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SUSTAINABLE COOLING PATHWAYS TOWARDS NET-ZERO BUILDINGS IN VIETNAM: EMPIRICAL DIAGNOSIS AND MULTI-SCENARIO ENERGY MODELLING

Senior Media & Communication Specialist[1]*, Environment and Ecology Institute Research Team[2]

[1]Department of Media & Strategic Communications, Sustainability Research Group

[2]Environment and Ecology Institute (EEI), Hanoi, Vietnam

ABSTRACT

Surging cooling demand across Vietnam's commercial building sector places severe stress on the national power grid, posing a major bottleneck to achieving the national Net-Zero target by 2050. This study presents a comprehensive multi-regional evaluation of energy performance, microclimate dynamics, and Indoor Air Quality (IAQ) across 15 representative commercial facilities (hotels, office buildings, and shopping malls) in Hanoi, Da Nang, and Ho Chi Minh City. Integrating empirical field measurements with dynamic building energy simulations via OpenStudio/EnergyPlus, we diagnose key architectural vulnerabilities — such as low envelope performance and indoor CO_2 accumulation — and evaluate targeted retrofitting interventions. Results indicate that combined intervention strategies (Envelope Retrofit + HVAC Upgrade + Rooftop Solar PV) can yield total building energy reductions of up to 42%. While rooftop Solar PV yields rapid payback periods (8–9 years), deep envelope insulation retrofits exhibit high upfront capital costs and extended payback periods (>50 years). We outline strategic policy and operational roadmaps for commercial decarbonization in tropical climates.

Keywords: Sustainable Cooling, Net-Zero Buildings, Building Energy Simulation, Indoor Air Quality, Dynamic Retrofitting, Vietnam Energy Transition.

1. INTRODUCTION

Rapid economic growth and accelerated urbanization in Vietnam have escalated modern indoor thermal expectations. Concurrently, climate change has heightened mean ambient temperatures and amplified extreme heat events nationwide. Consequently, space cooling has become the primary energy consumer in commercial infrastructure. According to the International Finance Corporation (IFC) and the Ministry of Construction, cooling accounts for 34% of office building electricity consumption in Hanoi, 41% in Da Nang, and 44% in Ho Chi Minh City.

However, artificial microclimate regulation creates critical trade-offs between energy security, occupant wellbeing, and carbon mitigation. Inadequately ventilated sealed environments frequently trigger Sick Building Syndrome (SBS), characterized by dangerous CO_2 accumulation and volatile organic compound (VOC) exposure. To honor its commitments under COP26 to reach Net-Zero emissions by 2050, Vietnam must transition its commercial building stock toward sustainable cooling models that harmonize high thermal efficiency with rigorous indoor environmental quality standards.

2. RESEARCH METHODOLOGY

This investigation applies a combined framework integrating real-time microclimatic measurement, architectural envelope auditing, and dynamic energy modelling.

2.1. Empirical Field Measurements

On-site diagnostics were executed across 15 commercial buildings in Hanoi (Northern humid subtropical), Da Nang (Central tropical monsoon), and Ho Chi Minh City (Southern tropical equatorial). Key monitored parameters encompassed dry-bulb temperature, relative humidity, air velocity, mean radiant temperature, particulate matter (PM2.5), carbon dioxide (CO_2), TVOCs, and airborne microbial counts. Equipment deployed included Testo 400

IAQ multimeters, SIBATA gravimetric samplers, and Lutron 2010SD weather stations positioned in accordance with TCVN 13521:2022 and draft TCVN 14214:2024 sampling protocols.

2.2. Building Energy Simulation & Evaluation Criteria

Dynamic thermal and energy simulations were performed using OpenStudio coupled with the EnergyPlus engine. Models were calibrated using site-specific Typical Meteorological Year (TMY) weather files and detailed asset operational schedules. Scenario-based interventions were categorized into Phase 1 (Passive Envelope Design), Phase 2 (HVAC Active Upgrades), Phase 3 (Onsite Solar PV Integration), and Phase 4 (Combined Packages). Financial feasibility was quantified using Cost-Benefit Analysis (CBA) incorporating localized tariff structures (Decision No. 1279/QĐ-BCT).

