216-2020: Method of Test for Determining Application Data of Overhead Circulator Fans." Atlanta, GA, US.

Archdaily. 2023. "Given the Growing Awareness of the Search for Alternative Cooling Solutions Aimed at Reducing Reliance on Air Conditioning for Climate Change and Carbon Emission Mitigation." https://www.archdaily.com/872018/how-to-design-a-building-that-breathes-a-sustainable-case-study-of-colombias-edu-headquarters.

ASHRAE. 2018. “ASHRAE 90.1: Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings.”

———. 2022. “ASHRAE 90.2: Newly Revised for Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings.”

Asian Development Bank. 2020. “Regional Support to Build Disease Resilient and Energy Efficient Centralized Air-Conditioning Systems.” https://www.adb.org/projects/54210-001/main.

Auffhammer, Maximilian, Patrick Baylis, and Catherine H. Hausman. 2017. “Climate Change Is Projected to Have Severe Impacts on the Frequency and Intensity of Peak Electricity Demand across the United States.” *Proceedings of the National Academy of Sciences* 114 (8): 1886–91. https://doi.org/10.1073/pnas.1613193114.

Ballester, Joan, Marcos Quijal-Zamorano, Raúl Fernando Méndez Turrubiates, Ferran Pegenaute, François R. Herrmann, Jean Marie Robine, Xavier Basagaña, Cathryn Tonne, Josep M. Antó, and Hicham Achebak. 2023. “Heat-Related Mortality in Europe during the Summer of 2022.” *Nature Medicine*, 1–10.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. 2016. “Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century.” *Journal of Political Economy* 124 (1): 105–59.

Berardi, Umberto. 2017. “A Cross-Country Comparison of the Building Energy Consumptions and Their Trends.” *Resources, Conservation and Recycling* 123:230–41.

Bhandari, Manoj, and Nelson Fumo. 2022. “A Review of Ductless Mini Split HVAC System.” *Energy Reports* 8:5930–42. https://doi.org/10.1016/j.egyr.2022.03.209.

Birol, F. 2018. “The Future of Cooling: Opportunities for Energy-Efficient Air Conditioning.” *International Energy Agency*.

Bobb, Jennifer F., Roger D. Peng, Michelle L. Bell, and Francesca Dominici. 2014. “Heat-Related Mortality and Adaptation to Heat in the United States.” *Environmental Health Perspectives* 122 (8): 811–16. https://doi.org/10.1289/ehp.130739.

Brager, Gail, and Lindsay Baker. 2009. “Occupant Satisfaction in Mixed-Mode Buildings.” *Building Research & Information* 37 (4): 369–80. https://doi.org/10.1080/09613210902899785.

British Columbia Codes. 2018. “BC Building Code 2018.” https://www.bccodes.ca/index.

Burillo, Daniel, Mikhail V. Chester, Stephanie Pincetl, Eric D. Fournier, and Janet Reyna. 2019. “Forecasting Peak Electricity Demand for Los Angeles Considering Higher Air Temperatures Due to Climate Change.” *Applied Energy* 236 (February):1–9. https://doi.org/10.1016/j.apenergy.2018.11.039.

California Building Code. 2022. “2022 California Building Standards Code (Cal. Code Regs., Title 24).” https://codes.iccsafe.org/content/CABC2022P1.

CEN/ISO. 2021. “CEN/ISO 11855: Building Environment Design - Design, Dimensioning, Installation and Control of Embedded Radiant Heating and Cooling Systems.”

Ciampi, M, Francesco Leccese, and G Tuoni. 2003. “Ventilated Facades Energy Performance in Summer Cooling of Buildings.” *Solar Energy* 75 (6): 491–502. https://doi.org/10.1016/j.solener.2003.09.010.

CIBSE. 2020. “CIBSE TM40 - Health and Wellbeing in Building Services.” https://www.cibse.org/TM40.

Clean Cooling Collavorative. n.d. “Cooling as a Service Initiative.” https://www.cleancoolingcollaborative.org/.

Cuce, Pinar Mert, and Saffa Riffat. 2016. “A State of the Art Review of Evaporative Cooling Systems for Building Applications.” *Renewable and Sustainable Energy Reviews* 54 (February):1240–49. https://doi.org/10.1016/j.rser.2015.10.066.

