SUSTAINABLE COOLING APPROACHES FOR A WARMING WORLD: A LITERATURE REVIEW

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Abstract: As the urgency to combat climate change intensifies, sustainable cooling strategies are essential to manage high temperatures. This paper presents a literature review of sustainable cooling approaches that reduce temperatures in extreme conditions. It analyses 64 peer-reviewed publications using a four-tiered cooling pyramid framework proposed by the authors. The framework categorises cooling approaches into urban cooling, passive buildings, appliances without refrigeration, and air-conditioning with refrigeration. The findings show that "urban cooling" strategies as the most promising approach, with temperature reduction over 10°C, while passive buildings and non-refrigerant appliances achieve reductions of 5ºC and 7ºC respectively. When combined, these strategies offer a potential reduction of 20ºC before deploying refrigerant based cooling. By synthesising these cooling potential of each strategy and highlighting the gaps, the review provides an overview of sustainable cooling in urban environments makes the case for a layered and integrated approach. This work serves as a vital resource for funders, policymakers, and researchers seeking to develop and implement climate-resilient cooling solutions in the built environment.

Keywords: *Sustainable Cooling, Urban cooling, Literature review, Extreme climate, Passive Buildings, Air conditioning*

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1. Introduction

The world is facing an unprecedented challenge of global warming, leading to more frequent and intense extreme climate conditions. Among the consequences, heat waves pose a severe threat to human health and mortality (Hughes et al., 2016). As climate change progresses, heat waves are projected to grow in frequency and intensity, especially in urban areas where the Urban Heat Island effect exacerbates the problem (Stanganelli & Gerundo, 2017) (Li et al., 2023). With higher population, urban areas are sites for increased vulnerability to heat waves, which can lead to increased energy consumption for cooling, peak electricity demand, and heat-related morbidity and mortality (Santamouris, 2020) (Shandas et al., 2019). Addressing this challenge requires a multi-pronged approach of sustainable cooling solutions that can effectively mitigate the effects of extreme heat while minimizing the broader environmental and social impacts. One promising approach is the integration of urban green infrastructure, such as parks, gardens, and green roofs (Stanganelli & Gerundo, 2017) (Li et al., 2023). These natural cooling solutions can provide significant reductions in local temperatures through evapotranspiration and shading, while also offering additional benefits like improved air quality, biodiversity, and recreational opportunities (Li et al., 2023). However, the distribution and configuration of green spaces within urban areas play a crucial role in their effectiveness, and careful planning is required to optimise their cooling potential (Stanganelli & Gerundo, 2017). Beyond green infrastructure, other sustainable cooling strategies, such as the use of reflective surfaces, shading, and passive building designs, have also been explored (Hagishima, 2018). These approaches aim to reduce heat absorption and increase heat dissipation, thereby lowering the demand for energy-intensive air conditioning. These approaches can be categorised and broadly defined to help understand their significance and potential in mitigating extreme heat by reducing the temperatures experienced by people.

As climate change adaptation becomes increasingly crucial, the integration of these sustainable cooling solutions into urban planning and design is paramount. The co-benefits of these strategies, which include reduced energy consumption, improved thermal comfort, and enhanced resilience, make them a promising way forward in addressing the challenges posed by extreme heat waves (He et al., 2019) (Battisti et al., 2018). In this paper, we present a comprehensive review of sustainable cooling approaches. We propose a four-tiered cooling pyramid that puts sustainable cooling in a comprehensive framework, and we categorise cooling approaches and analyse them. We evaluate the location, climate zone, method, and the temperature reduction each strategy is reported to achieve. This provides a documentation of the cooling potential of other approaches before refrigerant-based cooling needs to be deployed.

By reviewing 64 peer-reviewed studies, this paper identifies and evaluates the cooling potential of various sustainable strategies across different climate zones. The analysis highlights that urban cooling approaches, such as green infrastructure

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and reflective surfaces, can reduce local temperatures by over 10°C. Passive building strategies, including shading and thermal mass, offer reductions exceeding 5°C, while non-refrigerant appliances achieve cooling of more than 7°C. When layered effectively, these strategies provide a cumulative cooling potential of up to 20°C, delaying or even eliminating the need for refrigerant-based air conditioning in many scenarios.

These findings demonstrate that sustainable cooling solutions can offer substantial temperature reductions, making them vital tools for mitigating extreme heat, particularly in urban environments. However, the effectiveness of these strategies varies by region and climate, emphasizing the need for further research in multiple climate zones. This review is significant because it provides a comparative overview and identifies gaps in a comprehensive sustainable cooling approach. It is expected to be an important resource for funders, policymakers, researchers seeking to develop and implement climate-resilient cooling solutions in the built environment.

2. Methodology

This study is conducted in two stages (see Figure 1). The first stage involves gathering relevant literature through research and identifying trends, while the second stage involves categorising the literature and analysing it.

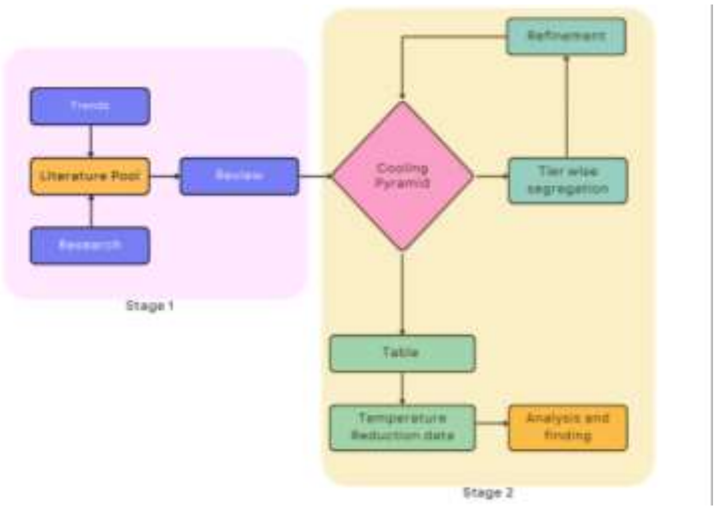

Figure 1, Basic framework of the workflow for the methodology

2.1 SUSTAINABLE COOLING PYRAMID

Before starting the literature review, the authors have developed a cooling pyramid (Figure 2), to categorise and analyse various cooling approaches. The pyramid framework organizes cooling strategies into tiers based on their accessibility and scope of impact. The larger size of a tier indicates larger accessibility of that cooling approach. Thus, urban cooling is at the base of the pyramid as the largest tier, denoting that almost everyone, including outdoor workers, are likely to have access to the cooling provided by this approach. Passive buildings in the second tier provide access to its cooling effect to those who inhabit buildings. The third tier of appliances without refrigerants such as ceiling fans is affordable and can provide cooling to large number of people. The top-most tier of refrigerant-based air-conditioning (AC) is expensive and while providing cooling to an affluent few, this approach in effect pumps the indoor heat to the outdoors, worsening conditions for everyone else. It is noteworthy that while access to cooling increases as we move down from the top of the pyramid, typically access to investments and funding increases in the opposite direction.

