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"Sustaining the Resilient, Beautiful and Safe Cities for a Better Quality of Life"

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ASSESSMENT FRAMEWORK OF BUILDING ENVELOPES ON ENERGY EFFICIENCY FOR PUBLIC BUILDINGS IN MALAYSIA: THE LITERATURE REVIEW

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Abstract

Measuring building envelopes with modern technologies is very important in determining the performance of energy efficiency. It has a significant impact on the environment, comfort for the users as well as energy consumption. Before heating, ventilating, and air-conditioning (HVAC) were introduced in Malaysia, building facades were created as part of passive design strategies for allowing natural ventilation and change in air pressures (stack effect) especially for public buildings. When HVAC was integrated into buildings, the building facades no longer provided these services. This paper aims to develop an assessment framework on the use of appropriate technology for environmentally efficient building envelopes in public buildings. Apart from that, this paper will research the passive design strategies in order to be applied to the public building envelopes that will solve the problems of providing protection against humidity and weather conditions. The approach of Design Quality Indicator (DQI) should be considered to address the quality of building envelope technology and external skin configuration, which includes functionality, build quality, and impact for evaluating qualitative improvements and adding value for the end-users. Highlights and summaries of the literature review will be made so that it can be used as a useful reference and source of advice for the construction business.

***Keywords**: Building envelopes, Energy efficiency, Ventilation, Technology.*

INTRODUCTION

Most of the countries are responsible to reduce the energy consumption of the existing buildings even though if it require additional budget in construction. In most countries, the climate change is projected to have a significant influence. Besides that, Malaysia is known as a tropical climate, which means that the majority of the time it is both hot and humid throughout the year. The tropical environment, which is hot and humid, is one of the most intense and challenging in terms of building design. As a result of global warming, both outdoor and indoor temperatures are going up all over the world (Abdul Tharim & Samad, 2016). In order to mitigate the climate change, the existing buildings will play a major role in reducing their energy consumption. In Malaysia now days, the construction industry have been only concerned about the construction budget and came out with low-cost design especially for public building without using the right mechanism for the environmental purposes. The artificial lighting and air-conditioning system especially from the public buildings have substantial energy consuming within the commercial sector. According to *Pusat Tenaga Malaysia* (PTM), energy audit revealed that the majority of public buildings in Malaysia had Building Energy Intensity (BEI) in the range of 200 to 250 kWh/m²/year and it deviated from the minimum level of BEI (less than 200 kWh/m²/year). Therefore, in order to enhance the building's energy savings, some criteria should be considered and highlighted from the literature review on the use of appropriate technology for the environmentally efficient building envelopes. This paper aims to establish a framework for evaluating the adoption of suitable technology for ecologically efficient building envelopes in public buildings. The main objectives are purposely conducted to investigate the passive design strategies in order to be applied to the public building envelopes and to evaluate the quality of building envelope technology and exterior skin configuration, including functionality, construction quality, and influence on end-users.

LITERATURE REVIEW

Recently, the building envelopes has been used in many construction technology to obtain the optimum performance in building systems in order to improve the indoor environmental quality. Engineering had a significant influence on contemporary architecture, which was ushered in by the Industrial Revolution. The phrase 'Industrial Revolution' refers to the effect of 'engineering' on architecture (Hassan & Al-Ashwal, 2015). During the day, buildings get excessively warm as a result of solar heat uptake via the building envelope and radiant solar penetration through windows. In the same way, it turns out that many of these structures aren't well-planned or managed, which makes the building envelope less efficient at keeping heat in. As a result of shoddy passive thermal design, building cooling or heating loads are increased. Heating, ventilation, and air conditioning (HVAC) systems consume more than 68 percent of all energy, exacerbating the problem of energy waste (Hassan & Al-Ashwal, 2015). Rather than relying only on mechanical systems for heating and cooling, passive design makes use of the sun, wind, and other elements of the environment to keep occupants at a comfortable temperature. Researchers have previously concluded that the market for sustainable buildings is growing because the construction industry has come to realise that sustainable construction may reduce environmental effects and increase the social and environmental advantages of all countries throughout the globe. Apart from that, more owners of public buildings are interested in developing environmentally friendly structures, but it was very little study has been conducted on the construction industry's use of new standards in order to address the concerns of owners. Therefore, several energy conservation techniques may be implemented in the building envelope to reduce peak cooling load, which has a direct influence on cooling energy and, as a result, reduces overall energy consumption (Wang et al., 2005). For example, adding thermal insulation to the outer walls while keeping in mind the right selection of thermal insulation qualities and thickness is among these procedures. The reduction in energy consumption is brought about by installing insulation of 25 millimetres in thickness and replacing all windows with tinted glass (Hassan & Al-Ashwal, 2015). In addition, the impact of wall insulation thickness and its location on peak cooling demand and energy consumption was evaluated. According to the findings of the research, cooling energy consumption might be lowered by around 7 percent by installing thermal insulation on the outside of the envelope walls. The right type of glazing will affect how much heat is lost or gained through the windows, which will cut down on the amount of cooling energy needed to keep the temperature at the right level. The overall energy consumption of the building was reduced by 46 percent for the low-technology plan and by about 50 percent for the high-technology proposal. In the final analysis, good lighting is one of the most important variables in interior comfort, and it has been shown to have a favourable impact on health and productivity. During certain times of the day, the completely transparent facade allows more light in, but it also causes a lot of glare and heat. This means that extra design solutions must be used to avoid these problems. There are two types of building envelope's technologies such as low technology and high technology.

