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INTEGRATING PASSIVE AND ACTIVE STRATEGIES: A CONCEPTUAL FRAMEWORK FOR BUILDING ENERGY EFFICIENCY IN HIGHER EDUCATION INSTITUTIONS

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Abstract

Facility management in higher education institutions face the challenge of improving building energy efficiency due to the large size and high energy demand. In Malaysia, polytechnics confront additional challenges of operating on ageing building and limited operational budgets. Existing approaches in operation and maintenance and energy monitoring remain fragmented which hindering energy efficiency efforts. This paper introduces a proposed framework to measure building energy efficiency among Malaysian polytechnics using passive and active parameters while supported by technologies. Passive parameters include building orientation, natural ventilation, daylighting, and building envelope, while active parameters are HVAC and lighting systems. The framework is systematically strengthened by the adaptation of Technology-Organization-Environment framework, Six Sigma and Business Process Redesign principles. Research Methodology used is mixed method that combining questionnaire surveys and case studies of identified Malaysian polytechnics. Findings from this study will assist facility managers and policymakers to optimise energy monitoring protocols and drive operational decisions making towards sustainable facility management practices aligned with national and international goals.

Keywords: Building Energy Efficiency, Sustainable Facility Management, Higher Education Institutions, Energy Performance Framework, Passive and Active Strategies

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INTRODUCTION

Background

The building sector represents one of the most massive energy consumers across the globe while substantially adding to both energy consumption rates and greenhouse gas emissions. Heating, cooling, ventilation, lighting and equipment usage make the operational phase of building lifecycles consume the most energy (Amaral et al., 2020). Malaysian polytechnics and other higher education institutions (HEIs) manage sophisticated building facilities which consume substantial energy resources and therefore sustainability requires a strong focus on energy efficiency in their facility management (FM) processes.

Malaysian public HEIs struggle to enhance energy performance because of outdated infrastructure combined with sporadic FM practices and traditional O&M methods (Dzulkifli et al., 2021). Global progress in digitalization and data-focused energy management practices has not yet reached many Malaysian polytechnics which continue to use reactive maintenance approaches that cause operational inefficiencies and higher costs alongside greater energy consumption. Due to the nation's dedication to sustainability through programs like the United Nations Sustainable Development Goals (SDGs) and Malaysia's Low Carbon City Framework (LCCF), it is critical to develop structured and innovative methods to improve building energy efficiency (UNDP, 2023).

Problem Statement

Different global frameworks and methods such as ISO 50001 (Energy Management Systems), Building Energy Index (BEI), and Building Information Modeling (BIM)-integrated energy performance monitoring serve as the basis for measuring building energy efficiency (Rahman, 2021). A standardized framework which addresses the unique institutional structures and resource constraints of Malaysian polytechnics remains undeveloped.

Malaysian polytechnics face several ongoing difficulties within their O&M practices which are:

- Lack of cohesive energy data management systems creates problems for energy use monitoring and optimization efforts.
- Reactive maintenance approaches create operational inefficiencies through postponed repairs and increased expenses.
- Digital integration remains inadequate because of the low adoption rate of technologies like BIM, IoT and automated energy management systems.
- Current energy efficiency policies remain disconnected from institutional FM strategies within their operational framework.

Thus, this research attempts to provide a conceptual framework incorporating passive and active energy systems alongside digital monitoring to aid energy efficiency enhancements in Malaysian polytechnics. Integrating technical interventions with organisational and technological aspects allows for this framework to assess buildings holistically. Hence, results from this study may add value towards sustainable facility management (SFM) and act as institutional energy management practices that may be implemented by HEIs.

Significance of the Study

This conceptual framework advances SFM through its support of Malaysian polytechnics as a case study whereby institutional needs should guide the creation of data-driven energy performance benchmarks. Predictive analytics and digital monitoring tools will empower Facility Managers with better decision-making capabilities. The framework also supports institutions in meeting the sustainability requirements according to ISO 50001 and Malaysia's National Energy Policy 2022-2040. In practical terms, it optimizes campus facilities by decreasing operational expenses and advancing environmental sustainability. This study develops a comprehensive approach to digital integration in facility energy management by adapting the Technology-Organization-Environment (TOE) Framework with Six Sigma and Business Process Redesign (BPR).