Figure 2, Sustainable Cooling Pyramid

The authors used this pyramid as a framework to assess the impact of cooling strategies and identify gaps across various scales of the built environment.

2.1.1 Urban Cooling

In this tier, we will cover the definition and intent of urban cooling, exploring its various techniques and their benefits. Urban cooling, or urban heat mitigation, involves strategies to reduce temperatures in urban environments addressing the Urban Heat Island effect and heat waves. This temperature difference between urban areas and rural areas results from human activity and the built environment (Oke, 1982). Techniques like increasing vegetation cover, such as parks and green roofs, and enhancing surface reflectivity help mitigate the impact of extreme heat, improve comfort, and reduce reliance on AC, thereby lowering electricity consumption and carbon emissions (International Energy Agency et al., 2018).

2.1.2. Passive Buildings

Passive design strategies in buildings use strategies like shading, insulation, or thermal mass, to reduce heat ingress, while using natural heat sinks such as air, water, ground, and sky to dissipate absorbed heat through natural ventilation, thermosyphons, or radiative cooling. They regulate indoor temperatures and reduce the need for mechanical and electrical energy-based systems (Abady, 2023). Together, they improve energy efficiency and occupant comfort while minimising environmental impacts (Kwok & Grondzik, 2007; Givoni, 1995). The effectiveness of these strategies is dependent on the local climate and the building typology.

2.1.3. Appliances without refrigerants

'Appliances without refrigerant' refers to cooling technologies and appliances that do not rely on refrigerants, which are known contributors to high energy use, ozone depletion and global warming. These systems typically use low-energy methods such as forced ventilation, evaporative cooling or advanced materials like phase-change materials (PCMs) and thermoelectric cooling, to achieve temperature control. They are also referred to as active cooling approaches. They reduce or eliminate the use of conventional refrigerant based cooling, thereby lowering greenhouse gas emission and promoting sustainability in building cooling solutions. (Airplusrefrigeration, 2023) (Xue et al., 2023)

2.1.4. Air conditioning, with refrigerants

Air conditioning (AC) is preferred as a cooling system because it provides the necessary cooling in almost any situation as long as there is an abundance of electricity, and unlike many passive techniques, can be deployed as a retrofit. It results in environmental degradation due to its refrigerants and electricity use. Since the refrigerant cycle moves heat to the outdoors, an indiscriminate use of AC results in higher outdoor temperature in the microclimate.

In a comprehensive and integrated view of Sustainable Cooling it is important consider AC as the last resort, so that other approaches that have lower environmental impacts are deployed with higher priority (Asim et al., 2022). This Sustainable Cooling approach also ensures that more accessible methods of cooling are deployed first, and by reducing the hours and places where AC moves indoor heat to the outdoor urban environment, we protect vulnerable populations that cannot afford AC.

2.2 LITERATURE REVIEW/STUDY SELECTION PROCESS

A comprehensive literature review was conducted to identify and synthesize the most relevant research on sustainable cooling approaches for temperature reduction during extreme climate events. The search strategy involved querying multiple academic databases (e.g., Google Scholar, Scopus, MDPI) using a well-defined set of keywords, including "sustainable cooling," "urban heat mitigation," "extreme heat adaptation," "ceiling fan cooling," "evaporative cooler," "passive design," and "green infrastructure." This strategy was designed to capture a broad spectrum of studies on sustainable cooling solutions and urban heat adaptation strategies. In addition, the authors referenced proceedings from peer-reviewed publications and followed a thematic approach presented at the Comfort at the Extremes (CATE) Conference 2023, held at CEPT University in Ahmedabad, India.

The selection of sources followed a systematic approach, with articles evaluated based on their relevance to the research question, scientific rigor, and contribution to understanding sustainable cooling technologies. While the search was primarily limited to recent journals, references from older but relevant studies (up to 16 years ago) were also included if they provided critical insights. The selected publications adhered to the following criteria:

1. The papers were peer-reviewed and published in English, with non-English language papers being translated for analysis.
2. Studies were assessed based on the "sustainable cooling pyramid," categorizing them into one of four tiers: (a) urban cooling, (b) passive building design, (c) appliances without refrigerants, and (d) refrigerant-based cooling (e.g., air conditioning).
3. Only studies that presented measured or simulated results of cooling strategies in predominantly hot-dry and warm-humid climates were included, as these regions typically experience more extreme heat events. However, the study was not limited exclusively to these climate zones.

4. Preference was given to studies providing empirical data for meta-analysis, such as temperature reduction and energy savings metrics, as well as thermal comfort evaluations. Studies that focused solely on theoretical strategies without empirical evidence were excluded.

2.3 DATA EXTRACTION

We classified the cooling approaches in these publications into the four tiers of the pyramid. A tabular arrangement included the title, year, author(s), study focus, strategies used, findings, study location, study method, climate type/zone, temperature reduction achieved, and additional remarks. Under study method, we noted if publication reported on field measurements or computer simulations, or a combination of both.

2.4 DATA ANALYSIS

The selected literature was analysed based on the study's purpose, and the findings. The locations were extracted and mapped according to the Köppen-Geiger climate classification system. Visual representations illustrated the effectiveness of the different cooling strategies and provided a comprehensive understanding of the geographic scope and climate contexts. Through the reported findings, we analysed the temperature reductions, the scope of the study, and the overall impact.

3. Results

This review reports on 64 peer reviewed publications largely from India, categorised into the four tiers: ‘Urban Cooling’, ‘Passive Design’, ‘Appliances (without refrigerant)’, and ‘AC’. Each tier contains 15, 22, 18, and 9 publications on the subject matter, respectively.

3.1. GEOGRAPHICAL AND CLIMATE ZONE/TYPE DISTRIBUTION

The geographic distribution of study shows 15 publications (24%) from India, followed by 7 (11%) from the USA, 4 (6%) from China, 3 each from Australia and Republic of Korea, and 2 each from UAE, Saudi Arabia, Canada, Italy, France, Turkey, Germany, and Brazil. The other 16 publications are 1 each from various other countries.

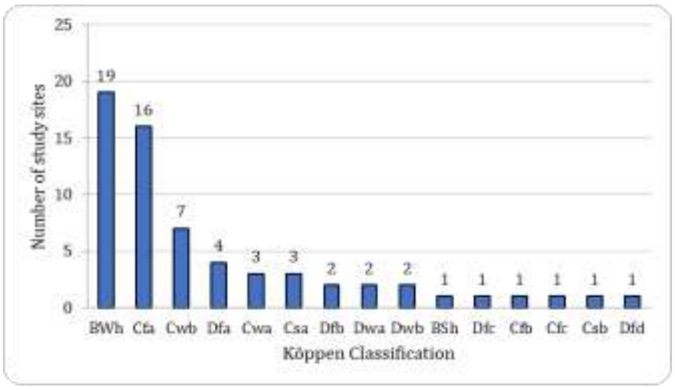

Figure 3, Climate Zone distribution of study sites.