Delgado, MCarmen Guerrero, José Sánchez Ramos, and Servando Álvarez Domínguez. 2020. “Using the Sky as Heat Sink: Climatic Applicability of Night-Sky Based Natural Cooling Techniques in Europe.” *Energy Conversion and Management* 225:113424.

Diego, Romero. 2024. “Power Outage in West Edmonton over after More than 24 Hours amid Heat Wave.” CTV News. 2024. https://edmonton.ctvnews.ca/power-out-for-1-200-epcor-customers-in-west-edmonton-1.6969750.

Dong, B., V. Prakash, F. Feng, and Z. O’Neill. 2019. “A Review of Smart Building Sensing System for Better Indoor Environment Control.” *Energy and Buildings* 199:29–46. https://doi.org/10.1016/j.enbuild.2019.06.025.

Engebretsen, KA, Jeanne Duus Johansen, S Kezic, Allan Linneberg, and JP Thyssen. 2016. “The Effect of Environmental Humidity and Temperature on Skin Barrier Function and Dermatitis.” *Journal of the European Academy of Dermatology and Venereology* 30 (2): 223–49.

Ferman, Mitchell. 2022. “Texans Asked to Conserve Energy to Protect the Power Grid for the Second Time in a Week.” *The Texas Tribune*. https://www.texastribune.org/2022/07/13/texas-power-grid-ercot-conservation/.

Ford, Brian, Rosa Schiano-Phan, and Juan A Vallejo. 2019. *The Architecture of Natural Cooling*. Routledge.

Frank, Th. 2005. “Climate Change Impacts on Building Heating and Cooling Energy Demand in Switzerland.” *Research That Inspires 125 Years of EMPA* 37 (11): 1175–85. https://doi.org/10.1016/j.enbuild.2005.06.019.

Gagliano, A, F Patania, F Nocera, A Ferlito, and A Galesi. 2012. “Thermal Performance of Ventilated Roofs during Summer Period.” *Energy and Buildings* 49:611–18. https://doi.org/10.1016/j.enbuild.2012.03.007.

Holzer, Peter. 2022. “International Energy Agency EBC Annex 80| Resilient Cooling of Buildings–State of the Art Review.” https://www.building-research.at/1052776/b7288c/.

Housing and Development Board. 2012. “General Technical Requirements.” https://www.hdb.gov.sg/-/media/doc/BQG/hdb-arch-technical-requirements.ashx.

la Rue du Can, Stephane de, and Lynn Price. 2008. “Sectoral Trends in Global Energy Use and Greenhouse Gas Emissions.” *Energy Policy* 36 (4): 1386–1403. https://doi.org/10.1016/j.enpol.2007.12.017.

IEA. 2020. “How Cooling as a Service Is Set to Revolutionise the Cooling Industry.” https://www.iea.org/events/how-cooling-as-a-service-is-set-to-revolutionise-the-cooling-industry.

IEA EBC Annex 80. 2019. “IEA EBC Annex 80 on Resilient Cooling for Residential and Small Non-Residential Buildings.” https://annex80.iea-ebc.org/Data/Sites/10/media/documents/supporting/ebc-annex-80-annex-text-190616.pdf.

International Energy Agency. 2022. “Space Cooling.” https://www.iea.org/reports/space-cooling.

International Living Future Institute. 2019. “Living Building Challenge 4.0: A Visionary Path to a Regenerative Future.” https://living-future.org/wp-content/uploads/2022/08/LBC-4_0_v14_2_compressed.pdf.

International WELL Building Institute. 2016. “WELL Building Standard V1.” https://standard.wellcertified.com/sites/default/files/The%20WELL%20Building%20Standard%20v1%20with%20May%202016%20addenda.pdf.

Isai, V. 2021. “Heat Wave Spread Fire That ‘Erased’ Canadian Town.” *The New York Times*. https://www.nytimes.com/2021/07/10/world/canada/canadian-wildfire-british-columbia.html#:~:text=Lytton%20was%20hit%20particularly%20hard,in%20a%20July%206%20statement.

Jani, D. B., Manish Mishra, and Pradeep Kumar Sahoo. 2018. “A Critical Review on Application of Solar Energy as Renewable Regeneration Heat Source in Solid Desiccant–Vapor Compression Hybrid Cooling System.” *Journal of Building Engineering* 18:107–24. https://doi.org/10.1016/j.jobe.2018.03.012.