LITERATURE REVIEW

Energy Efficiency in Buildings

Sustainable facility management needs energy efficiency because it allows facilities to use less energy while maintaining necessary performance standards alongside comfort and productivity. According to Polat & Yildirim, (2023), buildings worldwide account for 35% of energy usage while generating approximately 38% of carbon emissions which demonstrates their importance in reducing climate change impacts and operational expenses. The extensive use of buildings within Malaysian polytechnics and other HEIs heightens the need for energy-efficient practices to maintain sustainable operations.

Energy-efficient buildings bring multiple advantages which include minimized utility expenses and decreased greenhouse gas emissions along with better indoor environments that improve productivity according to Pandya et al. (2022). The implementation case becomes stronger when institutions comply with international standards such as ISO 50001, LEED and Green Building Index (GBI) (João Delgado et al., 2022). Research shows that passive design methods such as insulation and daylighting together with active systems like smart HVAC and LED lighting demonstrate international effectiveness (CK Tang & Nic Chin, 2017; Hossain et al., 2023). Building Management Systems (BMS), IoT sensors,

and AI-driven analytics provide modern capabilities for real-time monitoring and energy optimization.

Malaysian Polytechnics struggle with outdated infrastructure and face challenges in integrating digital systems and maintaining effective energy monitoring practices (Ismail, 2022). The SmartGreen PolyCC 2021–2026 framework provides several improvement strategies but standard policies and smart technology adoption show limited progress (JPPKK, 2020). Therefore, Malaysian Polytechnic institutions require a tailored framework to assess their energy efficiency levels.

Existing Methodologies in Measuring Building Energy Efficiency

Several frameworks measure building energy efficiency, each with distinct advantages and limitations. The Building Energy Index (BEI), widely used in Malaysia, quantifies annual energy consumption per square meter but overlooks climatic variables (Arjunan et al., 2019). ISO 50001 offers a structured energy management approach but suffers from financial and skills-related implementation gaps in local HEIs (Schützenhofer, 2021).

BIM presents a data-rich solution for modeling energy performance and predictive maintenance, with studies indicating potential energy savings of up to 30% (Cao et al., 2022). However, its adoption is hindered by high initial costs and technical demands. Similarly, frameworks like LEED v4.1 and MyCREST evaluate energy efficiency through sustainability scoring and systems assessments, though their applicability to Malaysian polytechnics remains partial.

These limitations call for a tailored conceptual framework specific to polytechnics, incorporating both passive and active design variables.

Theoretical Underpinning

Passive and Active Design

Effective energy-efficient building design requires combining passive strategies with active systems for optimal results. Passive methods leverage environmental factors to lower mechanical dependency whereas active systems utilize technological solutions to enhance performance.

According to CK Tang & Nic Chin (2017), passive design works to minimize thermal absorption while optimizing airflow and daylight access. Building orientation along the east-west axis serves to reduce solar exposure. The use of natural ventilation through design features such as cross-ventilation and operable windows minimizes the requirement for air conditioning systems. Cooling loads can be reduced by as much as 30% when shading systems such as overhangs and louvers are implemented (Shukla et al., 2023). Indoor heat transfer reduction benefits from insulation and material choices including reflective roofing materials and low-E glass (CK Tang & Nic Chin, 2017).

The Active Design approach incorporates high-efficiency HVAC systems and LED lighting technology. The integration of VRF systems and demand-controlled ventilation methods achieves optimal cooling performance (CK Tang et al., 2017). LED lighting retrofits and smart control systems with sensors achieve up to 60% energy reduction in lighting. Through real-time energy monitoring and automated adjustments enabled by BMS and IoT sensors buildings experience significant efficiency improvements (Tariq et al., 2024).

A robust energy management model for HEIs emerges from combining passive orientation and insulation with smart HVAC technology and renewable systems through an integrated strategy.

