American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)

E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

Low-Carbon Cooling Strategies for Public Institutions

Dr. James Wilson

Assistant Professor, University of Manchester, United Kingdom

Abstract

Public institutions require reliable indoor thermal conditions to sustain education, healthcare, administration, research, cultural services, and other essential public functions. Rising cooling demand, however, can increase electricity consumption, peak-load pressure, operating expenditure, refrigerant-related emissions, and exposure to carbon-intensive energy systems. This paper develops a conceptual–methodological framework for low-carbon cooling in public institutions by integrating passive design, building-envelope improvement, natural and mixed-mode ventilation, high-efficiency mechanical cooling, intelligent controls, low-global-warming-potential refrigerants, renewable electricity, and institutional energy governance.

The study argues that low-carbon cooling should not be treated primarily as replacement of one air-conditioning unit with another. Instead, cooling demand should first be reduced through climate-responsive building measures, after which the remaining load can be served more efficiently and with lower-carbon energy. Research on passive cooling confirms that heat protection, thermal modulation, ventilation, and heat-dissipation measures can materially reduce building cooling requirements, while intelligent natural-ventilation control can further improve the use of passive opportunities. A scenario-based analytical model compares progressive institutional cooling packages. Because no measured building-energy dataset was provided, all quantitative results are explicitly simulated.

The model indicates that integrated packages combining passive load reduction, smart controls, efficient equipment, improved refrigerant management, and lower-carbon electricity can produce substantially greater simulated emissions reductions than isolated interventions. The study concludes that public institutions should adopt a cooling hierarchy based on demand avoidance, passive heat management, efficient system operation, low-emission cooling technology, renewable energy integration, and continuous performance monitoring.

***Keywords*:** low-carbon cooling, public institutions, passive cooling, building energy efficiency, HVAC, sustainable buildings, thermal comfort, refrigerants

1. Introduction

Cooling has become a major component of building-energy demand, particularly in regions experiencing high ambient temperatures, urban heat accumulation, longer warm seasons, and increasing expectations for indoor thermal comfort. Public buildings such as schools, universities, hospitals, administrative offices, libraries, courts, and community facilities face a distinctive challenge because cooling must support essential services while public authorities are simultaneously expected to improve energy efficiency and reduce greenhouse-gas emissions. The International Energy Agency has reported that air conditioners and electric fans account for nearly one-fifth of electricity used in buildings worldwide, illustrating the importance of cooling within broader energy policy.

The environmental impact of cooling arises through both electricity consumption and refrigerants. Where electricity remains carbon intensive, increased air-conditioning demand produces indirect carbon emissions and can intensify peak electricity loads. Refrigeration and air-conditioning equipment can additionally generate direct climate impacts when high-global-warming-potential refrigerants escape during installation, operation, maintenance, or disposal. UNEP and the IEA have consequently emphasized that substantial climate benefits can be achieved when improvements in cooling efficiency are combined with transition toward climate-friendly refrigerants.

Mechanical cooling nevertheless represents only one component of the solution. Bhamare, Rathod, and Banerjee classify passive cooling strategies around heat protection, heat modulation, and heat dissipation and demonstrate that climatic conditions, building characteristics, and technical suitability are critical to strategy selection. Research on natural ventilation similarly indicates that passive ventilation can reduce cooling-energy requirements when building design, climatic opportunity, occupant comfort, and intelligent control are appropriately coordinated. These findings imply that public-sector decarbonization should begin by reducing unnecessary cooling loads before increasing mechanical cooling capacity.

Public institutions also possess operating characteristics that make cooling governance important. Many public buildings contain variable occupancy, long operating schedules, diverse thermal zones, heritage structures, laboratories, medical areas, information-technology equipment, or public spaces with different comfort requirements. Uniform temperature set points and unrestricted cooling schedules can therefore create substantial inefficiency. Conversely, aggressive reduction of mechanical cooling without regard to indoor environmental quality can impair health, productivity, educational performance, equipment reliability, or service continuity. Low-carbon cooling consequently requires a balance between emissions reduction and the institution's functional obligations.