Jomehzadeh, Fatemeh, Hasanen Mohammed Hussen, John Kaiser Calautit, Payam Nejat, and M. Salim Ferwati. 2020. “Natural Ventilation by Windcatcher (Badgir): A Review on the Impacts of Geometry, Microclimate and Macroclimate.” *Energy and Buildings* 226 (November):110396. https://doi.org/10.1016/j.enbuild.2020.110396.

Kalanki, Ankit, Caroline Winslow, and Iain Campbell. 2021. “Global Cooling Prize: Solving the Cooling Dilemma.” *Rocky Mountain Institute*. https://rmi.org/insight/global-cooling-prize-solving-the-cooling-dilemma.

Khabbaz, Mohamed, Brahim Benhamou, Karim Limam, Pierre Hollmuller, Hassan Hamdi, and Amin Bennouna. 2016. “Experimental and Numerical Study of an Earth-to-Air Heat Exchanger for Air Cooling in a Residential Building in Hot Semi-Arid Climate.” *Energy and Buildings* 125:109–21. https://doi.org/10.1016/j.enbuild.2016.04.071.

Khan, Zarrar, Gokul Iyer, Pralit Patel, Son Kim, Mohamad Hejazi, Casey Burleyson, and Marshall Wise. 2021. “Impacts of Long-Term Temperature Change and Variability on Electricity Investments.” *Nature Communications* 12 (1): 1643. https://doi.org/10.1038/s41467-021-21785-1.

Khovalyg, Dolaana, and Yann Ravussin. 2022. “Interindividual Variability of Human Thermoregulation: Toward Personalized Ergonomics of the Indoor Thermal Environment.” Obesity 30 (7): 1345–50. https://doi.org/DOI: 10.1002/oby.23454.

Kim, Joyce, Fred Bauman, Paul Raftery, Edward Arens, Hui Zhang, Gabe Fierro, Michael Andersen, and David Culler. 2019. “Occupant Comfort and Behavior: High-Resolution Data from a 6-Month Field Study of Personal Comfort Systems with 37 Real Office Workers.” *Building and Environment* 148:348–60. https://doi.org/10.1016/j.buildenv.2018.11.012.

Klinenberg, Eric. 2015. *Heat Wave: A Social Autopsy of Disaster in Chicago*. University of Chicago Press.

Kovats, R. Sari, and Shakoor Hajat. 2008. “Heat Stress and Public Health: A Critical Review.” *Annu. Rev. Public Health* 29:41–55. https://doi.org/10.1146/annurev.publhealth.29.020907.090843.

Lal, Shiv, S. C. Kaushik, and P. K. Bhargav. 2013. “Solar Chimney: A Sustainable Approach for Ventilation and Building Space Conditioning.” *International Journal of Development and Sustainability* 2 (1): 277–79.

Levinson, Ronnen, Ed Arens, Emmanuel Bozonnet, Vincenzo Corrado, Haley Gilbert, Peter Holzer, Pierre Jaboyedoff, Amanda Krelling, Anais Machard, and Wendy Miller. 2023. "Policy Recommendations from IEA EBC Annex 80: Resilient Cooling of Buildings." https://eta-publications.lbl.gov/sites/default/files/iea_ebc_annex_80_policy_recommendations_2023-06-26_-_ronnen_levinson_0.pdf.

Levinson, Ronnen, George Ban-Weiss, Paul Berdahl, Sharon Chen, Hugo Destaillats, Nathalie Dumas, Haley Gilbert, Howdy Goudey, Sébastien Houzé de l'Aulnoit, and Jan Kleissl. 2019. "Solar-Reflective 'Cool' Walls: Benefits, Technologies, and Implementation." https://www.energy.ca.gov/publications/2019/solar-reflective-cool-walls-benefits-technologies-and-implementation.

Lizana, Jesus, Nicole D. Miranda, Larisa Gross, Antonella Mazzone, Francois Cohen, Giovani Palafox-Alcantar, Patrick Fahr, Anant Jani, Renaldi Renaldi, and Malcolm McCulloch. 2022. "Overcoming the Incumbency and Barriers to Sustainable Cooling." *Buildings and Cities* 3 (1). https://doi.org/DOI: 10.5334/bc.255.

