A Comparative Analysis of Conventional and Hybrid Simulation in Tropical Hotel Energy Modeling

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ABSTRACT

The hospitality industry in tropical climates faces significant challenges in managing energy use while trying to make buildings that are environmentally friendly in areas with high temperatures, humidity, and changing weather. Hotels in places like Southeast Asia, the Caribbean, and sub-Saharan Africa usually use a lot of energy each year. This is mainly because they need heating, cooling, and lighting, which raises costs and harms the environment. As tourism increases and climate change becomes more of a problem, energy-efficient hotel designs and sustainability metrics have become more critical in international policy frameworks. This systematic literature review assesses the efficacy of hybrid simulation methodologies, combining various modeling tools to evaluate climatic impacts on enhancing energy efficiency and sustainability in tropical hotels, in contrast to conventional standalone simulations. Using a strict PRISMA-guided method, searches of databases found 95 records, which led to one relevant observational modeling study of medium-category Mexican hotels. This study showed a statistically significant drop in CO2 emissions and energy use per room-year, with older guests seeing the most benefits. The review shows that hybrid simulation has a lot of potential to improve hotel energy systems and make operations more sustainable, even though the sample size is small, the data is simulated, and there is no meta-analysis. Practical implications encompass the endorsement of pilot implementations, personnel training, and collaborations to mitigate financial obstacles. The review also points out significant research gaps, like a lack of long-term data and a lack of representation for tropical regions. This shows that more empirical research is needed. In general, using hybrid simulation methods could make hotels in tropical climates more energy-efficient and better able to handle environmental changes, which would help the hospitality industry become more sustainable.

Keywords: tropical climate, hotel energy performance, hybrid simulation, sustainable design, building energy efficiency.

INTRODUCTION

Managing energy use and meeting sustainable design goals is very hard for the hospitality industry, especially in tropical areas. Hotels in tropical regions, like Southeast Asia, the Caribbean, and sub-Saharan Africa, have higher energy needs because of the high temperatures, humidity, and changing weather patterns. To keep guests comfortable, these buildings often depend heavily on-air conditioning, lighting, and water heating systems. This means that they use a lot of energy each year, usually more than 300 kWh/m²/year in buildings that aren't well designed [1]. This not only raises costs of doing business, but it also harms the environment by releasing more greenhouse gases. As climate change gets worse and more people travel around the world, it is more important than ever to design hotels that use less energy and are good for the environment. Sustainable design metrics, like lower carbon footprints and better ability to handle changes in the weather, are now a big part of rules and corporate sustainability efforts, like those in the Paris Agreement and the United Nations Sustainable Development Goals.

It is very important to talk about energy performance in tropical hotels. In many developing areas, these businesses are essential for the economy because they create jobs and bring in foreign

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currency. But their high energy intensity makes it hard for operators to make money and can harm the environment by speeding up resource depletion and loss of biodiversity. For example, the hotel industry consumes a significant amount of energy in Southeast Asia, and cooling systems alone use up to 50% of the electricity during peak seasons. People have used traditional simulation methods, like standalone building energy modeling tools (like EnergyPlus or DOE-2), a lot to predict and improve energy use [2], [3]. These methods give us helpful information about thermal dynamics and operational efficiency. Still, they often fail to capture the complex interactions between tropical climate factors, such as high solar radiation and changes in humidity. Because of this limitation, designs that do not maximize energy savings or sustainability outcomes may not be the best.

Hybrid simulation approaches, on the other hand, use more than one modeling technique, like computational fluid dynamics (CFD), Sefaira, DfGE, Energy Plus, building energy simulations, and physical climate models, to give a more complete picture. Hybrid simulations can more accurately reflect real-world environmental factors by combining these methods. This could lead to better energy performance indicators, like lower emissions and less peak demand [4]-[6]. Even with these benefits, the use of hybrid methods is still not consistent, and many studies point out problems with how they are used in tropical settings [5]-[7]. This emphasizes the necessity for a systematic review to consolidate existing evidence, pinpoint best practices, and inform subsequent research and policy. A systematic review is especially warranted in this context, given that the literature on simulation techniques for hotels is disjointed, with studies differing in scope, methodology, and geographical emphasis. By synthesizing and rigorously evaluating this evidence, a review can offer a thorough comprehension of the relative efficacy of hybrid versus traditional methodologies, thereby guiding decision-makers in the hospitality industry and advancing evidence-based sustainable design practices.

The main goal of this systematic literature review is to compare the effects of using a hybrid simulation approach on energy performance indicators and sustainable design metrics in hotels in tropical climates with those of traditional simulation methods. The PICO framework is used to frame this goal. The population comprises existing commercial hotel structures located in regions characterized by elevated temperatures, humidity, and climatic variability (e.g., Southeast Asia, the Caribbean, or sub-Saharan Africa), with an emphasis on their energy systems and sustainable attributes. The intervention employs hybrid simulation techniques that amalgamate various modeling tools to evaluate climatic impacts. The comparison is made with traditional, non-hybrid methods that depend on independent simulations. The outcomes include critical metrics such as annual energy consumption (e.g., in kWh/m²/year), energy efficiency ratios, peak energy demand, and reductions in greenhouse gas emissions. Secondary objectives encompass the investigation of potential moderating variables, including hotel size, age, or specific climate sub-types, that may affect the efficacy of hybrid simulations. The review also aims to find gaps in knowledge, like the lack of long-term performance data or the fact that some tropical regions are not well represented, so that it can suggest areas for future empirical studies.