Technology-Organization-Environment (TOE) Framework

TOE by Tornatzky & Fleischer (1990), is a framework for understanding technology adoption based on three elements: technological, organizational, and environmental drivers. These forces consist of technological readiness (e.g., IoT, smart meters), organizational commitment (e.g., motivation, leadership, resources), and environmental pressures or incentives such as policies and regulations (Abdelalim et al., 2024; Ahmad et al., 2023). TOE has proven effective in assessing technology integration for energy management (Qin et al., 2020). It can be leveraged to identify several challenges and enablers for implementing energy efficiency practices and tools in Malaysian polytechnics.

Regarding technology, digital energy management such as Building Management Systems (BMS), Building Automation Systems (BAS), smart sensors, and Building Information Modelling (BIM) can serve as tools that facility managers could leverage to gain data-driven insights on their buildings' energy performance in real-time (Rahman, 2021).

Organizationally, leadership engagement, budget allocation, and facility managers' expertise could determine an institution's readiness and ability to manage energy efficiency practices. While externally, policies, rating systems, and benchmarking standards such as MyCREST and ISO 50001 may encourage institutions to implement specific energy management practices or enhance the SFM (Ahmad et al., 2023).

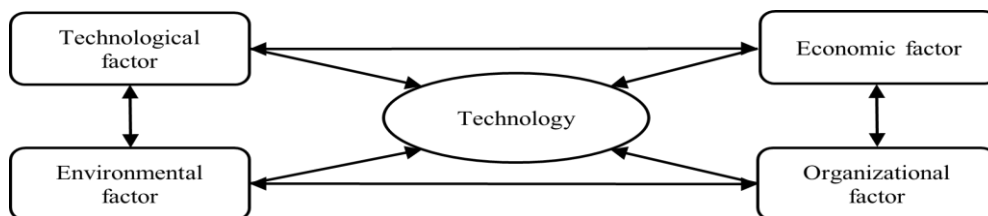


Figure 1: Improved TOE Framework
 Source: (Qin et al., 2020)

Six Sigma

The Six Sigma methodology functions as an essential component in energy efficiency optimization through its systematic data-driven method which helps organizations detect inefficiencies and enhance operational processes. With the Define-Measure-Analyze-Improve-Control (DMAIC) process, Six Sigma offers organizations a systematic method to evaluate energy consumption patterns while removing waste and maintaining continuous performance monitoring (Monday, 2022). The application of Six Sigma methodologies to commercial buildings reveals up to 20% improvements in energy performance through real-time energy audits and predictive maintenance (Durdyev et al., 2021).

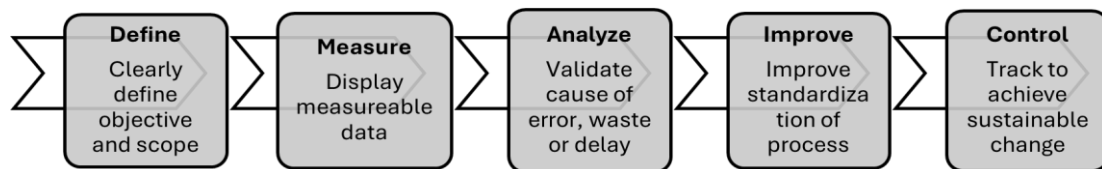


Figure 2: Define-Measure-Analyze-Improve-Control (DMAIC) process
Source: (Monday, 2022)

Business Process Redesign (BPR)

Business Process Redesign (BPR) prioritizes the re-engineering of existing Operations and Maintenance (O&M) processes to improve energy efficiency. BPR proves essential for facility management because existing energy monitoring methods struggle to integrate new digital technologies. BPR achieves successful implementation of energy efficiency strategies through streamlined energy audits and automated data collection, along with improved cross-departmental collaboration (Ezeh et al., 2024). Research shows that combining BPR with BIM and smart building technology eliminates manual inefficiencies and enhances facility operations, which results in considerable energy savings (Schützenhofer, 2021).