Luo, Maohui, Edward Arens, Hui Zhang, Ali Ghahramani, and Zhe Wang. 2018. "Thermal Comfort Evaluated for Combinations of Energy-Efficient Personal Heating and Cooling Devices." *Building and Environment* 143:206–16. https://doi.org/10.1016/j.buildenv.2018.07.008.

Maierhofer, Dominik, Martin Röck, Marcella Ruschi Mendes Saade, Endrit Hoxha, and Alexander Passer. 2022. "Critical Life Cycle Assessment of the Innovative Passive nZEB Building Concept 'Be 2226'in View of Net-Zero Carbon Targets." *Building and Environment* 223:109476. https://doi.org/10.1016/j.buildenv.2022.109476.

McIntyre, DA, and ID Griffiths. 1972. "Subjective Response to Radiant and Convective Environments." *Environmental Research* 5 (4): 471–82. https://doi.org/10.1016/0013-9351(72)90048-5.

McLauchlan, D., and D. Lavan. 2010. "Efficiency by the Book; Case Study: The Richard J. Klarchek Information Commons Building." *High Performing Buildings Magazine*.

Moazami, Amin, Vahid M. Nik, Salvatore Carlucci, and Stig Geving. 2019. "Impacts of Future Weather Data Typology on Building Energy Performance – Investigating Long-Term Patterns of Climate Change and Extreme Weather Conditions." *Applied Energy* 238 (March):696–720. https://doi.org/10.1016/j.apenergy.2019.01.085.

Morris, Nathan B., Georgia K. Chaseling, Timothy English, Fabian Gruss, Mohammad Fauzan Bin Maideen, Anthony Capon, and Ollie Jay. 2021. "Electric Fan Use for Cooling during Hot Weather: A Biophysical Modelling Study." *The Lancet Planetary Health* 5 (6): e368–77. https://doi.org/10.1016/S2542-5196(21)00136-4.

Murphy, Michelle. 2006. *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers*. Duke University Press.

"National University of Singapore's SDE4 Building Is a Prototype of Sustainable Design." 2023. July 10, 2023. https://www.dezeen.com/2019/03/01/university-of-singapore-sde4-building-serie-architects-multiply-architects/.

NYC Building Code. 2014. "Chapter 12: Interior Environment, NYC Building Code 2014." https://www.nyc.gov/assets/buildings/apps/pdf_viewer/viewer.html?file=2022BC_Chapter12_InteriorEnvironmentWBwm.pdf&section=conscode_2022.

Olonscheck, Mady, Anne Holsten, and Jürgen P. Kropp. 2011. "Heating and Cooling Energy Demand and Related Emissions of the German Residential Building Stock under Climate Change." *Energy Policy* 39 (9): 4795–4806. https://doi.org/10.1016/j.enpol.2011.06.041.

O'Neill, Marie S., Antonella Zanobetti, and Joel Schwartz. 2005. "Disparities by Race in Heat-Related Mortality in Four US Cities: The Role of Air Conditioning Prevalence." *Journal of Urban Health* 82 (2): 191–97.

Passe, Ulrike, and Francine Battaglia. 2015. *Designing Spaces for Natural Ventilation: An Architect's Guide. Routledge*.

Pasut, Wilmer, Hui Zhang, Ed Arens, and Yongchao Zhai. 2015. "Energy-Efficient Comfort with a Heated/Cooled Chair: Results from Human Subject Tests." *Building and Environment* 84:10–21. https://doi.org/10.1016/j.buildenv.2014.10.026.

Patel, Kasha, and Niha Masih. 2022. "Climate Change Is Worsening Heat Wave in India and Pakistan." *The Washington Post*. https://www.washingtonpost.com/weather/2022/05/18/heat-climate-change-india-pakistan/.

Rafique, M. Mujahid, P. Gandhidasan, Shafiqur Rehman, and Luai M. Al-Hadhrami. 2015. "A Review on Desiccant Based Evaporative Cooling Systems." *Renewable and Sustainable Energy Reviews* 45:145–59. https://doi.org/10.1016/j.rser.2015.01.051.