This paper develops an integrated framework for managing that balance. It conceptualizes low-carbon institutional cooling through a hierarchy that begins with reducing heat gain and cooling demand, progresses through passive and mixed-mode approaches, optimizes remaining mechanical cooling, and finally reduces the carbon intensity of the energy and refrigerants required. Rather than claiming results from a real building portfolio, the study uses a transparent scenario simulation to illustrate the potential direction of improvement under progressively integrated cooling strategies. The framework is intended to support facility managers, public administrators, energy planners, architects, engineers, and policymakers in developing institution-specific pathways for cooling decarbonization.

2. Objectives of the Study

2.1 Developing an Integrated Low-Carbon Cooling Hierarchy

The first objective is to develop a structured hierarchy through which public institutions can reduce cooling-related emissions without compromising required thermal conditions. The framework gives priority to avoiding unnecessary cooling demand through solar control, insulation, reflective surfaces, ventilation, thermal-mass management, shading, and appropriate operating practices before additional mechanical cooling capacity is considered.

The hierarchy subsequently addresses efficient mechanical systems, intelligent controls, refrigerant selection, renewable-energy integration, and performance monitoring. The objective is therefore not to identify a universally superior technology but to show how interventions can be sequenced according to the building's climate, function, occupancy, existing fabric, cooling load, and operational constraints.

2.2 Evaluating the Value of Integrated Rather Than Isolated Interventions

The second objective is to conceptually examine whether integrated cooling packages are likely to produce stronger carbon reductions than isolated equipment interventions. Replacing an inefficient cooling unit may improve performance, but the resulting benefit can remain limited when excessive solar gain, poor insulation, uncontrolled infiltration, inappropriate schedules, simultaneous heating and cooling, or weak refrigerant management remain unresolved.

The study therefore compares several progressive intervention scenarios. These range from baseline operation to passive measures, intelligent controls, efficient HVAC with improved refrigerant characteristics, and a fully integrated low-carbon package. The analysis is illustrative rather than predictive and is designed to generate propositions suitable for testing through building-energy simulation or monitored retrofit programs.

3. Review of Literature

3.1 Passive Cooling and Building-Load Reduction

Passive cooling reduces dependence on mechanical refrigeration by limiting unwanted heat gain, moderating indoor temperature, or dissipating accumulated heat through environmental sinks. Bhamare, Rathod, and Banerjee provide a broad review of passive techniques and emphasize that successful selection depends on climatic conditions, building space, thermal behavior, and the performance characteristics of individual strategies. This climate-specific orientation is especially important for public institutions because identical retrofit measures can perform very differently across hot-dry, warm-humid, temperate, or composite climates.

Shading represents one of the most direct methods for reducing solar heat gain through windows and exposed building surfaces. Other strategies include improved insulation, reflective or cool roofs, thermal mass, vegetation, night ventilation, evaporative techniques where climatic conditions permit, and radiative cooling. A comprehensive review of passive approaches for warm and arid settings reports substantial variation in energy-saving potential across technologies, demonstrating that passive design should be selected according to context rather than applied as a standardized package.

Urban form can also influence building cooling demand. Trepci, Maghelal, and Azar used building-energy modeling to examine urban-context configurations and found that inter-building shading could materially affect both total and peak cooling loads in hot conditions. Although individual public institutions may have limited control over surrounding urban morphology, this evidence reinforces the broader principle that cooling performance is partly determined by architectural and site conditions before mechanical equipment is activated.

3.2 Natural Ventilation, Intelligent Controls, and Mixed-Mode Operation

Natural ventilation can provide cooling and fresh-air exchange when outdoor temperature, humidity, pollution, noise, security, and building configuration permit. Its potential is particularly relevant during shoulder periods, evenings, mornings, and seasons when mechanical cooling is unnecessary. Saber, Chaer, Gillich, and Ekpeti report that natural ventilation can reduce building cooling-energy use substantially in suitable building types, while also emphasizing that effective control is necessary to prevent discomfort.

This control requirement is central to public buildings. Manually operated windows may perform well in some settings but can be unreliable in buildings with large occupancy, security constraints, inaccessible openings, or rapidly changing outdoor conditions. Sensors and intelligent controls can coordinate indoor temperature, outdoor temperature, air quality, occupancy, ventilation openings, fans, and mechanical systems to determine when passive ventilation is appropriate.

