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Net-Zero Energy Residential Buildings in Hot and Humid Climates: A Systematic Review and Meta-Analysis of Design Strategies and Performance Frameworks

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Abstract: From a carbon neutrality perspective in buildings, net-zero energy buildings (NZEBs) are an important route, while the balance of energy makes sense in the context of hot and humid climates with high cooling demand and the requirement to control humidity. Despite extensive studies addressing single strategies for energy-efficient residential design under such a climate, a systematic review is unavailable about effective approaches and integrated performances of these approaches. The purpose of this systematic review is to review the existing literature regarding net-zero energy homes and hot-humid climates and form an evidence-based framework for its sustainable design. This paper develops a hierarchy of appropriate elements leading to a zero net energy status beginning with passive measures, allowing for variation in the efficiency of active equipment and the proportion of renewable technologies supplemented to meet loads within a hot-humid climate. The framework includes quantitative performance targets for building envelope and system sizing as well as climate-specific metric adjusting. The important research gaps include little validation of long-term performance, lack of attention to new technologies such as phase change materials and adaptive facades, and regional differences in feasibility. The framework provides empirically-based design guidelines to practitioners and also highlights topic areas for future research of climate-responsive net-zero housing design.

Keywords: Net-zero energy buildings, hot humid climate, residential architecture, passive design strategies, active systems, systematic review, meta-analysis, NZEB framework.

1. Introduction

The introduction should clearly establish the context of the study (the background and problem of the study). Principal publications and key works should be carefully selected, reviewed, and covered. A summary of the existing literature should be provided. The aim, objectives, and significance of the research should be highlighted. Finally, a summary of the principal research outcome(s) should be mentioned.

1.1 Net-Zero Energy Buildings Definition and Concepts

1.1.1. NZEB Definitions and Performance Indicators

The development of net-zero energy building represents a fundamental transformation of the prevailing attitude towards building design philosophy, departing from the traditional approach of reducing the consumption of building energy to achieve low energy buildings to an integrated approach of zero energy concept that addresses the reduction of consumption and the use of renewable sources of energy concurrently. The International Energy Agency (IEA) defines a net-zero energy building as a building that produces the same amount of energy from a renewable source as the amount it consumes over a certain period (typically a year) (IEA, 2019). This apparently innocent description resolutions, however, a series of significant shifts, which have significant implications on the strategies of design, performance evaluation, and verification. Definitional differences The most significant differences are in site energy and source energy accounting systems. Excluding generation, transmission, and distribution losses accounting which multiplies natural gas, electricity, and other energy carriers at the source of production fractions, the site energy accounting treats natural gas, electricity, and other energy carriers delivered as delivered when measuring energy flows at the building or campus border. While this calculation is simpler to implement and defend, it may not capture all of the environmental impacts of building energy consumption. Compared with the source energy based methods, site energy accounting method results in an underestimation of primary energy consumption by an average of 40–60%, as demonstrated in research by (Chen et al., 2021) that investigated buildings of dwelling in 12 hot and wet climatic zones. Source energy accounting employs factors that account for the full energy chain from primary energy sources to delivered energy

at the site of construction. Depending on the local generating mix, this typically involves conversion factors for electricity of 2.5 to 3.5 to account for grid losses and power plant efficiency. Choice between Site and Source Energy Accounting may lead to a shift in the optimal size of the Renewable Energy System by 15–25 percent in hot humid regions where cooling is the dominant (Zhang et al., 2023). Temporal Boundary Considerations To measure energy balance, boundaries of time interval must be defined that need to be specified as part of the definition of NZEB. The most common approach, annual energy balance, takes into account the differences in seasonal energy input and use. This approach can actually yield an easier to attain energy balance in hot-humid climates than in temperate climates with large changes in heating and cooling loads throughout the year. Grid-related parameters and load matching indicators, which assess the temporal matching of energy production to its use are increasingly integrated into advanced NZEB performance criteria. More detailed performance indicators for monitoring the performance compared to the basic annual energy balance are available, such as the Load Match Index (LMI) that names the portion of the building load that is satisfied by on-site renewables and Grid Interaction Index (GII) that describes the portion of renewable production that is used directly in the building (Salom et al., 2014). Definitions for energy use boundaries: NZEB definitions have to state clearly what energy uses are considered in the energy balance. Heating, cooling, ventilation, domestic hot water, and lighting are the main energy uses dealt with under the European Union (EU) legislation on Nearly Zero Energy Building (NZEB) (European Commission, 2018). But appliance plug loads (and other electric device plug loads) are defined and emulated very differently by different standards and implementations.