Reilly, Aidan, and Oliver Kinnane. 2017. "The Impact of Thermal Mass on Building Energy Consumption." *Applied Energy* 198 (July):108–21. https://doi.org/10.1016/j.apenergy.2017.04.024.

Rim, Minyeop, Uk-Joo Sung, and Taeyeon Kim. 2018. "Application of Thermal Labyrinth System to Reduce Heating and Cooling Energy Consumption." *Energies* 11 (10): 2762.

Romanov, D., and B. Leiss. 2022. "Geothermal Energy at Different Depths for District Heating and Cooling of Existing and Future Building Stock." *Renewable and Sustainable Energy Reviews* 167:112727.

Ruefenacht, Lea, and Juan Angel Acero. 2017. "Strategies for Cooling Singapore: A Catalogue of 80+ Measures to Mitigate Urban Heat Island and Improve Outdoor Thermal Comfort."

Sand, James R., Steven K. Fischer, and Van D. Baxter. 1997. *Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies*. Citeseer.

Schiavon, Stefano, Arsen K. Melikov, and Chandra Sekhar. 2010. "Energy Analysis of the Personalized Ventilation System in Hot and Humid Climates." *Energy and Buildings* 42 (5): 699–707. https://doi.org/10.1016/j.enbuild.2009.11.009.

Shah, Nihar, Max Wei, Virginie Letschert, and Amol Phadke. 2015. "Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning." Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

Sherwood, Steven C, and Matthew Huber. 2010. "An Adaptability Limit to Climate Change Due to Heat Stress." *Proceedings of the National Academy of Sciences* 107 (21): 9552–55. https://doi.org/10.1073/pnas.0913352107.

Shetabivash, H. 2015. "Investigation of Opening Position and Shape on the Natural Cross Ventilation." *Energy and Buildings* 93:1–15.

Song, Jinglu, Hanchen Yu, and Yi Lu. 2021. "Spatial-Scale Dependent Risk Factors of Heat-Related Mortality: A Multiscale Geographically Weighted Regression Analysis." *Sustainable Cities and Society* 74:103159. https://doi.org/10.1016/j.scs.2021.103159.

Standard, ASHRAE. 2017. "Standard 55–2017 Thermal Environmental Conditions for Human Occupancy." *American Society of Heating, Refrigerating and Air Conditioning Engineers: Atlanta, GA, USA*.

Swiss Society of Engineers and Architects. 2009. "Heizwärmebedarf." http://shop.sia.ch/normenwerk/architekt/380-1_2016_d/D/Product.

The Guardian. 2023a. "India Heatwave: 96 People Dead Reportedly from Heat-Aggravated Conditions." July 10, 2023. https://www.theguardian.com/world/2023/jun/19/india-heatwave-scores-dead-warning-stay-indoors-during-day-heat-wave-uttar-pradesh-eastern-bihar.

———. 2023b. "Southern Europe Braces for Second Heat Storm in a Week," 2023. https://www.theguardian.com/world/2023/jul/16/thousands-forced-out-of-homes-la-palma-canary-islands-as-heatwave-grips-europe.

———. 2023c. "Vietnam Records Highest Ever Temperature of 44.1C." 2023. https://www.theguardian.com/world/2023/may/07/vietnam-records-highest-ever-temperature-of-441c.

Transsolar. 2009. "Manitoba Hydro Place, Winnipeg, MB, Canada." 2009. https://transsolar.com/projects/manitoba-hydro.

UN Environment Programme. 2022. "Kigali Cooling Efficiency Programme." https://www.unep.org/ozonaction/kigali-cooling-efficiency-programme.

United States Environmental Protection Agency. 2021. "Recent International Developments under the Montreal Protocol." https://www.epa.gov/ozone-layer-protection/recent-international-developments-under-montreal-protocol.

U.S. Green Building Council. 2019. "LEED v4.1 Building Design +Construction." https://www.usgbc.org/leed/v41.

Wargocki, Pawel, David P Wyon, Jan Sundell, Geo Clausen, and P Ole Fanger. 2000. "The Effects of Outdoor Air Supply Rate in an Office on Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity." *Indoor Air* 10 (4): 222–36.

Yang, Bin, Stefano Schiavon, Chandra Sekhar, David Cheong, Kwok Wai Tham, and William W. Nazaroff. 2015. "Cooling Efficiency of a Brushless Direct Current Stand Fan." *Building and Environment* 85:196–204. https://doi.org/10.1016/j.buildenv.2014.11.032.