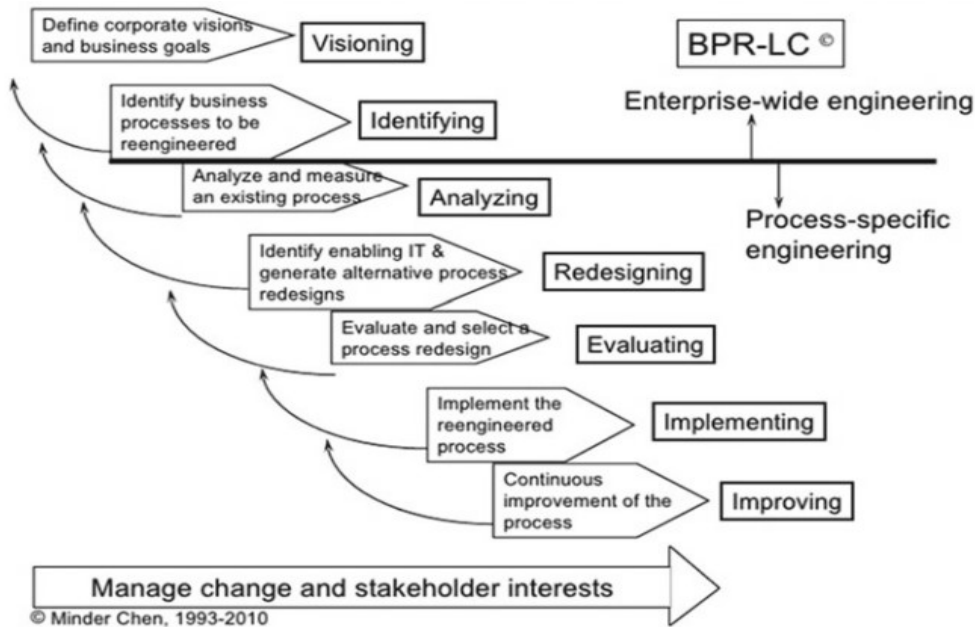


Figure 3: Business Process Redesign Lifecycle
 Source: (Harika et al., 2021)

Challenges in Energy Efficiency Implementation

The implementation of energy efficiency in Malaysian polytechnics is challenged by technological limits as well as organizational and regulatory barriers. The initial expenses of smart systems including BIM and IoT surpass the financial limits of institutional budgets. The lack of infrastructure creates challenges for real-time monitoring and inadequate staff skills lead to less effective implementation. The energy efficiency standards such as MyCREST and GBI policies are not mandatory which restricts enforcement. The variations in climate and campus use patterns in Malaysia make the standardization of energy measures difficult which demonstrates the necessity for bespoke energy benchmarks.

RESEARCH METHODOLOGY

To obtain extensive information about energy efficiency in Malaysian polytechnics, researchers use a mixed methods approach. Structured questionnaires will be used to collect quantitative data about energy consumption patterns along with facility management techniques and energy-efficient technology adoption. The research will gain qualitative insights from case studies of chosen Malaysian polytechnic institutions, where facility managers will be

interviewed to reveal detailed operational realities around energy efficiency implementation (Mohamad Munir et al., 2023).

Survey results will be analysed using both descriptive and inferential statistics. Descriptive statistical tests, including averages, standard deviation, and frequency distributions, will be used to establish the current status of passive and active energy efficiency measures taken in the shortlisted institutions. Results from the descriptive analysis will provide insight into current practices on facilities management and energy conditions on-site. Inferential statistics will then be used to test the relationships between variables that have been identified in the conceptual framework. Correlation testing will be conducted to determine the associations between passive design measures, active systems, and building energy performance (Mohamad Munir et al., 2023). Regression tests will also be performed to understand the impact of selected variables towards energy efficiency.

Qualitative information gathered through interviews and site visits will be analysed thematically. Themes will be extracted to highlight common operational problems, technology trends, and institutional policies that directly or indirectly affect energy consumption issues. The mixed methods approach strengthens empirical framework validation by connecting it directly with theoretical foundations and verifying its practical use (Creswell & Creswell, 2018).