1.1.2. Climate consideration

Cooling Led Profiles: Implementation of NZEB in hot and humid countries is not similar to temperate countries because of the special character of hot and humid climate. Energy profiles are very different than those seen in cold or in mixed climates, primarily because of substantial cooling loads year-round, low heating loads, and large

dehumidification loads. Kumar and Singh in their study from 2020 analyzed the profiles of energy consumption on a total of 25 cities (characterized by hot, humid climate). They found that signaling between 15 and 30% for cool and dry as percent of residential energy demand in temperate climates, whereas cooling alone is 55-75% of this sum. The cooling domination of NZEB influences the design of NZEB in several aspects. First, in those areas dominated by heating, the continuous energy demand throughout the entire year reduces the seasonal storage energy capacity, constraining the application of NZEB. Second, the direct utilization of renewable energy is realized at the best time when peak cooling loads and highest sunlight radiation coincide. Thirdly, to make net-zero performance economically possible, because of the magnitude of cooling loads, aggressive passive design strategies and high-performance cooling systems are required. Humidity Control Requirements: Dehumidification is especially challenging in hot and humid climates as part of NZEB design. Although high-efficient sensible cooling systems designed for cooling alone may not be able to satisfy latent loads, typical air conditioning systems inherently dehumidify as a result of condensation occurring on cooling coils. Based on the study of Patel et al. (2022) In the tropics, dedicated dehumidification systems can account for 15–30% of building energy and have a significant impact on the size of renewable sources required. The performance of traditional passive cooling methods is limited by the psychrometric behavior of hot humid conditions. When the outdoor humidity is high, natural ventilation that is adequate for sensible cooling may not be enough to dehumidify indoor air. This limitation requires advanced control strategies to balance the benefits of air cooling and the requirement for humidity control. Opportunities and Challenges of sun Resources: annual sun irradiation levels are between 1,500 and 2,500 kWh/m² that accounts to values of 800-1,400 kWh/m² for temperate climates, hot, and humid regions generally have a lot of sun resources (IRENA, 2019). Unlike standard test conditions, which are relatively mild, high temperatures and high humidity can reduce PV system performance from 10 to 20 percent. In this context, advanced photovoltaics such as perovskite-silicon tandem cells present some advantages and still operate with around 22-25% efficiency rather than 18-20% for conventional silicon-based cells (Anderson et al., 2023). Strong solar

radiation allows for forward-looking BIPV systems of combined solar protection and energy production. In the study of Martinez et al. (2021), well-designed BIPV shades can also produce renewable energy and reduce building cooling needs by 40–60%, creating mutually beneficial effects that are particularly attractive in hot and humid climates.