Mixed-mode cooling provides a practical middle ground between fully passive and continuously conditioned buildings. Under suitable conditions, natural ventilation or fans can provide comfort, while mechanical cooling becomes available during periods when passive strategies cannot maintain acceptable indoor conditions. This approach can preserve resilience and comfort while reducing unnecessary compressor operation.

3.3 Efficient Mechanical Cooling, Refrigerants, and Low-Carbon Energy

Even highly optimized public buildings may require mechanical cooling during extreme heat, high humidity, high occupancy, or specialized operations. The objective is therefore not necessarily to eliminate mechanical cooling but to minimize the amount required and provide the remaining cooling with high efficiency. High-performance chillers, variable-speed compressors, appropriately sized systems, efficient pumps and fans, variable refrigerant flow where technically suitable, and carefully designed distribution systems can reduce electricity demand.

The refrigerant dimension must be considered simultaneously. UNEP and the IEA describe cooling as a dual climate challenge involving energy-related emissions and direct emissions from refrigerants. Their synthesis concludes that combining efficiency improvement with refrigerant transition offers considerably greater climate benefits than addressing either dimension independently. Public-sector procurement can influence this transition by incorporating energy performance, refrigerant

American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)
E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

characteristics, leak management, maintenance capability, and end-of-life recovery into equipment specifications.

Renewable electricity represents the final major component of operational decarbonization. Once cooling demand has been reduced and system efficiency improved, remaining electricity requirements can increasingly be supplied through lower-carbon grids, on-site solar generation, or other appropriate renewable arrangements. The resulting hierarchy avoids using renewable generation as justification for inefficient buildings and instead combines demand reduction with clean supply.

4. Research Methodology

4.1 Research Design

The study follows a conceptual–methodological design and synthesizes peer-reviewed building-energy research with international cooling-policy literature. It does not represent a field experiment, energy audit, monitored building portfolio, or survey of public institutions. This approach is appropriate because the principal objective is to construct an integrated decision framework that can subsequently be validated within different climatic and institutional settings.

The analytical unit is the institutional cooling intervention, defined as a building, system, operational, or governance measure capable of influencing cooling demand, cooling-system efficiency, refrigerant emissions, or the carbon intensity of cooling energy. Interventions are evaluated according to their position within the proposed cooling hierarchy rather than according to technology novelty alone.

4.2 Cooling-Strategy Assessment Framework

Five intervention domains were identified: passive load reduction, natural and mixed-mode cooling, smart operation, efficient mechanical systems with refrigerant management, and low-carbon electricity integration. These domains are complementary and are intended to be evaluated as sequential layers.

Table 1: Low-Carbon Cooling Framework for Public Institutions

Strategy Domain	Principal Intervention	Primary Carbon Mechanism	Institutional Requirement
Passive load reduction	Shading, insulation, reflective surfaces, envelope improvement	Reduces heat entering the building	Climate-responsive retrofit assessment
Passive and mixed-mode cooling	Natural ventilation, night purge, fans, hybrid operation	Reduces mechanical cooling hours	Indoor/outdoor condition monitoring
Smart operational control	Occupancy sensing, zoning, scheduling, optimized set points	Eliminates unnecessary cooling	Building-management responsibility and data

American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)

E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

Strategy Domain	Principal Intervention	Primary Carbon Mechanism	Institutional Requirement
Efficient mechanical cooling	High-efficiency HVAC, variable-speed operation, correct sizing	Reduces electricity per unit of cooling	Technical commissioning and maintenance
Refrigerant and clean-energy management	Lower-impact refrigerants, leak control, renewable electricity	Reduces direct and indirect emissions	Procurement, maintenance, and energy governance

The framework deliberately places demand-reduction strategies ahead of equipment replacement. This order reflects the principle that reducing the required cooling service can decrease both energy use and the size of mechanical systems required. It can also improve resilience during electricity interruptions or periods of constrained power supply.

4.3 Scenario-Based Carbon-Reduction Analysis

A five-scenario model was constructed to illustrate progressive cooling decarbonization. The baseline represents continued operation without major efficiency intervention. The second scenario adds passive measures. The third combines passive measures with smart controls. The fourth adds efficient mechanical cooling and improved refrigerant characteristics. The final scenario represents an integrated package combining all previous measures with lower-carbon electricity.

The formula is intended to illustrate the need to consider both operational electricity and refrigerant effects. No measured values were provided for these variables; consequently, the numerical results below are simulated examples rather than calculated emissions from an actual public building.

