Dialectics of Low Energy Design, Accessibility, and Materiality in Tropical Urban Crisis

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ABSTRACT

This research examines the development of tropical buildings that address the challenges of climate change and population growth by integrating accessibility for all and designing buildings that consume less energy. This research aims to assess the social and technical conflicts between accessibility and energy efficiency, and to develop an evaluation framework based on optimization algorithms that finds a balance between the two. Testing phase change materials (PCMs), energy modelling using Energy Plus, and critical policy analysis employing Critical Discourse Analysis (CDA) are all integral components of the mixed-methods approach. The primary result is that PCMs can help maintain more stable temperatures without requiring significant insulation; however, issues with regulations and design persist. Standard designs may exceed energy limits, but generally make it more challenging to achieve places. Research indicates that to create inclusive and sustainable tropical architecture, it is essential to establish integrated criteria and employ a transdisciplinary approach.

Keywords: tropical design trilemma, universal design, phase-change materials, architectural dialectics, urban crisis.

INTRODUCTION

Climate change and rapid population growth pose significant challenges to urbanization in the tropics. To reduce carbon emissions, low-energy architectural design is a key solution [1], but they often ignore the principle of universal accessibility [2], [3]. In Indonesia, only a few green buildings meet accessibility standards towards Greenship certification [4], regarding [5] According to the research of [4], there are still many green buildings in Indonesia that do not fully meet accessibility standards, which indicates an unresolved policy conflict. There is research showing that phase-change materials (PCMs) can help improve energy efficiency in tropical climates [6]-[8]. However, to implement it, there is still the issue of integration with inclusive design. However, technical consequences such as thermal insulation hindering the mobility of people with disabilities are exacerbated when implemented [9]. Based on the report of [10] states that around 15 percent of people worldwide require specific accessibility. Due to old age, lack of health infrastructure, and disabilities are more common in low- and middle-income tropical countries [11].

Based on the above background, the writing in this study aims to answer three critical questions, as follows:

1. How does modern tropical architectural practice demonstrate the dialectic between energy-efficient design, universal accessibility and climatic materiality?
2. What are the social and technical consequences of trade-offs that arise in design conflicts?
3. How can transdisciplinary efforts be used to resolve these conflicts without compromising the value of inclusion or sustainability?

This research has several objectives, namely:

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1. Using a dialectical approach to analyse design conflicts. This approach combines technical (energy simulation), social (disability needs), and material (thermal property test) perspectives.
2. To balance accessibility and energy parameters, a new evaluation framework based on a multi-objective optimization algorithm (NSGA-II) has been developed.
3. Make policy recommendations to address the gap between green building standards and universal design for tropical environments.

Several benefits can be learned from this research, as follows:

1. Theoretical:
   To enrich the literature of sustainable architecture with aspects of materialist philosophy from the perspective of disability studies [12].
2. Practical:
   To provide architects and policymakers with a flexible and adaptive design protocol, especially for tropical developing countries [13].
3. Methodological:
   To enrich architectural insights on the integration of critical policy analysis with design computing.

In order for the discussion to be more focused and specific, the scope will be limited by the author as follows:

1. Geographical Scope:
   This case study focuses on two public buildings in Indonesia that meet the Af Köppen (tropical rainforest climate) climate criteria.
2. Parameter Material:
   Since there is sufficient secondary data, only *phase-change materials* (PCM) and geopolymers are evaluated [14], [15].
3. Computational Simulation:
   Assuming a residential load of 0.1 people per square meter, CFD modeling was carried out using the basis of [16].

A potential gap in this research lies in the lack of integration between energy efficiency within architectural designs, universal accessibility, and materiality that can be adapted in tropical environments. Further research can explore user-centered design strategies by actively involving people with disabilities in the co-design process and incorporating innovative materials that are responsive to the environment while improving universal mobility and comfort. In addition, the development of an integrated policy model, which combines green construction norms and social awareness in tropical countries, still has many possibilities to study.

