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A NARRATIVE REVIEW TO ACHIEVE NET-ZERO ENERGY HOMES IN MALAYSIA

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ABSTRACT

Malaysia is heavily reliant on fossil fuels for electricity production but aims to reduce carbon emission intensity by 45% by 2030 and achieve net zero carbon emission by 2050. As residential buildings are one of the major energy consumers, achieving net-zero energy in homes is essential. This paper reviews the development of Net-Zero Energy Homes (ZEHs) globally and evaluates their relevance to Malaysia's tropical climate. A narrative review approach was used to examine ZEH definitions, energy consumption factors, and green retrofitting strategies. The findings highlight the need for tailored policies and design standards suited to the local climate and socio-economic conditions. Recommendations are proposed to guide future development and policy actions for achieving energy-efficient residential housing in Malaysia.

Keywords: Net-Zero Energy Homes, Building Energy Consumption, Residential Buildings in Malaysia, Sustainable Retrofit, Green Intervention Features.

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1. INTRODUCTION

The global climate is drastically changing. The Intergovernmental Panel on Climate Change (IPCC) 2018 report urged to limit the global warming within 1.5°C to avoid catastrophic effects on the ecosystems (Hoegh-Guldberg et al., 2018). Since 2010, the global energy consumption has doubled due to higher heating and cooling demands, resulting increased demand for fuels, especially natural gases. Therefore, energy-related CO2 emissions soared 1.7% to a historic high of 33.1 Gt CO2 (IEA, 2019). Current policies are estimated to cause global energy-related CO2 emissions to peak by 2025, at 37 billion tonnes (Gt) annually, which then will decrease to 32 Gt annually by 2050. The outcome will be a 2.5 °C rise in the global average temperatures by 2100. To ensure the 1.5 °C stabilisation in the rise in global average temperature, the annual CO2 emissions should be reduced to 23 Gt by 2030 and to net zero by 2050 (International Energy Agency, 2022).

In 2021, the building sector consumed about 135 EJ of energy, or 30% of global final energy consumption. Electricity accounted for 35%, which 6.5% used for space cooling. Buildings contributed 27% of total energy sector emissions with 8% from direct emissions, while 19% are produced by electricity and heat consumed in buildings (IEA, 2022). Most carbon emission (80-90%) is produced during the operating stage of a building (UNEP-SBCI, 2010). For instance, a high-rise residential housing block in Hong Kong in showed 85.82% of GHG are contributed by operating energy (Yim et al., 2018). Typically, embodied GHG emissions in buildings is approximately 20–25% of overall life cycle GHG emissions. However, it can reach 45–50% for highly energy-efficient buildings and over 90% in extreme cases (Röck et al., 2020).

Malaysia's urbanization rate increased to 24.4 million (75.1%) in 2020 as compared to 19.5 million (70.9 %) in 2010, with urban households reaching 6.3 million (76.6%) (Department of Statistics Malaysia, 2022). This caused increased energy consumption in residential buildings, primarily due to usage of modern home appliances (Hassan et al., 2014; Suratman et al., 2018). Globally, residential buildings accounted for 21.2% of total final energy consumption in 2021. In Malaysia, residential buildings contributed 5.2% of the final energy consumption which include fossil fuels and electricity in 2018 (Energy Commission, 2020a). The residential sector consumed 33,322 kWh of electricity (21%) out of the total annual national electricity consumption in 2019 (Energy Commission, 2020b).

Net-Zero Energy homes (ZEH) are increasingly becoming more popular to achieve building energy efficiency in many countries (Berry et al., 2014). Musall et al. (2010) discovered that over 280 residential net zero energy buildings in USA, Canada, Europe and the UK adopt key strategies for energy reduction such as passive solar strategy, good insulation, energy efficient appliances and photovoltaics panels. Studies shown that energy savings level and performance of ZEH can be maintained in cold climates (Berry et al., 2014).

While significant progresses have been made in the development and implementation of ZEHs in temperate and cold climate regions, limited attention has been given to their applicability in tropical climates. Most existing studies and policy frameworks are designed for regions with distinct seasonal variations, which differ greatly from the year-round heat and humidity experienced in tropical countries like Malaysia. This lack of contextualised research and policy guidance presents a critical gap in the literature. Therefore, this study aims to address this gap by reviewing global ZEH strategies and assessing their relevance, adaptability, and challenges in the Malaysian context.

This paper begins by introducing the evolution and definition of Zero Energy Building (ZEB) and then the development of net zero energy homes. The net zero carbon goal, the established ZEB standards for residential buildings as well as the existing efforts to develop ZEBs in Malaysia are explored. This paper also discusses on the factors affecting residential building energy consumption. Conclusively, this paper provides perspectives and recommendations for advancement and retrofitting of existing residential buildings towards achieving ZEH.

The aim of this research is to comprehensively review and analyse the present state of ZEH development in the global context and the applicability in Malaysia. By identifying the factors influencing residential energy consumption and evaluating green interventions for retrofitting existing homes, this study seeks to provide insights and recommendations for policymakers, practitioners, and scholars to facilitate the transition towards building and retrofitting sustainable high-rise and landed residential buildings in Malaysia.

The objectives of this study are: (1) to identify terms and definitions of ZEBs and ZEHs in the global and Malaysia context; (2) to investigate the factors influencing residential building energy consumption; (3) to identify green intervention features for retrofitting of existing residential buildings; and (4) to identify the challenges in the implementation of ZEHs in Malaysia and propose potential pathways for future development.

2. METHODOLOGY

This study adopts a narrative review methodology to synthesise current knowledge on the development of ZEHs and their applicability in Malaysia. A narrative review is considered appropriate due to the interdisciplinary nature of the topic, which encompasses energy policy, building design, climate adaptation, and socio-economic considerations. Unlike a systematic review, which requires narrow and highly specific research questions, the narrative approach allows for broader exploration and contextual analysis, which is crucial for emerging fields such as ZEHs in tropical regions.