The Köppen-Geiger climate classification (Kottek et al., 2006) show that a large number these 64 publications have studies from climate zones with hot summers (see Figure 3), (19, 30%) studies conducted in Hot-Dry (BWh) climate, closely followed by (16, 25%) in Humid subtropical (Cfa) climate, (7, 11%) in Temperate climate (Cwb). Studies also focused on the Hot-Mediterranean (Csa) (3, 5%) (Cwa) (3, 5%), the Humid Continental (Dfa) (4, 6%).

3.2. SUSTAINABLE COOLING AND TEMPERATURE REDUCTION

In this section, we delve into the various sustainable cooling strategies and technologies identified in the reviewed literature, focusing on their temperature reduction and outcome across different tiers and climate zones. Figure 4 shows temperature reductions in Tier 1 urban cooling strategies range from 1.26°C to 15°C. The most substantial temperature reduction of 15°C was observed in the study by Sunmin et al. (2023), with 10°C observed by D. Alessandro et al. (2024). For Tier 2 passive building strategies, the temperature reductions range from 0.7°C to 7.5°C, with a broad spectrum of effectiveness. The most significant reduction was observed in the study by Roberts et al. (2024), which reported a temperature decrease of 7.5°C. For Tier 3 appliances without refrigerants, the temperature reduction ranged from 0.17°C to 11°C. A particularly notable reduction in temperature was observed with a thermally insulated radiative cooler using pre-cooling scheduling, as reported by Jeong et al. (2018), a temperature reduction of 11°C. For Tier 4 AC, most studies reported reduced energy consumption instead of the temperature reduction achieved. One integrated system was able to reduce energy consumption by 76.7% according to Illie et al. (2017), while Ketwong et al. (2021) reported a temperature reduction of 13°C through a direct evaporative cooling system integrated with an air conditioner thereby reducing electricity consumption and increasing the efficiency of the condenser.

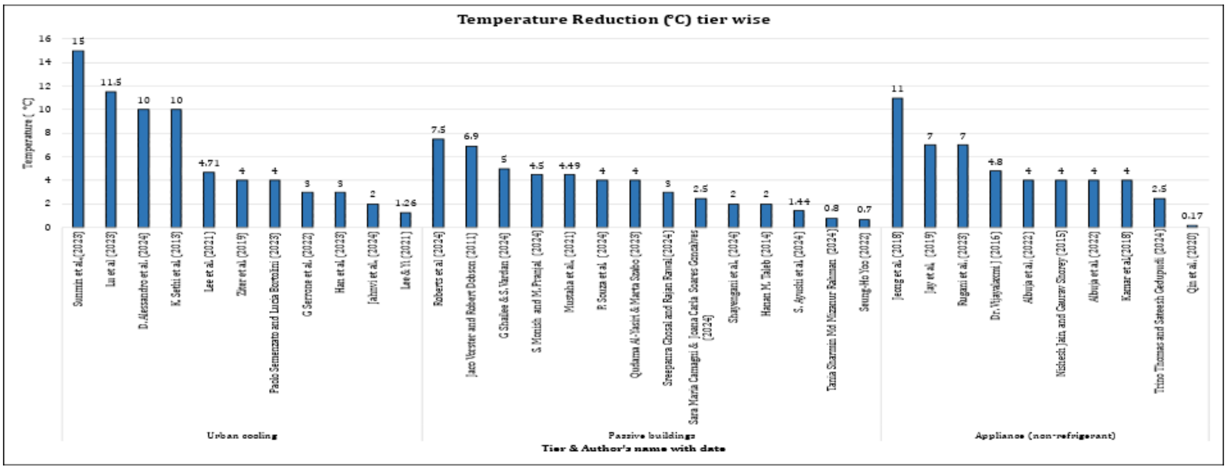

Figure 4, Tier wise chart with temperature reduction in °C, and Authors' name and year

3.2.1 Urban cooling

In this tier, the strategies reviewed include increasing building heights to reduce surface temperatures by optimizing urban morphology, enhancing shading, and improving outdoor thermal comfort. These methods help mitigate the Urban Heat Island (UHI) effect and can even create Urban Cool Island (UCI) conditions (Mehta et al., 2024; Yang et al., 2016). Additionally, using reflective materials like cool roofs and pavements lowers surface temperatures and improves microclimates. For example, in Rome, integrating green infrastructure with 15-meter-high trees significantly enhanced thermal comfort (Del Serrone et al., 2022).

Other strategies, as shown in Table 1a, focus on similar approaches, though the methods vary with different materials and tools used to process and evaluate the results. These variations highlight the adaptability of sustainable cooling techniques to different environmental and technological contexts.

Table 1 a) Summary of Tier 1 Urban Cooling.

Author (Year)	Location & Climate	Strategy	Temp. Reduction/Remarks
Mehta et al., (2024)	Ahmedabad, India (Hot & Dry)	High-rise development plan	2 °C
D. Alessandro et al. (2024)	São Paulo, Brazil (Humid Subtropical, Temperate)	Increasing building surface albedo, urban morphology adjustment, and strategic shading	10 °C
Sunmin et al., (2023)	Gimhae, South Korea (Warm and Humid)	Cool roofs and cool pavements	15 °C
G. Serrone et al. (2022)	St. Peter's Square, Rome, Italy (Hot & Dry)	Green infrastructure and cool pavements, light concrete pavement and high tree density	3 °C
Ziter et al. (2019)	Madison, Wisconsin, USA (Warm & Humid)	Canopy cover in excess of ~40% over an area	4 °C
Lee & Yi (2021)	Cheongju, South Korea (Humid Continental)	Cooling fog, cool roofs, and urban forest	0.17, 0.01, 1.26 °C
Trepci et al. (2020)	Dallas, USA (Humid Subtropical)	Height, distance, and plot orientation	24-26% cooling load savings
Paolo Semenzato and Lucia Bortolini (2023)	Padova, Italy (Humid Subtropical)	i-Tree cool air model - increasing vegetation particularly tree canopy	4 °C
Han et al. (2023)	Beijing, China (Humid Continental)	Building density, vegetation percentage (PLAND_veg), and landscape shape index (LSI)	3 °C
Cho et al. (2021)	Mugye-ri, Jangyu-myeon, Gimhae, Gyeongsangnam-do, South Korea (Humid Subtropical)	Cool roofs, green roofs, cool pavements with heat insulation, cool pavements with insulation blocks	4.7, 3.4, 0.4, 0.85 °C
Vigue et al. (2020)	Paris, France (Oceanic, Temperate)	Urban greening, and building insulation along with behavioral changes in AC use	60% energy reduction in AC use
Yang et al. (2016)	Hong Kong (Humid Subtropical)	High-rise, high-density urban environment with green spaces	UCIdh 27.1 °C for high density city. UCI effect last longer
Lu et al. (2023)	Ottawa, Canada (Humid Continental)	Cool roofs and urban vegetation	11.5 °C
K. Setaih et al. (2013)	Madinah, Saudi Arabia (Hot & Dry)	Cool surface material, vegetation, and shading elements	10 °C

3.2.2 Passive Buildings

The implementation of passive design strategies yielded significant reduction in temperature, improvements in energy efficiency and thermal comfort within the studied buildings in various study locations. Techniques like natural ventilation, solar control, (Al-Shamkhee et al., 2022) architectural layout design (Lapisa et al., 2018), and use of materials with high thermal mass were found to be effective in moderate to hot and dry climates. The strategies listed below in (Table 1b) provide temperature reduction achieved for various building types and climates: In hot and humid climates, evaporative & evapotranspiration cooling technique, (Siripurapu & Maheshwari, 2024) shading, and high-performance glazing (Wu et al.,

2023) (Soi & Goswami, 2024) were found to be effective passive cooling strategies. In continental humid climates, strategies like enhanced insulation, thermal mass, and natural ventilation were found to be effective (Kader, 2024; Sharmin & Rahman, 2024).