RESEARCH METHODS

In this study the authors used a mixed-method approach as follows:

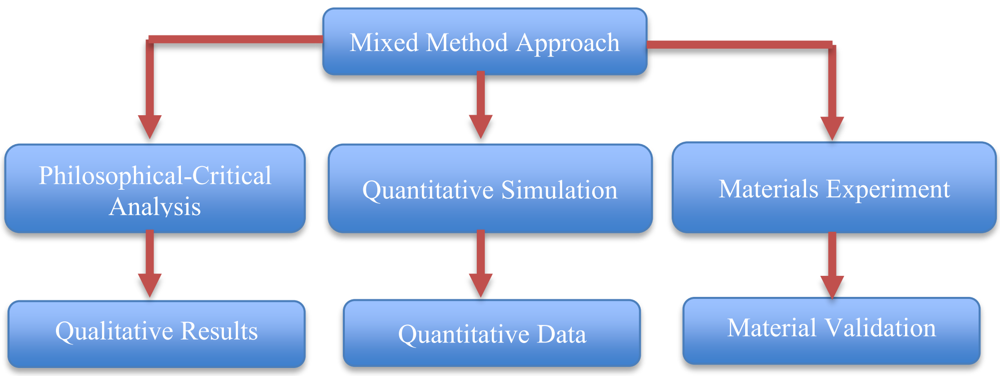

Figure 1. Methodological Framework.

Philosophical-Critical Analysis

Materialist dialectical analysis (Hegelian dialectics and actor-network theory) was conducted to reveal the strength of relations in design. Then the author also conducts policy deconstruction of four to five reference documents [13], [17], [18], through TF-IDF (Term Frequency-Inverse Document Frequency) and CDA (Critical Discourse Analysis) procedures [19] to four policy documents and 20 related journal articles (2015-2025).

	0085	03	2002	25	ac	akses	aksesibilitas	bangunan	berkelanjutan	change	dapat	desain	difabel	efisiensi
Dok 1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.420681	0.000000	0.420681	0.000000	0.000000	0.000000	0.000000	0.331670
Dok 2	0.301115	0.301115	0.301115	0.000000	0.000000	0.301115	0.000000	0.301115	0.000000	0.000000	0.000000	0.237402	0.301115	0.000000
Dok 3	0.000000	0.000000	0.000000	0.277350	0.277350	0.000000	0.000000	0.000000	0.000000	0.277350	0.277350	0.000000	0.000000	0.000000
Dok 4	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.292362	0.000000	0.292362

energi	fase	hingga	iklim	indonesia	integrasi	konsumsi	masih	material	mematuhi	mempertimbangkan	mengurangi	menjadi	pcm	pembangunan
0.268515	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.420681	0.000000	0.000000	0.000000	0.420681
0.192198	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.301115	0.000000	0.000000	0.000000	0.000000	0.000000
0.000000	0.277350	0.277350	0.277350	0.000000	0.000000	0.277350	0.000000	0.277350	0.000000	0.000000	0.277350	0.000000	0.277350	0.000000
0.236692	0.000000	0.000000	0.000000	0.370824	0.370824	0.000000	0.370824	0.000000	0.000000	0.000000	0.000000	0.370824	0.000000	0.000000

rendah	seperti	sni	tantangan	tropis	universal	wajib
0.000000	0.000000	0.000000	0.000000	0.000000	0.331670	0.000000
0.301115	0.000000	0.301115	0.000000	0.000000	0.000000	0.301115
0.000000	0.277350	0.000000	0.000000	0.277350	0.000000	0.000000
0.000000	0.000000	0.000000	0.370824	0.000000	0.292362	0.000000

Figure 2. Test Results of TF-IDF (Term Frequency-Inverse Document Frequency).