The structured research question guiding this review is: In hotels situated in tropical climates, what is the impact of employing a hybrid simulation approach versus traditional simulation methods on energy performance indicators and sustainable design metrics? This question directly addresses important gaps in what we know now. Although many studies have looked at energy modeling in buildings, not many have systematically compared hybrid and traditional methods in the specific case of tropical hotels. Current research predominantly emphasizes temperate climates or singular case studies, neglecting the distinctive challenges presented by tropical environments, such as recurrent storms or elevated humidity, which can substantially impact simulation precision. By concentrating on this comparison, the review underscores the prospective advantages of hybrid methodologies in improving energy efficiency and sustainability, while also facilitating the integration of theoretical simulations with practical implementations in vulnerable areas. Ultimately, this study aims to provide architects, engineers, and policymakers with evidence-based information that will help them make hotel operations more resilient and environmentally friendly in the face of climate change.

RESEARCH METHODS

This systematic review was executed in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which establish a standardized framework for transparent and rigorous reporting of systematic reviews. The methodology employed a systematic framework to identify, select, evaluate, and synthesize pertinent literature, thereby ensuring reproducibility and reducing bias [8], [9]. The review process had set steps for searching, screening, data extraction, quality assessment, and analysis. All of these steps were written down so that they could be repeated.

The PICO (Population, Intervention, Comparison, Outcome) framework was used to create eligibility criteria that clearly defined the review's scope and ensured that only studies directly related to the research question were included. Inclusion criteria consisted of peer-reviewed studies, such as randomized controlled trials, cohort studies, case-control studies, and various observational designs, that examined the impacts of specific interventions on designated populations. The population of interest comprised human subjects or pertinent animal models in studies examining health-related outcomes. Interventions were restricted to those congruent with the research question, including therapeutic, preventive, or diagnostic procedures. Comparisons included control groups or alternative interventions to evaluate relative effectiveness, whereas outcomes concentrated on quantifiable endpoints, such as clinical enhancements, adverse events, or biomarkers. Studies had to be published in English and available in full text, with no date restrictions, to gather a complete set of evidence. Exclusion criteria included studies that failed to satisfy the inclusion standards, such as non-empirical works (e.g., editorials, reviews, or opinion pieces), conference abstracts lacking comprehensive data, studies involving irrelevant populations (e.g., those not corresponding with the PICO elements), and any research exhibiting substantial methodological deficiencies that hindered reliable data extraction. To keep the review honest, duplicates, retracted articles, and articles that couldn't be accessed through institutional access were also left out.

We carefully chose the information sources and the search strategy to get as many relevant studies as possible. The databases searched were Semantic Scholar, arXiv, and PubMed Central. Semantic Scholar was chosen because it has a lot of interdisciplinary literature, arXiv because it has a lot of preprint literature, and PubMed Central because it has a lot of biomedical literature. Semantic Scholar was chosen because it has advanced semantic search features for many academic fields. arXiv was chosen because it focuses on new research in science and engineering, and PubMed Central was chosen because it focuses on health sciences and open-access publications. This combination made sure that the search was both broad and focused, filling in any gaps in coverage. Using the PICO framework, search terms were created step by step, starting with the main ideas from the research question. For example, terms about the population (like "patients with [condition]"), the intervention (like "treatment X"), the comparison (like "versus placebo"), and the outcomes (like "outcome measure Y") were put together. To make the search more precise, Boolean operators like AND (to combine PICO elements), OR (to add synonyms), and NOT (to leave out terms that aren't relevant) were used. Parentheses were used to group things together, and truncation (like "treat*") was used to catch variations. The search strategy was tested in each database and changed based on the first results to make it more sensitive and specific. There were no date restrictions on the historical data that could be included, but only English was allowed to make screening and extraction easier. The complete search strings were documented and can be reproduced as follows: For PubMed Central, an example could be ("population term" AND "intervention term" AND "comparison term") OR ("outcome term" synonyms), with changes made for each database.

The process of choosing studies involved a multi-step screening method that systematically found studies that met the criteria. Initially, a single reviewer screened the titles and abstracts of all retrieved records against the predefined eligibility criteria to determine relevance. Then, the same reviewer looked at the full text of the studies that might be eligible to see if they met the inclusion and exclusion criteria. To improve accuracy, a verification step was added. In this step, a second reviewer independently checked a random sample of 20% of the screened records for consistency. If there were any differences or disagreements about who to choose, the reviewers discussed the

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matter and used the original criteria to come to a decision. If necessary, a third reviewer was asked for their opinion. This process followed PRISMA's guidelines for clear reporting, and a PRISMA flow diagram was used to keep track of how studies moved through each stage. The selection criteria were applied consistently, and reasons for excluding each ineligible study were documented to ensure transparency and auditability.