Low Technology

Low technology can be categorised as a simple technology that can be summarised as a simple construction method. In order to provide a stable comfortable environment, they often applied traditional or non-mechanical methods as the passive design strategies (Khalil et al., 2018). Besides that, reusable and recycled materials as well as long term use of building parts also applied in many parts of building in order to minimise energy consumption. Typically, the low technology method is available in most low-cost buildings, low-rise buildings as well as government office buildings. Low technology makes use of passive solar gain or loss devices. To achieve low-tech goals, shading parts, thermal mass, insulation, and natural ventilation should be built correctly. The water wall system is employed in the low-tech plan because it is the simplest, smallest, and most cost-effective means of delivering a significant amount of thermal mass. In conclusion, water walls are made to keep heat in during the summer and let it move around during the winter, so that the highest level of thermal comfort can be achieved.

High Technology

High technology makes the best use of all current potentials, including cutting-edge science, information, materials, and machines. Traditional building materials such as stone, wood, and mud are used in high-tech construction (Khalil et al., 2018). However, it typically uses manufactured materials such as metals, fiberglass, and plastics, through the implementation of advanced procedures such as intelligent facades and high-tech construction methods such as the advanced concept of assembled and disassembled buildings.

A Set of Tactics

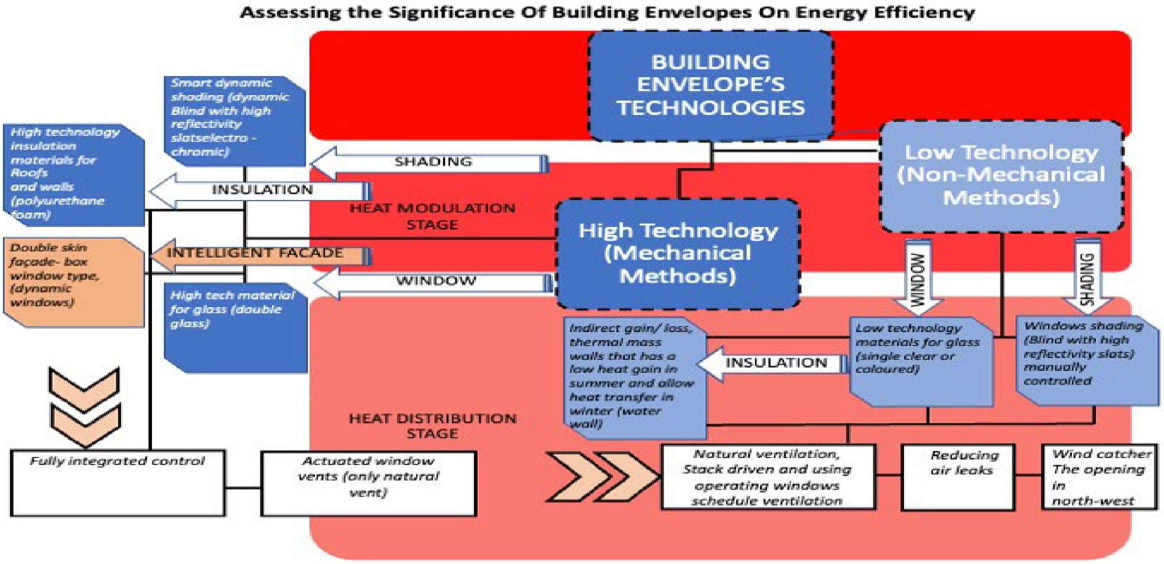
Additionally, technologies utilised in building envelopes should aid in the application of economic advantages throughout the course of the structure's life cycle, enable light transmission without the transfer of heat, and minimise energy consumption for cooling, heating, and lighting. These systems should take into account international requirements for indoor air quality, health, comfort, moisture management, noise control, and protection of the interior environment from external toxins, as well as use renewable energy resources. Numerous research conducted in low-income nations has shown that they rely on low-tech solutions to achieve thermal comfort since they have a positive influence on energy consumption reduction (Khalil et al., 2018). Nevertheless, solar radiation and ventilation are controlled manually in all components of the building envelopes, most notably the shading elements, using minimal technology.