The literature search was conducted using Scopus and Web of Science databases. Keywords used in the search included: "Net-Zero Energy Homes", "Zero Energy Buildings", "residential energy consumption", "green retrofit", and "energy efficiency in tropical climates". The search was limited to peer-reviewed journal articles, conference papers, and policy documents published between 2006 and 2023.

The inclusion criteria were:

- Publications related to residential buildings or homes.
- Articles addressing energy efficiency, renewable energy, or retrofitting in the building sector.
- Studies relevant to tropical or Southeast Asian climates.

The exclusion criteria were:

- Studies focused solely on commercial or industrial buildings.
- Articles not written in English.
- Publications lacking empirical or technical content.

After removing duplicates and irrelevant titles, 93 publications were selected for full-text review and thematic analysis. The findings were categorised into five key areas: ZEH definitions and evolution, global and local standards, factors influencing energy consumption, green retrofit strategies, and challenges and opportunities in the Malaysian context.

3. TERMS AND DEFINITIONS

The concept of a "net zero energy house" was first introduced in Belgium in 2009 and it is being revised for consistency with inadequacy and new issues every year (Mlecnik et al., 2011). The earliest definition and classification of NZEB is identified by Torcellini et al. (2006), which the primary definitions of NZEBs consists of net zero site energy, net-zero source energy, net-zero energy costs and net zero emissions. An NZEB is defined as "a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies" (Torcellini et al., 2006). Furthermore, another foundational publication classified the NZEB definitions by the type of renewable resources: (1) footprint renewables; (2) on-site renewables; (3) imported renewables; and (4) off-site purchased renewables (Pless & Torcellini, 2010).

To achieve a NZEB, significant reduction in energy consumption is needed while maintaining the quality of indoor and outdoor environments as well as incorporating renewable energy to offset the remaining energy consumed by the building operation. The generation and consumption of renewable energy is a crucial element in the planning and design stage of a ZEB. However, priority should be given to minimizing the energy consumption by passive and active design approach. For example, implementation of energy-efficient active systems, and utilization of energy management systems that optimize building energy performance (ISO, 2021).

The International Organisation for Standardization (ISO) have introduced a three-tiered nomenclature for ZEBs as illustrated in Figure 1 to accommodate the limitations of achieving a NZEB immediately due to regional and climatic circumstances, high initial investments, etc (ISO, 2021).

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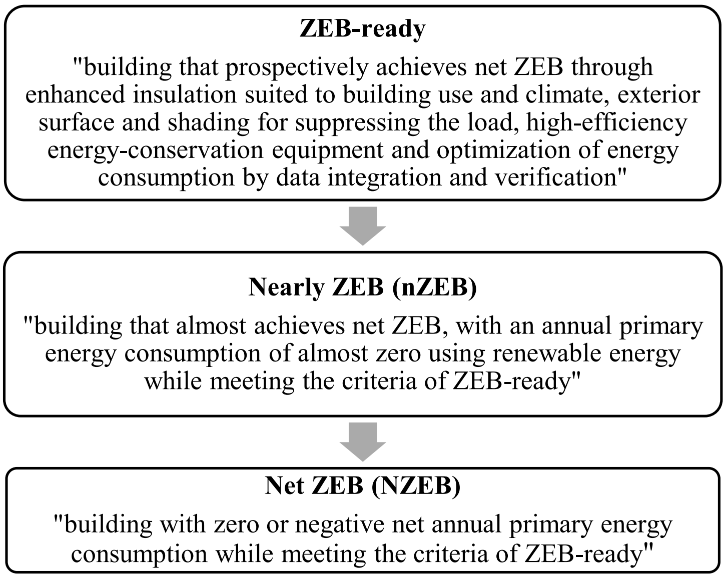

Figure 1**:** Three-tiered nomenclature for ZEBs (Source: ISO, 2021).

4. NET ZERO ENERGY HOMES

Globally, the majority of the zero energy buildings are low rise buildings (Lin et al., 2020). Wu and Skye (2021) reviewed that among NZEBs, residential NZEBs constitute the majority and are primarily concentrated in Europe and North America. Li (2018) verified that for residential buildings achieving net -zero energy consumption, the highest number of storeys typically does not exceed three, with energy solely supplied by photovoltaic panels installed on the roof. Pettit et al. (2015) summarized the ten crucial principles for designing ZEHs as follows, namely:

1. Prioritize design for both comfort and functionality;
2. Establish a building enclosure that is airtight;
3. Implement controlled ventilation systems;
4. Incorporate insulation that exceeds current energy code requirements;
5. Ensure effective control of water and moisture movement within the building enclosure;
6. Optimize building orientation for maximized renewable energy production;
7. Choose efficient mechanical equipment;
8. Choose efficient lighting, plumbing fixtures, and appliances;
9. Utilize energy modelling to forecast total building energy consumption, determine on-site renewables sizing, and identify high-impact enhancements to energy efficiency; and
10. Develop project plans that coordinate and oversee the commissioning of systems.

5. ZEB STANDARDS FOR RESIDENTIAL BUILDINGS

In 2016, the European Commission have published its benchmark thresholds for primary energy across the European Union based on four main climatic zones: (a) Mediterranean; (b) Oceanic; (c) Continental; (d) Nordic. The recommended benchmark values for single family houses are summarized in Table 1. Based on the recommended benchmark values, the countries in milder climates are anticipated to have both the lowest net primary energy requirements and the highest portion of renewables. To summarize, the benchmark range by the European Commission with reference to the primary energy threshold including supplied from renewable sources is 50 to 90 kWh/m^2/year for single family houses (BPIE (Buildings Performance Institute Europe), 2021).