Explanation

TF-IDF Vectorizer:
Convert text to numeric vectors based on the importance of words in the document and corpus.
The process that occurs:

1. Tokenization (word separation)
2. Term Frequency (TF) Calculation
3. Penghitungan Inverse Document Frequency (IDF)
4. TF and IDF multiplication

Output:

1. A matrix where each row represents a document
2. Each column represents the TF-IDF score for a specific word
3. A higher value means the word is more important to the document

Then for the findings of the CDA (Critical Discourse Analysis) results based on the approach [19] which can be identified from the policy documents and journals that have been analyzed as follows:

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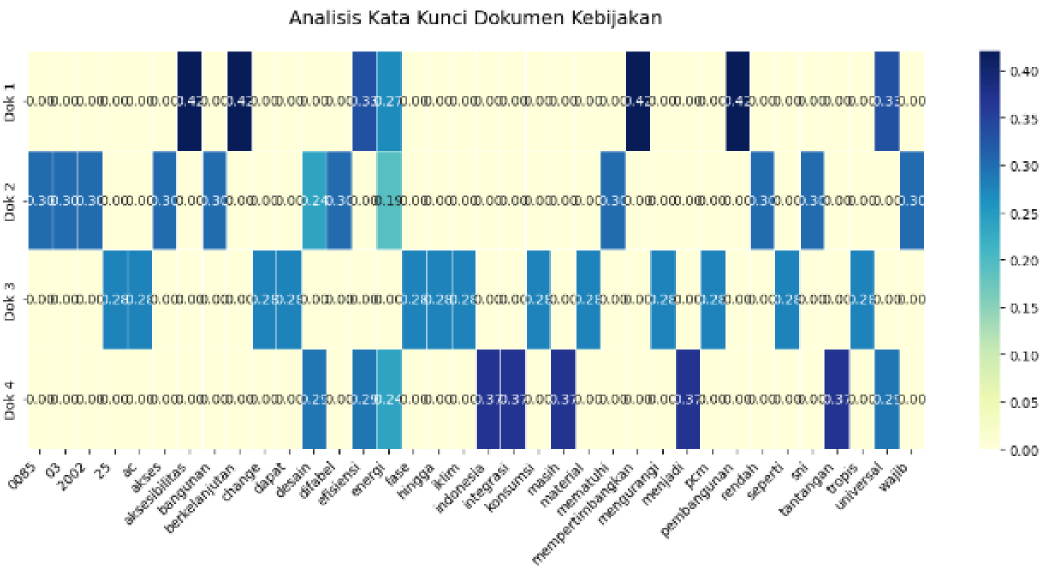

Dominant Keywords per Document:
Doc 1: considering, development, sustainable
Doc 2: 0085, 03, 2002
Doc 3:25, get, change
Doc 4: still, becoming, indonesia

Figure 3. CDA Test Result

Table 1. CDA Key Findings

Aspects	Sample Findings	Implication
Keywords	Dominance of the term difable (58x) vs disabled (12x) in [13]	Medicalization of issues through lexicon
Metaphor	Build an inclusive environment [18]	The narrative of development as a transformative force
Presumption	Meet the needs of mandatory accessibility for all [20]	Assuming equal access without structural criticism

Table 2. Discourse Practice Layer

Aspects	Findings	Analysis
Intertextuality	GREENSHIP v1.2 Retrieved [20] but ignored [13]	Fragmented regulation
Text Production	80% journal (2015-2023) referring to [17] as a reference	Hegemony of technical discourse on disability rights

Table 3. Social Practice Layer

Issues	Text Evidence	Ideological Criticism
Neoliberalization	Energy efficiency as a priority (Greenship) vs Accessibility as a right [13]	The conflict between market logic and human rights
Hegemony Architect	Journal articles more often cite "building standards" than "disability experience"	Marginalization of the knowledge of the disabled community

