Influence of Construction Materials on the Energy Efficiency of the Building Stock in Temperate and Tropical Climate

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Abstract

Global policy identifies the need to achieve climate neutrality, especially in the most energy-intensive sectors of the economy, as a key focus. Climate neutrality is closely linked to the reduction of energy demand and the use of materials and technologies with a low embedded carbon footprint. The economic sector with some of the highest energy intensity and CO2 emissions is construction. In the case of newly designed buildings, most countries have already implemented measures to reduce energy demand by introducing a near-zero energy building standard (nZEB standard). The problem is not only the new built but mostly existing building stock, which requires deep thermo-modernisation measures. These measures will reduce energy consumption in the building sector and thus reduce emissions of harmful gases into the atmosphere. In the article, the authors, using the example of two countries with different climates: Poland and Vietnam, they analysed in terms of embedded carbon footprint the available technologies dedicated to thermal modernisation measures. The countries were chosen for the analysis because of the differences in climate that determine the scope of thermomodernisation measures taken. In the case of Poland, it is a temperate climate, where buildings should be designed to reduce heat loss in the winter season and ensure thermal comfort in the summer season. In the case of Vietnam, it is a humid subtropical climate, where the emphasis should be on protecting buildings from overheating. The analyses presented here show both traditional and modern innovative technologies used in the thermal modernisation of existing buildings. The analyses carried out by the authors show how modern technologies affect the thermal insulation of building partitions and thus reduce energy consumption. The article also presents analyses of the technologies in terms of the embedded carbon footprint, which characterises the phases of material manufacture. The conclusions presented by the authors allow informed choices to be made when deciding which materials and technologies to use for deep thermo-modernisation measures in existing buildings, so as to reduce energy demand and minimise the embedded carbon footprint.

Keywords: *energy efficiency of the buildings, energy efficiency in different climate, traditional materials for sustainable architecture*

1. Introduction

The juxtaposition of contemporary materials used in architectural practices within varying climatic contexts presents a compelling arena for investigation, particularly in contrasting locales like Poland and Vietnam. This study aims to delve into the intricate interplay between historical/traditional materials and modern counterparts within the framework of climatic disparities. Both nations, with their rich cultural heritage and distinct climatic profiles, offer fertile ground for comparative analysis, shedding light on the nuanced relationship between materiality, climate, and architectural design.

In Poland, where temperate climates dominate, the utilization of materials is deeply rooted in historical precedents, reflecting a synthesis of tradition and innovation. Conversely, Vietnam's tropical climate necessitates materials and architectural strategies that navigate challenges posed by heat, humidity, and monsoonal patterns, thus showcasing a different facet of material adaptation.

This study explores the influence of construction materials on the energy efficiency of building stocks in temperate and tropical climates by drawing on interdisciplinary methods from architectural history, climatology, and urban planning. By analyzing the strengths and weaknesses of contemporary materials compared to historical and traditional counterparts, we seek to understand their impact on energy efficiency. Through site visits, stakeholder engagement, and scenario development, we aim to identify improvement pathways that reconcile modernity with heritage while enhancing climate resilience and sustainability. Our research contributes to the discourse on architectural sustainability, cultural conservation, and resilient urban futures, offering universally relevant insights.

1.1 The comparison of climatic conditions in Poland and Vietnam

Poland and Vietnam exhibit starkly contrasting climatic profiles, shaping not only the architectural landscape but also influencing lifestyle patterns and building orientation strategies.