Table 1: Recommended benchmark values for single family houses in the EU

Climates in the European Union	Net primary energy (kWh/m^2/year)	Energy supplied from renewable energy sources (kWh/m^2/year)	Primary energy threshold including that supplied from renewable sources (kWh/m^2/year)	Renewables as % of total primary energy (based on mid-point)
Mediterranean	0-15	30	50-65	87%
Oceanic	15-30	35	50-65	61%
Continental	20-40	30	50-70	50%
Nordic	40-65	25	65-90	32%

(BPIE (Buildings Performance Institute Europe), 2021)

The ISO/TS 23764:2021 Methodology for Achieving Non-residential ZEBs that outlines the annual energy consumption of a ZEB and renewable energy supply can be used as a reference for designing nearly zero energy homes (nZEH) in Malaysia as it is applicable to all climate zones.

In the Malaysia context, there are limited standards for nearly zero energy residential buildings. Lojuntin (2022) stated that the energy consumption to achieve zero energy consumption for new non-residential buildings should be targeted to be at least 50% lower than the baseline as per minimum energy consumption stated in MS1525. MS1525:2019 states that the Building Energy Intensity (BEI) Benchmark for office building is 200 kWh/m^2/year (Department of Standards Malaysia, 2019). Besides, the total energy reduction should consist of energy efficient measures that contribute minimum 50% reduction from the baseline energy. MS2680:2017 outlines the guidelines on the design, selection of materials and electrical appliances and efficient use of energy including the application of renewable energy in new and residential buildings.

The requirements for the energy efficiency criteria for certified green residential buildings by Green Building Index (GBI) Malaysia are outlined in Table 2. The requirements by GBI Malaysia can be used as a reference to design a nZEH in Malaysia.

Table 2: Energy Efficiency Criteria by GBI Malaysia

GBI Code	Energy Efficiency Criteria	Description	Requirements
EE1	Minimum Energy Efficiency Performance	Establish minimum energy efficiency (EE) performance to reduce energy consumption in buildings, reducing CO_2 emission to the atmosphere.	• OTTV ≤ 50 • RTTV ≤ 25 • Roof U-value ≤ 0.4 W/m²K (Lightweight), • U-value ≤ 0.6 W/m²K (Heavyweight).
EE2	Renewable Energy	Consumption of renewable energy to offset energy cost and promote green energy use.	Low rise residential buildings: 20% to 100% or 1kWp to 5 kWp of total electricity consumption is generated by renewable energy.
EE3	Advanced Energy Efficiency Performance Based on OTTV & RTTV	To provide a thermally comfortable environment to reduce the consumption of air-conditioning in residential building, thereby reducing CO_2 emission.	• OTTV: ≤ 46 W/m² • Lightweight Roof U-value: ≤ 0.35 W/m²K • Heavyweight Roof U-value: ≤ 0.5 W/m²K
EE4	Home Office and Connectivity	To encourage dual use spaces and working from home, thereby discouraging commuting, and reducing CO2 emission	Multiple use type developments, OR High-Speed Internet access available at homes > 1MB/s.

(GBI, 2010).

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Table 3 provides a comparative overview of international and Malaysian standards related to ZEBs and ZEHs. The European Union (EU) benchmarks offer specific primary energy thresholds that vary by climatic zones, emphasising a high share of renewable energy integration. Similarly, the ISO/TS 23764:2021 provides a flexible, climate-adaptive methodology applicable across regions, although it is primarily targeted at non-residential buildings. In Malaysia, the MS1525:2019 serves as the main guideline for non-residential energy performance, while MS2680:2017 outlines design strategies for residential buildings, focusing on energy efficiency and passive design. Additionally, the Green Building Index (GBI) provides residential-specific performance criteria, including renewable energy targets and envelope performance benchmarks. Unlike EU standards, Malaysian standards are less prescriptive, often serving as voluntary or advisory guidelines, which highlights the need for more robust, enforceable standards tailored to local residential building conditions.

Table 3: Comparison of International and Malaysian ZEB/ZEH Standards

Standard/ Guideline	Region	Building Type	Primary Energy Threshold	Renewable Energy Requirement	Key Notes
EU ZEB Benchmarks (BPIE, 2021)	European Union	Single-family residential	50–90 kWh/m²/year (varies by climate zone)	High share: up to 87% in Mediterranean zones	Climate-specific thresholds for Mediterranean, Oceanic, Continental, Nordic
ISO/TS 23764: 2021	International	Non-residential buildings	Not specified (flexible, climate-adaptive)	Encourages onsite RE, prioritising energy reduction	Defines tiered approaches to accommodate climate/investment constraints
MS1525:2019	Malaysia	Non-residential buildings	BEI: ≤ 200 kWh/m²/ year (office buildings)	Encouraged but not mandatory	Focuses on passive design and minimum HVAC efficiency; references ASHRAE.
MS2680:2017	Malaysia	Residential buildings	No fixed BEI, but design guidance given	RE use encouraged (e.g., PV), with recommendations on appliance efficiency	Provides voluntary guidelines on material selection, envelope design, and RE integration
GBI Malaysia (Residential New Construction Guide)	Malaysia	Low-rise residential	OTTV ≤ 50, RTTV ≤ 25	20–100% electricity offset by RE (1–5 kWp typical PV range)	Includes points for RE, high insulation, and shading; scoring-based system.

6. EFFORTS TO DEVELOP NEARLY TO NET ZERO ENERGY BUILDINGS IN MALAYSIA

The Malaysian government have introduced many policies and plan to commit to reduce greenhouse gases emissions by 45% by 2030 compared to 2005 levels and to be a carbon-neutral country by 2050 in the Paris Agreement (UNDP, 2023).

The Green Technology Application for the Development of Low Carbon Cities (GTALCC) is an ongoing 5-year national project that is funded by the Global Environment Facility (GEF), conducted by UNDP Malaysia in conjunction with the Ministry of Energy, Science, Technology, Environment and Climate Change. The project aims to provide policy support to promote integrated low carbon urban development; create awareness and institutional capacity development as well as encourage low carbon technology investments and demonstration projects in cities. The GTALCC project is aimed to generate greenhouse gases emissions reduction of 346,442-ton CO2-eq by the completion of the project (GTALCC, 2022).