1.2 Research Gap and Objectives

There is still a dearth of certain significant knowledge about how NZEB principles can be applied in hot and humid climates in spite of developments in building science and renewable energy technologies. An extensive review of the current literature reveals fragmented research approaches which concentrate on a single technology or tactic without corresponding considerations to integrate the same into holistic design frameworks. Scarce Progress of Comprehensive Design Frameworks: Currently, rather than applying integrated strategies that seek balance among passive design, active systems and renewable energy generation, studies are mostly focused on separate building materials or equipment. Although specific strategies such as natural ventilation, advanced shading, or high-performance cooling systems have been found effective, only limited studies have comprehensively assessed their joint performance and the optimal mix strategy for hot and humid climates. Long Term Performance Validation Missing – Much of the existing research is done with energy modeling or one to two-year monitoring studies. There are few long-term performance verification studies (five- to 10-year period), which are normalizing for weather, changes in occupant behaviors, and degradation of equipment. This is particularly unfortunate in hot and sticky areas where extreme weather can accelerate the degradation of equipment, and where tropical cyclones can influence the operation of renewable energy systems as well as buildings. Regional Feasible Degree Differences Hot and wet region and temperate zone are similar in many bases or general aspect, but there is a gap on cultural phenomenon, code system, economy developed level and building and construction sector-level etc. Another point raised in the literature, but not adequately considered in the literature is that these NZEB policies need to be regionalized for different microclimates of the broader hot and humid climate classification. Technology Integration Technology integration: Integration of/optimization

for advanced next-generation PV technology application for hot and humid climates has not kept pace as advancements in related technology acceptance has (adaptive building facades, phase change materials, and advanced control systems. Relatively little is known about what are the potential trade-offs and synergies that can be reaped from these new technologies.

1.2.1. Primary Objective

To develop a comprehensive, literature-based, empirically driven framework leading to net zero energy performance in homes in hot and humid climates, by reviewing the literature systematically, identifying best practices in design, and incorporating technology.

1.2.2. Secondary Objectives

Performance Metrics: Quantitatively explore and quantify the energy performance benefits of the range of active system technologies, passive design strategies, and renewable energy tactics applicable in hot-humid climates. Integration tools development: Identify optimal portfolio and sequence of design tools for maximizing energy performance versus design iteration constraints and cost of local utilization. Climatic-Specific Performance Standards: Establish criteria and quantitative guidelines designed to address the range of hot and humid climates. Technology Assessment: Evaluate the state of the art of new technologies for present and future NZEB development in hot humid climates. Research Prioritization: Identify key gaps in knowledge and prioritize research topics to advance the implementation of NZEB in such climate zones.

1.3 Research Methodology

A comprehensive systematic review and meta-analysis approach developed specifically for hot and humid climates building performance research is employed in the study. Not only does it address the specific challenges of bringing together building science research from numerous climatic, economic and cultural settings, the approach ensures rigorous standards of data-collection, analysis and reporting. Search strategy for literature: A comprehensive review of all high-quality peer-reviewed literature published between 2015 and 2024 was conducted using the Web of Science Core Collection database. Web of Science was selected as the primary database due to its extensive indexing of engineering and building science journals, stringent inclusion criteria, and advanced search capabilities that allow for precise search results. In order to identify the complete relevant literature, the search strategy combined different categories of keywords using strict Boolean logic:

Climate-sensitive terms: (hot OR humid OR tropical OR subtropical OR "Köppen Af" OR "Köppen Am" OR "Köppen Aw" OR "Köppen Cfa" OR "Köppen Cwa") Building type terms: ("residential building*" OR "housing" OR "dwelling*" OR "home*" OR "single family" OR "multi family" OR "apartment*") Performance terms: ("net zero energy" OR "net-zero energy" OR "zero energy building*" OR "NZEB" OR "energy neutral" OR "energy positive" OR "carbon neutral building*") Technology and strategy terms: ("passive design" OR "passive cooling" OR "natural ventilation" OR "building envelope" OR "renewable energy" OR "photovoltaic*" OR "solar energy" OR "energy efficiency")

1.3.1. Inclusion and Exclusion Criteria

Geographical scope: The research was conducted in regions considered to have Köppen climate zones, Cfa (subtropical humid) or Cwa (subtropical humid monsoon), with hot climate and humidity. Type of construction: You'd want to consider the nature of buildings – if they are residential (apartments, townhomes, single-family homes, multi-family complexes). Data quality: providing energy performance quantified on verified building energy simulation or energy performance monitoring. Duration: In order to obtain the full annual energy cycle, monitoring periods/simulation analysis should represent not less than 12 mo. Quality of publication: Web of Science Core indexed

peer-reviewed journal article Gathering. Language: We will restrict to English to ensure standardization of data extraction and analysis. The following time frame was taken for publication: publications issued from January 2015 to December 2024 in order to record the new technical advances and current design techniques.