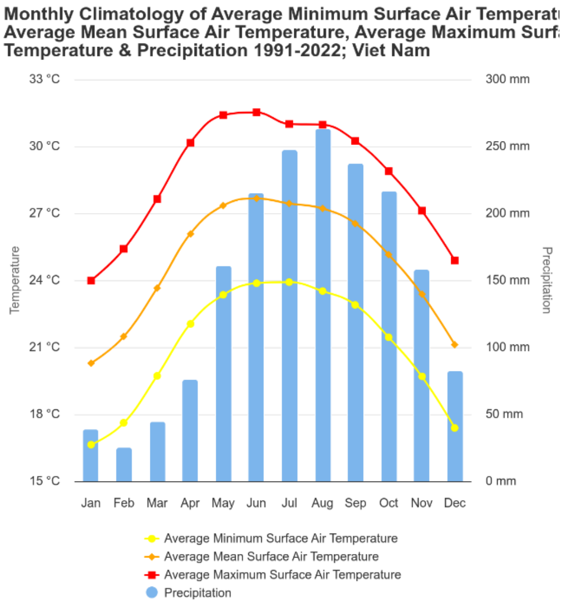

Fig 1. Climate chart Vietnam [1]

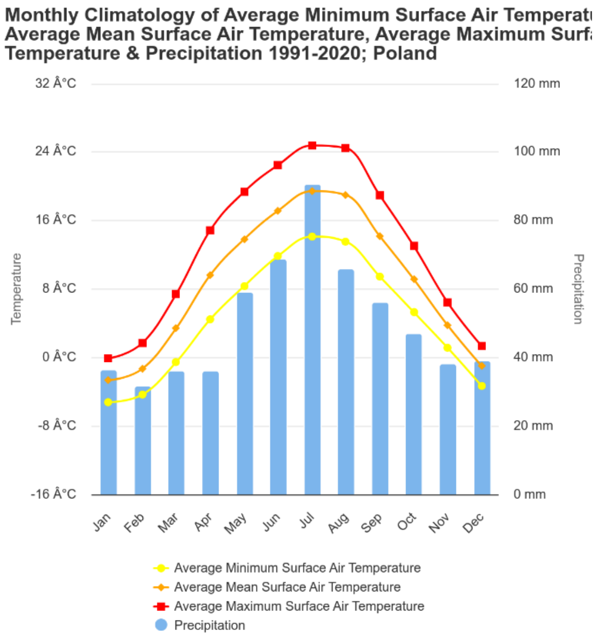

Fig 2. Climate chart Poland [2]

Poland has a temperate climate with both oceanic and continental influences. Winters are cold and snowy, especially in the eastern and northeastern regions, with temperatures often dropping below freezing. Summers are mild to warm, with average temperatures ranging from 18°C to 30°C (64°F to 86°F). Rainfall is moderate and well-distributed throughout the year, with the wettest months being June and July. The western part of Poland experiences more oceanic conditions, with milder winters and cooler summers, while the eastern part experiences more extreme temperatures. Poland also experiences occasional extreme weather, including thunderstorms and strong winds. (Fig. 1.)

Vietnam has a tropical monsoon climate with regional variations. The north experiences four distinct seasons, with hot, humid summers and cool, dry winters. The central region is often hit by typhoons and heavy rain from September to December. The south has a tropical climate, marked by a wet season from May to October and a dry season from November to April, with consistently warm temperatures year-round. The highlands and mountainous areas are cooler than the coastal and lowland regions. Overall, Vietnam experiences high humidity and significant rainfall, particularly during the monsoon season, contributing to its lush landscapes and diverse ecosystems.(Fig. 2.)

Poland has a temperate climate with cold winters and mild summers, leading to higher energy consumption for heating, especially from October to March. The need for heating is significant due to temperatures often dropping below freezing. In contrast, Vietnam’s tropical monsoon climate is hot and humid year-round, with the highest energy demand for cooling, particularly during the sweltering summer months. In the north, there is some heating demand during the cooler winter months, but overall, air conditioning is the primary energy consumer. Poland prioritizes insulation and heating systems, while Vietnam focuses on ventilation and cooling technologies to manage energy needs.

1.2 Building stock characteristics in Vietnam and Poland

Examining the building stock distribution by construction period in Vietnam and Poland highlights the unique renovation needs in each country, providing insights into climate-responsive strategies. In Vietnam, a significant portion of the building stock dates back to the French colonial period and the post-1975 era, necessitating upgrades to improve energy efficiency and climate resilience. Many older buildings require modernization to address issues such as poor insulation and inadequate ventilation. Meanwhile, Poland’s building stock includes many structures from the socialist era, characterized by standardized residential blocks of flats that often need renovations to meet contemporary standards. (fig.3) These blocks require updates to improve insulation, reduce energy consumption, and incorporate sustainable technologies. By understanding these historical contexts, Poland can draw lessons from Vietnam’s tropical architecture to inform renovation strategies, focusing on enhancing energy efficiency and climate adaptability while preserving historical value.