Table 1 b) Summary of Tier 2 Passive Buildings

Author (Year)	**Location & Climate**	**Strategy**	**Temp. Reduction/Remarks**
Tania Sharmin Md Mizanur Rahman (2024)	Ahmedabad, India (Hot & Dry)	Natural ventilation, architectural layout design (shading, chimney, cross ventilation)	0.8 °C
Siripurapu and Maheshwari (2024)	Hyderabad, India (Composite)	Terracotta-based cooling system, evapotranspiration cooling facade	4.5 °C
Seung-Ho Yoo (2022)	Chung-Nam Province, Republic of Korea (Temperate)	Passive intelligent radiant cooling system	0.7 °C
Elnabawi et al. (2024)	Al Ain, UAE (Hot & Dry)	Insulation, glazing, roofing	25% reduction in cooling load through insulation
N. Yeswanth and A. Lily Rose (2024)	Vijayawada, Andhra Pradesh, India (Hot - Humid)	Straw bale wall assemblies and Mangalore tile with Palmyra beam roofs	Lowered wall and roof U-value
Jaco Vorster and Robert Dobson (2011)	Stellenbosch, South Africa (Mediterranean)	Roof pond, roof spray, active mass cooling, and night flushing	6.9 °C
Alexander Kader (2024)	Potsdam, Germany (Humid Continental)	Window enhancement, cross ventilation, insulation, thermal massing	27% energy savings in favor of internal insulation
Chen et al. (2023)	Hong Kong (Hot & Humid)	Radiative cooling walls	1.6 and 2.2 x yearly energy savings
G. Shailee & S. Vardan (2024)	Mumbai, India (Warm-Humid)	High-performance glazing	5 °C
Shayengani et al. (2024)	Vienna, Austria (Humid Continental)	Windcatcher design (2.5 m height, 90 cm x 140 cm inlet dimensions)	2 °C
Mathew. D et al. (2024)	Greater Dublin, Ireland (Maritime Temperate)	Curtains, blinds, shutters combined on single glazing windows	Heat loss reduced through secondary glazing and strategy by 58% compared to single glazing
S. Ayushi et al. (2024)	Ahmedabad, India (Hot & Dry)	Lime mortar with XPS block and plaster	1.44 °C
P. Souza et al. (2024)	Cuiaba, Mato Grosso, Brazil (Hot & Dry)	Responsive facade	4 °C
Baba et al. (2023)	Montreal, Canada (Humid Continental)	Exterior blind roll shading and night cooling combined with low Solar Heat Gain Coefficient (SHGC) glazing	Overheating hours of blind roll and NC + SHGC low is around 32 hours.
Chen et al. (2023)	Honolulu, Tampa, Tucson, Atlanta, Seattle, Rochester, New York, Denver, USA (Various)	Passive envelope system integrating radiative cooling roofs, colored cooling walls, and thermally insulated glazing windows	29% energy saving in Honolulu
Eda Köse G and Ülten Manioğlu (2019)	Istanbul and Diyarbakır, Turkey (Temperate-Humid & Hot-Dry, respectively)	Thicker PCMs in the building envelope	Energy consumption decreased by 3.67 in Diyarbakir
Sara Maria Camagni & Joana Carla Soares Goncalves (2024)	Cairo, Egypt (Hot & Dry)	Vernacular urban canyon configuration, WWR adjustments, and shading devices	2.5 °C
Roberts et al. (2024)	Tamale, Ghana (Tropical Wet & Dry)	Ventilated roof, thin wooden wall	7.5 °C
Qudama Al-Yasiri & Marta Szabo (2023)	Baghdad, Basra, Iraq (Hot Desert Climate)	Compacting phase change materials (PCMs) into building envelope elements	4 °C
Sreepanra Ghosal and Rajan Rawal (2024)	Bhubaneshwar, India (Composite, Tropical Savanna)	EPS core wall	3 °C
Hanan M. Taleb (2014)	Silicone Oasis, UAE (Hot & Dry)	Shading devices and appropriate building openings	2 °C
Mustaha et al. (2021)	Gaza, Palestine (Temperate)	Natural ventilation, external shading devices, and construction materials of building envelope	2.86, 1.39, 4.49 °C respectively
Wu et al. (2023)	Dongfang, Haikou, Guangzhou, Chongqing, Beijing, Hami, Shenyang, Harbin, Mohe, China (Various)	Thermochromic windows	Highest potential in hot climates. 4% energy savings compared to LowE and ordinary windows

3.2.3 Appliances (without refrigerants)

In addition to passive design strategies, high-efficiency cooling appliances such as ceiling fans, electric fans, exhaust fans, and thermoelectric coolers can further enhance the temperature reduction potential. For instance, the use of ceiling fans in hot and humid conditions was found to provide a 2-7 °C reduction in indoor temperatures (Lin, 2019), and strategically placed exhaust fans (Kamar et al., 2023). While thermoelectric coolers were found to be much more environmentally friendly and compact, currently have lower performance compared to traditional HVAC systems (Güçlü et al.,2017). However, with advancements, the technology can improve its performance. There have also been efforts of integrating systems, such as incorporating photovoltaic (PV), proton exchange membrane fuel cell and thermoelectric systems, that gives us insight into its potential in temperature reduction whilst improving performance and efficiency (Marefati et al., 2019). Integrated thermoelectric cooler with phase change materials (PCMs) and liquid-cooled system can boost the cooling performance. With liquid-cooled system, coefficient of power (COP) was 40% higher than conventional thermoelectric cooler (Güçlü et al.,2017). Refer to (Table 1 c) for strategies across various climates.

Table 1 c), Summary of Tier 3 Appliances without refrigerants.