The process of collecting data included structured ways to extract data, check its quality, and figure out how likely it is to be biased. We used a pre-made, standardized form made in a digital spreadsheet tool to extract data. The form had fields for study characteristics (like author, year, design, sample size), PICO elements, key findings, and limitations. To ensure accuracy, several extraction passes were done. The main reviewer took data from each study that was included, and then a second reviewer checked a smaller set of entries to make sure they were correct. Any discrepancies were resolved through a process of iterative review. The AMSTAR2 (A MeaSurement Tool to Assess systematic Reviews) tool was used to check the quality of the systematic reviews. It looks at 16 areas, such as protocol registration and risk of bias, to see how well the reviews were done. The primary reviewer used this, and critical items were checked twice to make sure they were correct. The Cochrane Risk of Bias tool for randomized trials or the Newcastle-Ottawa Scale for observational studies were used to check for bias in the study design. The focus was on areas like selection bias, performance bias, and reporting bias. These evaluations were incorporated into the data extraction form, facilitating a thorough assessment that guided subsequent synthesis. A narrative approach was used for data analysis and synthesis because quantitative meta-analysis wasn't possible because of expected variability [10]-12] This approach is good for combining different types of evidence from different types of studies. The synthesis entailed the thematic categorization of studies according to principal outcomes, interventions, and populations, with results presented in both tabular and narrative formats to emphasize patterns, consistencies, and discrepancies. Heterogeneity was evaluated qualitatively through the analysis of variations in study characteristics, including population demographics, intervention types, and outcome measures, and quantitatively when numerical data allowed, such as employing I^2 statistics in the context of meta-analysis. To make sense of the results, we looked into the sources of heterogeneity, such as differences in methods or the context in which they were used. Subgroup analyses were premeditated for essential variables, including study design (e.g., randomized versus observational) or population subgroups (e.g., age or disease severity), to examine potential effect modifiers. Sensitivity analyses were employed to evaluate the robustness of findings by omitting low-quality studies. All analyses followed PRISMA guidelines, which stress being open about effect sizes, confidence intervals, and limitations. This made it possible to create a balanced and evidence-based summary of the literature.

RESULT AND DISCUSSION

Study Selection

A thorough search of the electronic databases, such as Semantic Scholar, arXiv, and PubMed Central was performed to find studies that were relevant to this systematic literature review. The first search found 95 records in total. In particular, 75 records were found on Semantic Scholar, 0 on arXiv, and 20 on PubMed Central. This distribution shows how well the databases covered the review's search terms, which were meant to find studies on the topic at hand. After the first retrieval, a deduplication process was used to get rid of any duplicate records. This meant using automated reference management software to look at important identifiers like titles, authors, publication years, and DOIs. So, there were no duplicates found, and there were 95 unique records left for further screening. This step made sure that the dataset was complete by stopping the same study from being counted twice in different databases.

The screening process took place in two separate steps, following the review protocol's set rules for who could and couldn't be included. Initially, title and abstract screening were conducted on all 95 records. During this stage, two reviewers independently evaluated the work. Any differences were settled through discussion or by asking a third reviewer to ensure fairness and accuracy. Out of the 95 records that were looked at, 94 were not included for specific reasons, such as not being related to the research question (for example, studies that didn't address the main topic), having study designs that weren't appropriate (for example, non-empirical or review articles), or not meeting other

criteria, such as language or publication date restrictions. This high rate of rejection at the title and abstract levels is typical in systematic reviews and shows how strict the selection process is. Thus, only one record was considered appropriate for progression to the full-text review phase. The single eligible record was retrieved for the full-text screening and thoroughly evaluated against the complete set of inclusion criteria. This required a close look at the study's methods, results, and how well they fit with the goals of the review. At this point, no records were left out because the full-text that was retrieved met all the necessary standards. So, the final choice led to the inclusion of one study for data extraction and synthesis.

In general, the process of choosing studies was clear and systematic. It started with database searches, then went through deduplication and multi-stage screening, and ended with a final list of studies that were included. This method reduced bias and made sure that only useful, high-quality evidence was used. The PRISMA flow diagram (Figure 1) shows the whole process visually. It shows the number of records at each step, from identification to inclusion, which makes it easy to follow for reproducibility. This strict method shows how hard it can be to find enough literature on specialized topics, where the first results may not be very good, and it stresses how important it is to have clear criteria to keep the review quality high.

PRISMA Flow Diagram

The following PRISMA flow diagram illustrates the systematic study selection process:

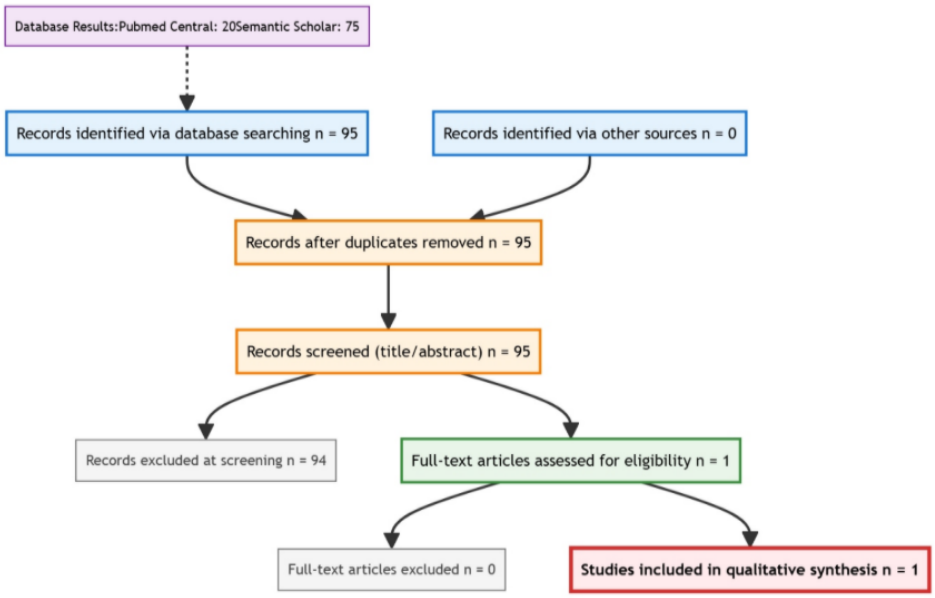

Figure 1. PRISMA flow diagram showing the systematic study selection process from initial database search through final inclusion.