Poland has a higher percentage of older buildings from the pre-1950s era due to its long history and significant urban development before World War II. The country is rich in architectural heritage, with many historic buildings that survived the war or were meticulously reconstructed afterward. In contrast, Vietnam has fewer pre-1950s buildings, largely because of its colonial history and the devastating impacts of wars, which led to substantial destruction of its architectural heritage.

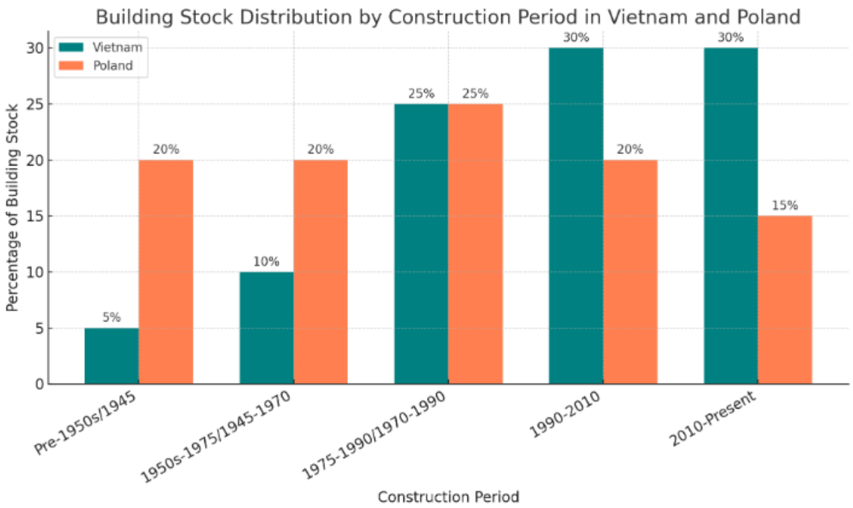

Fig 3. Building stock distribution by construction period in Vietnam and Poland [3,4,5,6,7] (source: P. Haupt)

From the 1950s to 1990, both Vietnam and Poland experienced significant construction driven by socialist influences and post-war rebuilding efforts. In Poland, this period was marked by extensive reconstruction after WWII, with an emphasis on socialist realism and functional architecture. Vietnam's focus during the 1975-1990 period was on post-war reconstruction, as the country worked to rebuild its infrastructure and housing after the Vietnam War, often using Soviet-influenced designs. The period from 1990 to 2010 saw increased construction in both countries due to economic reforms and transitions. Vietnam and Poland embraced modern architecture, expanding urban areas and reflecting globalization's impact on their architectural landscapes. This era marked the rise of modern high-rises and commercial developments. Since 2010, Vietnam has seen a high percentage of recent buildings, emphasizing contemporary and sustainable designs. Poland also focuses on modern, eco-friendly architecture, though it has a smaller proportion of new constructions due to its already established urban landscape and ongoing preservation of historical areas.

A significant portion of Vietnam's building stock is likely in need of renovation. Many buildings, especially those constructed before the 1990s, are outdated and may not meet current safety or efficiency standards. Rapid urbanization has led to a large number of older buildings in cities that were not designed for modern demands. Studies suggest that a substantial percentage of these buildings have poor energy performance and may not comply with updated seismic and fire safety standards. Estimates indicate that up to 50% or more of the building stock in urban areas could require significant upgrades.