High Technology Strategies

The intelligent skins may be modified dynamically without affecting the fabric of the structure in order to lower the building's energy consumption and enhance the interior atmosphere. As Walter Kroner has said, ''intelligent design means striving to have outbuildings in harmony with nature, to protect its qualities, and to recognize its dynamic (and unpredictable) qualities, whether assets or liabilities" (Wigginton and Harris, 2002). Similarly, a double skin facade as a kind of intelligent skin. It is a technology that entails the installation of a second glass exterior, which allows for increased daylighting and energy efficiency. The double facade lowers solar gain throughout the day.

A natural stack effect aids in the movement of air and the reduction of heat (Khalil et al., 2018). In addition, the construction of double skin facade, which includes glass and shutters, reflects solar radiation back into space. The double facade works as a buffer zone between the building and the surrounding environment, reducing heat loss and lowering U-values while maintaining or enhancing energy efficiency. It also serves as a heat absorber in certain cases. The types of building envelope's technologies is provided in Figure 1.

Figure 1
Types of Building Envelope's Technologies



Building Envelope Criteria

In construction regulations, energy and cost efficiency are prioritised, followed by resource efficiency. Retrofitting buildings should be done to a high quality of energy efficiency and at an affordable cost (Cronhjort, 2018). The structural state of the building, energy efficiency (including thermal insulation and airtightness), user happiness, and architectural image are the building aspects that are often addressed in a facade retrofit (quality) (Cronhjort, 2018). Even though there are not many options to increase accessibility as part of a building envelope retrofit, it is still vital to make accommodations for individuals who need them due to the ageing of the general population. The Design Quality Indicator (DQI) was created by the Construction Industry Council in 1990. In 2003, it was introduced online in the United Kingdom. This is clearly that, the methodology was based on the three-pronged approach of DQI, which includes functionality, build quality, and impact for evaluating qualitative improvements and adding value for the end-users. In fact, this is specifically include accessibility, ventilation, lighting conditions, the building's structural frame, exterior cladding (facade material), window U-value, thermal insulation, airtightness, the building's aesthetic appeal, and its volume (form). All of these factors also impact the user experience of the façade, building, and living areas. The factors are assessed on a scale ranging from 0 to 3. Since the goal should be to improve the user experience, negative ratings that show that some parts are getting worse are not taken into account. The assessed characteristics are provided in Table 1.

Table 1
Suggested criteria and scale to evaluate building envelope

Level of measures		Minor Improvement	Upgraded	Excellent
Score		**1**	**2**	**3**
USER EXPERIENCE (FUNCTIONALITY)	Accessibility	Small changes including, for example, added handrails	Accessibility on the refurbishment design agenda	Accessibility measures like an improved access to the balcony / added new balconies to facilitate outdoor areas to apartments
	Ventilation	Openable windows or air inlets, mechanical exhaust air system	Openable windows and air inlets, mechanical exhaust air system	Air ventilation system with heat recovery
	Light	Small changes including, for example, narrower window frames	Limited amounts of larger window area or some new, additional windows	Extensive amount of larger window areas and/or new windows
ENGINEERING AND ENERGY EFFICIENCY (BUILD QUALITY)	Frame of the facade	Maintenance and repair work	Structurally improved	New
	External cladding/ facade material	Repair of the Existing material	New, maintenance requirements close to original	New, expected lifetime up to 50 years or more, limited maintenance requirements
	Windows U-value	New windows, Uvalue less than current building regulations for new built or national aim for building retrofits	New windows, according to current building regulations for new built or national aim for building retrofits	New windows, average value of all windows as installed $U \leq 0.85$ W/(m²K) in accordance with the EnerPHit suggestion (Feist, 2010)
	Thermal insulation	Added thermal insulation as compared to state prior to façade retrofit	According to current building regulations for new built or national aim for building retrofits	Passive house level local standard or better
	Airtightness	Minor repair	According to current building regulations for new built or national aim for building retrofits	$n50 \leq 1.0$ h-1 as a limit, target value $n50 \leq 0.6$ h-1 in accordance with the EnerPHit suggestion (Feist, 2010)
ARCHITECTURAL QUALITY (IMPACT)	Visual appearance of the building	Small changes in visual appearance affecting only parts of the building	Aim to change visual appearance of the single building by e.g. changes in a	Aim to change visual appearance of the single building and affect the

		monotonous original visual image of the building; visual changes limited	surrounding built environment by, for example, changes in a monotonous original visual image of the building; strong architectural vision
Building volume/form	Small changes affecting only parts of the building	Aim to change visual appearance of the single building by e.g. changing the original building volume with a new roof; visual and structural changes limited	Aim to change visual appearance of the single building and affect the surrounding built environment by, for example, changes in the building volume like building extensions; strong architectural and structural vision

(Yrsa Cronhjort, 2018).