The case study institutions were chosen by campus age, size, and operations intensity throughout Malaysia's polytechnic campuses. Campus age was a major factor since many institution buildings in Malaysia are ageing, which can contribute to larger energy loads (Dzulkifli et al., 2021). Institution size and operations were considered since larger and more complex institutions tend to have longer operational hours and more facilities to maintain. Case studies may not be generalizable due to institutional differences, which can affect the results. Building age, maintenance budget, and technology could differ from one institution to another, affecting energy efficiency implementations. However, since the chosen case studies share the same function as an educational institution, they should be able to portray common operational conditions.

CONCEPTUAL FRAMEWORK DEVELOPMENT

The proposed framework utilizes the Building Energy Efficiency Technical Guideline (BSEEP) passive and active strategies and theoretical concepts from the Technology-Organization-Environment (TOE) Framework, Six Sigma, and Business Process Redesign (BPR) to establish a structured approach for assessing and improving energy performance within Malaysian polytechnic institutions. The conceptual framework segregates key variables into passive and active strategies which adhere to best practice standards set by the BSEEP guidelines.

Passive Design Variables

Passive design strategies serve as principal methods and as a first phase of measures for lowering energy demand by exploiting natural environmental factors. The BSEEP identifies essential passive design components as shown in table 1.

Table 3: Essential Passive Design Components

Component	Description
Building Orientation	The building orientation should be optimized to reduce heat gain from direct sunlight while maximizing natural ventilation. The correct east-west alignment of buildings decreases cooling requirements by restricting unnecessary solar radiation exposure.
Natural Ventilation	Design elements like cross-ventilation and stack ventilation alongside atrium spaces optimize airflow to reduce mechanical cooling dependency.
Daylighting	The design includes overhangs and louvers along with external shading devices and low-E glass to manage solar radiation which reduces heat entering the building but still allows enough daylight inside.
Building Envelope	High-reflectivity roofing materials and insulated walls together with green roofs improve insulation and regulate indoor temperatures to enhance thermal comfort.

Active Design Variables

Second phase of measures, active strategies concentrate on efficient energy usage through advanced technologies and automation while passive strategies aim to minimize energy demand. The key active design variables identify are as below:

Table 2: Essential Active Design Components

Component	Description
HVAC Systems	High-efficiency chillers and demand-controlled ventilation (DCV) systems work together with variable refrigerant flow (VRF) systems for optimized cooling performance, which leads to reduced energy waste.
Lighting Systems	Buildings switch to LED lighting solutions while implementing motion sensors and daylight harvesting controls to minimize wasted energy consumption.
Mediator (Third Phase of Measures)	
Building Automation System (BAS) and Building Management Systems (BMS)	IoT-enabled sensors and artificial intelligence alongside data analytics enable real-time energy monitoring to identify inefficiencies and enhance energy consumption optimization.

Relationships Between Variables

The conceptual framework achieves its effectiveness through the interplay of both passive and active design strategies and organizational and environmental conditions that affect energy performance outcomes.

Passive design elements have a direct effect on how active energy systems perform. A well-designed building orientation combined with daylighting systems minimizes indoor heat gain which leads to reduced cooling demand and better HVAC energy consumption efficiency. Natural ventilation systems contribute to reduced mechanical ventilation needs which leads to lower operational energy costs.

Active energy efficiency methods including smart lighting controls and energy-efficient HVAC systems support passive strategies through optimized and automated solutions that meet residual energy demands. Real-time monitoring through BAS and BMS technology strengthens energy management systems by tracking consumption patterns while spotting inefficiencies and supporting predictive maintenance operations.

The success of energy efficiency measures depends heavily on the organizational structure and environmental conditions which determine both their adoption and effectiveness. The execution of passive and active energy strategies depends on institutional policies alongside funding availability and staff expertise. The Green Building Index (GBI) from Malaysia and ISO 50001 regulations serve as external guidelines that influence energy efficiency projects in polytechnic institutions.

Integration with Existing Theories

The conceptual framework is built upon three key theoretical underpinnings: the Technology-Organization-Environment (TOE) Framework, Six Sigma and Business Process Redesign (BPR). The various theories support distinct elements of energy efficiency measurement and improvement.