In Poland, a substantial portion of the building stock is in need of renovation. About 30% to 40% of residential buildings are considered outdated and require significant upgrades to meet current standards for energy efficiency, safety, and comfort. Many of these buildings were constructed before modern regulations were established, leading to issues with insulation, heating, and structural integrity. Additionally, around 60% of public buildings, including schools and offices, are also in need of modernization to improve energy performance and ensure safety. The urgency for renovation is driven by the need to enhance energy efficiency, reduce carbon emissions, and comply with updated safety standards. Addressing these issues is crucial for improving the overall quality of housing and public infrastructure in Poland.

1.3 City quarter townhouses

During the French colonial period in Vietnam (1885-1945), the architectural landscape shifted with the introduction of European styles like Neoclassical, Art Nouveau, and Art Deco. The French introduced modern materials such as reinforced concrete, steel beams, and colorful tiles, which were used to create monumental buildings that symbolized colonial power. Despite their grandeur, these styles felt oppressive to locals but continue to influence contemporary Vietnamese architecture.(fig. 4)


Fig. 4. An Art Deco style building in Hanoi (source: Patrycja Haupt)


Fig. 5. XIX-th century housing, Karmelicka Street Kraków (source: Patrycja Haupt)

In Poland, the late 19th and early 20th centuries saw rapid industrialization leading to the development of townhouses in cities like Warsaw, Łódź, and Kraków. These multi-story buildings often featured ornate façades influenced by Art Nouveau and Neoclassicism. Designed to accommodate growing populations, they were dense and sometimes cramped, with shared facilities and limited amenities. Despite the challenges, these townhouses fostered community and cultural exchange, reflecting Poland's resilience and urban heritage. Both architectural traditions reflect their respective historical contexts and societal needs.(fig. 5)

1.4 Totalitarian regime in modern period architecture

In Vietnam, the post-unification period, especially from the 1990s onwards, marked a significant architectural evolution due to rapid economic growth and international engagement. The Doi Moi reforms and the end of the U.S. embargo facilitated an influx of global investment and modernization. This period saw a shift towards contemporary designs featuring high-rise buildings, mixed-use developments, and innovative use of materials. Modern Vietnamese architecture often integrates traditional elements with international styles, emphasizing functionality, aesthetics, and environmental sustainability. For example, the use of glass facades and sustainable materials reflects a blend of global influences and local heritage.

In contrast, Poland's socialist era from the 1970s left a legacy of standardized residential blocks, characterized by their repetitive facades and functional design. These structures, such as the Muranów district in Warsaw and Osiedle Słowackiego in Wrocław, Osiedle Widok in Kraków (T. Borejza, Wspaniałe osiedle Widok. Krzysztof Bień o wzorowym osiedlu PRL, https://krowoderska.pl/wspaniale-osiedle-widok/, (access: 22.07.2024)) were built using prefabricated concrete panels to provide affordable housing. While these blocks prioritized mass production and uniformity, they also included communal facilities to foster social cohesion. Today, Poland is reevaluating these structures, aiming to integrate modern amenities and sustainable design while preserving their historical significance.

Both countries' modern architectural landscapes reflect their historical influences-Vietnam's vibrant, globalized approach and Poland's transformation of utilitarian socialist blocks into contemporary urban spaces.

Fig. 6. Quang Trung Collective Building, Vinh City, is a typical example funded and built by the German Democratic Republic (source: https://www.americanacademy.de/ruination-and- reconstruction/)

Fig 7. Bronowice Nowe complex, Kraków, arch. K. Bień, 1974-75 (source: Patrycja Haupt)

2. Energy efficient Solutions deriving from building tradition

Vernacular architecture in Vietnam and Poland demonstrates adaptive responses to their distinct climates, utilizing traditional bio-based materials to create sustainable and culturally resonant structures. In Vietnam, architecture prioritizes passive cooling with features like open courtyards and raised floors to mitigate tropical heat and humidity. Meanwhile, Polish architecture focuses on insulation, using thick walls and steep-pitched roofs to withstand harsh winters. These approaches provide valuable insights for developing climate-responsive and sustainable building practices today.