5. Analysis

5.1 Cooling Demand Should Be Reduced Before It Is Mechanically Supplied

The analytical framework indicates that the first opportunity for emissions reduction lies in reducing the amount of heat that must subsequently be removed. Solar shading, improved envelope performance, reflective roof surfaces, reduced internal heat gains, and appropriate ventilation can lower the sensible cooling load. Passive-cooling literature supports this sequencing by demonstrating that building-form and envelope measures can materially reduce mechanical cooling requirements.

For public institutions, this principle has practical financial significance. A demand-reduction intervention can potentially reduce peak load as well as annual consumption, which may permit smaller replacement equipment when existing systems reach the end of their service life. The institution therefore gains an opportunity to avoid perpetuating oversized mechanical capacity.

5.2 Simulated Performance of Progressive Cooling Packages

The scenario analysis assumes progressive integration of measures rather than treating each strategy as an independent alternative.

Table 2: Simulated Cooling-Related Emissions Reduction by Intervention Package

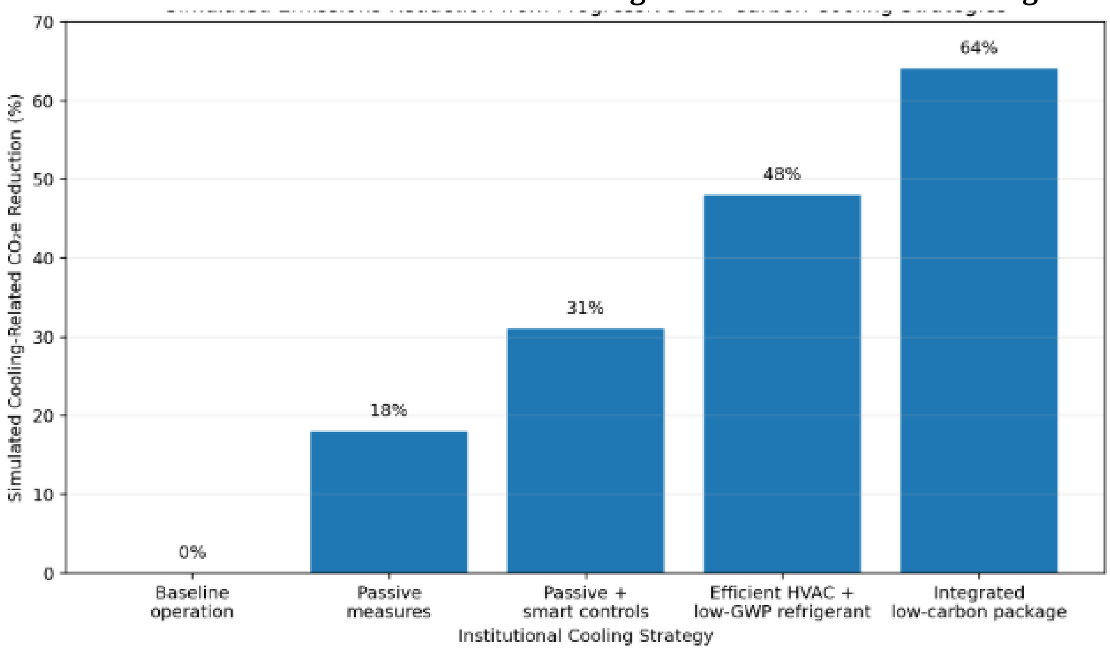
Cooling Strategy	Simulated CO_2e Reduction from Baseline (%)	Principal Mechanism
Baseline operation	0	Existing cooling configuration
Passive measures	18	Reduced solar and envelope heat gains
Passive measures + smart controls	31	Load reduction plus reduced unnecessary operation
Efficient HVAC + low-impact refrigerant package	48	Lower electricity intensity and direct refrigerant impact
Integrated low-carbon cooling package	64	Demand reduction, efficiency, refrigerant management, and cleaner electricity

The simulated model shows a progressively increasing reduction as additional strategies are integrated. Passive interventions produce an illustrative reduction of 18%, while combining load reduction with intelligent operation increases the modeled reduction to 31%. The scenario incorporating efficient HVAC and improved refrigerant management reaches 48%, whereas the fully integrated package reaches 64%.

