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Energy conservation strategies on academic buildings using interpretive structural modeling to develop energy sustainability

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Abstract: Effective energy conservation strategies are required to be implemented in academic buildings as they consume significant energy while considering the comfort and function of the buildings. However, the influencing factors are interrelated and complex, requiring an appropriate approach to unravel the complexity. Therefore, this study aims to identify, analyse, and map the interaction relationship between factors affecting energy conservation in academic buildings. This study used Interpretive Structural Modeling (ISM) procedure starting from developing the Structural Self Interaction Matrix (SSIM), converting SSIM into a Reachability Matrix, revising the matrix, and categorizing the factors by MICMAC. This study involved 9 factors, including architectural design, illumination technology, education and awareness, energy monitoring and management, renewable energy use, efficient HVAC system, energy-saving equipment, institutional policies, and campus community participation. The study found that renewable energy use at level 3 were factors that were not influenced by and did not interact with any other factors. Meanwhile, the illumination technology was a factor that interacted with the efficient HVAC System factor which was at level 1 where these two factors were influenced by seven other factors. This study aligns with current developments in energy conservation, including an increased focus on renewable energy and energy efficiency in academic buildings, supported by global and national policies aimed at achieving sustainability targets. It provides a comprehensive understanding of developing sustainable energy conservation strategies in academic buildings.

Keywords: Energy conservation; Academic buildings; Sustainability strategies; Sustainable cities and communities

1. Introduction

The increasing energy consumption in the building sector, particularly in academic buildings, has been becoming a global concern in order to conserve energy and climate change mitigation (Huang et al., 2022; Kurniawan et al., 2023). Academic buildings such as university, school, and other educational facilities, commonly need a massive energy supply to support learning process, research, and administrative activities. Academic buildings comprise many types of facilities such as classrooms, laboratories, libraries, and administrative offices which each of them requires a different need of energy. Therefore, a systematic and structured approach is needed in designing energy conservation strategies in academic buildings. It is also essential to take into account the resistance to change of the building occupations and the need to maintain the comfort and function of the building when designing this strategy.

Moreover, energy use patterns in academic buildings tend to vary based on academic schedules, weather, and ongoing activities. For instance, energy consumption can significantly increase during exams or intensive research periods. However, it significantly decreases during the holiday period. The implementation of effective energy conservation policies on higher education institutions can reduce operational costs and environmental impacts, as well as enhance the institution's reputation as an ecologically responsible entity (Mohammadalizadehkorde & Weaver, 2018; Sufian Hasim et al., 2020). Previous studies have shown that Interpretive Structural Modeling (ISM) can be helpful in formulating energy conservation policies by uncovering causal relationships between factors such as user awareness, energy-efficient technologies, and incentive policies (Ahmad & Qahmash, 2021; Poduval et al., 2015). Although numerous previous studies have investigated many factors that influenced the use of energy, only few of them have analyzed energy conservation in academic buildings where these factors play a complex relationship and are interrelated (Apdeni et al., 2024; Chou et al., 2023; Efrah Ali & Sarkar, 2024; Pan et al., 2023; Wang et al., 2021). This requires creating a strategic framework which can identify and analyze the factors that influence energy consumption, as well as understanding how those factors interact.

One effective method to describe these complex relationships is Interpretive Structural Modeling (ISM). ISM is an analytical method used to map the relationships between factors in a complex system by identifying hierarchical structure from those factors. Through the ISM approach, various elements that influence the energy system in academic buildings can be identified, ranked based on the level of influence, and analyzed their interaction (Sorooshian et al., 2023). ISM has been used in a variety of contexts, including policy development, supply chain management, and natural resource management (Gorzeń-Mitka, 2019). This method allows whom it may concern to devise structural models that reflect the dynamics and interactions between factors so that they can formulate more effective and targeted strategies (Anwar et al., 2024; Faniama et al., 2024; Liu et al., 2018). Thus, ISM can help decision makers to focus on key factors that have a major influence on energy efficiency, while formulating a more holistic and integrated strategy (Ali et al., 2020). The ISM not only helps constructing policies, but also makes their implementation more effectively (Esad Demirci & Cicek, 2023; Mukeshimana et al., 2021; Sushil, 2018; Wankhade & Kundu, 2020). Therefore, this study uses ISM to identify, analyze, and map the interaction relationship between factors affecting energy conservation in academic buildings. It could provide valuable insights into how structural analysis methods can be used to address energy challenges in the campus environment and contribute to broader sustainability goals.