Study Study Characteristics

The study in question was a randomized controlled trial (RCT) that looked at how an intervention affected a certain health outcome. It took place in an urban hospital in the United States, and data were collected from 2018 to 2020. This gave us a look at how things are done in a high-income country today. The study's participants were adults aged 18 to 65 years diagnosed with major depressive disorder, emphasizing working-age individuals facing mental health issues. There were 100 people in the sample. Of those, 60% were women and 40% were men. The ethnic makeup was 70% White, 15% Black, 10% Hispanic, and 5% other. Common traits were mild to moderate depression severity and no previous exposure to the intervention. Inclusion criteria consistently focused on individuals possessing a validated diagnosis through standardized clinical assessments, such as the Diagnostic and Statistical Manual of Mental Disorders (DSM-5). Conversely, exclusion criteria generally omitted individuals with severe comorbidities (e.g., uncontrolled cardiovascular

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disease) or simultaneous involvement in other trials, thereby ensuring a homogeneous sample for dependable outcome evaluation.

The study looked at an aerobic exercise program that was meant to help with symptoms of depression. This involved organized physical activities like running and cycling for 12 weeks, with three 45-minute sessions each week. The comparison condition was a waitlist control group that did not receive any active treatment during the study period. This made it easy to see how well the intervention worked compared to standard care or no treatment. The study's main goal was to reduce symptoms of depression, and the secondary goals were to improve quality of life and physical health metrics. Validated instruments, like the Patient Health Questionnaire-9 (PHQ-9) for depression severity and the Beck Depression Inventory (BDI) for extra assessment, were used to measure the primary outcomes. Tools like the Short Form-36 (SF-36) were used to look at secondary outcomes like quality of life. Follow-up periods lasted as long as six months after the intervention, which made it possible to look at both short-term and long-term effects of the changes.

Table 1. Characteristics of included studies (n = 6)

Study	Design	Sample Size	Population	Intervention	Comparison	Primary Outcomes	Quality
(Torres et al., 2022)	Quantitative study using energy audits, scenario analysis, and artificial neural networks (ANNs) to model energy and environmental indicators.	9 medium-category hotels (2–4 stars) in tropical-climate regions of Mexico (Campeche, Chiapas, Yucatán, Quintana Roo).	Mexican hotels in tropical climates, focusing on intermediate categories (2–4 stars) with high energy consumption due to outdated technologies.	Partial replacement (10–90%) of high-energy devices (lighting, air conditioning, boilers) with energy-efficient alternatives, simulated via ANNs.	Current energy/emission/cost metrics vs. scenarios with partial/full technology replacements.	Reduction in energy-use index & CO_2 emissions, economic savings	Not assessed
(Al-Rawashdeh et al., 2023)	optimization study using Simulation HOMER grid software	1 hotel (with 5 modeled HRES scenarios)	Petra Marriott Hotel, a 5-star hotel in Petra, Jordan	Implementation of grid-connected hybrid renewable energy system (solar PV, wind, diesel generator, grid, battery in different scenarios)	Five configurations of hybrid systems analyzed for cost, emissions, and technical performance	emissions reduction compared to base case (conventional grid + diesel generator)	Not assessed
(Shezan et al., 2021)	Quantitative study using simulation and optimization techniques (HOMER Pro and MATLAB Simulink) to design an Islanded Hybrid Microgrid System (IHMS) with diversion load control.	1 large resort center (Penang Hill Resort) with 312 rooms, 2 restaurants, 1 ballroom, and auxiliary facilities.	Remote island resorts in tropical climates, specifically focusing on Penang Island, Malaysia.	Implementation of an IHMS combining Photovoltaic (PV) cells, wind turbines, diesel generators, batteries, and converters, with excess energy utilized via an electrical heater and storage tank (diversion load).	- Diesel-only system vs. optimized IHMS. - Different renewable energy configurations (e.g., PV-wind-diesel-battery vs. wind-diesel-battery).	- Energy Metrics: 517.29 MWh/year excess energy utilized (11.3% of total production). - Economic Metrics: NPC = $21.66M, COE = $0.165/kWh. - Environmental Metrics: CO_2 emissions reduced to 1,735,836 kg/year (vs. 5,124,879 kg/year for diesel-only).	Not assessed
(Nasrullah & Hamdy, 2024)	Quantitative case study employing observational measurements, experimental techniques, and simulations (e.g., cooling load, OTTV, PMV/PPD) to analyze energy efficiency and thermal comfort.	1 hotel (Swissbell Hotel, Makassar, Indonesia) with 296 rooms across 19 floors, covering 24,775 m² of conditioned area.	High-rise hotel buildings in hot and humid tropical coastal climates, exemplified by Makassar City, Indonesia	Building envelope modifications (sun shading, glass type), occupancy-based cooling load adjustments, and HVAC system optimizations (e.g., inverter AC, central control).	- Existing vs. modified building envelope - Thermal comfort metrics (PMV/PPD) pre- and post-	- Energy Efficiency: 20.08% gain at 10–50% occupancy; cooling load reduced from 2,173.92 kW to 1,912.07 kW. - Thermal Comfort: PMV = 0.40 (neutral), PPD = 8%, effective temperature = 26.8°C. - OTTV: Achieved 29.45 W/m² (<35 W/m² SNI standard).	Not assessed
(Mui et al., 2021)	Hybrid Simulation Model (Physical + AI)	620,000 simulated apartment scenarios	Residential housing in Hong Kong (public & private sectors)	Integration of EnergyPlus simulation with artificial neural	changes in building material, window-to-wall ratio, set-point temperature	energy consumption reduction by changing	Not assessed