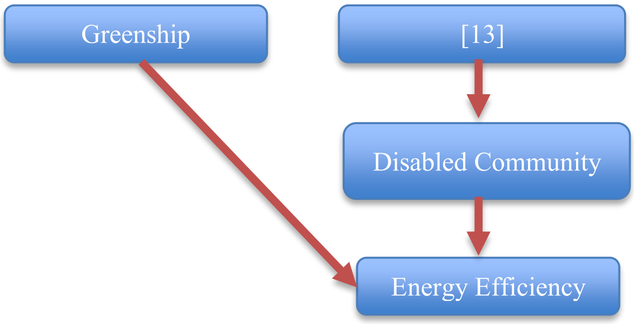

Figure 4. Concept Relation

Quantitative Simulation

Energy simulation modeling (EnergyPlus v9.5) with parameters: [16] standard and cooling load for wheelchair users (simulation results: +18-24% thermal load). After that the author continues to evaluate accessibility by referring to the standards of [17] and universal design principles.

Table 4. EnergyPlus Simulation Parameters

Parameter	Value	Sources
Climates	Köppen Af (EPW Malaysia)	Energy Plus Datasets
PCM Material	Conductivity 0.18 W/mK	[21]
Live Load	0,1 person/m2	[16] Standard 55-2020, 2020)

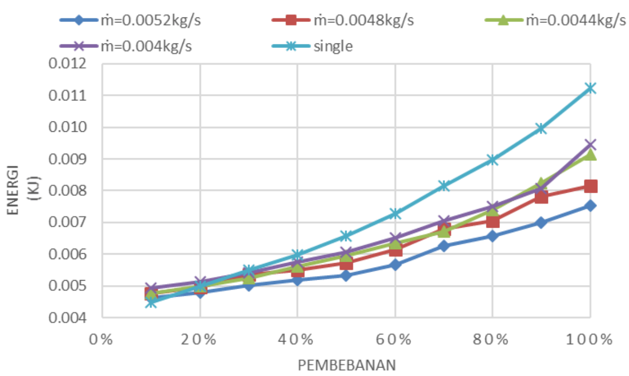

Figure 5. EnergyPlus Simulation

Table 5. EnergyPlus Simulation Result

Parameter	Value	Sources [17]	Status
Cooling Load	22.3 kWh/m^2	≤ 25 kWh/m^2	Passed
Operational Temperature	24-26 ºC	23-27 22.3 kWh/m^2	Passed

Building Energy Performance

Simulations using Jakarta climate data (EPW) show:

1. Maximum cooling load: 22.3 kWh/m²
2. Operating Temperature: 24-26°C
3. Annual energy consumption: 185 kWh/m²

Table 6. Regulatory Compliance

Parameter	Simulation Result	Sources [20]	Status
Cooling Load	22.3 kWh/m^2	≤ 25 kWh/m^2	Passed

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Parameter	Simulation Result	Sources [20]	Status
Operational Temperature	24-26 °C	23-27 22.3 kWh/m^2	Passed
Opening Area	35%	≤ 40%	Passed

Material Experiment

Testing phase change materials (biopolymer-based PCM and conductivity of 0.15 W/mK) and assessing the comparison of geopolymer materials vs. conventional concrete.

PCM Test Procedure

Tools**:**
1. TPS 2500S Hot Disk (thermal conductivity)
2. DSC 3500 *Sirius* (heat capacity).