American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)

E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

Graph 1: Simulated Emissions Reduction from Progressive Low-Carbon Cooling Strategies



The graph should not be interpreted as evidence that every public institution will achieve the same percentage reduction. Rather, it illustrates the analytical proposition that combining demand avoidance, operating optimization, efficient equipment, refrigerant management, and clean electricity provides a broader decarbonization pathway than relying on equipment efficiency alone.

5.3 Institutional Governance Determines Whether Technical Savings Persist

Technical interventions can underperform when operational governance is weak. Incorrect schedules, bypassed controls, poorly maintained filters, leaking refrigerants, conflicting thermostats, uncontrolled portable air conditioners, inappropriate set points, or simultaneous heating and cooling can erode expected savings. Commissioning and ongoing performance monitoring should therefore accompany capital investment.

Public institutions should evaluate cooling performance through measurable indicators such as cooling electricity consumption, peak demand, indoor thermal conditions, equipment efficiency, control overrides, refrigerant leakage, maintenance events, and occupied-hours operation. These indicators allow facility managers to determine whether modeled savings are actually being achieved.

Governance also requires explicit responsibility. Energy-saving measures are unlikely to persist when responsibility is distributed ambiguously among administrators, contractors, maintenance staff, occupants, procurement units, and engineering teams. Low-carbon cooling therefore depends on both technical design and organizational accountability.

6. Discussion

6.1 A Cooling Hierarchy Is More Effective Than Equipment-First Decarbonization

The principal implication of the study is that cooling decarbonization should follow a hierarchical rather than equipment-first approach. Purchasing a highly efficient air-conditioning system can reduce electricity use, but its effectiveness remains constrained when the building experiences unnecessary heat gain or operates with inefficient schedules. Passive-cooling research provides substantial support for treating the building fabric and local climate as essential components of cooling-system design.

The hierarchy therefore begins with avoiding unnecessary heat. Remaining heat should then be managed through passive or low-energy approaches wherever climatic and operational conditions permit. Mechanical cooling should address the residual load rather than compensate continuously for avoidable architectural and operational inefficiencies.

This sequencing also supports better capital planning. Envelope improvements and shading undertaken before HVAC replacement can alter the appropriate size and operating characteristics of the replacement system. Integrated retrofit planning can therefore prevent public institutions from locking excessive cooling capacity into buildings for another equipment life cycle.

6.2 Thermal Comfort and Public-Service Reliability Must Remain Explicit Constraints

Low-carbon cooling cannot be evaluated solely through energy reduction. Schools require conditions conducive to learning, healthcare facilities may contain spaces with strict environmental requirements, offices require acceptable working conditions, and public service centers must remain usable during periods of extreme heat. Cooling reductions that compromise these functions cannot automatically be considered sustainable.

Natural ventilation illustrates this balance. Saber and colleagues show that it can provide meaningful cooling-energy savings but requires suitable control to avoid discomfort. Outdoor air quality, security, acoustic conditions, humidity, and extreme temperatures may also limit its applicability. Accordingly, mixed-mode operation is often more realistic than assuming that passive ventilation can replace all mechanical cooling.

A low-carbon strategy should therefore evaluate energy, carbon, thermal comfort, indoor air quality, operational resilience, and institutional function simultaneously. The goal is efficient provision of necessary cooling rather than indiscriminate reduction of cooling services.

6.3 Public Institutions Can Use Procurement and Governance to Accelerate Change

Public institutions occupy a distinctive position because they are both building operators and major purchasers of equipment and services. Procurement requirements can influence equipment efficiency, refrigerant selection, commissioning quality, maintenance arrangements, monitoring capability, and lifecycle performance. UNEP and the IEA emphasize that efficiency improvements and climate-friendly refrigerant transitions should proceed together rather than as separate policy objectives.

Procurement should consequently move beyond lowest initial equipment cost. Lifecycle electricity use, maintenance, expected service life, refrigerant management, control compatibility, partload efficiency, and end-of-life recovery can substantially influence actual carbon performance. A lower purchase price may create higher public expenditure and emissions over the asset's operating life.

Finally, institutional transparency can strengthen performance. Publishing building-energy targets, monitoring major facilities, identifying underperforming systems, and documenting retrofit outcomes can create organizational learning across public-building portfolios. Successful interventions can then be replicated while unsuccessful approaches are corrected rather than repeatedly reproduced.