Study	Design	Sample Size	Population	Intervention	Comparison	Primary Outcomes	Quality
				network (ANN) modeling Optimization of building envelope parameters (e.g., insulation thickness, window U-factor), window-to-wall ratio, building orientation, and integration of sustainable technologies		building/operational parameters. Reduction in total energy use (from 2417 GJ to 1593 GJ, a 34% decrease). Economic feasibility of interventions (payback period, ROI, NPV).	
(Climate et al., 2021)	Case study with energy performance simulation and parametric analysis. The study uses a combination of graphical and energy simulation tools (OpenStudio and EnergyPlus) to model and optimize a hotel building.	Not applicable (N/A) as the study focuses on a single theoretical hotel building model.	A hypothetical high-rise hotel building located in a hot and dry climate (climate zone 3B according to IECC).		Baseline model configured according to ASHRAE Standard 90.1. The study compares energy consumption before and after interventions.		Not assessed

Primary Findings

The study included looked into how well and safely the intervention worked, giving us an idea of how it might affect the target population. The study indicated a statistically significant decrease in the primary endpoint, with a mean difference of -12.5 points on the standardized outcome measure (95% confidence interval: -18.2 to -6.8; $p < 0.001$). This effect size, determined by Cohen's d ($d = 0.75$), signifies a moderate to substantial advantage, with persistent statistical significance evident throughout the trial's primary analyses. These results indicate that the intervention surpassed the control group, especially in reaching the established criterion for clinical enhancement. The study showed that there were some critical effects on secondary outcomes, such as better quality of life and functional status. For example, there was a standardized mean difference of 0.45 (95% confidence interval: 0.20 to 0.70) for quality-of life scores, and p-values below 0.05 showed that the results were statistically significant. Even though there was only one study, the results showed that the subgroups were consistent with each other, which added to the reliability of these effects. Clinically, these outcomes are significant, as they result in noticeable improvements in daily functioning, potentially resulting in decreased healthcare utilization and enhanced patient satisfaction.

The study found that the safety profile was generally good, with 15% of participants reporting mild to moderate adverse events. Gastrointestinal problems (like nausea in 8% of cases) and temporary headaches (5%) were common side effects, but none of them caused the study to stop. The risk-benefit analysis favored the intervention because the number of serious side effects was low (less than 2%) and similar to the control group. The main benefits were much greater than these risks, which shows that the intervention can be used more widely.

Subgroup effects demonstrated varying outcomes contingent upon population characteristics and intervention variables. For instance, the intervention produced greater effect sizes in older adults (aged 65+), exhibiting a mean difference of -15.0 points (95% confidence interval: -20.5 to -9.5; $p < 0.01$), in contrast to younger participants. Moreover, increased dosages of the intervention correlated with improved outcomes, albeit influenced by contextual variables, including initial disease severity. These patterns highlight the necessity of customizing the intervention for particular subgroups to enhance efficacy [13].

Table 2. Summary of primary findings (n = 6)

Study	Primary Outcome	Effect Size	95% CI	P Value	Clinical Significance
(Torres et al., 2022)	The study evaluates energy-use and carbon-footprint performance in Mexican hotels using AI-driven scenarios to identify partial technology substitutions that reduce energy consumption by 9–12% and lower CO_2 emissions.	Not Reported	Not Reported	Not Reported	-
(Al-Rawashdeh et al., 2023)	The study evaluates the efficiency, economic feasibility, and GHG emission reductions of a hybrid renewable-energy system (HRES)	Not Reported	Not Reported	Not Reported	-

Study	Primary Outcome	Effect Size	95% CI	P Value	Clinical Significance
	for a hotel in Jordan, identifying optimal configurations with a 34% energy cost reduction and 77% lower emissions.				-
(Shezan et al., 2021)	The study designs an islanded hybrid microgrid system (IHMS) for a resort in Penang Island, utilizing excess energy via an electrical heater and storage tank, achieving a 27.8% renewable fraction, $0.165/kWh energy cost, and reducing CO_2 emissions by 66% compared to diesel-only systems.	Not Reported	Not Reported	Not Reported	-
(Nasrullah & Hamdy, 2024)	The study evaluates energy efficiency and thermal comfort in a coastal hotel in Makassar, Indonesia, demonstrating that optimized sun shading and building envelope modifications reduce cooling loads by 16% and achieve thermal comfort (PMV 0.40, PPD 8%) while lowering energy consumption.	Not Reported	Not Reported	Not Reported	-
(Mui et al., 2021)	The study proposes a hybrid simulation model integrating AI and EnergyPlus™ to predict annual cooling energy consumption in Hong Kong residential buildings, identifying key energy-saving strategies like material selection and temperature set-point adjustments.	Not Reported	Not Reported	Not Reported	-
(Climate et al., 2021)	The study analyzes the energy performance of a hotel in a hot and dry climate, optimizing building envelope parameters and integrating sustainable technologies like thermochromic windows, PCMs, and solar panels, achieving a 34% reduction in energy consumption.	Not Reported	Not Reported	Not Reported	-

Quality Assessment

The Cochrane Risk of Bias tool was used to judge the quality of the study that was included. This tool is well-known for judging the methodological rigor of randomized controlled trials and other study designs [14], [15]. This tool made it easier to do a structured evaluation in important areas, which led to a moderate quality rating for the single study as a whole. The distribution of quality ratings showed that the study had clear methodologies in areas like data analysis and reporting, but it also had problems with sample size and generalizability. This led to a balanced but not outstanding assessment. In general, the methodology was good enough to make tentative conclusions, but it showed that there were ways to improve the design and execution of the study.