The Sustainable Energy Development Authority (SEDA) Malaysia have introduced the ZEB Facilitation Programme that has the objective: "to promote the adoption of super low carbon green building by using alternative method focusing purely on sustainable energy practices, starting with advanced energy efficiency (EE) measures in reducing overall energy demand or consumption and offsetting the balance of minimum energy needed by using on-site renewable energy (RE)" (SEDA Malaysia, 2019). SEDA Malaysia have introduced the Sustainable Low Carbon Building Assessment by using UNEP-SBCI Common Carbon Metric or CIDB's CIS20-GreenPASS as an assessment tool to evaluate the achievement of initiatives on sustainable energy low carbon buildings in Malaysia (SEDA Malaysia, 2021).

The Kuala Lumpur Climate Action Plan 2050 (KLCAP2050) was introduced in 2021 by the Kuala Lumpur City Hall (DBKL) to facilitate the achievement of carbon-neutral city by 2050 (Kuala Lumpur City Hall, 2021b). The KLCAP2050 have introduced the development of a Near Zero Emissions Building (nZEB) roadmap that outlines the minimum requirements, timeframes for periodic performance rating assessments and implementation considerations (Kuala Lumpur City Hall, 2021b). DBKL will ensure that the Low Carbon Building (LCB) Checklist specifications in incorporated into the One Stop Centre approval process. DBKL envisions that 75% of Kuala Lumpur's building will meet the checklist's standards by 2025 while targeting more than 30% of all buildings to meet minimum energy consumption targets before 2050. (Kuala Lumpur City Hall, 2021a).

To achieve a near zero energy building scenario in 2040, the Energy Efficiency and Conservation Act (EECA) 2024 was gazetted in November 2024 and came into force on 1 January 2025 (Suruhanjaya Tenaga, 2025). The act establishes mandatory standards for energy performance, including comprehensive building energy codes, energy intensity labelling, and minimum energy performance standards for appliances across both residential and commercial sectors. Under EECA, the Energy Commission is empowered to enforce these standards, require energy audits, and register energy managers and auditors. It also mandates revisions to existing standards, such as MS1525 and MS2680 to align with updated Building Energy Intensity (BEI) targets needed to realize the near-zero-energy objective. Figure 2 summarizes the conceptual model of near zero energy building to be implemented in Malaysia which comprises of three main aspects: construction, operations, and maintenance (Ministry of Energy Green Technology and Water Malaysia, 2017).

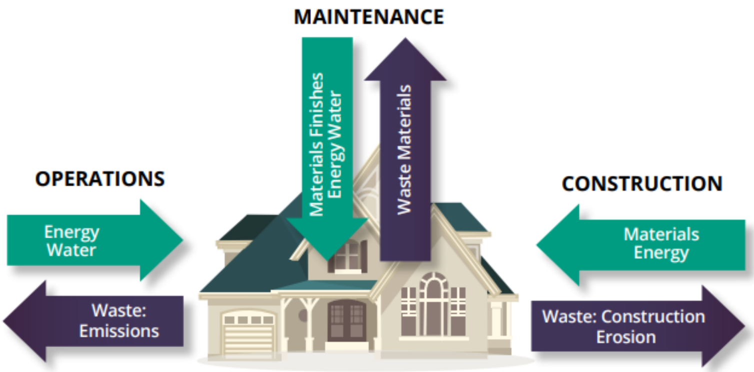

Figure 2: Conceptual Model of Near Zero Energy Building
(Source: Ministry of Energy Green Technology and Water Malaysia, 2017)

7. FACTORS INFLUENCING RESIDENTIAL BUILDING ENERGY CONSUMPTION

Energy efficiency is the capability of a building to provide adequate comfort conditions with minimum energy (Bektas Ekici & Aksoy, 2011). Yu et al. (2011) identified seven categories influencing building energy consumption: (1) climate; (2) building characteristics; (3) occupants' characteristics; (4) building systems; (5) occupants' behaviour; (6) social and economic factors; and (7) indoor environmental quality. Furthermore, Fathi et al. (2015) identified that building services, building envelope, climate, and human factors as the key contributors to energy consumption. Kim et al. (2022) highlighted that residential energy consumption factors, emphasizing energy use information, occupancy rates, and indoor environment parameters such as temperature and humidity. In a nutshell, the scope of this study focuses on human factors, passive design factors and active design factors as summarized in Figure 3, to comprehensively address building energy efficiency.

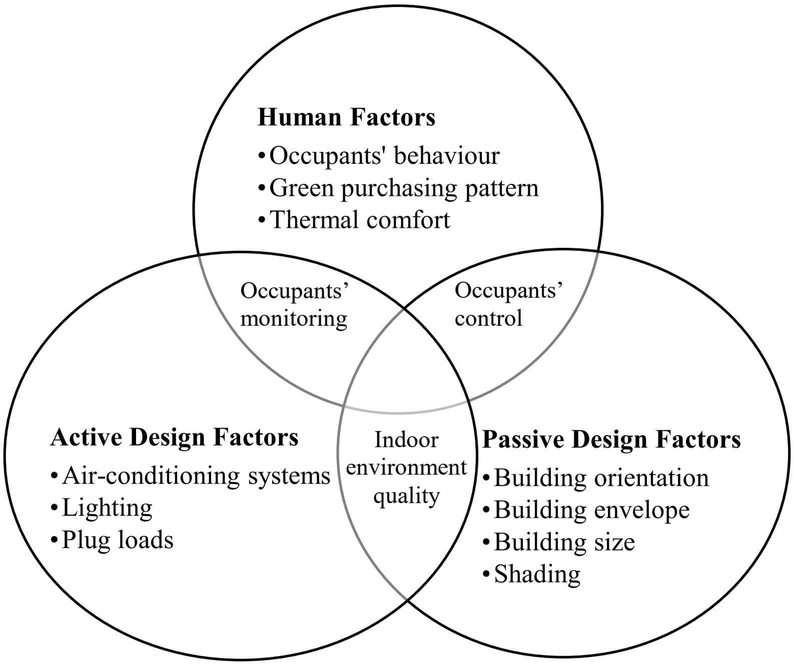

Figure 2: Factors affecting energy consumption in buildings. (Source: Author, 2024)

7.1 Human Factors

7.1.1 Occupants' behaviour

Building occupants' behaviour has a significant influence on the building energy consumption. Previous studies have proved that electricity is wasted due to occupant's negligence and lack of awareness (Chakraborty & Pfaelzer, 2011; Lindelöf & Morel, 2006; Mann & Becerik-Gerber, 2012; Masoso & Grobler, 2010). In addition, Lindelöf and Morel (2006) as well as Pan et al. (2017) discovered that the impractical design of switches contributes to occupants' reluctance to switch off building systems when they are not in use.