The TOE Framework establishes a basis to study what drives energy efficiency adoption at polytechnic institutions. The technological aspect involves integrating smart energy monitoring systems together with IoT sensors and BIM-based energy modeling tools. The organizational aspect investigates institutional preparedness along with leadership dedication and the financial structures supporting energy efficiency programs. Energy management initiatives are driven by regulatory policies alongside sustainability trends and external pressures that fall under environmental considerations.

Six Sigma methodologies strengthen the framework through their data-oriented techniques which identify operational inefficiencies and enhance energy performance. Polytechnic institutions can methodically assess energy usage through the Define-Measure-Analyze-Improve-Control (DMAIC) process which

enables them to establish specific solutions and track ongoing advancements. HVAC system efficiency audits achieve better performance through Six Sigma principles which identify energy wastage areas to be optimized with data-based solutions.

Business Process Redesign (BPR) serves as a fundamental method for reorganizing the energy management processes within polytechnic organizations. Traditional facility management methods typically consist of maintenance practices that lack cohesion and focus on responding to problems after they occur. Business Process Redesign enables institutions to enhance their energy management by implementing predictive maintenance techniques and refining data collection methods while improving interdisciplinary decision-making processes. BPR combined with BIM and IoT technologies delivers energy efficiency processes that operate efficiently while being scalable and sustainable.

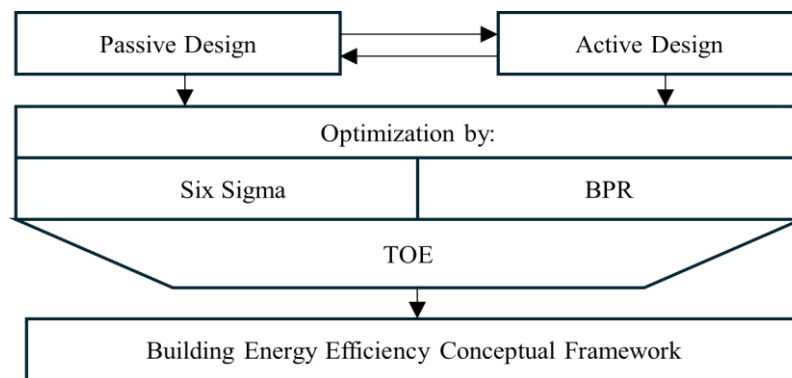


Figure 4: Utilisation of Theory Underpinning in Conceptual Framework

Validation Approach

The proposed conceptual framework requires a systematic validation process to maintain its reliability and applicability. Selected Malaysian polytechnic institutions will participate in expert reviews along with case studies and pilot implementations for validation purposes.

Expert reviews from facility managers, energy consultants, and sustainability professionals make up the first step of validation. The experts will analyse both the practical feasibility and potential challenges of the framework while suggesting areas for improvement. Feedback from experts will help modify the framework components to match real-world energy management practices.

The second step of validation will utilize case studies performed at multiple polytechnic institutions. The case studies will assess how well the framework works across multiple building types and varied climate conditions and operational environments. The framework's impact assessment will be

conducted by analysing key performance indicators such as energy consumption per square meter alongside HVAC efficiency.

The study will finally conduct pilot tests that utilize BIM-based energy simulations to evaluate passive and active strategies across different design scenarios. The simulations will deliver numerical evaluations of achievable energy savings and identify optimization opportunities.

The validation process demonstrates that the conceptual framework functions effectively in practice and can be adapted to different situations while delivering quantifiable building energy efficiency gains in Malaysian polytechnics.