2. Methods

This study uses a quantitative approach with the Interpretive Structural Modeling (ISM) method. This study was conducted in a higher education institution in West Sumatera, Indonesia. ISM was developed to form a solid concept of the interaction between factors affecting energy conservation in building academics. Furthermore, MICMAC analysis was used to identify indirect relationships between these factors, revising the matrix, and categorizing the factors. Significant factors that affect energy conservation in building academics were identified through a questionnaire. The questionnaire was distributed to the main stakeholders including administrative staff, lecturers, and students. This questionnaire is designed to identify factors that affect energy conservation. The questions in the questionnaire cover various aspects, such as energy awareness, campus policies, and existing conservation initiatives. In addition, in-depth interviews were conducted with several experts in energy and campus management expertise to gain further insight into specific relevant issues. Thus, nine factors affecting the conservation energy in academic buildings were architectural design (E1), illumination technology (E2), education and awareness (E3), energy monitoring and management (E4), renewable energy use (E5), efficient HVAC system (E6), energy saving equipment (E7), institutional policies (E8), and campus community participation (E9).

The contextual relationship between each pair of factors is built on the domain of knowledge, indicating whether or not the factors influence each other. Four symbols were used to express the relationship between two factors (i and j):

V: constraint (i) affects constraint (j), but not the other way around
A: constraint (j) affects constraint (i), but not the other way around
X: constraint (i) and constraint (j) affect each other
O: constraint (i) and constraint (j) do not affect each other

Structural Self Interaction Matrix (SSIM) was converted into a binary matrix called the initial reachability matrix, by replacing those values to 1 or 0 according to the transformation rules listed in Table 1. After obtaining the initial reachability matrix, the sustainability of the transitivity properties should be checked to obtain the final reachability matrix.

Table 1. Initial reachability matrix

If (i, j) Entry in SSIM	Initial Reachability Matrix Input	
	(i, j)	(j, i)
V	1	0
A	0	1
X	1	1
O	0	0

In the ISM model, the first step was the development of the SSIM, where the f-factors of the Energy Conservation actors were compared to the correlation criteria and the four symbols V, A, X, or O. Architectural design (E1) is more important than lighting technology (E2), so the symbol used is V. Campus community participation (E9) is more important than institutional policy (E8), so that the symbol used is A. Education and awareness (E3) are as important as energy monitoring and management (E4), so the symbol used is X. The recapitulation of the SSIM can be seen in Figure 1.

NO	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1		V	X	V	X	V	X	V	X
A2			A	A	A	X	X	X	A
A3				X	V	V	X	V	X
A4					X	V	X	V	X
A5						V	X	V	X
A6							A	X	A
A7								V	X
A8									A
A9									

Figure 1. Structural Self Interaction Matrix (SSIM)

The initial reachability matrix resulted in affordability and a set of factors of its predecessor. For a given factor, the "affordability set" consisted of the factor itself and other factors that might help achieve it, and the "antecedent set" consisted of the factor itself and other factors that might help achieve it. The intersection of this set was derived for all factors. Furthermore, the next step was to convert SSIM into a reachability matrix with the value V, X became 1 and A, O became 0 on (i,j). On the input (j,i), the value of A,X became 1 and V,O became 0. The reachability matrix can be seen in Figure 2.

NO	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1	1	1	1	1	1	1	1	1
A2	0	1	0	0	0	1	1	1	0
A3	1	1	1	1	1	1	1	1	1
A4	0	1	1	1	1	1	1	1	1
A5	1	1	0	1	1	1	1	1	1
A6	0	1	0	0	0	1	0	1	0
A7	1	1	1	1	1	1	1	1	1
A8	0	1	0	0	0	1	0	1	0
A9	1	1	1	1	1	1	1	1	1

Figure 2. Reachability Matrix (RM)

The factors for which the affordability and the intersection set were the same as the first level, separated from the other factors for the next level, iteration process. The same level iteration was done repeatedly until all levels of each factor were completed. The initial model of ISM with regard to transitivity was drawn based on the level of each factor and the final reachability matrix. Then, the final version of ISM was calculated by removing the transitivity of the node. The conceptual inconsistencies of the model were tested and corrected (Figure 3). The inconsistency index value obtained in the revision matrix was 11.11%, meaning that the results were quite consistent because they were below 20%.