Building Performance

The selection of the façade is determined by the available materials, the kind of structure, and aesthetic needs (Jovanović et al., 2022). The highest feasible thermal insulation is a fundamental function of the facade. Through so-called "thermal bridges," inadequate thermal insulation may result in significant heat losses and gains, resulting in a cost increase of around 20 percent. Thermal bridging in buildings reduces how well they use energy and lets condensation and thermal comfort problems happen, which can lead to problems with indoor air quality and damage to the building itself. Thermal Insulating Rendering Mortars (TIRM) are used to increase the energy efficiency of the envelope of renovated and new buildings (Silvestre et al., 2019). It may be used as an exterior or interior finish or as exterior wall insulation. The primary characteristic of TIRMs is their low thermal conductivity, which is achieved by substituting lightweight particles for sand in the mixture. The building's envelope is one of the parts that significantly influences the 3E (environmental, economic, and energy) performance of a building (Silvestre et al., 2019). The building's external walls influence directly the 3E performance of the building's envelope due to their large weight within the envelope's initial whole-life cost, life cycle energy consumption, embodied energy, and users' comfort. So, it's important to have a system that compares different options and helps choose the best one to use in every new or updated building envelope design. Therefore, if the building envelope is constructed properly, fewer mechanical systems will be required to provide the ideal thermal comfort conditions.

METHODOLOGY

Systematic Literature Review

Systematic literature reviews provide an established methodological strategy for assessing empirical data from a variety of fields, often including results from both qualitative and quantitative research (McAndrew, 2021). Consequently, this systematic literature evaluation adheres to the outlined procedures for enhancing the evidence foundation for energy policy. Scopus and Science Direct were used in the search for relevant material. These databases include over 100 records of published research in the disciplines of building envelope technology and external skin configuration, such as functionality and construction quality. The steps of the review process, as shown in Table 2, begin with a clear explanation of the research topic or questions to be answered, followed by an intensive search of the existing literature. Then, the quality of the included studies is evaluated using clear and standardised criteria, and lastly, the findings are objectively summarised and synthesised.

Table 2
The phases of the systematic review method

Stages	Details
Review Questions	The clear question to be answered and/or hypotheses to be tested.
Search Process	Attempt to locate all relevant published and unpublished studies to limit selection bias.
Study Quality Assessment	Examine in a systematic manner the methods used and investigate potential biases and sources of heterogeneity between study results.
Synthesis	Base conclusions on the studies which are most.

(Steve Sorrell, 2007).

For the purposes of this study, each study's evidence of how well it worked was judged based on how well it measured up.

Research Questions (RQ)

The following research questions were addressed to achieve the purpose and objective of the study:

RQ 1: Which theories and conceptual frameworks are used for environmentally efficient building envelopes in public buildings?

RQ 2: Which technologies are used to evaluate the quality of building envelope technology and exterior skin configuration, including functionality, construction quality, and influence on end-users?

RESULT

As per the hypothesis, it is expected that the Design Quality Indicator (DQI) for public buildings would be able to represent the ultimate thermal comfort of the spaces, therefore resolving the challenges associated with providing protection from humidity and weather conditions. In addition, it is anticipated that the users of the public buildings would have the highest levels of experience satisfaction. Therefore, this study will be a beneficial reference for architects and developers in the process of constructing good design quality especially for public buildings through the implementation of suitable building envelopes for hot and humid countries like Malaysia. This study will help evaluate the quality of building envelope technology and exterior skin configuration, including functionality, construction quality, and influence on end-users. Moreover, this study will be a beneficial reference for architects and developers in the process of constructing good indoor thermal comfort buildings.

DISCUSSION AND CONCLUSION

This paper offers assessment technique options for assessing environmental effects or architectural excellence. However, an evaluation of a building based only on quantitative indicators does not adequately represent the use appropriate technology for environmentally efficient building envelopes. There is not yet an established procedure for thoroughly assessing the efficacy of proposed new building envelopes. This paper suggests a set of evaluation criteria reflecting the quality and extent of refurbishment measures undertaken in a facade retrofit. Variables are narrowed down to aspects of the building envelope. The suggested qualitative evaluation approach is reflective of the results of a facade upgrade in terms of end-user satisfaction and enhancements to the building's functionality, construction quality, and effect.

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