Author (Year)	Location & Climate	Strategy	Temp. Reduction/Remarks
Ulpiani et al. (2021)	Kensington campus of the University of New South Wales, Sydney, Australia (Temperate)	IoT systems to monitor environmental parameters	Provides real-time data to help assess mitigation strategies
Trino Thomas and Sateesh Gedupudi (2024)	Ahmedabad, India (Hot and Dry)	Ceiling fan and exhaust fan combined	2.5 °C
Nishesh Jain and Gaurav Shorey (2015)	Bhubaneshwar, India (Warm and Humid)	Ceiling fan	4 °C
Jay et al. (2019)	New South Wales, Australia (Warm and Humid)	Electric fans	7 °C
Rugani et al. (2023)	Sacramento, USA; Madrid, SPA; Riyadh, KSA; Rome, ITA (Hot and Dry: USA, SPA, KSA; Humid: Rome)	Coupling fan and evaporative coolers	7 °C
Qin et al. (2020)	Kyoto, Japan (Hot - Humid)	Ceiling exhaust placed closer to the thermal plume in a large room with a single jet supplier	0.17 °C
Ruellan et al. (2016)	Paris, France (Warm - Humid - Cold)	Electric appliance in a well-insulated building dissipating heat	Heating energy reduction by 36% from electric heater.
Hsin-Hung Lin (2019)	Taichung, China (Hot-Humid)	Ceiling fan at 1.34 m/s air speed	Increase air temps but maintain thermal comfort. 32.5-29.3 °C
Jeong et al. (2018)	Hong Kong (Hot-Humid)	Thermally well-insulated radiative cooler - pre-cooling ambient air	11 °C
Tadepalli et al. (2021)	Tiruchirappalli, Tamil Nadu (Warm and Humid)	Two ceiling fans at 0.45 m/s air speed and 4 different seating layouts	Able to extend comfort temperature range from 24-32°C to 27-35°C at 0.45m/s
Albuja et al. (2022)	Santa Lucia, Atlántico, Colombia (Hot-Humid)	Membrane-assisted radiant cooling system	4 °C
Malik et al. (2022)	New South Wales, Queensland, Tasmania, Western Australia (Various climate types)	Ceiling fan used alone without AC, at air speed 1.2 m/s	76% electricity consumption reduction
Güçlü et al. (2017)	Bayburt, Turkey (Hot and Dry)	TEC module installed and monitored in a small custom cabin room	TEC system with a payback period of 6.4 years
Dr. Vijayalaxmi J (2009)	Chennai, India (Hot-Humid)	Ceiling fans, most effective when opening sizes are 10%-60% of the floor area	4.8 °C
M. Alizadeh and S.M. Sadrameli (2019)	Tarbiat Modares, Iran (Hot -Dry)	PCM unit integrated with a ceiling fan-assisted ventilation system	Reduced overheating by 13.83%
Kamar et al. (2018)	Johor Bahru, Malaysia (Warm and Humid)	Exhaust fan with a 1-meter diameter on the south side wall, 6 meters above the floor	4 °C
Knudsen et al. (2023)	Dilligen, Germany; Ulm, Potsdam, & Mannheim (Warm)	Ceiling fans when used with night ventilation	Night ventilation and fan reduced slight warm feeling by 50%. Discomfort reduced by 20%

3.2.4 Air Conditioning with refrigerants

As we approach the final tier, innovative integrated HVAC systems such as pre-cooling using semi-indirect evaporative cooling and control scheduling reduces the cooling load of Air conditioning unit (Socci et al., 2024).

Integrating direct evaporative cooling with air conditioner can reduce the cooling load of the system alone by 41% thereby increasing its cooling capacity as the direct evaporative cooler reduces 13 °C temperature from the outdoor temperature of 40 °C in hot and dry climate. (Ketwong et al., 2021). When coupled with Air conditioner, ceiling fans significantly improve air circulation, reduce thermal stratification, and enhance overall comfort (Ho et al., 2008). (Table 1d) shows such integrative systems and their temperature reduction potential and savings.

Table 1 d) Summary of Tier 4 Air Conditioning with refrigerants.

Author (Year)	Location & Climate	Strategy	Temp. Reduction/Remarks
B. Soumyadip et al. (2024)	Ahmedabad, India (Hot & Dry)	Thermal storage + HVAC	Load-shaving up to 38% for office buildings
Miller et al. (2021)	Stockton, Fresno, CA, USA (Hot & Dry)	Automated ceiling fans + AC	36% compressor energy savings, increased indoor temperature by 1.9 °C but maintained thermal comfort
Miguel Chen Austin et al. (2023)	Panama City (Hot-Humid)	VGHE + heat pump (COP 4.1)	Reduced electricity consumption by 33.5%
Ketwong et al. (2021)	Chiang Ma, Thailand (Hot-Dry)	Direct evaporative cooling + AC	13°C reduction
Lim et al. (2019)	Riyadh, Saudi Arabia & Seoul, South Korea (Semi-arid & Temperate)	Inverter AC	Energy savings: Riyadh 18.3-47.1%, Seoul 36.3-51.7%

Illie et al. (2017)	Bucharest, Romania (Hot-Humid, Cold Winters)	Heat recovery exchanger + hybrid absorption system	76.7% energy consumption reduction
Socci et al. (2024)	Florence, Italy (Warm Temperate Continental)	Pre-cooling with semi-indirect evaporative cooling in wet mode	100% efficiency ratio, improving ACU performance
H. Ho et al. (2008)	Florida, USA (Hot-Humid)	Ceiling fan in AC room	PMV and PPD metrics shows ceiling fan significantly improves overall comfort.
Zeng et al. (2021)	Fresno, USA (Hot & Dry)	Rule-based control, optimized pre-cooling	Pre-cooling reduces UDH by 60% but increases cooling electricity cost

4. Conclusion

This paper underscores the importance of a comprehensive approach to sustainable cooling to provide affordable, accessible, and environmentally friendly cooling. The cooling pyramid offers a framework for layering different approaches and recognizing air-conditioning with refrigerants as the last resort.

The literature review shows that urban cooling strategies can provide temperature reduction of 10ºC and above, passive buildings provide 5ºC and above, and appliances without refrigerants provide 7ºC and above. Layering these strategies in urban environments may provide 20ºC of cooling before resorting to any refrigerant based air-conditioning. This implies that for extreme heat conditions of 50ºC, most people may have access to cooling that gives them 30ºC environments.

5. Limitations

Currently, the analysis is limited to 64 peer-reviewed papers, with a predominant focus on India with 15 publications (24%), followed by 7 (11%) from the USA, 4 (6%) from China. Some of the methods carried out in the strategies of each tiers require extensive technical as well as manual skills to implement, while the paper provides an overview of the impact, the feasibility context needs to be studied rigorously to be able to integrate and use the strategies effectively.

In the light of this, the authors recommend systematic research to build evidence of that this potential can be realised in climate zones with hot summers such as Hot-Dry (BWh) Humid subtropical (Cfa) Temperate climate, Hot-Mediterranean (Csa) (Cwa), and Humid Continental (Dfa).