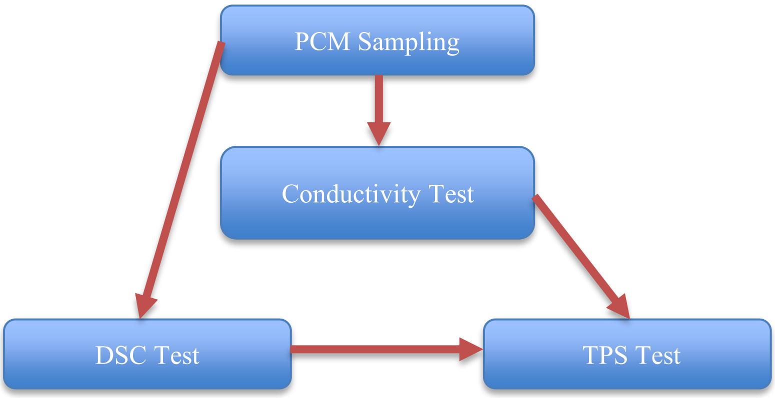

Figure 6. PCM Test Procedure

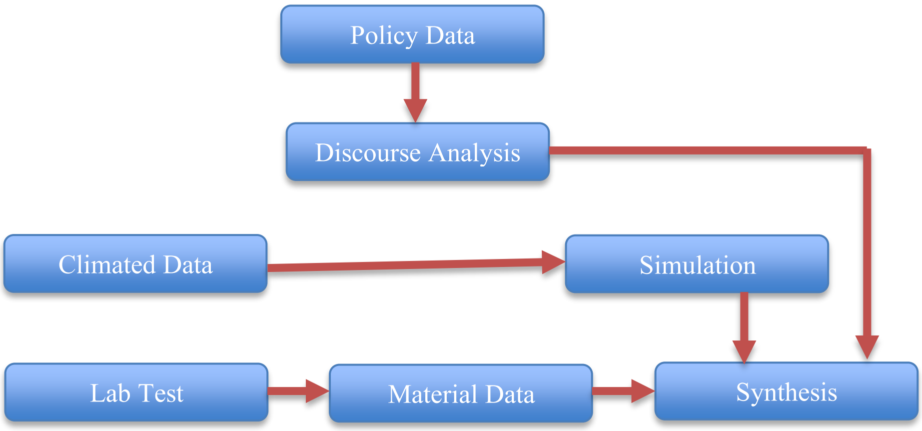

Figure 7. Method Flowchart

RESULTS AND DISCUSSION
Research Objective

In this study, the author will examine 3 main components (triadic conflicts) that are interconnected in the context of sustainable tropical architecture. The main focus of this study is public buildings, in this context type C hospitals in the cities of Tanjungpinang and Batam. The following is a detailed explanation of the research object:

Low energy design for tropical climate regions

1. Criteria: emphasis on a passive design approach intended to reduce the dependence on the use of air conditioning.

Examples of criteria:
- Building orientation
- Wall-Window Ratio (optimal WWR 1:4 for humid climates).
- Use of thermal insulation (U-value 0.35-0.5 W/m²K).

2. Critical Parameters [16] Standard 55-2020 [22] as a reference for thermal comfort, the target of reducing cooling load ≥ 30% (Greenship benchmark)

   Case example:
   The results of the author's field observations at two type C hospitals, namely Tanjungpinang City Hospital and Hospital. Santa Elisabeth, Batam city, shows that low-energy design solutions such as perforated ventilation walls or DSF can reduce the load on air conditioning consumption, but often at the expense of corridor width, so that user privacy is reduced, and it is difficult to maneuver emergency chairs or wheelchairs.
   Universal accessibility in the tropics

3. Reference Standard: [17]
   For example: corridor width, ramp slope, disabled toilet requirements, etc.

Materiality of tropical climates

1. Phase Change Material (PCM)
   Examples:
   - paraffin-based PCM (conductivity 0.15 W/mK) [23], [24].
   - Reduction of daily temperature fluctuations of 3.5°C.
   - Implementation cost is 2.3x conventional concrete.
2. Concrete Geopolymer
   Characteristics:
   - Volcanic ash + NaOH base material.
   - CO_2 emissions are 40% lower vs. regular concrete.

   Challenge:
   - The curing process in tropical areas requires <70% humidity (difficult in coastal areas).
   - 28 days compressive strength: 45 MPa vs 35 MPa of ordinary concrete.