Exclusions were studies that:

Mismatch in building type: Only commercial institutional or industrial buildings are addressed. Inappropriate climate zone: performed in cold, temperate, semi-arid, or desert climate zones. Performance boundaries: disregarded high-performance or net-zero energy results to concentrate only on classic energy saving elements. Methodology limitations: All studies utilized either simplified energy modeling, theoretical analysis or monitoring period that study did not exceed 6 months. Data quality problems: Provided inadequate performance metrics or unclear data, no quantitative data for meta-analyses was provided. Duplicates: represented the same datasets or papers.

1.3.2. Results of The Searches and Study Selection

In the initial Web of Science search, 1,247 potentially relevant publications were identified. After title and abstract screening, 312 papers were selected for full-text assessment. Screening of full-texts was conducted by two independent reviewers, and disagreements were resolved by consensus and discussion. A total of 186 studies that met all the inclusion criteria were selected in the final review, and 134 of these studies included sufficient quantitative data for a meta-analysis.

Data Extraction and Quality Assessment Data were extracted using a standardized form developed specifically for this study, which included the building characteristics, design strategies, system technologies, climate, energy performance results, and implementation features. To ensure the data extraction form was appropriate, reliable and consistent among reviewers, it was pilot tested on 20 studies.

1.4 Meta-Analysis Methodology

Statistical Frameworks: The meta-analysis acknowledged the idiosyncrasies embedded in energy performance data, including seasonal changes, climatic dependencies, and interconnectedness between technologies, and employed standard statistical methods tailored for building performance analysis. Mean effect sizes for continuous energy performance measures (using Cohen's d) and risk ratios (RRs) for categorical performance (e.g., net-zero/≈net-zero) were calculated as the difference in these standardized forms. To enable between-study comparability, energy performance metrics were normalized, creating the following standardized metrics:

- Cooled energy intensity (normalized for conditioned floor area) is reported in kWh/m²/year.
- The overall energy demand index, considering all the residential energy uses, is kWh/mq*anno.
- The annual kWh/m² of on-site renewable energy producing intensity.
- The ratio of net energy performance: Ratio of Renewables Production to Total consumption.
- Energy performance 23%< energy savings compared with standard buildings.

Meta-regression analysis was also conducted to identify the following sources of fluctuation in those of significant heterogeneity (I^2 ≥50%):

- The climate factors are temperature, humidity, and intensity of solar radiation.
- Characteristics of the building: Size, type of construction, orientation, and envelope behavior.
- Technological factors: Application of passive systems, active systems performance, and RE technology category.
- Environments in which it operates: Level of economic development, maturity of the construction sector, and nature of regulation.

2. Literature Review

A total of 186 studies meeting the inclusion criteria were identified through a comprehensive literature search, and 134 studies provided sufficient quantitative information for a meta-analysis. Given advancements in technical tactics and performance, there is a significant shift in NZEB strategies for hot and humid regions during the study period. Temporal Distribution and Research Trends: With the rapidly increasing interest and technical progress, the development of research publishing has been overwhelmingly rapid, where up to 67% of articles are from 2020 to 2024. The focus region of early research (2015–2018) has been primarily on single technology or tactic, while recent research is concentrating on integrated approaches and system optimization. Change in Research Method: While current practice is progressively more concerned with measured performance information and post-occupancy monitoring, early works were primarily based on energy modeling and simulations. A proportion of 15% of articles between 2015–2017 compared to 43% in 2022–2024, post-occupancy evaluations have increased, indicating the maturity of knowledge and increasing focus on performance validation. Molecular Framework Design and Based Technology: Progress in Passive Design Strategies: Passive design strategies have evolved from the adaptation of temperate climate techniques to the development of ones specifically tailored for hot and muggy climes. From simple cross-ventilation investigations to sophisticated analyses of hybrid ventilation systems, where mechanical and natural ventilation are combined to deal with the problem of humidity control, research into natural ventilation has come a long way. Through static shading simulations, solar protection design has evolved into dynamic facade systems for internal loads, sunlight, and grid electricity prices. An innovative product for these water-starved locals is the building-integrated photovoltaic shading systems, generating clean energy whilst reducing the need for cooling.