6. References

Hughes, L., Fenwick, J., & Hanna, E. (2016). The Silent Killer: Climate Change and the Health Impacts of Extreme Heat. 1-29.ISBN 9780994492630

Stanganelli, M., & Gerundo, C. (2017). Understanding the Role of Urban Morphology and Green Areas Configuration During Heat Waves. International Journal of Agricultural and Environmental Information Systems, 8(2), 50–64. https://doi.org/10.4018/ijaeis.2017040104

Li, Y., Svenning, J., Zhou, W., Zhu, K., Abrams, J. F., Lenton, T. M., Teng, S. N., Dunn, R. R., & Xu, C. (2023). Global Inequality in cooling from Urban Green Spaces and its Climate Change Adaptation Potential. arXiv (Cornell University). https://doi.org/10.48550/arxiv.2307.09725

Santamouris, M. (2020). Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change. Energy and Buildings, 207, 109482. https://doi.org/10.1016/j.enbuild.2019.109482

Shandas, V., Voelkel, J., Williams, J., & Hoffman, J. (2019). Integrating satellite and ground measurements for predicting locations of extreme urban heat. Climate, 7(1), 5. https://doi.org/10.3390/cli7010005

Hagishima, A. (2018). Green infrastructure and urban sustainability. AIP Conference Proceedings. https://doi.org/10.1063/1.5024056

He, B., Zhu, J., Zhao, D., Gou, Z., Qi, J., & Wang, J. (2019). Co-benefits approach: Opportunities for implementing sponge city and urban heat island mitigation. Land Use Policy, 86, 147–157. https://doi.org/10.1016/j.landusepol.2019.05.003

Battisti, A., Laureti, F., Zinzi, M., & Volpicelli, G. (2018). Climate mitigation and adaptation strategies for roofs and pavements: a case study at Sapienza University Campus. Sustainability, 10(10), 3788. https://doi.org/10.3390/su10103788

Indian Meteorological Department. (n.d.). In Cold and Heat Wave Indices and Methodology (pp. 17–21) [Chapter 2]. https://mausam.imd.gov.in/responsive/pdf_viewer_css/met2/Chapter%20-2/Chapter%20-2.pdf

Oke, T. R. (1982). The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society, 108(455), 1–24. https://doi.org/10.1002/qj.49710845502

International Energy Agency, Birol, F., Dean, B., Dulac, J., Morgan, T., Remme, U., & Menecon Consulting. (2018). The future of cooling. In The Future of Cooling [Report]. https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf

Abady, M. (2023, December 26). Passive cooling systems for sustainable architecture: A guide to the best options - Arch2O.com. Arch2O.com. https://www.arch2o.com/passive-cooling-systems/

Kwok, A. G., & Grondzik, W. T. (2007). The Green Studio Handbook: Environmental Strategies for Schematic Design. Enquiry the ARCC Journal for Architectural Research, 4(2). https://doi.org/10.17831/enq:arcc.v4i2.47

Givoni, B. (1995). Passive and low energy cooling of buildings. Choice Reviews Online, 32(05), 32–2759. https://doi.org/10.5860/choice.32-2759

Airplusrefrigeration. (2023, December 12). Zero-Energy Refrigeration: The path to a Sustainable future. Airplus Refrigeration, Inc. https://airplusrefrigeration.com/zero-energy-refrigeration-the-path-to-a-sustainable-future/

Xue, T., Wan, Y., Huang, Z., Chen, P., Lin, J., Chen, W., & Liu, H. (2023). A comprehensive review of the applications of hybrid evaporative cooling and solar energy source systems. Sustainability, 15(24), 16907. https://doi.org/10.3390/su152416907

Asim, N., Badiei, M., Mohammad, M., Razali, H., Rajabi, A., Haw, L. C., & Ghazali, M. J. (2022). Sustainability of Heating, Ventilation and Air-Conditioning (HVAC) Systems in Buildings—An Overview. International Journal of Environmental Research and Public Health, 19(2), 1016. https://doi.org/10.3390/ijerph19021016

Minister of Environment, Forest and Climate Change. (2023). INDIA'S JOURNEY TOWARDS SUSTAINABLE COOLING. In Message (p. 67). https://www.undp.org/sites/g/files/zskgke326/files/202401/indias_journey_towards_sustainable_cooling_0.pdf

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Rahman, M. M., & Hasan, J. (2024). Evaluating the impact of green spaces on urban heat reduction in Rajshahi, Bangladesh using the INVEST model. Land, 13(8), 1284. https://doi.org/10.3390/land13081284

Mehta, J., Rawal, R., & Shukla, Y. (2024). An assessment of the universal thermal climate index of urban outdoor spaces- a case study of Central Business District (CBD), Ahmedabad. Proceedings of the Comfort at the Extremes Conference, https://doi.org/10.62744/cate.45273.1162-380-388

Yang, X., Li, Y., Luo, Z., & Chan, P. W. (2016). The urban cool island phenomenon in a high-rise high-density city and its mechanisms. International Journal of Climatology, 37(2), 890–904. https://doi.org/10.1002/joc.4747

Lee, S., Cho, Y., Lee, M., & Lim, Y. (2023). The evaluation of the temperature reduction effects of cool roofs and cool pavements as urban heatwave mitigation strategies. Applied Sciences, 13(20), 11451. https://doi.org/10.3390/app132011451

Del Serrone, G., Peluso, P., & Moretti, L. (2022). Evaluation of microclimate benefits due to cool pavements and green infrastructures on urban heat islands. Atmosphere, 13(10), 1586. https://doi.org/10.3390/atmos13101586

Dardin, A., & Monteiro, L. (2024). Impact of extreme weather events on the thermal comfort of vulnerable populations in the city of Sao Paulo. Proceedings of the Comfort at the Extremes. https://doi.org/10.62744/cate.45273.1155-396-405

Ziter, C. D., Pedersen, E. J., Kucharik, C. J., & Turner, M. G. (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. Proceedings of the National Academy of Sciences, 116(15), 7575–7580. https://doi.org/10.1073/pnas.1817561116

Lee, S., Cho, Y., Lee, M., & Lim, Y. (2023). The evaluation of the temperature reduction effects of cool roofs and cool pavements as urban heatwave mitigation strategies. Applied Sciences, 13(20), 11451. https://doi.org/10.3390/app132011451

Trepci, E., Maghelal, P., & Azar, E. (2021). Urban built context as a passive cooling strategy for buildings in hot climate. Energy and Buildings, 231, 110606. https://doi.org/10.1016/j.enbuild.2020.110606

Semenzato, P., & Bortolini, L. (2023). Urban heat island mitigation and urban green spaces: Testing a model in the city of Padova (Italy). Land, 12(2), 476. https://doi.org/10.3390/land12020476

Han, D., Xu, X., Qiao, Z., Wang, F., Cai, H., An, H., Jia, K., Liu, Y., Sun, Z., Wang, S., & Han, W. (2023). The roles of surrounding 2D/3D landscapes in park cooling effect: Analysis from extreme hot and normal weather perspectives. Building and Environment, 231, 110053. https://doi.org/10.1016/j.buildenv.2023.110053

Cho, Y. D. J. M. (2021). Comparative analysis of the effects of heat island reduction techniques in urban heatwave areas using drones. koreascience.or.kr. https://doi.org/10.7780/kjrs.2021.37.6.3.7

Lu, H., Gaur, A., Krayenhoff, E. S., Jandaghian, Z., Lacasse, M., & Moore, T. (2023). Thermal effects of cool roofs and urban vegetation during extreme heat events in three Canadian regions. Sustainable Cities and Society, 99, 104925. https://doi.org/10.1016/j.scs.2023.104925