7.1.2 Thermal Comfort

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55 defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE Standard 55, 2017). Table 4 shows the 7-point thermal sensation scale which is based on the human body's heat balance. Thermal balance will be achieved when the internal heat production of human body is equivalent to the loss of heat to the environment. In a moderate environment, the thermoregulatory system of the human body will try to modify skin temperature and secrete sweat to maintain heat balance (ASHRAE Standard 55, 2017; ISO 7730:2005, 2005).

Table 4: 7-point thermal sensation scale

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

(ISO 7730:2005, 2005)

In Malaysia, buildings equipped with air-conditioning and mechanical ventilation (ACMV) system adhere to the Malaysian Standard (MS) 1525 code, referencing the ASHRAE Handbook. The MS1525:2019 specifies ideal thermal comfort conditions: relative humidity between 50% to 70%, room temperature within 24°C to 26°C and air velocity maintained within 0.15 m/s to 0.50 m/s (Department of Standards Malaysia, 2019). Despite this, studies show that Malaysians tend to prefer cooler indoor environments, even when within the bounds of thermal comfort (Aliagha & Cin, 2013; Taib et al., 2022).

7.1.3 Adaptive Behaviour

Building occupants often adapt to thermal discomfort though behavioural adaptations (Indraganti et al., 2013). de Dear and Brager (1998) categorized these behavioural adjustment into: (1) personal (e.g., removing clothes); (2) technological (e.g., turning on an air-conditioner); and (3) cultural responses (e.g., having a siesta in the heat of the day). Nicol et al. (2012) outlined the five basic types of adaptive actions such as: regulating the rate of internal heat generation; regulating the rate of body heat loss; regulating the thermal environment; selecting a different thermal environment; and modifying physiological comfort conditions.

However, such adaptive behaviour can lead to increased building energy consumption. Studies in Malaysia revealed that the most common adaptive actions among building occupants are switching on the air-conditioning system and adjusting the set-point temperature of air-conditioning to achieve thermal comfort (Damiati et al., 2016; Zaki et al., 2017).

7.2 Passive Design Factors

Sustainable building design substantially lowers energy demand. Factors like building orientation, shape, and the ratio of external surface to building volume have a significant impact on energy demand (Pacheco et al., 2012) The building envelope, comprising elements separating the indoor and outdoor environment, plays a significant role in energy consumption, as it influences the indoor heat accumulation (Azis, 2021; Sadineni et al., 2011). Passive design strategies, such as well-designed facades with sun shading devices, site planning, and efficient daylighting strategies based on sun movement, are crucial in maximizing daylight and optimizing thermal comfort (Department of Standards Malaysia, 2019). Adopting adaptive passive designs, such as external shading devices and cool roofs, has shown a 33% reduction in cooling demand during summer, significantly impacting building energy consumption (De Masi et al., 2021).

7.3 Active Design Factors

Birkha Mohd Ali et al. (2021) found that in Malaysian institutional buildings, air-conditioning system were the largest electricity consumers at 34%, followed by lighting (18%), server racks at 17% and other appliances (7%). Similarly, Tahir et al. (2015) observed that air-conditioning system consumed the most energy at 51%, followed by lighting system (34%), plug load at 8% while other office appliances at 7% in his study on three Malaysian government office buildings.

Comparatively, Kim et al. (2011) discovered in their study that HVAC systems had the most significant impact on building energy consumption compared to other elements such as lighting efficiency, control systems, and building construction materials. The rising demand for space cooling due to climate change has amplified the need for electricity capacity, which can be expensive to maintain for peak demand periods. Moreover, global CO_2 emissions from cooling have tripled since 1990, reaching 1,130 million tonnes (Mt) (IEA, 2018).

8. GREEN INTERVENTION FEATURES FOR RETROFITTING OF EXISTING RESIDENTIAL BUILDINGS

To optimize energy consumption in existing residential buildings, integrating passive designs retrofits is crucial. These retrofits are effective in mitigating heat gain from the exterior environment as well as eliminating heat from the interior. Additionally, incorporating green design features further enhances energy efficiency by generating renewable energy to reduce the reliance on energy supply from the grid. Besides, green design interventions can also reduce indoor temperature, utilize daylight and water recycling. The summary of retrofit strategies for passive design and active design features are illustrated in Table 5.

Table 5: Passive design and green design features.