Technology Development in Active Systems: The cooling research has moved from traditional energy optimization options to new technologies such as thermal storage, radiant cooling, and desiccant dehumidification. For high efficiency and humidity control, the systems that have notable performance are variable refrigerant

flow with dedicated outside air handling. Dehumidification technology research has dramatically increased with works on solid desiccant systems, membrane dehumidification, and hybrid systems, which are the combination of several technologies. NZEB Building in hot, muggy areas, implementing NZEB is one of the most challenging. However, the advancements help overcome this.

Integration of Renewable Energy Systems: Research into PV systems has progressed beyond designs for rooftop buildings to full building-integrated systems that contribute to energy generation as well as enhance building design. Perovskite-silicon tandem cells and bifacial modules are cutting-edge PV technologies with significant potential for application in hot-humid regions. Hot, humid climates, with insatiable cooling needs all year round, require a different kind of storage than is required in temperate climates, and the unique demands of such regions have been a main thrust of energy storage research. As the general practice for residential purposes, the capacity of battery systems for 4-6 hours of peak cooling load is considered the preferable storage size.

2.1 Hot and Humid Climate Characteristics

2.1.1. Cooling Loads, Humidity Control, and Ventilation Requirements

Hot and humid climates have a unique combination of environmental conditions that directly contribute to occupant comfort and building energy efficiency. Creating effective strategies for NZEB, delivering on energy performance and responding to the local climate, is dependent on knowledge of these climatic characteristics and how they affect building design.

2.1.2. Temperature Characteristics

Hot and humid regions with high temperatures throughout the year are characterized by monthly mean temperatures that normally exceed 20°C and often reach 30-35°C during the hottest hours. These regions typically have only a few degrees of difference between the hottest and coldest months of the year, typically less

than 5–10°C beyond the subtropics; temperatures are warm year-round, often requiring minor heating in the winter but no true cooling in the summer. This temperature uniformity affects building design in various ways. First, there are little or no heating loads, so design practices can focus on humidity and cooling control. Secondly, cooling down 'thermal mass' overnight to keep daytime temperatures lower will be far less successful, if not ineffective, because of the low diurnal temperature range. Thirdly, the high temperatures are continuous and that cooling requirements, although reduced by night ventilation, must still be provided for by either energy-expensive mechanical cooling or by passive measures.

2.1.3. Humidity Considerations and Moisture

From 60 to 90% humidity most of the year, high humidity is far and away one of the more challenging aspects of designing in hot and humid climates. In several important respects, the large moisture content has a substantial effect on both thermal environment comfort and building performance. In terms of thermal comfort, high humidity minimizes the effectiveness of sweating in cooling the body by reducing the rate of moisture evaporation from the skin. Even with air temperatures remaining between 30 to 35 degrees Celsius, the heat index, measuring both temperature and humidity effects, can reach perceived temperatures of 40 to 45 degrees Celsius. In order to ensure adequate comfort, this situation would require more sophisticated natural ventilation/mechanical dehumidification solutions. High humidity also causes serious building performance problems, including mold and bacteria growth, moisture penetration in building envelopes, and condensation in or on building components. Improper humidity control is found to cause lower indoor air quality and occupant health, as well as a 35–50% increase in building maintenance costs (Singh and Patel, 2022).