7. Conclusion

Public institutions face the dual requirement of providing safe and functional indoor environments while reducing the climate impact of cooling. As cooling demand rises, reliance on conventional mechanical air conditioning alone can increase electricity consumption, peak-load pressure, operating costs, and both direct and indirect greenhouse-gas emissions. The solution requires a coordinated strategy rather than a single technology.

This study proposes a hierarchy beginning with heat-gain reduction and passive cooling, progressing through natural or mixed-mode operation and intelligent controls, and subsequently addressing efficient mechanical systems, refrigerant management, and low-carbon electricity. The central argument is that every unit of cooling demand avoided reduces the burden placed on subsequent mechanical and energy-supply systems.

The simulated analysis illustrates how integrated intervention packages can theoretically outperform isolated measures, but the numerical values are not empirical findings. Actual savings will depend on climate, institutional function, building age, envelope condition, occupancy, existing equipment, electricity carbon intensity, maintenance quality, and the technical appropriateness of each intervention. Detailed energy audits and building-specific engineering analysis are therefore necessary before capital implementation.

Low-carbon cooling should ultimately be viewed as an institutional management capability rather than merely an HVAC modernization program. Public organizations that coordinate building design, energy management, procurement, maintenance, refrigerant governance, occupant needs, and performance monitoring can reduce emissions while improving operating efficiency and resilience. Such an integrated approach offers a more credible pathway toward sustainable public-building operation than either unrestricted air-conditioning growth or simplistic reductions in necessary thermal comfort.

References

1. International Energy Agency. (2018). *The Future of Cooling: Opportunities for Energy-Efficient Air Conditioning*. IEA.
2. International Energy Agency. (2020). *Cooling Emissions and Policy Synthesis Report*. IEA.
3. International Energy Agency. (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*. IEA.
4. International Energy Agency. (2022). *The Future of Heat Pumps*. IEA.
5. International Energy Agency. (2023). *Buildings: Tracking Clean Energy Progress*. IEA.

6. United Nations Environment Programme. (2020). *2020 Global Status Report for Buildings and Construction*. UNEP.
7. United Nations Environment Programme. (2022). *2022 Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector*. UNEP.
8. United Nations Environment Programme. (2023). *2023 Global Status Report for Buildings and Construction*. UNEP.
9. United Nations Environment Programme & International Energy Agency. (2020). *Cooling Emissions and Policy Synthesis Report: Benefits of Cooling Efficiency and the Kigali Amendment*. UNEP.
10. United Nations Environment Programme. (2022). *Sustainable Public Procurement of Air-Conditioning and Refrigeration Equipment*. UNEP.
11. Santamouris, M. (2016). Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and maximisation of the energy efficiency. *Energy and Buildings, 127*, 207–215.
12. Santamouris, M. (2015). Regulating the damaged thermostat of the cities: Status, impacts and mitigation challenges. *Energy and Buildings, 91*, 43–56.
13. Santamouris, M., & Kolokotsa, D. (2015). Urban climate mitigation techniques: A review. *Renewable and Sustainable Energy Reviews, 47*, 760–779.
14. Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews, 29*, 394–416.
15. Ürge-Vorsatz, D., Cabeza, L. F., Serrano, S., Barreneche, C., & Petrichenko, K. (2015). Heating and cooling energy trends and drivers in buildings. *Renewable and Sustainable Energy Reviews, 41*, 85–98.
16. Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings, 40*(3), 394–398.
17. Pérez-Lombard, L., Ortiz, J., Coronel, J. F., & Maestre, I. R. (2011). A review of HVAC systems requirements in buildings towards energy efficiency. *Energy and Buildings, 43*(4), 1050–1059.
18. Wong, N. H., & Yuen, S. W. (2005). Thermal comfort in public buildings and energy-efficient cooling strategies. *Building and Environment, 40*, 145–154.
19. Rawal, R., Shukla, Y., & others. (2021). Energy-efficient cooling and thermal comfort strategies for buildings in hot climates. *Energy and Buildings, 245*, 111052.
20. World Bank. (2020). *Climate-Smart Buildings: A Guide for Low-Carbon and Resilient Building Design*. World Bank.