Design features	Functions	Retrofit strategies	Energy/temperature reduction	Citations
Passive design features	Reduce heat gain from the exterior environment	Apply tint films on glazing	7.5 – 19%	Somasundaram et al. (2020); Babalagama and Pathirana (2021). Shaik et al. (2022); Li et al. (2023)
		Additional shading for balcony	2.6 – 65.2%	Chan (2015); Alhuwayil et al. (2023); Shamseldin (2023)
		Additional shading for windows/doors	3% - 22%,	Ghosh and Neogi (2018); Jie and Sheng-xia (2011) Babalagama and Pathirana (2021)
		Additional shading to the main façade	20 – 25%	Aathaworld (2017); Rossi et al. (2022); KE Outdoor Design (2023)
		Insulation in the roof	40 – 50%	Budaiwi et al. (2002). Ran et al. (2017); Meddage et al. (2022)
	Eliminating heat from interior environment	Turbine ventilator in the roof	Reduce indoor temperature by 8.08°C to 9.58°C	Lien and Ahmed (2012); Jadhav et al. (2015); Al-Obaidi et al. (2016); Chia et al. (2017)
Green design features	Renewable energy source	Photovoltaic panels	20.45 – 60%	Sarasook (2020); Xiang and Matusiak (2022); Panicker et al. (2023); Malay Mail (2023).
	Reducing indoor temperature	Green walls	52 - 65%	Chen et al. (2013); Pirouz et al. (2020); Palermo and Turco (2020); Widiastuti et al. (2020); Carlucci et al. (2023);
	Daylighting strategy	Skylight roofs	Reduce lighting energy consumption	Robertson (2003); Al-Obaidi et al. (2014).
	Reducing solar heat gain	Green roofs	14.7 – 49%	Volder and Dvorak (2014); Al-Yasiri and Szabo (2021); (Azis, 2021)

9. NET ZERO ENERGY HOMES: CHALLENGES AND THE WAY FORWARD

Abdellah and Masrom (2018) found that the challenges to implement ZEBs in Malaysia are cost, technical and technologies, and government policy. Renewable energy technologies such as the PV system that are available in Malaysia is costly and the construction industry practitioners does not prioritize these technologies in construction projects. Besides, the availability of some technologies needed for nZEBS in Malaysia are limited while lack of government enforcement on sustainability in construction also act as the barrier for nZEBs concept to be successful in Malaysia (Abdellah & Masrom, 2018).

The construction of a ZEB can be costly. However, Marszal et al. (2011) argues that the operation costs for ZEBs are lower due to low energy consumption and generation of renewable energy on site. Silva et al. (2016) proved that the ZEB renovation facilitates decrease of 73% in annual energy demand. The renovation cost of a ZEB is 65% more than the maintenance cost, but it has the lower lifetime costs as compared to a conventional building. Besides constructing ZEBs, the existing buildings should also be taken into consideration in developing the ZEB concept as they are accountable for the existing energy consumption of the building sector. Thus, existing buildings are seen to have great potential to be retrofitted into ZEBs. However, retrofitting existing buildings faces the challenge of restricted technical solutions especially in dense urban areas or for multi-story buildings (Marszal et al., 2011).

10. DISCUSSIONS

This review contributes by consolidating global knowledge on ZEH strategies and contextualising it for Malaysia's tropical climate and residential building sector. It identifies that while there is increasing policy attention on energy efficiency in buildings, existing Malaysian frameworks, such as MS1525 and MS2680, are primarily advisory and not extensively enforced, especially for residential applications. A significant implementation gap exists due to the absence of enforceable regulations, targeted financial incentives, and comprehensive energy codes tailored specifically for the residential sector.

Moreover, end-user challenges are often overlooked in national strategies. Many homeowners lack awareness or technical knowledge of retrofitting options, and the high upfront cost of renewable energy technologies remains a key barrier. Additionally, there are limited financial mechanisms such as tax rebates, low-interest green loans, or feed-in tariff schemes that directly target individual homeowners. Without addressing these user-level concerns, ZEH adoption will remain limited to Malaysians.

The findings suggest that Malaysia must prioritise clear, enforceable policy frameworks, supported by financial incentives and awareness programmes tailored to households. As such, Malaysians are encouraged to participate in the national energy transition, enabling a wider adoption of ZEH concepts nationwide.

11. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

A ZEB is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. To achieve zero energy building, significant reduction in energy consumption is needed while maintaining the quality of indoor and outdoor environments as well as incorporating renewable energy to offset the remaining energy consumed by the building operation. The generation and consumption of renewable energy is a crucial element in the planning and design stage of a ZEB. However, priority should be given to minimizing the energy consumption by passive and active design approach.

Globally, majority of the ZEHs are low-rise residential buildings. The maximum storeys for a net zero energy home are three storeys when it is solely powered by solar energy. Although Malaysia has a vision to achieve net zero carbon, the existing policies is still lacking on developing and retrofitting ZEHs as residential buildings is the dominant building type in Malaysia. The major factors influencing residential building energy consumption are human factors which include occupant's behaviour, thermal comfort, and adaptive behaviour to achieve thermal comfort. Passive design factors like the building orientation, shape and shading devices. Active design factors include the energy consuming systems, dominant by air-conditioning, followed by lighting, and lastly other appliances.

To retrofit existing residential buildings into ZEHs through passive design retrofits, it is recommended to incorporate features such as tint films, shadings, green walls, and turbine ventilators. These additions function to reduce heat gain from the exterior environment as well as eliminating heat from the interior environment. Skylight roofs can significantly reduce lighting energy consumption by maximizing daylight entry. In aspects of active design, photovoltaic panels can reduce the monthly energy consumption as much as 60%. The challenges to develop nZEBs in Malaysia are cost, technical and technologies, and government policy. Besides constructing ZEBs, the existing buildings should also be retrofitted into ZEBs as they are accountable for the existing energy consumption of the building sector.

For future research, a comparative analysis can be carried out between Malaysia and ZEHs in other countries with similar climatic conditions to identify best practices in ZEH implementation in Malaysia. Besides, assessment on the effectiveness of the ongoing zero energy building policies in Malaysia can be conducted to identify gaps of improvement. Exploration of emerging technologies such as building simulation programmes and energy management system in residential buildings could further enhance energy efficiency and reduce cost in ZEH development.