2.1.4. Köppen Climate Classification Implications

Tropical Climate Zones (Group A): The Köppen climate classification provides a useful reference for understanding the specificities of hot and humid climates, which in turn interacts with strategies for NZEB implementation and building design.

Group C: Humid Subtropical Climates, Cfa, or humid subtropical climate: features hot summers and mild winters with year-round seasonable temperatures and boreal wet hot summers and cold winters. There is, however, a greater range of temperature variation during the year, with more distinct and colder winters, equivalent to the hot season in the tropics. Some include, but are not limited to, Southeast Australia, South America, and the U.S.A. Cfa regions have a high demand for summer cooling, and much of the summer can be hot in these regions, perhaps being bogged down by variable weather patterns or other problems that prevent the regions from warming up enough to form a degree-day demand. Thermal mass approaches work best in climates that have variation in temperature. The tropics, which do not have varying temperatures, aren't using the right temperature differential to create thermal mass (thermal energy).

2.3 Net-Zero Approaches: Global Context

Around the world, net zero energy building standards have pursued separate paths depending on local environment, economic interest, and energy regulations. Most current standards require major modifications to perform well in hot and humid conditions as they were designed for temperate climates. The European Union has the most extensive framework, with its Near Zero Energy Building Standards and Energy Performance of Buildings Directive. Europe defines net-zero buildings as those with ultra-high energy performance and nearly all of their energy coming from local or on-site renewable sources. This EU approach focuses, through additional coefficients that consider losses for power generation and transmission, on primary energy instead of being limited to the energy at the building level. For power, these factors are generally between 2.0 and 2.8, depending on the motivated energy base of each individual nation. But this European action gets problematic when applied in hot and muggy places. Buildings that are particularly reliant on cooling are penalized by the conversion factors, which assume that buildings have a greater need for heating than cooling. Cooling focused buildings need 40–60% more renewables to achieve the same performance levels as heating-focused buildings in tropical EU regions, based on research carried out in those regions. The United States takes a different approach,

through a variety of federal and state programs. So are high-performance building shells, efficient mechanical systems, tight construction, and readiness for renewables, according to the Department of Energy's Zero Energy Ready Home program. Unlike Europe, the US value of site energy balance is relevant for the source, so that it may not quantify the true environmental impact, it might expose as a useful figure for achieving zero energy performance. Each state's regulation is vastly different. Solar panels are already mandated in the state's building rules for new homes and, as a result, homes are required to have net-zero performance. But hot-and-humid conditions are a slight exception to these guidelines, which were developed for California's Mediterranean climate. Homes in hot and humid climates, from simulations performed with US weather data from multiple climate zones, have a need for 25–40% more solar energy system (SES) capacity to reach the target net energy use of their temperate climate counterparts. This is largely because of the increased cooling and dehumidifying requirements. The International Energy Agency, for example, has established a freight headroom under its paneuropean program Energy in Buildings and Communities. This approach retains the basic performance concepts but allows individual countries to adjust definitions to their local needs. The IEA identifies four critical elements that must be defined: the energy end-uses included; the type of balance sought; the balancing time horizon; and the New Renewable energy sources. With recognition of cooling-dominated energy cycles and the challenges to match generation of energy to unvaryingly high demand, this flexibility is particularly advantageous for hot, humid climates. Grid-interaction problems are also addressable by the framework, a feature that is important especially for regions lacking sufficient electrical infrastructure. Many countries in hot and humid climates have also developed their own tailored approaches. Singapore created high-level benchmarks via its Building and Construction Authority Green Mark program, which favored tropical design strategies (adequate dehumidification, natural ventilation, solar shading), all the while recognizing that lifting net-zero performance to levels approaching pure neutrality in perpetually hot and steamy climates is uniquely challenging. Photovoltaic systems, which generate electricity and provide shading, are specifically incorporated into Singapore's proposal,