NO	A1	A2	A3	A4	A5	A6	A7	A8	A9
A1	1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1	1
A3	1	1	1	1	1	1	1	1	1
A4	1	1	1	1	1	1	1	1	1
A5	1	1	1	1	1	1	1	1	1
A6	0	1	0	0	0	1	1	1	0
A7	1	1	1	1	1	1	1	1	1
A8	0	1	0	0	0	1	1	1	0
A9	1	1	1	1	1	1	1	1	1

Figure 3. Revision Matrix

The final matrix (Figure 4) reflected all the direct and indirect relationships between the factors. This matrix was then used to identify the hierarchical level of each factor, aiding in the visualization of the structure of the analyzed system.

NO	A1	A2	A3	A4	A5	A6	A7	A8	A9	DP	R
A1	1	1	1	1	1	1	1	1	1	9	1
A2	1	1	1	1	1	1	1	1	1	9	1
A3	1	1	1	1	1	1	1	1	1	9	1
A4	1	1	1	1	1	1	1	1	1	9	1
A5	1	1	1	1	1	1	1	1	1	9	1
A6	0	1	0	0	0	1	1	1	0	4	2
A7	1	1	1	1	1	1	1	1	1	9	1
A8	0	1	0	0	0	1	1	1	0	4	2
A9	1	1	1	1	1	1	1	1	1	9	1
D	7	9	7	7	7	9	9	9	7		
L	2	1	2	2	2	1	1	1	2		

Figure 4. Final matrix

Based on the driving force and strength of each dependency, the factors in the MICMAC analysis were divided into four groups: Sector I is for the autonomous factors, which were relatively separated from the system and depended mainly on other factors; Sector II is for the dependent factors which mainly relied on other factors; Sector III is for the correlation factors which linked unstable factors and most influenced other factors; and Sector IV is for independent factors which have the ability to independently control other factors (Figure 5).

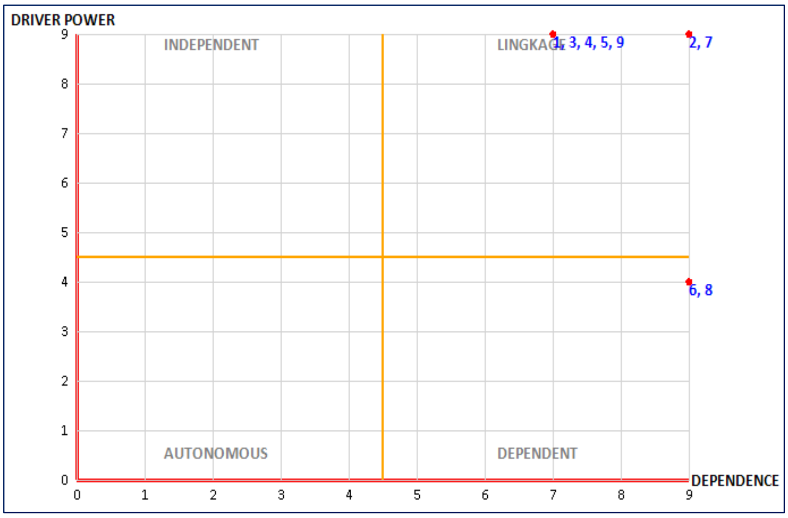

Figure 5. Power driver graph

In sector 3: strong driver-strongly dependent variables (linkage), filled by E1, E2, E3, E4, E5, E7 and E9. Since the relationship between elements was unstable, so it must be studied in depth because the changes will have an impact on other elements. Meanwhile, in sector 2, weak drivers – strongly dependent variables (dependent) containing E6 and E8 were bound to each other.

3. Results and discussion

ISM method resulted in the hierarchical structure of factors affecting the energy conservation in academic buildings (Figure 6). The results of ISM showed a hierarchical structure that identified various factors that influence energy conservation in campus academic buildings. This structure was broken down into three main levels, with each level reflecting the level of influence and interdependence between factors.