2.1 Vernacular architecture in Vietnam and Poland as response to the climate

These climatic nuances profoundly influence lifestyle patterns, with Polish dwellers seeking warmth and coziness indoors during long winters, while Vietnamese communities embrace outdoor living and communal spaces to mitigate tropical heat. Understanding these climatic differences is imperative for architects and urban planners, informing design decisions that prioritize comfort, sustainability, and cultural appropriateness.

Vietnam is a country with a diverse terrain and climate. It is located in the hot and humid tropical monsoon climate zone and has seven different climate zones. The terrain is mostly mountainous, covering three-quarters of the country, while the coastline is over 3,000 km long. As a result, the climate ranges from temperate in the northern mountainous region to tropical, hot and humid in the central region, and hot and dry in the south. There are also seven cultural regions in Vietnam (from mountainous cultural regions in the North to the coastal cultural regions as well as the unique Central Highlands cultural regions), each with its own unique architectural culture.

Traditional architecture in Vietnam is designed to withstand and adapt to the local climate. Buildings in the northern mountainous region are constructed to withstand the cold and snow in the winter, with thick walls made of bricks and earth, small doors and windows, and multi-layer roofs for good insulation. In hot and humid areas, buildings are designed to provide ventilation and protection from the elements, with "openings" on the floor, walls, and roofs, corridors surrounding the house to create effective heat-insulating buffer zones, and large roofs to shield direct heat radiation and prevent rain from falling during heavy storms.

In Poland, characterized by a temperate climate with distinct seasonal variations, architectural responses traditionally prioritize thermal insulation to mitigate harsh winters. Thick masonry walls and pitched roofs are ubiquitous features, fostering coziness and warmth within interiors. Building orientation often maximizes solar gain during colder months while minimizing exposure to prevailing winds. The architectural vernacular reflects a synthesis of pragmatism and aesthetic sensibility, with steep-pitched roofs shedding snow efficiently and timber detailing adding rustic charm.

Conversely, Vietnam's tropical climate, typified by high temperatures, humidity, and heavy monsoonal rains, necessitates architectural strategies that prioritize passive cooling and ventilation. Traditional Vietnamese architecture often features raised floor levels, open courtyards, and louvered windows to encourage airflow and mitigate heat gain. Building orientation considers prevailing winds and solar angles to optimize natural ventilation and shading. The architectural aesthetic embraces lightness and flexibility, with bamboo and thatch commonly used for their thermal comfort properties and cultural significance.

2.2 Traditional bio-based materials

Materials play a crucial role in determining architectural form, spatial quality, and emotional impact on humans. They are the physical embodiment of design ideas, transforming them into tangible shapes that serve human needs. It is important to note that materials cannot be considered in isolation, as they are closely linked with design, structural solutions, and other key aspects of architecture.

Vietnamese architectural history is rich and diverse, with materials playing a pivotal role in shaping the country's distinct architectural styles during different periods. For thousands of years, from the Oc Eo and Dong Son civilizations to the Nguyen Dynasty, natural materials, such as unburnt bricks, bluestone, laterite, soil, bamboo, and wood, were used across the country to construct houses of the same details but varying in scale, including public buildings (palaces, communal houses, pagodas, temples) and residential homes. The most common type of house was a one-story structure (with or without a mezzanine) that stretched across the ground and featured a large sloping roof to protect from rain and sun while also preventing overturning during storms. (fig. 8,9)These houses were built using a column-beam frame system made of bamboo and wood, with later additions of brick walls. Covering materials were typically made of wooden or bamboo walls combined with plaster made from soil and straw, as well as brick and stone walls. The base material was mostly comprised of soil, but sturdy rocks were sometimes used in place of bamboo and wooden columns to bear weight and prevent moisture from soil damage.