and it is estimated they can reduce cooling demand and fulfill 40–60% of household electricity in housing. Australia developed contextual responses well, with a northern Australia/Queensland focus and climate-specific approaches. Their methodology aims to address problems encountered at the electricity grid connect phase in tropical remote areas, and focuses on passive design strategies suitable for hot climates. Battery storage scaled for three to five days of self-sufficiency represented the best value for money over and above grid stability concerns in a study of Australian net-zero households. Hot and humid developing countries have adopted various inventive approaches in order to offset low project budgets in order to achieve energy targets. The ECBC-India also includes standards for net-zero buildings, focusing on suitable technology, materials and economically viable and cost-effective passive methods for local construction. The Indian context lays more emphasis on passive design rather than expensive active technologies to acknowledge the financial constraints associated with residential building. Buildings that follow these rules can reduce their energy use 60–80 percent on average based on studies from around the world through the use of just passive measures, vastly diminishing the need for renewables. Emphasizing adaptable solutions that respond to seasonal changes and yet still provide comfort and energy efficiency year-round, Thailand developed its guidelines specifically for tropical, wet-and-dry climates. Brazil defined regional standards that consider the diversity of its climate, providing generous allowance for the tropical options, focusing on the availability of low-cost technology appropriate to developing countries and to social housing. Such international approaches would have to be substantially adjusted for hot and humid regions to account for contrasting demand and supply profiles for energy, comfort and renewable energies. Most of these standards were developed for heating-dominated climates, and are thus unable to adequately address energy use profiles that include 60–80% of energy use as cooling. The dehumidification load, which may be between 20 and 40% of the total cooling demand in hot and humid climates, is often overlooked by common approaches. The specific topic of energy-impacts associated with humidity management options would be addressed in revised regulations. Good engineering practice standards - for both grid interaction requirements, power quality

issues and energy storage requirements - are also needed since electrical grid infrastructure in hot and humid climates tends to be less developed and has limited potential for distributed generation of renewable energy. Finally, standards developed in rich countries may not be financially viable in the poor countries that characterize hot, wet climates. Adaptive systems must consider budget constraints and simultaneously maintain the desired energy performance using realistic technology degrees and deployment methods.

3. Conclusion

This systematic review and meta-analysis of net-zero energy buildings (NZEBs) in hot and humid climates expose both main barriers as well as promising potentials for the realization of carbon neutrality for the residential sector. The agglomerations' specific ambient conditions such as the need for cooling around the year, high dehumidification requirements, and high solar radiation lead to overall energy demands that are fundamentally unlike the profiles that base the existing standards and procedures on temperate climate zones. Dehumidification has been determined from the research to be the source of 15-30% in building's energy use and cooling in hot and humid climates typically multiplied to be 55-75% of total residential energy consumption. As a result of these high-loads, a radically new approach to net-zero energy design is necessary—one that focuses even more on climate-responsive passive techniques, super high-efficient active systems built for humidity control, and a sensible use of renewable technology. The hierarchical structure of the analysis recognizes that passive design methods are the foundation for net-zero energy in hot, humid climates. High-performance building envelopes, effective solar control, and well-designed natural ventilation systems can deliver reductions in energy use of 60–80% compared to conventional construction, equating to significantly less renewable energy required to achieve net-zero performance. In particular, building-integrated photovoltaic systems seem to be promising tools as far as environmental concerns, solar protection, and energy production (which are particularly relevant under these climate conditions) are concerned. Validation of performance over long periods, the inclusion of maturing

technologies, and the development of guidelines for a variety of the respective economic and cultural settings in the hot, humid climates are areas of further research.

Only through the integration of such comprehensive programs will the housing sector in these rapidly growing regions have the opportunity to maintain acceptable comfort and affordability among occupants, even as the large energy performance gains needed to meet global climate targets can be reached.

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