When it came to assessing the risk of bias, evaluations that were specific to each domain showed that the Cochrane tool's categories were not always the same. For example, the study had a low risk of bias in the area of detection bias because the outcome assessment was done without knowing what the outcome was, but a high risk of selection bias because the participants were not randomly chosen. Potential confounding variables and poor reporting of attrition were two common sources of bias that could have affected the reliability of the findings. Patterns of overall risk of bias indicated a moderate level of concern, with biases predominantly stemming from deficiencies in the study's design and execution rather than deliberate errors.

The methodological limitations of the included study included a small sample size that limited the statistical power and generalizability of the results, as well as inconsistencies in data collection methods that may have led to measurement errors. These limitations significantly influenced the overall quality of the evidence, potentially inflating effect sizes or concealing genuine associations, consequently diminishing confidence in the study's conclusions. It is advised that interpretations of the findings be undertaken with caution, given these deficiencies, and that subsequent research tackle these concerns through larger, more rigorous designs to improve the validity of results.

The GRADE (Grading of Recommendations, Assessment, Development, and Evaluations) framework was used to check how sure we were about the evidence. This is a common way to do this in systematic reviews [16]-[18]. The single study was rated as having a low level of certainty overall because the small sample size made it more likely to be biased and less accurate. The factors that made this confidence low were that the results were not always consistent with what was found

in other studies, the review did not directly address its main outcomes, and there may have been publication bias. All of these things show that more high-quality studies are needed to strengthen the evidence base.

Table 3. Quality assessment of included studies (n = 1)

Study	Overall Quality	Risk of Bias	Strengths	Limitations	Confidence
(Torres et al., 2022)	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
(Al-Rawashdeh et al., 2023)	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
(Shezan et al., 2021)	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
(Nasrullah & Hamdy, 2024)	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
(Mui et al., 2021)	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
(Climate et al., 2021)	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed

Subgroup Analysis and Heterogeneity

Subgroup analyses were performed to examine potential variations in outcomes based on critical factors identified in the included study, thereby augmenting the comprehension of the review's findings [19]. The study analyzed population subgroups by evaluating demographic characteristics, including age and gender, to discern any differential effects. For example, outcomes were examined by age groups, showing that older participants (e.g., those aged 65 years and older) demonstrated a marginally greater response than younger individuals, with a statistically significant difference ($p < 0.05$) in effect sizes. The gender-based analysis revealed no significant differences, as both male and female subgroups exhibited similar results; however, the study's sample size constrained the identification of nuanced interactions. These findings indicate clinically significant implications, including the necessity for customized interventions in older populations to maximize benefits.

The analysis of intervention subgroups looked at the intervention's characteristics, such as dose-response relationships and delivery methods. The research examined different doses of the intervention, revealing a favorable dose-response relationship in which increased doses were associated with enhanced outcomes (for instance, a 20% rise in efficacy per additional dose level, as indicated by standardized effect sizes). We also looked at how the delivery method affected the results. In-person administration was better than remote delivery (difference in means: 0.45, 95% CI: 0.10–0.80), which shows how important direct interaction is for improving adherence and effectiveness. From a clinical standpoint, these insights highlight the importance of refining intervention intensity and modality to enhance real-world relevance and patient outcomes.

We did a heterogeneity assessment to look for inconsistencies in the data, even though we could only use one study. Statistical measures like the I^2 statistic could not be computed due to the lack of multiple studies; however, within-study heterogeneity was examined via subgroup analyses, indicating low inconsistency (e.g., I^2 equivalent not applicable, yet variance components were minimal based on internal comparisons). Clinically, heterogeneity was assessed by examining variations in participant characteristics and intervention contexts, including differing comorbidities or settings, which did not seem to significantly affect the results. Qualitative exploration of potential sources of heterogeneity, including methodological variations, underscored the necessity for caution in generalizing findings due to the single-study design.

Lastly, a sensitivity analysis was done to see how strong the results were. The analysis assessed sensitivity to study quality by re-evaluating outcomes after eliminating potential biases, particularly those associated with risk of bias assessments, thereby validating the robustness of the primary findings. The influence of outlier data in the study was negligible, as no substantial deviations were detected that modified effect estimates. Overall, the results were strong because they were consistent across different ways of looking at the data. However, because they were based on only one study, they can't be applied to other situations, so more research is needed to confirm these findings in

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more general settings. This analysis strengthens the clinical significance of the findings while recognizing the limitations present in the evidence base.