In Poland, the vernacular architecture is deeply intertwined with the country's climatic conditions, with wood emerging as a primary material choice owing to its abundance, versatility, and insulative properties. (fig.10) Wooden architecture in Poland, particularly prevalent in rural areas and historic towns, reflects a harmonious blend of craftsmanship, cultural heritage, and environmental adaptation. One notable example is the Zakopane style, originating from the mountainous region of Podhale. Characterized by steeply pitched roofs, intricate wooden carvings, and ample use of timber, Zakopane architecture embodies a response to the harsh alpine climate, providing warmth, durability, and aesthetic charm. (fig. 11) Similarly, the Mazovian region boasts traditional wooden cottages with thatched roofs, featuring timber-framed structures enveloped in weather-resistant cladding. (fig. 12) These buildings, with their compact layouts and efficient use of space, exemplify a vernacular approach to architecture that prioritizes functionality and resilience in the face of fluctuating temperatures and precipitation. The use of wood in Polish vernacular architecture transcends mere materiality, embodying a cultural ethos rooted in sustainability, craftsmanship, and adaptability. As climate change poses new challenges, the lessons gleaned from centuries-old wooden architecture offer invaluable insights for contemporary designers seeking to create resilient, environmentally responsive built environments.

Fig.8. The communal house of Mong Phu village (source: Le Chien Thang)

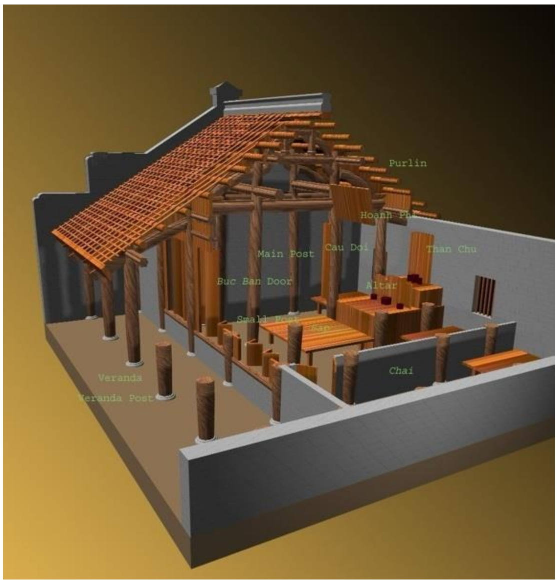

Fig 9. The image simulates the structure of a traditional house (source: Le Chien Thang)

Fig.10. The house of Pomerania (source: Patrycja Haupt)

Fig.11. The house of Podhale (source: Patrycja

Fig.12. The house of Mazovia (source: Patrycja

2.3 Modern materials for renovation

The Trias Energetica, introduced in the late 1980s, outlines a three-step approach to sustainable building: reducing energy consumption by improving thermal performance, using renewable energy sources, and efficiently exploiting non-renewable energy when necessary [8]. In 2002, the Cradle to Cradle (C2C) concept emerged, focusing on closing material cycles and using waste as a resource for new life cycles [9]. Building on C2C, proposed a strategy with three main steps: reducing energy demand (passive or bioclimatic design), recycling waste flows internally and externally, and supplying sustainable energy while treating waste as a resource [10,11]. In Vietnam, the National Technical Regulation on Energy Efficiency Buildings (NTREEB) mandates technical standards for energy efficiency in new and retrofitted buildings, covering areas like building envelopes, ventilation, air-conditioning, and lighting, aligning with both Trias Energetica and C2C principles (MOC, 2013) [12, 13]. Modern materials for renovation increasingly address comfort and sustainability, aligning with principles of sustainable development goals. These materials are designed to be climate-adaptive, as highlighted by Loonen et al., emphasizing dynamic building shells that respond to environmental conditions, enhancing energy efficiency and occupant comfort [14]. Additionally, simulation tools discussed by Kisilewicz aid in optimizing solar architecture, ensuring that these materials not only reduce energy consumption but also minimize environmental impact throughout their lifecycle, supporting sustainable building practices [15,16]

Tab. 1. Comparison of state-of-the-art solutions used in renovation.