Zhang, Chen, Ongun Berk Kazanci, Ronnen Levinson, Per Heiselberg, Bjarne W. Olesen, Giacomo Chiesa, Behzad Sodagar, et al. 2021. "Resilient Cooling Strategies – A Critical Review and Qualitative Assessment." *Energy and Buildings* 251 (November):111312. https://doi.org/10.1016/j.enbuild.2021.111312.

Zhao, Dongliang, Ablimit Aili, Yao Zhai, Shaoyu Xu, Gang Tan, Xiaobo Yin, and Ronggui Yang. 2019. "Radiative Sky Cooling: Fundamental Principles, Materials, and Applications." *Applied Physics Reviews* 6 (2): 021306.

Zhao, Xiaojing, Wei Pan, and Weisheng Lu. 2016. "Business Model Innovation for Delivering Zero Carbon Buildings." *Sustainable Cities and Society* 27:253–62. https://doi.org/10.1016/j.scs.2016.03.013.

Zhen, Li, D. M. Lin, H. W. Shu, Shuang Jiang, and Y. X. Zhu. 2007. "District Cooling and Heating with Seawater as Heat Source and Sink in Dalian, China." *Renewable Energy* 32 (15): 2603–16. https://doi.org/10.1016/j.renene.2006.12.015.

About the Authors

This article was written by the 42 authors listed on the next page and led by Dorit Aviv, Adam Rysanek, Nan Ma, and Donna Vakalis.

Dorit Aviv is an assistant professor of architecture and director of the Thermal Architecture Lab at the University of Pennsylvania Stuart Weitzman School of Design, specializing in sustainability and environmental performance. She is a licensed architect with a Ph.D. in architectural technology from Princeton University.

Adam Rysanek is an assistant professor of environmental systems at the University of British Columbia School of Architecture and Landscape Architecture. He is an expert in green building design, construction, and operation, with over ten years of experience with high-performance building projects in Canada, Europe, and Asia.

Nan "Nancy" Ma is an assistant professor of architectural engineering at Worcester Polytechnic Institute and founding director of the Laboratory for Healthy, Environmental, and Resilient Buildings. She holds a Ph.D. in architecture from the University of Pennsylvania; and a master of architecture and bachelor of environments from the University of Melbourne.

Donna Vakalis is a postdoctoral researcher at Mila, a Montreal-based research institute. Her current research focuses on reducing carbon emissions from buildings using machine learning for decision support. She holds a Ph.D. in civil engineering and a master's degree in architecture.