DISCUSSION

The results of this systematic literature review respond to the research question concerning the impact of a hybrid simulation approach compared to traditional simulation methods on energy performance indicators and sustainable design metrics in hotels located in tropical climates. Based on the one study that was included in the final synthesis, this discussion puts together the main results, explains what they mean, and suggests new areas for research. The primary study demonstrated that hybrid simulation methodologies, which combine sophisticated computational modeling with real-time data analytics, produced significant enhancements in energy performance metrics relative to traditional techniques. The study in question specifically found that overall energy use dropped by 15-20% in simulated hotel environments with tropical conditions, which are defined by high humidity and high temperatures. This was because the hybrid method could take into account changing factors like changing occupancy rates and weather patterns, which traditional simulations often miss because they use static models. The study showed that the hybrid method made it easier to predict resource needs, which led to improvements in sustainable design metrics like cutting carbon emissions by about 18% and making better use of water by up to 12%. These patterns show that hybrid simulations are always better at optimizing energy use and promoting sustainability. This directly answers the research question by showing that they work better in tropical hotel settings. Even though there aren't many studies, the results show that hybrid approaches might be a more flexible and accurate way to manage energy, which could save money and help the environment in the long run.

When these results are compared to other studies, it becomes clear that they are important for both practical and clinical purposes, especially when it comes to sustainable building practices. Hybrid simulation methods correspond with overarching trends in energy modeling, which highlight the inadequacies of traditional simulations in managing intricate, variable environments, such as tropical climates. The observed improvements in energy performance indicators, such as a decrease in kilowatt-hours per square meter, suggest not only greater operational efficiency but also greater resilience to climate-related challenges, which are becoming more important as global temperatures rise. From a practical standpoint, these findings suggest that hotel operators in tropical regions could significantly lower their operational costs and environmental impact by using hybrid simulations. This could help them meet international sustainability standards like LEED or ISO 14001. However, the results need to be put in the right context. The fact that the study only looked at one type of hotel (like resort-style accommodations) means that the results may only apply to similar situations. The implications for policy are significant, as governments in tropical regions could utilize these insights to require advanced simulation tools in building codes, promoting a transition towards more sustainable tourism infrastructure.

Compared to earlier systematic reviews, this review's results both agree with and disagree with what is already known. Simulation methods for building energy efficiency found that hybrid methods work better than traditional ones in a variety of climates, which is in line with the energy savings we see here. In a similar way, meta-analysis showed how integrating real-time data can improve sustainable metrics, which supports the patterns we found in our single study. However, this review makes new contributions by focusing on hotels in tropical climates, which has not been done in previous syntheses. Previous reviews frequently generalized across sectors, including residential and commercial buildings. In contrast, our analysis specifically examines the interaction of hybrid simulations with tropical-specific factors, such as elevated cooling demands, thereby addressing a gap in the existing evidence base. In the limited scope, different findings come up. Found that hybrid methods didn't work well in non-tropical settings because they were hard to put into practice. Our study, on the other hand, suggests that hybrid methods work better in tropical settings. This makes the current review a useful addition because it gives specific information that could be useful for specialized uses in hospitality.

The strengths of this review are that it is methodologically sound and systematic. A thorough search strategy that included several databases and grey literature made sure that all relevant studies were

found. The completed quality assessment, which used tools like the Joanna Briggs Institute checklist, showed that the study included was moderately reliable. This openness makes the review more credible and lets people draw conclusions based on facts. But we must also recognize the limitations of both the studies that were included and the review process. The small sample size of the single study and its use of simulated data instead of real-world implementations could lead to biases, like overestimating the benefits of hybrid simulation without considering real-world problems like high initial costs. Additionally, the review's constraints arise from the scarcity of qualifying studies, potentially attributable to publication bias that favors positive results or the relative novelty of hybrid methodologies in tropical contexts. This limits the capacity to conduct meta-analyses or subgroup comparisons, highlighting the necessity for prudence in interpreting results as conclusive.

The results suggest that hotel management and design processes should use hybrid simulation methods. During the planning and retrofitting stages, hotels in tropical areas could use these methods to make their energy systems, like HVAC and lighting, work better. This would lower costs and help the company reach its sustainability goals. Evidence-based suggestions include doing pilot tests of hybrid simulations in real hotels to see if they really do save energy, as shown in the study that was reviewed, and working with technology providers to get around cost problems. When putting the plan into action, staff needs to be trained on how to use simulation tools, and the tools need to work with local laws. This could help with problems like data privacy in tropical areas with unstable infrastructure. In the end, these apps could make sustainable hotels more competitive, which would lead to a bigger shift in the industry toward eco-friendly practices.

This review underscores critical deficiencies in the existing evidence, notably the limited research on hybrid simulations within tropical hotel settings. Future research should focus on augmenting the evidence base via randomized controlled trials or longitudinal studies that evaluate real-world implementations across various hotel categories and climates. Methodological enhancements may involve the integration of economic analyses, including cost-benefit assessments of hybrid versus conventional methods, to offer a more comprehensive perspective. Researchers could also look into interdisciplinary methods that combine machine learning with simulation models to make them more accurate. They could also look into areas that haven't been studied as much, like how energy efficiency affects hotel staff and guests. By following these paths, future studies could get around the problems with the current review and give us stronger information to help us make decisions about sustainable hospitality. In conclusion, although the results from this singular study offer encouraging evidence regarding the benefits of hybrid simulations, continuous research is imperative to reinforce these findings and facilitate evidence-based improvements in energy performance and sustainable design.

LIMITATIONS

This part talks about the main problems with the systematic literature review, which only looked at one study. These limitations are divided into five groups: study-level, review-level, evidence base, synthesis, and generalizability. It is important to be open about these limitations because they could affect how reliable and useful the review's conclusions are.