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12. REFERENCES

Aathaworld. (2017). *Awning Contractor Malaysia*. https://www.aathaworld.com/single-post/2017/10/26/awning-contractor-malaysia

Abdellah, R., & Masrom, M. A. (2018). Exploring the Barriers of Net Zero Energy Buildings (NZEBS) Implementation in Malaysia: Perception of Malaysian Construction Practitioners. *International Journal of Integrated Engineering*, *10*, 110-115. https://doi.org/10.30880/ijie.2018.10.09.003

Al-Obaidi, K. M., Ismail, M., & Abdul Rahman, A. M. (2014). A study of the impact of environmental loads that penetrate a passive skylight roofing system in Malaysian buildings. *Frontiers of Architectural Research*, *3*(2), 178-191. https://doi.org/https://doi.org/10.1016/j.foar.2014.03.004

Al-Obaidi, K. M., Ismail, M., & Abdul Rahman, A. M. (2016). A comparative study between unvented and vented attics powered by the hybrid turbine ventilator in Malaysian houses. *International Journal of Sustainable Energy*, *35*(2), 148-160. https://doi.org/10.1080/14786451.2013.873801

Al-Yasiri, Q., & Szabo, M. (2021). A short review on passive strategies applied to minimise the building cooling loads in hot locations. *Analecta Technica Szegedinensia*, *15*, 20-30. https://doi.org/10.14232/analecta.2021.2.20-30

Alhuwayil, W. K., Almaziad, F. A., & Abdul Mujeebu, M. (2023). Energy performance of passive shading and thermal insulation in multistory hotel building under different outdoor climates and geographic locations. *Case Studies in Thermal Engineering*, *45*, 102940. https://doi.org/https://doi.org/10.1016/j.csite.2023.102940

Aliagha, G. U., & Cin, N. Y. (2013). Perceptions of Malaysian Office Workers on the Adoption of the Japanese Cool Biz Concept of Energy Conservation. *Journal of Asian and African Studies*, *48*(4), 427-446. https://doi.org/10.1177/0021909613493603

ASHRAE Standard 55. (2017). *ANSI/ASHRAE Standard 55-2017 Thermal Environment Conditions for Human Occupancy*. ASHRAE.

Azis, S. S. A. (2021). Improving present-day energy savings among green building sector in Malaysia using benefit transfer approach: Cooling and lighting loads. *Renewable and Sustainable Energy Reviews*, *137*, 110570. https://doi.org/https://doi.org/10.1016/j.rser.2020.110570

Babalagama, V. H. M. S., & Pathirana, S. M. (2021, 27-29 July 2021). Optimum Utilization of Daylighting in Office Buildings. 2021 Moratuwa Engineering Research Conference (MERCon),

Bektas Ekici, B., & Aksoy, U. T. (2011). Prediction of building energy needs in early stage of design by using ANFIS. *Expert Systems with Applications*, *38*(5), 5352-5358. https://doi.org/https://doi.org/10.1016/j.eswa.2010.10.021

Berry, S., Whaley, D., Davidson, K., & Saman, W. (2014). Near zero energy homes – What do users think? *Energy Policy*, *73*, 127-137. https://doi.org/https://doi.org/10.1016/j.enpol.2014.05.011

Birkha Mohd Ali, S., Hasanuzzaman, M., Rahim, N. A., Mamun, M. A. A., & Obaidellah, U. H. (2021). Analysis of energy consumption and potential energy savings of an institutional building in Malaysia. *Alexandria Engineering Journal*, *60*(1), 805-820. https://doi.org/https://doi.org/10.1016/j.aej.2020.10.010

BPIE (Buildings Performance Institute Europe). (2021). *Nearly Zero: A review of EU Member State implementation of new build requirements*. https://www.bpie.eu/publication/nearly-zero-a-review-of-eu-member-state-implementation-of-new-build-

Budaiwi, I., Abdou, A., & Al-Homoud, M. (2002). Variations of Thermal Conductivity of Insulation Materials Under Different Operating Temperatures: Impact on Envelope-Induced Cooling Load. *Journal of Architectural Engineering*, *8*(4), 125-132. https://doi.org/10.1061/(ASCE)1076-0431(2002)8:4(125)

Carlucci, S., Charalambous, M., & Tzortzi, J. N. (2023). Monitoring and performance evaluation of a green wall in a semi-arid Mediterranean climate. *Journal of Building Engineering*, *77*, 107421. https://doi.org/https://doi.org/10.1016/j.jobe.2023.107421

Chakraborty, A., & Pfaelzer, A. (2011). An overview of standby power management in electrical and electronic power devices and appliances to improve the overall energy efficiency in creating a green world. *Journal of Renewable and Sustainable Energy*, *3*. https://doi.org/10.1063/1.3558870

Chan, A. L. S. (2015). Investigation on the appropriate floor level of residential building for installing balcony, from a view point of energy and environmental performance. A case study in subtropical Hong Kong. *Energy*, *85*, 620-634. https://doi.org/https://doi.org/10.1016/j.energy.2015.04.001

Chen, Q., Li, B., & Liu, X. (2013). An experimental evaluation of the living wall system in hot and humid climate. *Energy and Buildings*, *61*, 298-307. https://doi.org/https://doi.org/10.1016/j.enbuild.2013.02.030

Damiati, S. A., Zaki, S. A., Rijal, H. B., & Wonorahardjo, S. (2016). Field study on adaptive thermal comfort in office buildings in Malaysia, Indonesia, Singapore, and Japan during hot and humid season. *Building and Environment*, *109*, 208-223. https://doi.org/https://doi.org/10.1016/j.buildenv.2016.09.024

de Dear, R., & Brager, G. S. (1998). Developing an Adaptive Model of Thermal Comfort and Preference. *ASHRAE Transactions 1998*, *104*, 19.

De Masi, R. F., Gigante, A., Ruggiero, S., & Vanoli, G. P. (2021). Impact of weather data and climate change projections in the refurbishment design of residential buildings in cooling dominated climate. *Applied Energy*, *303*, 117584. https://doi.org/https://doi.org/10.1016/j.apenergy.2021.117584

Department of Standards Malaysia. (2019). MS1525:2019 Energy efficiency and use of renewable energy for non-residential buildings - Code of practice (Third revision).