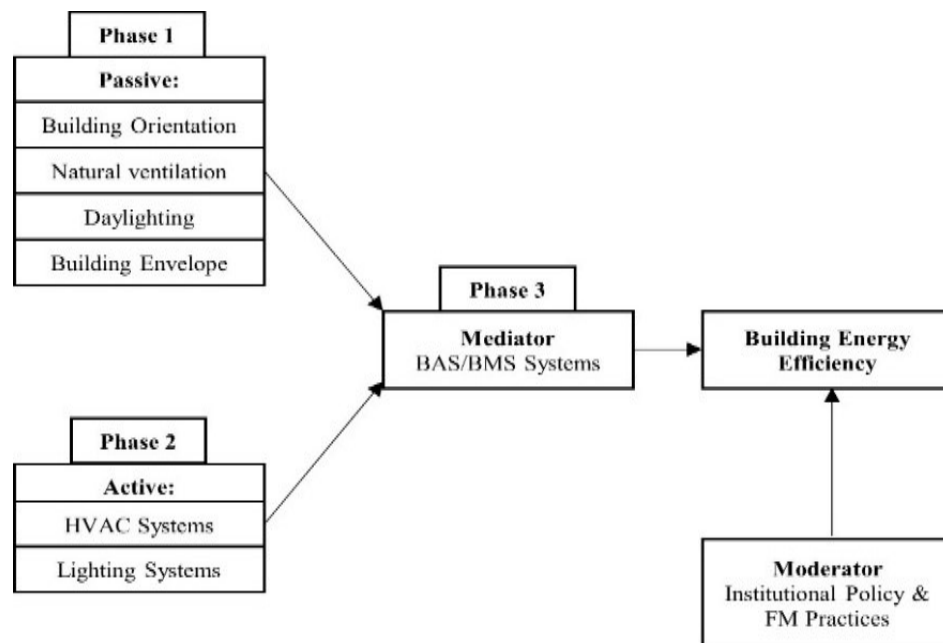


Figure 5: Conceptual Framework

ANALYSIS AND DISCUSSION

Findings Hypothesis

The validated conceptual framework which will be used to measure building energy efficiency in Malaysian polytechnics produced important findings about current energy efficiency practices alongside the role of passive and active strategies and digital tool integration in facility management. The main hypothesis from the research indicates that Malaysian polytechnic institutions are less energy efficient due to disjointed energy monitoring practices combined with reactive maintenance methods and minimal use of digital technology tools like

BIM and IoT. The case study analysis will demonstrate energy efficiency with structured energy policies and digital monitoring systems compared to other institutions that operate using conventional O&M practices.

The proposed framework will demonstrate high energy optimization effectiveness when combining passive and active strategies. Passive design methods including building orientation optimization together with increased insulation and effective shading can achieve cooling load reductions of up to 30% which decreases HVAC system dependency. Active systems like smart HVAC solutions and automated lighting technologies along with real-time energy tracking achieved a further 25–40% energy consumption reduction when correctly executed. The outcomes of this research will support the Building Sector Energy Efficiency Project (BSEEP) Technical Guidelines which highlight that long-term energy efficiency advancements in tropical climates depend on a comprehensive strategy.

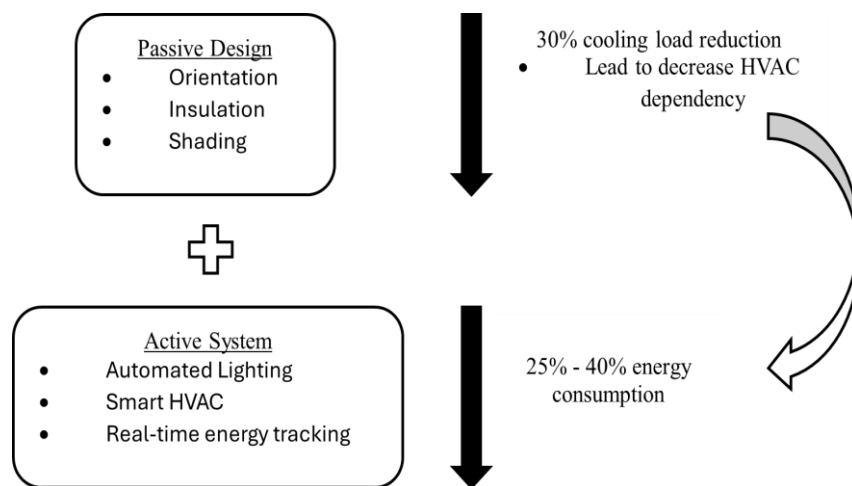


Figure 6: Cost Benefit Hypothesis

Through expert reviews and case studies, the framework's validation will show the critical need for structured energy management approaches. According to Gerarden et al. (2017), institutions use random methods to evaluate energy efficiency because there is no uniform methodology which results in varied performance outcomes. The proposed conceptual framework combines the TOE Framework, Six Sigma, and BPR principles to create a systematic data-based method for monitoring and improving energy consumption at higher education institutions.