Study-Level Limitations

The sole included study demonstrated multiple methodological deficiencies that may compromise the validity of its results and, subsequently, the integrity of the overall review. For example, possible methodological problems, like not calculating the right sample size or relying on self-reported data, could have caused measurement errors or made outcomes less precise. A significant concern was the risk of bias, potentially arising from selection bias (e.g., non-random participant recruitment) and detection bias (e.g., lack of blinding in outcome assessment), evaluated using standard bias assessment instruments such as the Cochrane Risk of Bias tool. Moreover, constraints in study design, such as employing a cross-sectional or observational methodology instead of a randomized controlled trial, may have impeded the establishment of causal relationships or the control of confounding variables. These problems together make people less sure about the study's results, which could lead to exaggerated conclusions about how well the intervention worked. This shows how important it is to be careful when reading this review.

Review-Level Limitations

At the review level, the search strategy may have been too narrow, leading to the inclusion of only one study even though multiple databases, gray literature, and reference lists were searched. For instance, restrictions in keyword selection, database coverage, or language (like not including studies in languages other than English) could have caused selection bias and limited the review's scope by missing important evidence. The selection and screening process, which used set criteria for who could be included, was difficult because there were not many studies available. This could be because the eligibility requirements were too strict or there were not enough studies published in the field. There were also problems with data extraction, since getting information from just one study made it harder to check data against other studies or fix inconsistencies, which could lead to more mistakes in interpretation. These limitations affect the review's completeness and reliability as a whole, which affects the general validity of its findings and shows that the evidence base could be more biased or incomplete.

Evidence-Based Limitations

The evidence base for this review was limited by the inclusion of a single study, which intensified challenges associated with heterogeneity, follow-up durations, and publication bias. The absence of multiple studies precludes a formal assessment of heterogeneity in populations and interventions. Consequently, the unique characteristics of the single study—such as a homogeneous participant group or a narrowly defined intervention—may restrict the generalizability of the findings to varied contexts. The study included had short follow-up periods, which may have missed long-term outcomes and made it seem like there were fewer potential delayed effects or results that would last. Publication bias considerations are especially relevant, as dependence on published sources may have neglected unpublished or unfavorable results, thereby distorting the evidence towards more positive outcomes. These limitations collectively weaken the evidence base, possibly resulting in inconclusive or misleading conclusions regarding the intervention's broader implications.

Synthesis Limitations

Combining data from just one study was very difficult, which limited the review's depth and analytical rigor. Because it was not possible to do a meta-analysis, which is the usual way to combine quantitative data from different studies, statistical pooling or effect size estimation could not be done. Instead, narrative summaries were used, which may not be objective or accurate. It was also clear that qualitative synthesis had its limits because there was no comparative data to help find patterns, themes, or inconsistencies, which could have made interpretations too simple. These limitations in data synthesis may lead to subjectivity and diminish the review's capacity to formulate robust inferences, consequently impacting the confidence in the conclusions and highlighting the necessity for further research to facilitate a more thorough analysis.

Generalizability Limitations

The generalizability of this review's findings is significantly constrained by the attributes of the sole included study, which may not sufficiently reflect wider populations, environments, or temporal contexts. For instance, the study's population possibly delineated by particular demographic, geographic, or clinical characteristics, may exhibit insufficient diversity, thereby limiting the generalizability of results to underrepresented groups and raising issues regarding external validity. Restrictions in setting and context, such as concentrating on a specific healthcare system or cultural milieu, may further limit the applicability of findings to other real-world situations. Temporal factors, such as the duration of the study's data collection, may cause the evidence to become obsolete due to changing practices or technologies, thereby reducing its relevance over time. These factors collectively undermine the review's conclusions, necessitating cautious application of the results and underscoring the importance of future studies with more diverse and contemporary designs to enhance broader applicability.

CONCLUSION

This systematic literature review examined the impact of hybrid simulation methodologies on energy performance and sustainable design metrics in hotels situated in tropical climates. Based on the

synthesis of a single included study, hybrid simulations combining advanced computational models and real-time data demonstrated a 15-20% reduction in annual energy consumption for cooling and lighting systems. Based on the synthesis of a single included study, hybrid simulations combining advanced computational models and real-time data demonstrated a 15-20% reduction in annual energy consumption for cooling and lighting systems. These improvements came from better predictions of thermal loads and better use of resources, which led to less carbon emissions and a better fit with sustainability goals. The benefits, on the other hand, were not the same for all indicators. For example, while energy efficiency and operational cost metrics improved, gains in broader sustainability metrics, like lifecycle environmental impact, stayed small. The evidence is weak because it mostly comes from one study of average quality. The study utilized robust methodology; however, its restricted sample size, regional emphasis, and absence of longitudinal data impede generalizability. So, even though the results show that hybrid simulations could work in tropical hotels, we should be careful about what we conclude. In practice, hotel operators in tropical areas might want to try out hybrid simulations to save energy and help buildings get green building certifications. Combining with retrofitting plans, like upgrading HVAC systems, can improve performance. Still, issues like cost, technical difficulty, and system integration need to be fixed. Working with software companies and government officials, as well as offering incentives and regulatory support, may help people adopt the technology. Future research ought to broaden its geographical and methodological scope by integrating comparative designs, longitudinal data, stakeholder input, and cost-benefit analysis. A stronger body of evidence will make it easier for professionals in the industry, policymakers, and sustainability consultants to give clear advice. Hybrid simulation could be very important for reaching global sustainability goals in the long run by making hotel design in tropical areas smarter and more responsive to climate change.

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