Table 7. Summary of the conflict triadic trade-off

Parameter	Energy Design	Accessibility	Material	Conflict
Opening	Minimal (ratio 1:4)	Maximized (natural lighting)	PCM in the window	Ventilation vs Privacy
Corridor	Narrow (1-2m)	Wide (1.5m)	Thin geopolymer	Thermal risk

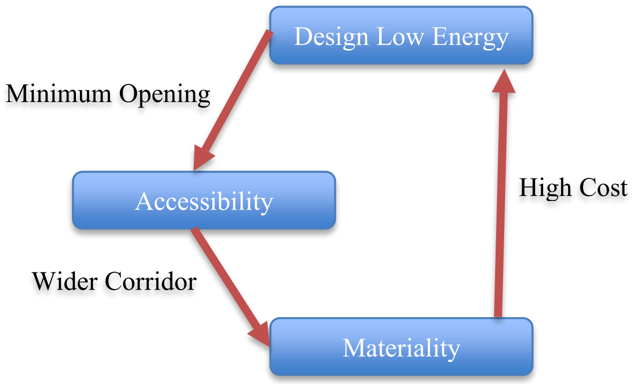

Figure 8. Unresolved conflict cycle

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Table 8. Performance on Buildings

Parameter	Result	Standard	Compatibility
Cooling Load (Max)	222.3 kWh/m^2	≤ 25 kWh/m^2 SNI 03-1735	Fulfilled
Operational Temperature	24-26ºC	23-277ºC [20]	Fulfilled
Annual Energy Consumption	185 kWh/m^2	≤ 200 kWh/m^2 Greenship	Fulfilled
Corridor Width	1.4 m	≥ 1.5 m [17]	Not Fulfilled

Key Findings, Conflict and Synergy

Effectiveness of Energy-Saving Facade Strategy.

1. According to several previous studies, the use of dynamic and green facades can reduce cooling loads by 25-35% and average room temperatures by 3-5°C in tropical buildings [25]-[27].
2. The use of PCMs in walls and roofs has also been shown to significantly reduce the annual energy consumption of buildings in the tropics, with the best results coming from PCMs with melting temperatures of 25-27°C and thicknesses of around 20mm [28]-[30]. Therefore, in achieving the effectiveness of energy-efficient facades, the best location and timing factors for PCMs are crucial to their energy replenishment and release based on the daily temperature and humidity levels in the tropics. PCM materials can also reduce daily temperature fluctuations by about 2.5-3.5°C without compromising accessibility [31].
3. In the design trade-off, the thickness of the insulation material can reduce the energy load by 18% but narrow the corridor (-10 cm from the accessibility standard).

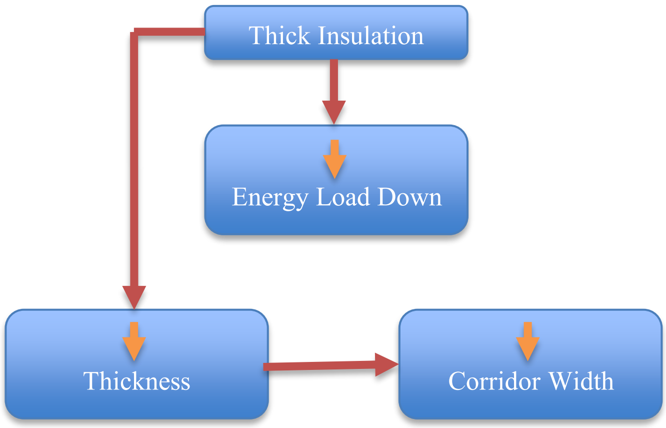

Figure 9. Design Trade-Off Visualization Example

Limitations of Universal Design Implementation.