Cover photo: istockphoto.com/portfolio/UT07

Authors

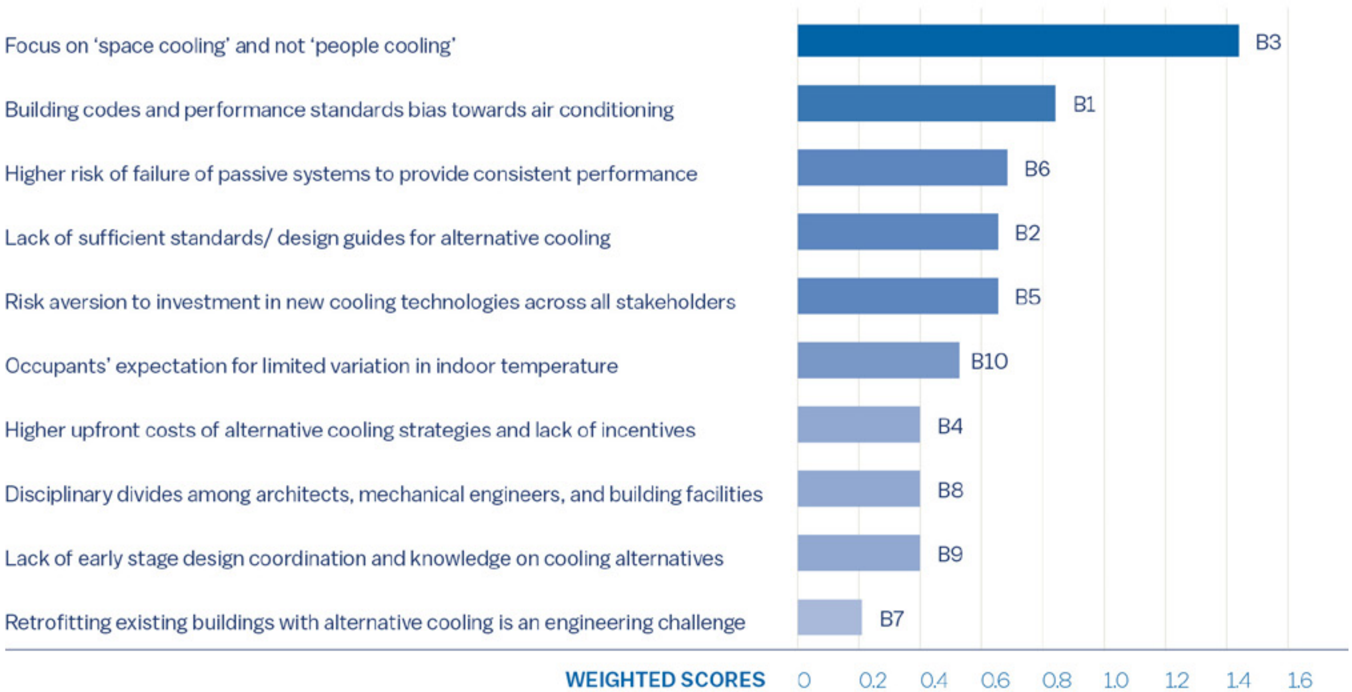
FIRST NAME	FAMILY NAME	AFFILIATION
Dorit	**Aviv**	University of Pennsylvania Weitzman School of Design
Adam	**Rysanek**	University of British Columbia School of Architecture and Landscape Architecture
Nan	**Ma**	Worcester Polytechnic Institute
Donna	**Vakalis**	Universite de Montreal
Thomas	**Auer**	Transsolar; Technical University of Munich
Tom	**Bamber**	Introba
Christiane	**Berger**	Aalborg University
Ongun Berk	**Kazanci**	Technical University of Denmark Department of Environmental and Resource Engineering
Kipp	**Bradford**	Gradient, Inc.
William	**Braham**	University of Pennsylvania Weitzman School of Design
Iain	**Campbell**	Rocky Mountain Institute
Carlos	**Cerezo Davila**	Kohn Pedersen Fox
Adrian	**Chong**	National University of Singapore Department of the Built Environment
Ruchi	**Choudhary**	University of Cambridge Department of Engineering
Salmaan	**Craig**	McGill University School of Architecture
Richard	**De Dear**	The University of Sydney School of Architecture, Design and Planning
Chiara	**Delmastro**	International Energy Agency
Billie	**Faircloth**	Kieran Timberlake
William	**Frantz**	Armstrong World Industries
Tianzhen	**Hong**	Building Technology and Urban Systems Division, Lawrence Berkeley National Laboratory
Dolaana	**Khovalyg**	École Polytechnique Fédérale de Lausanne; School of Architecture, Civil and Environmental Engineering
Li	**Lan**	Shanghai Jiao Tong University
Maohui	**Luo**	Tongji University
Ardeshir	**Mahdavi**	Technical University of Graz, Institute of Building Physics, Services, and Construction, Faculty of Civil Engineering Sciences
Dominic	**McGraw**	City of Philadelphia
Forrest	**Meggers**	Princeton University School of Architecture and Andlinger Center for Energy and the Environment
Clayton	**Miller**	National University of Singapore Department of the Built Environment
Kiel	**Moe**	Auburn University/Rural Studio
Leslie	**Norford**	Massachusetts Institute of Technology, School of Architecture and Planning
Bjarne	**Olesen**	Technical University of Denmark Department of Environmental and Resource Engineering
Kristina	**Orehounig**	Empa–Swiss Federal Laboratories for Materials Science and Technology; Singapore–ETH Centre
Jovan	**Pantelic**	Well Living Lab
Ulrike	**Passe**	Iowa State University, College of Design, Department of Architecture & Center for Building Energy Research
Tarek	**Rakha**	Georgia Institute of Technology
Rajan	**Rawal**	Centre for Advanced Research in Building Science and Enegry, CEPT University
Christoph	**Reinhart**	MIT, School of Architecture and Planning
Susan	**Roaf**	Heriot-Watt University School of Energy, Geoscience, Infrastructure and Society
Holly	**Samuelson**	Harvard University Graduate School of Design
Stefano	**Schiavon**	UC Berkeley, Dept of Architecture, Dept of Civil and Environmental Engineering, Center for the Built Environment
Arno	**Schlueter**	Institute of Technology in Architecture, ETH Zürich; Singapore–ETH Centre
Marcel	**Schweiker**	Faculty of Architecture, RWTH Aachen University & Healthy Living Spaces Lab, Institute for Occupational, Social and Environmental Medicine, Medical Faculty, RWTH Aachen University
Eric	**Teitelbaum**	AIL Research