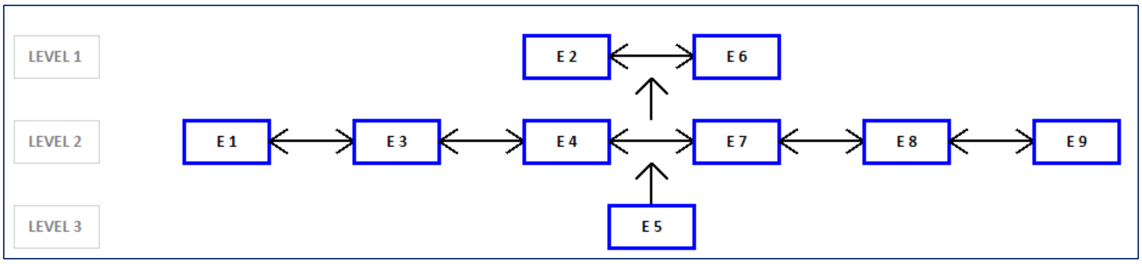

Figure 6. Hierarchical structure

In Level 1, there were two factors, illumination technology (E2) and efficient HVAC system (E6). These factors were the foundation of all ISM models, which means that they were not influenced by other factors in this approach. It showed that efficient lighting technology and HVAC system was the fundamental element in energy conservation strategy in academic buildings. This study found that lighting technology and HVAC systems were the most fundamental factors, confirming the importance of initial investment in this technology. The implementation of energy-efficient lighting technology and efficient HVAC can give a direct impact on reducing energy consumption. Due to its ability to be unaffected by other factors, this technology should be the main priority in planning and budgeting allocation for energy conservation initiatives. This also means that without the implementation of this technology, other energy conservation efforts may not produce optimal results (Lai et al., 2020).

Then, Level 2 were architectural design (E1), education and awareness (E3), energy monitoring and management (E4), energy saving equipment (E7), institutional policies (E8), and campus community participation (E9). This level included factors that were directly influenced by lighting technology and efficient HVAC systems, but had an influence on factors at lower levels. The existence of these factors at level 2 indicates that they were critical elements that were directly influenced by elements at level 1 (illumination and HVAC); it also plays a role in supporting and strengthening other energy conservation initiatives. For example, architectural design (E1) can be optimised to utilize natural lighting and efficient ventilation technologies, which in turn reduces reliance on artificial lighting and HVAC systems. Education and awareness played an important role in shaping the behavior of people on campus towards energy use. When energy-saving technologies are implemented, it is important to ensure that people in the building have sufficient awareness and understanding to operate and utilize these technologies optimally (Ambaum et al., 2024). Likewise with campus community participation (E9), where community involvement can strengthen the acceptance and success of energy conservation strategies. Furthermore, monitoring energy and management (E4) and institutional policies (E8) were two managerial factors which ensure that conservative initiatives can be done and maintained consistently. Effective energy monitoring enables the identification of sustainable energy savings opportunities, while strong policies provide the necessary framework to direct resources and attention to areas that need it the most (Lai et al., 2020).

In level 3, there was the use of renewable energy (E5) in IMS conservation energy strategy hierarchical structure which showed that this factor has a higher dependence on factors at the upper level, such as architectural design, institutional policies, and campus community participation. This indicates that the implementation of renewable energy in academic buildings is strongly influenced by the readiness of basic technology, supporting design, and existing policy frameworks. The use of renewable energy at this level spotted that the initiative to use this option cannot be successful without support from existing infrastructure and adequate policy. For instance, installation of solar panels or other renewable energy systems requires careful integration with existing architectural designs, and their use must be managed through policies that encourage and regulate their use (Algarni et al., 2023).

4. Conclusion

Interpretive Structural Modeling (ISM) was used to analyze energy conservation in academic buildings. Hierarchical structure resulted from this model provides clear guidance regarding the priority and sequence of implementing energy conservation strategies in academic building. Some of the key factors identified include architectural design, lighting technology, energy education and awareness, energy management, renewable energy, HVAC systems, energy-efficient alternatives, institutional policies, and campus community participation. The results of ISM indicate that energy conservation strategy in academic campus building should be started by implementing basic technology such as energy-efficient lighting and efficient HVAC systems. Starting from this point, there should be efforts to strengthen the architectural design, energy management, policy, and education and awareness of people in the building. Once these foundations are established, the campus can focus on renewable energy initiatives to further improve overall energy efficiency and sustainability. By following this hierarchical structure, academic buildings can achieve more effective and sustainable energy management. ISM provides a recommendation that in energy conservation in academic buildings, renewable energy can be used as one of the alternative sources of electrical energy in energy conservation.

Author contribution

Yaumal Arbi: Conceptualization, Methodology, and Software, Aldri Frinaldi: Data curation and Writing- Original Draft, Rembrandt: Data curation and Writing - Review & Editing, Dasman Lanin: Data curation and Writing - Review & Editing, Genius Umar: Visualization and Investigation.

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Conflict of interest

There are no competing interests for all authors.

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