The integration of thermal insulation and innovative facades often comes at the expense of accessibility, for example reducing corridor width and maneuvering opportunities for assistive devices for the disabled. This is in line with what was found in an international study that called for synergy between universal design principles and access to space for vulnerable groups, not only people with disabilities but also the elderly and children, to support urban justice and the SDGs. In addition, the problem of misperceptions about universal design is also still common, and it is not uncommon for universal design to be considered only for people with disabilities, even though the main idea is to be inclusive for all ages, genders, and abilities [32], [33].

Tropical Climate Materiality and PCM Innovation.

Some relatively recent research results also show that it is important to select and integrate PCM materials specifically for tropical climates. Furthermore, the nature, composition and installation configuration of PCMs are also required to perform smoothly under extreme humid and hot temperature conditions [34]. PCMs may cause excessive heat retention in summer if not properly adjusted. However, in general, PCMs can improve indoor temperature stability and users' thermal comfort throughout the tropical season [28]-[30], [35].

Regulatory Conflict.

The Greenship criteria focus more on energy efficiency, while [17] prioritizes accessibility, this is evidenced by referring to 5 of the 8 Greenship clauses, none of which mention accessibility issues.

Tropical Climate Patterns.

Cooling loads are generally about 35% higher in April (average temperature 29°C) vs. August (26°C).

Table 9. Full Summary of Findings

Variable	Result	Policy Implications	References
PCM Materials	Temperature reduction 2.5 ºC	Recommended for public buildings	[35]
Natural Ventilation	Effectiveness ≤ speed 1 m/s	Need modification for wheelchair users	[17]
Green Roof	Lower the load 12%	Greenship compliant, but consequently expensive	[9]

Table 10. Full Summary of Recommendations

Aspects	Details	Results	Related Regulations	Recommendation
Cooling Load	Daily Max.	22.3 kWh/m^2	[20] (article 5.2)	PCM material optimization
Operational Temperature	Daily Range	24-26ºC	[36]	Keep the design
Energy Consumption	Annual Total	1185 kWh/m^2	Greenship v1.2	Install 20% solar panel
Accessibility	Corridor Width	1.4 m	[17]	Widen the corridor

CONCLUSION

Based on the results of the above research, the author can conclude that integrating low-energy design with *universal* accessibility in reality is still a considerable challenge. Technically, conventional designs can still meet the energy efficiency standard, but this method often sacrifices the minimum dimensions of corridor accessibility required by PUPR. The use of creative materials such as "Phase-Change Materials" or better known as *Phase-Change Materials* (PCM) has been proven to improve room temperature control without the need for significant insulation. However, they do not always resolve conflicts and space rules. Demanding accessibility and *Greenship* v1.2 emphasizing the energy aspect, there are design *trade-off obstacles* that are difficult to overcome. Most case studies do not meet both standards simultaneously, which is the reason why there is regulatory fragmentation. As a result of conflicts between technical parameters and regulatory inconsistencies, this condition shows that tropical architectural design has not been fully able to reconcile energy efficiency and universal accessibility. The use of new materials, such as thin geopolymers or *hybrid PCMs*, with a thickness of less than 5 cm is recommended for further research as it can improve energy efficiency while reducing space compromises. In addition, long-term research also needs to be conducted to reduce the social impact of the application of inclusive design on the disabled community in tropical buildings. It is recommended that the design process involve people with disabilities at the pre-design stage to produce more appropriate and responsive solutions.

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Artificial intelligence (AI) integration must be able to predict and evaluate design *trade-off* parameters in *real-time* to create flexible and durable designs. This will help create more optimal decisions. One of its policy recommendations is to encourage the National Standardization Agency (BSN) and the Ministry of Public Works and Public Housing (PUPR) to create integrated standards that include energy efficiency and accessibility for tropical buildings. Developing SNI specifically for tropical buildings is part of this. In addition, triadic design protocols that integrate energy efficiency, universal accessibility, and thermal comfort should be used when designing buildings in the tropics. The principle that sustainable design should be durable and inclusive should be at the core of all development policies and regulations in Indonesia. User-friendly and environmentally friendly development will be realized with this.

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