Appendix A: Survey Results

Barriers

Figure A1 illustrates the identified barriers in order of importance per the survey with panel participants. The barriers ranked from the most important to the least important show that B3 is weighted twice as important as the middle tier's identified barriers (i.e., B1, B6, B2, and B5). B3, the most dominant barrier identified, is the misguided emphasis on "space cooling" rather than "people cooling." The second highest score is given to B1, related to the building codes and standards.

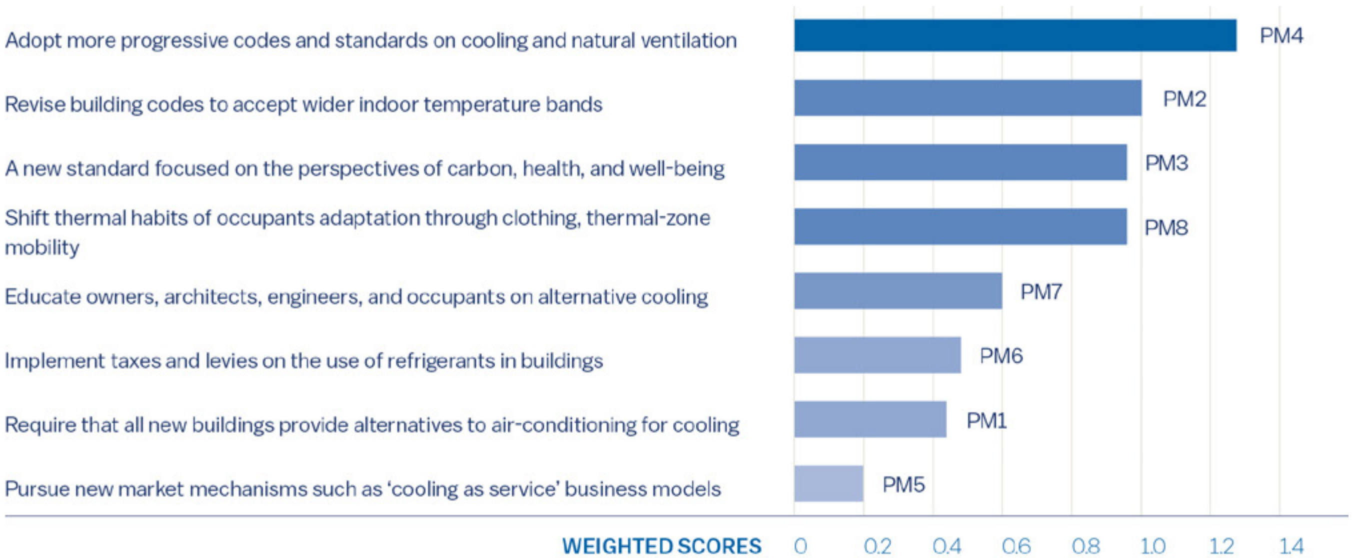
Figure A1: The Identified Barriers of Removing Barriers to Alternative Cooling



Policy Solutions

Figure A2 shows that adopting more progressive codes and standards on cooling and natural ventilation is considered.

Figure A2: The Identified Market and Policy Solutions for Cooling Alternatives



Stay up to date with all of our research.

kleinmanenergy.upenn.edu

Kleinman Center for Energy Policy

University of Pennsylvania
Stuart Weitzman School of Design
Fisher Fine Arts Building, Suite 401
220 S. 34th St.
Philadelphia, PA 19104

P 215.898.8502
F 215.573.1650

kleinmanenergy@upenn.edu