Implications for Facility Management

The proposed conceptual framework's implementation has major consequences for facility managers, policymakers and energy consulting professionals within Malaysian higher education institutions. Facility managers will benefit from a standardized approach to energy assessment and monitoring that allows them to transition from reactive maintenance practices to predictive energy management techniques. By focusing on real-time energy tracking and data-driven decision-making while combining passive and active strategies, the framework enables facility managers to detect inefficiencies while improving energy performance and cutting operational costs.

The framework operates as a directional tool to assist policymakers in creating national policies and institutional strategies focused on energy efficiency within higher education buildings. The Low Carbon City Framework (LCCF), MyCREST and National Energy Policy 2022-2040 showcase Malaysia's dedication to sustainable practices which emphasize the importance of energy-efficient institutional buildings. This research provides valuable insights to shape policy recommendations concerning obligatory energy audits and digital infrastructure funding, along with rewards for institutions implementing smart energy management solutions.

Sustainability experts and energy consultants can utilize the framework to create tailored energy efficiency solutions that meet the distinct requirements of other educational institutions' facilities. Consultants who use predictive analytics along with AI-based energy monitoring systems guide institutions in creating strategic energy efficiency plans which meet global best practices and sustainability objectives.

The framework promotes teamwork between facility managers and academic administrators along with top management to jointly bring energy efficiency initiatives to successful completion in institutions. By adopting this comprehensive approach, institutions can make right decision making on energy awareness which produces enduring advantages for operational management and environmental protection.

Limitations and Future Work

The proposed conceptual framework provides a structured methodology for building energy efficiency measurement but requires acknowledgment of its existing limitations. Data availability and consistency remain the main challenge among the identified obstacles. The framework validation process relied on case studies from specific polytechnics and expanding the dataset to include more institutions would enhance the generalizability of the results. Subsequent studies need to assess how well the framework functions across various higher education environments by testing it in schools, universities and other technical colleges.

Advanced digital energy monitoring systems face implementation challenges due to financial limitations and technical constraints. Polytechnic institutions encounter budget constraints and human resource shortages which hinder their ability to deploy BIM, IoT, and AI-driven analytics technologies that optimize energy performance. Researchers should examine affordable digital transformation methods and search for government incentives that promote smart energy management system implementation in universities.

The framework targets administrative and academic buildings specifically within polytechnic institutions. The framework requires adaptation to include campus facilities like laboratories and dormitories, along with recreational centers since they exhibit distinct energy consumption patterns. Further investigation into user behaviour and climate variations, combined with energy consumption patterns will improve the framework's relevance.

Future research needs to focus on real-world pilot implementations where institutions fully adopt the framework into their facility management processes. Longitudinal studies tracking energy performance improvements would provide empirical evidence about the framework's effectiveness while guiding its future development.

CONCLUSION

The research outcomes identified the potential benefits of passive design considerations, active building systems and digital monitoring technologies to enhance energy performance in Malaysian polytechnics. The findings establish a framework that adopts the TOE model together with Six Sigma and BPR methodologies for assessing building energy performance that offers policymakers and industry professionals a structured approach to energy efficiency in building O&M. The framework could aid institutions in their budget considerations towards energy improvements and business operations decisions in the longer term. This research highlights applications such as BIM-based energy modelling and BMS platforms to aid decision making in cost-benefit analyses and optimizing maintenance budgets. To confirm the usability, the framework needs to be tested in a few buildings within the institutions. Additionally, future researchers should consider longer observation periods to confirm the cost savings realized from its implementation and examine barriers to technology adoption, particularly in resource-constrained contexts.

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