Setaih, K., Hamza, N., & Townshend, T. (2013). Assessment of outdoor thermal comfort in urban microclimate in hot arid areas. Building Simulation Conference Proceedings. https://doi.org/10.26868/25222708.2013.2521

Al-Shamkhee, D., Al-Aasam, A. B., Al-Waeli, A. H., Abusaibaa, G. Y., & Moria, H. (2022). Passive cooling techniques for ventilation: an updated review. Renewable Energy and Environmental Sustainability, 7, 23. https://doi.org/10.1051/rees/2022011

Lapisa, R., Bozonnet, E., Salagnac, P., & Abadie, M. (2018). Optimized design of low-rise commercial buildings under various climates – Energy performance and passive cooling strategies. Building and Environment, 132, 83–95. https://doi.org/10.1016/j.buildenv.2018.01.029

Siripurapui, M., & Maheshwari, P. (2024). The green side of passive cooling: building facades inspired by evapotranspiration in trees. Proceedings of the Comfort at the Extremes. https://doi.org/10.62744/cate.45273.1160-131-139

Wu, S., Sun, H., Duan, M., Lin, B., & Huang, Z. (2023). Energy performance of thermochromic smart windows in office buildings in different climate zones. Building Simulation Conference Proceedings. https://doi.org/10.26868/25222708.2023.1149

Soi, V., & Goswami, S. (2024). Integrated evaluation for energy and comfort quantification of windows in a residential apartment of Mumbai. Proceedings of the Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1178-462-471

Kader, A. (2024). Passive cooling strategies for a better comfort during weather extremes – Adapting the existing building stock in German cities to future climatic conditions. Proceedings of the Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1157-287-295

Sharmin, T., & Rahman, M. M. (2024). Optimising energy efficiency and thermal comfort measures for a low-income residential building in Ahmedabad, India. Proceedings of the Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1166-523-531

Yoo, S. (2022). Thermal behavior of passive intelligent radiant cooling systems. Processes, 10(12), 2666. https://doi.org/10.3390/pr10122666

Elnabawi, M. H., Saber, E., & Bande, L. (2024). Passive Building Energy saving: building envelope retrofitting measures to reduce cooling requirements for a residential building in an arid climate. Sustainability, 16(2), 626. https://doi.org/10.3390/su16020626

N, Y., & Amirtham, L. R. (2024). Assessment of the thermal performance of alternative wall and roof assembly in buildings: a case in Vijayawada. Proceedings of Comfort at the Extreme Conference. https://doi.org/10.62744/cate.45273.1161-221-237

Vorster, J., & Dobson, R. (2011). Sustainable cooling alternatives for buildings. Journal of Energy in Southern Africa, 22(4), 48–66. https://doi.org/10.17159/2413-3051/2011/v22i4a3229

Chen, J., Lu, L., Jia, L., & Gong, Q. (2023). Performance Evaluation of High-Rise Buildings Integrated with Colored Radiative Cooling Walls in a Hot and Humid Region. Sustainability, 15(16), 12607. https://doi.org/10.3390/su151612607

Mathew, D., O'Hegarty, R., & Kinnane, O. (2024). Historic windows with passive heat loss reduction strategies and their effect on indoor thermal comfort. Proceeding of the Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1146-514-522

Singh, A., Damle, R., & Bhesaniya, N. (2024). An experimental investigation on the impact of lime and cement mortar/plaster material on the indoor hygrothermal environment of test spaces. Proceedings of Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1148-211-220

De Souza, P., Vallejo, J., Gonçalves, J., & Schiano-Phan, R. (2024). The Future of Responsive Facade for Multi-Storey Residential Buildings in Tropical Climates. Proceedings of the Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1130-093-101

Baba, F., Ge, H., Wang, L., Zmeureanu, R., & Qi, D. (2023). Passive adaptation strategies to mitigate the overheating risk in an existing Canadian school. Building Simulation Conference Proceedings. https://doi.org/10.26868/25222708.2023.1653

Chen, J., Gong, Q., & Lu, L. (2023). Evaluation of passive envelope systems with radiative sky cooling and thermally insulated glazing materials for cooling. Journal of Cleaner Production, 398, 136607. https://doi.org/10.1016/j.jclepro.2023.136607

Köse, E., & Manioğlu, G. (2019). Evaluation of the Performance of a Building Envelope Constructed with Phase-Change Materials in Relation to Orientation in Different Climatic Regions. E3S Web of Conferences, 111, 04003. https://doi.org/10.1051/e3sconf/201911104003

Camagni, S., & Goncalves, J. (2024). Enhancing Contemporary Envelope Design for Hot and Arid Climates: Integrating Vernacular Strategies for Window-to-Wall Ratios and Shading Devices. Proceeding of Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1121-406-414

Al-Yasiri, Q., & Szabó, M. (2023). Hourly analysis of temperature and heat gain reduction for building envelope-compacted phase change material in extremely hot conditions. Journal of Energy Storage, 68, 107838. https://doi.org/10.1016/j.est.2023.107838

Ghosal, S., & Rawal, R. (2024). Impact of naturally ventilated residential units on heat stress. Proceeding of Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1117-075-083

Taleb, H. M. (2014). Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings. Frontiers of Architectural Research, 3(2), 154–165. https://doi.org/10.1016/j.foar.2014.01.002

Mushtaha, E., Salameh, T., Kharrufa, S., Mori, T., Aldawoud, A., Hamad, R., & Nemer, T. (2021). The impact of passive design strategies on cooling loads of buildings in temperate climate. Case Studies in Thermal Engineering, 28, 101588. https://doi.org/10.1016/j.csite.2021.101588

Lin, H. (2019). Improvement of human thermal comfort by optimizing the airflow induced by a ceiling fan. Sustainability, 11(12), 3370. https://doi.org/10.3390/su11123370

Kamar, H. M., Kamsah, N., Ghaleb, F., & Alhamid, M. I. (2019). Enhancement of thermal comfort in a large space building. Alexandria Engineering Journal, 58(1), 49–65. https://doi.org/10.1016/j.aej.2018.12.011

Güçlü, T., Cüce, P. M., Beşir, A. B., & Cüce, E. (2017). Thermoelectric coolers (TECs) for potential air-conditioning applications in buildings. SETSCI Conference Proceedings, 1, 256–262. https://www.set-science.com/index.php/manage/uploads/ISAS2018-Winter_0039/manage/uploads/HORA2019_0073/SETSCI_HORA2019_0073_0021.pdf?go=d1001a2417e2b87d5b7c53e16c5e1675&conf_id=1&paper_id=60

Marefati, M., & Mehrpooya, M. (2019). Introducing a hybrid photovoltaic solar, proton exchange membrane fuel cell and thermoelectric device system. Sustainable Energy Technologies and Assessments, 36, 100550. https://doi.org/10.1016/j.seta.2019.100550

Ulpiani, G., Nazarian, N., Zhang, F., & Pettit, C. J. (2021). Towards a living lab for enhanced thermal comfort and air quality: Analyses of standard occupancy, weather extremes, and COVID-19 pandemic. Frontiers in Environmental Science, 9. https://doi.org/10.3389/fenvs.2021.725974