Building component	Material	Vietnam	Poland	Application
Thermal insulation	Insulating Concrete Forms (ICFs)	x		walls and foundations to improve thermal performance and reduce energy costs
	(PIR) foam extruded polystyrene	x	x	walls, roofs, and floors to enhance energy efficiency
	(XPS) reflective foil	x	x	walls, roofs, and floors to enhance energy efficiency in the hot and humid climate.
	Aerated Concrete (AAC)		x	walls and partitions to improve thermal performance and reduce construction weight.
Greenery solutions	Green roofs	x	x	layers of vegetation planted on building roofs, improve insulation, reduce heat island effect, and manage rainwater runoff.
	Living roofs		x	vegetation and sustainable materials, improving insulation, managing stormwater, and enhancing urban biodiversity
Glazing	Smart Glass and Low-E Windows	x		reduce heat transfer, improve energy efficiency and comfort
	Triple Glazing Windows		x	improved insulation
Recycled and Eco-friendly Materials	Recycled steel	x		promote sustainability and reduce the environmental
	Bamboo	x		footprint
	Low-impact concrete	x		
	Geopolymer materials		x	improve overall thermal efficiency and reduce energy consumption

In both Vietnam and Poland, modern construction materials are crucial for building renovation. Vietnam uses Insulating Concrete Forms (ICFs) for excellent thermal insulation, and high-performance materials like polyisocyanurate (PIR) foam and extruded polystyrene (XPS) to address its hot and humid climate. Green roof systems and smart glass with low-emissivity (Low-E) coatings further enhance energy efficiency and manage stormwater. Recycled and eco-friendly materials, such as bamboo and low-impact concrete, support sustainability [17,18,19]. The concept to maximize energy self-sufficiency of the housing stock in Central Europe is centered on leveraging renewable resources and enhancing efficiency improvements. This approach aligns with the Trias Energetica model by prioritizing energy reduction, renewable energy utilization, and the efficient use of remaining non-renewable resources [20,21,22]. In Poland, aerated concrete (AAC) is used for its lightweight and insulating properties, while triple glazing windows improve energy efficiency in colder climates. High-efficiency insulation materials, including mineral wool and polyurethane foam, meet stringent EU standards. Green roofs in Poland focus on urban biodiversity and energy efficiency, and thermal bridging solutions reduce heat loss. [23,24,25,26] Both countries use advanced materials suited to their climates, with Vietnam focusing on heat management and Poland adhering to rigorous energy regulations.

3. Conclusion

Vietnam is among the countries that have been seriously impacted by global climate change. The Vietnamese government has acknowledged this issue from an early stage and has taken measures to tackle it at both national and international levels. Vietnam has developed its Green Building Evaluation Criteria Systems with the help of government and non-governmental organizations. The most popular criteria sets in Vietnam include LEED, Edge, and Lotus. Additionally, the Vietnam Association of Architects has issued a green architectural design system, while the Vietnam Built Environment Association has issued a green building evaluation system.

In Vietnam, renovation methods predominantly focus on improving energy efficiency due to the country's rapid urban growth and high energy consumption. This involves installing better insulation, energy-efficient windows, and modern HVAC systems. Structural improvements are also critical, with many older buildings needing seismic retrofitting to address earthquake vulnerabilities. Facade upgrades are common to enhance aesthetics and performance, often using new materials for better thermal insulation. There is also a growing interest in green building practices, including the use of sustainable materials and renewable energy sources like solar panels.

In contrast, renovation in Poland emphasizes energy efficiency as well, but with a strong focus on compliance with EU regulations for energy performance. Historical preservation plays a significant role in Polish renovation methods, requiring careful restoration of original features while updating systems to meet modern standards. Facade renovations in Poland also aim to improve energy efficiency and aesthetics, but with a focus on maintaining historical integrity. Additionally, Polish renovations must adhere to stringent EU regulations, ensuring thorough assessments and certifications.

Comparatively, while both countries prioritize energy efficiency, Vietnam's renovation efforts are driven by rapid modernization needs, whereas Poland's methods are shaped by regulatory compliance and historical preservation. Vietnam emphasizes seismic safety due to natural disaster risks, whereas Poland integrates historical preservation with modern updates. Both countries are incorporating green building practices, but Poland's approach is more structured due to EU directives, while Vietnam’s green initiatives are still emerging.

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