3. EMPIRICAL RESULTS AND DIAGNOSTIC ANALYSIS

3.1. Envelope Thermal Vulnerabilities and Microclimate

Field audits revealed that extensive unshaded glazing with high solar heat gain coefficients (SHGC) is the primary driver of excessive indoor heat gains. Glass interior surface temperatures frequently soared between 34°C and 45°C during peak hours, inducing severe localized radiant discomfort. Furthermore, indoor relative humidity levels across most surveyed assets regularly exceeded the 60–70% optimal comfort threshold mandated by TCVN 5687:2024, exposing operational failures in HVAC latent load management.

3.2. Indoor Air Quality (IAQ) Disconnects

While sealed high-performance envelopes effectively blocked outdoor fine particulate infiltration (maintaining indoor PM2.5 levels well below the 50 µg/m³ limit), they created severe ventilation deficits. Internal CO_2 concentrations in densely populated office spaces and high-occupancy hotel rooms routinely breached safety limits (1,000 ppm), peaking above 1,500–1,800 ppm at several of the surveyed office and hotel facilities. Existing HVAC configurations prioritize sensible cooling while neglecting essential outdoor fresh air ventilation rates.

4. SIMULATION INTERVENTIONS AND COST-BENEFIT ANALYSIS

Multi-scenario simulations confirm significant decarbonization and energy-reduction potential across building typologies when targeted retrofits are deployed. To protect the commercial confidentiality of participating assets, results below are summarized at the building-type level rather than by individual site.

Table 1. Summary of Simulation Performance & Financial Outcomes by Building Type

Building Type	Sites	Combined Energy Savings (Range)	Primary Efficiency Driver	Solar PV Payback (Yrs)	Combined Payback (Yrs)
Shopping Mall	1	~42%	HVAC Upgrade	~8.2	~13.7
Office / Commercial Tower	2	22% – 25%	HVAC Upgrade	8.0 – 8.5	>50 – >100
Hotel	2	15.5% – 20%	HVAC Upgrade	8.1 – 8.3	>50
Residential / Serviced Apartment	1	~8.5%	HVAC Upgrade	~8.8	>100
University / Institutional	1	~10%	Passive Design	~8.4	>50

Note: Figures are aggregated by building type across the surveyed portfolio. Individual site names, addresses, and baseline consumption values are withheld from this public communication.

The comparative analysis demonstrates that active HVAC modernizations yield the highest immediate energy reductions across nearly all building types. Onsite rooftop Solar PV represents the most commercially viable

intervention, consistently yielding high ROIs and rapid payback periods of 8 to 9 years regardless of building type. Conversely, deep envelope structural insulation retrofits require extreme upfront capital expenditure, resulting in simple payback periods exceeding 50 to 100 years in several cases. Commercial facilities with large, consistent baseloads — such as shopping malls — tend to serve as ideal anchor projects for combined retrofit packages, achieving combined payback periods under 15 years.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

Achieving Net-Zero commercial buildings in Vietnam requires a phased, integrated implementation model:

- **Phase 1 (Immediate Operational Optimization):** Re-engineer HVAC controls to enforce outdoor fresh air supply rates, mitigating elevated CO_2 risks without increasing peak sensible cooling capacity.
- **Phase 2 (Capital-Efficient Deployment):** Accelerate rooftop Solar PV installations and target high-COP HVAC equipment retrofits to capture rapid economic returns and immediate carbon abatement.
- **Phase 3 (Policy-Supported Deep Retrofits):** Establish concessional green financing mechanisms, carbon credit frameworks, and mandatory building energy codes (QCVN 09 update) to unlock capital-heavy envelope retrofits.