Thomas, T., & Gedupudi, S. (2024). 3D CFD simulation of room air temperature and velocity with ceiling fan and exhaust fan and the resulting thermal comfort. Journal of Physics Conference Series, 2766(1), 012112. https://doi.org/10.1088/1742-6596/2766/1/012112

Jain, N., & Shorey, G. (2015). Achiveing Thermal Comfort by using Celing Fans in A Naturally Cooled Office Building in Hot and Humid Climate of India. Building Simulation Conference Proceedings. https://doi.org/10.26868/25222708.2015.3026

Jay, O., Hoelzl, R., Weets, J., Morris, N., English, T., Nybo, L., Niu, J., De Dear, R., & Capon, A. (2019). Fanning as an alternative to air conditioning – A sustainable solution for reducing indoor occupational heat stress. Energy and Buildings, 193, 92–98. https://doi.org/10.1016/j.enbuild.2019.03.037

Rugani, R., Pan, Y., Zhang, H., Huizenga, C., Arens, E., Fantozzi, F., & Picco, M. (2023). Dynamic simulation on the effectiveness of evaporative cooling and fan in reducing heat strain during a heatwave. Building Simulation Conference Proceedings. https://doi.org/10.26868/25222708.2023.1685

Qin, C., & Lu, W. (2021). Effects of ceiling exhaust location on thermal comfort and age of air in room under impinging jet supply scheme. Journal of Building Engineering, 35, 101966. https://doi.org/10.1016/j.jobe.2020.101966

Ruellan, M., Park, H., & Bennacer, R. (2016). Residential building energy demand and thermal comfort: Thermal dynamics of electrical appliances and their impact. Energy and Buildings, 130, 46–54. https://doi.org/10.1016/j.enbuild.2016.07.029

Jeong, S. Y., Tso, C. Y., Zouagui, M., Wong, Y. M., & Chao, C. Y. H. (2018). A numerical study of daytime passive radiative coolers for space cooling in buildings. Building Simulation, 11(5), 1011–1028. https://doi.org/10.1007/s12273-018-0474-4

Tadepalli, S., Jayasree, T., Visakha, V. L., & Chelliah, S. (2021). Influence of ceiling fan induced non-uniform thermal environment on thermal comfort and spatial adaptation in living room seat layout. Building and Environment, 205, 108232. https://doi.org/10.1016/j.buildenv.2021.108232

Albuja, R., Foliaco, B., Bula, A., & Gonzalez-Quiroga, A. (2022). Potential of hybrid radiant cooling with infrared-transparent membranes to improve thermal comfort in hot and humid climate. International Journal of Thermofluids, 16, 100214. https://doi.org/10.1016/j.ijft.2022.100214

Malik, A., Bongers, C., McBain, B., Rey-Lescure, O., De Dear, R., Capon, A., Lenzen, M., & Jay, O. (2022). The potential for indoor fans to change air conditioning use while maintaining human thermal comfort during hot weather: an analysis of energy demand and associated greenhouse gas emissions. The Lancet Planetary Health, 6(4), e301–e309. https://doi.org/10.1016/s2542-5196(22)00042-0

Vijayalaxmi, J. (2009). The Thermal Comfort of a Naturally Ventilated House resulting from the Evaporative Cooling of a Ceiling Fan in the Hot-Humid Climate of Chennai, India. International Journal of Ventilation, 8(2), 135–144. https://doi.org/10.1080/14733315.2006.11683839

Alizadeh, M., & Sadrameli, S. (2019). Indoor thermal comfort assessment using PCM based storage system integrated with ceiling fan ventilation: Experimental design and response surface approach. Energy and Buildings, 188–189, 297–313. https://doi.org/10.1016/j.enbuild.2019.02.020

Kamar, H. M., Kamsah, N., Ghaleb, F., & Alhamid, M. I. (2019b). Enhancement of thermal comfort in a large space building. Alexandria Engineering Journal, 58(1), 49–65. https://doi.org/10.1016/j.aej.2018.12.011

Knudsen, M., Rissetto, R., Carbonare, N., Wagner, A., & Schweiker, M. (2023). Comfort and economic viability of personal ceiling fans assisted by night ventilation in a renovated office building. Buildings, 13(3), 589. https://doi.org/10.3390/buildings13030589

Socci, L., Rey-Hernandez, J. M., Rocchetti, A., Dominguez-Muñoz, F., Rey-Hernandez, A., & Rey-Martínez, F. J. (2024). Use of Semi-Indirect Evaporative Cooling in HVAC systems: experimental study. Journal of Building Engineering, 95, 110158. https://doi.org/10.1016/j.jobe.2024.110158

Ketwong, W., Deethayat, T., & Kiatsiriroat, T. (2021). Performance enhancement of air conditioner in hot climate by condenser cooling with cool air generated by direct evaporative cooling. Case Studies in Thermal Engineering, 26, 101127. https://doi.org/10.1016/j.csite.2021.101127

Ho, S. H., Rosario, L., & Rahman, M. M. (2009). Thermal comfort enhancement by using a ceiling fan. Applied Thermal Engineering, 29(8–9), 1648–1656. https://doi.org/10.1016/j.applthermaleng.2008.07.015

Bhattacharyya, S., Amrith, S., Fennell, P., & Goyal, A. (2024). Onsite thermal energy storage for efficient and resilient air-conditioning in Indian buildings. Proceedings of the Comfort at the Extremes Conference. https://doi.org/10.62744/cate.45273.1191-151-160

Miller, D., Raftery, P., Nakajima, M., Salo, S., Graham, L. T., Peffer, T., Delgado, M., Zhang, H., Brager, G., Douglass-Jaimes, D., Paliaga, G., Cohn, S., Greene, M., & Brooks, A. (2021b). Cooling energy savings and occupant feedback in a two year retrofit evaluation of 99 automated ceiling fans staged with air conditioning. Energy and Buildings, 251, 111319. https://doi.org/10.1016/j.enbuild.2021.111319

Austin, M. C., Sánchez, D., & Bernal, A. (2023). Cooling Potential evaluation of a ground heat exchanger in a tropical climate: a case study of an office building. Journal of Physics Conference Series, 2648(1), 012091. https://doi.org/10.1088/1742-6596/2648/1/012091

Lim, J., Yoon, M. S., Al-Qahtani, T., & Nam, Y. (2019). Feasibility Study on Variable-Speed Air Conditioner under Hot Climate based on Real-Scale Experiment and Energy Simulation. Energies, 12(8), 1489. https://doi.org/10.3390/en12081489

Ilie, A., Dumitrescu, R., Girip, A., & Cublesan, V. (2017). Study on Technical and Economical Solutions for improving Air-conditioning Efficiency in building sector. Energy Procedia, 112, 537–544. https://doi.org/10.1016/j.egypro.2017.03.1113

Zeng, Z., Zhang, W., Sun, K., Wei, M., & Hong, T. (2022). Investigation of pre-cooling as a recommended measure to improve residential buildings' thermal resilience during heat waves. Building and Environment, 210, 108694. https://doi.org/10.1016/j.buildenv.2021.108694