Department of Statistics Malaysia. (2022). *Key Findings of Population and Housing Census of Malaysia 2020: Urban and Rural*. https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=509&bul_id=ZFRzTG9ubTkveFR4YUY2OXdNNk1GZz09&menu_id=L0pheU43NWJwRWVSZklWdzQ4TlhUUT09#:~:text=Key%20Findings%20of%20Population%20and,Malaysia%202020%3A%20Urban%20and%20Rural&text=The%20urbanisation%20rate%20in%20Malaysia,(19.5%20million)%20in%202010.

Energy Commission. (2020a). *Malaysia Energy Statistics Handbook 2020*. Suruhanjaya Tenaga (Energy Commission). https://www.st.gov.my/en/contents/files/download/116/Malaysia_Energy_Statistics_Handbook_20201.pdf

Energy Commission. (2020b). *National Energy Balance 2019*. https://www.st.gov.my/en/contents/files/download/111/NEB_2019.pdf

Fathi, A., El Bakkush, A., Bondinuba, F., & Harris, D. (2015). The Application of Building Modifications and their Effects on Energy Consumption in Buildings. *Journal of Energy Technologies and policy*, *5*.

GBI. (2010). *Residential New Construction (RNC) Design Reference Guide & Submission Format* (First Edition ed.).

Ghosh, A., & Neogi, S. (2018). Effect of fenestration geometrical factors on building energy consumption and performance evaluation of a new external solar shading device in warm and humid climatic condition. *Solar Energy*, *169*, 94-104. https://doi.org/https://doi.org/10.1016/j.solener.2018.04.025

GTALCC. (2022). *What is GTALCC*. http://gtalcc.gov.my/about-gtalcc/what-is-gtalcc/

Hassan, J., Mohamad zin, R., Abd Majid, M. Z., Balubaid, S., & Hainin, M. R. (2014). Building Energy Consumption in Malaysia: An Overview. *Jurnal Teknologi*, *707*, 2180-3722. https://doi.org/10.11113/jt.v70.3574

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K. L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S. I., Thomas, A., Warren, R., & Zhou, G. (2018). Impacts of 1.5°C of Global Warming on Natural and Human Systems. In *An IPCC Special Report on the impacts of global warming of 1.5°C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (pp. 175-312). Cambridge University Press https://doi.org/https://doi.org/10.1017/9781009157940.005

IEA. (2018). *The Future of Cooling: Opportunities for energy efficient air conditioning* https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf

IEA. (2022). *Buildings* https://www.iea.org/reports/buildings

Indraganti, M., Ooka, R., & Rijal, H. B. (2013). Thermal comfort in offices in summer: Findings from a field study under the 'setsuden' conditions in Tokyo, Japan. *Building and Environment*, *61*, 114-132. https://doi.org/https://doi.org/10.1016/j.buildenv.2012.12.008

International Energy Agency. (2022). *World Energy Outlook 2022*.

ISO 7730:2005. (2005). *ISO 7730:2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. https://www.sis.se/api/document/preview/907006/

ISO. (2021). In P. I. T. M. f. a. n.-r. z.-e. b. (ZEBs) (Ed.), (pp. 46). Switzerland: ISO.

Jadhav, G. K., Ghanegaonkar, P. M., & Garg, S. (2015). Performance Characteristics of Turbo Ventilator: A Review. *International Journal of Innovative Technology and Research*, *3*(4), 2276-2282. https://core.ac.uk/download/pdf/228547292.pdf

Jie, Z., & Sheng-xia, Y. (2011, 16-18 April 2011). The impact of external shading on energy saving of the residential building. 2011 International Conference on Consumer Electronics, Communications and Networks (CECNet),

KE Outdoor Design. (2023). *The Environmental Benefits of Using Awnings to Reduce Energy Consumption*. https://www.keoutdoordesign.com/en-us/the-environmental-benefits-of-using-awnings-to-reduce-energy-consumption/

Kim, H., Stumpf, A., & Kim, W. (2011). Analysis of an energy efficient building design through data mining approach. *Automation in Construction*, *20*(1), 37-43. https://doi.org/https://doi.org/10.1016/j.autcon.2010.07.006

Kim, J., Kwak, Y., Mun, S.-H., & Huh, J.-H. (2022). Electric energy consumption predictions for residential buildings: Impact of data-driven model and temporal resolution on prediction accuracy. *Journal of Building Engineering*, *62*, 105361. https://doi.org/https://doi.org/10.1016/j.jobe.2022.105361

Kuala Lumpur City Hall. (2021a). *Kuala Lumpur Climate Action Plan 2050*. Kuala Lumpur, Malaysia: Kuala Lumpur City Hall

Kuala Lumpur City Hall. (2021b). *Kuala Lumpur Climate Action Plan 2050*. Kuala Lumpur, Malaysia: Kuala Lumpur City Hall Retrieved from https://sdgcentrekl.com/wp-content/uploads/2024/07/C40_KLCAP2050.pdf

Li, C. (2018). Feasibility research on realizing net zero energy consumption of residential buildings in Beijing. *J. Harbin Inst. Tech*.

Li, Y., Shah, K. W., Li, W., & Xiong, T. (2023). Experimental investigation on indoor thermal environment improvement and energy-saving of electrochromic window under Singapore's tropical climate. *Journal of Building Engineering*, *73*, 106779. https://doi.org/https://doi.org/10.1016/j.jobe.2023.106779

Lien, J., & Ahmed, N. (2012). Numerical Evaluation of Wind Driven Ventilator for Enhanced Indoor Air Quality. *Procedia Engineering*, *49*, 124-134. https://doi.org/https://doi.org/10.1016/j.proeng.2012.10.120

Lin, Y., Zhong, S., Yang, W., Hao, X., & Li, C.-Q. (2020). Towards zero-energy buildings in China: A systematic literature review. *Journal of Cleaner Production*, *276*, 123297. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123297

Lindelöf, D., & Morel, N. (2006). A field investigation of the intermediate light switching by users. *Energy and Buildings*, *38*(7), 790-801. https://doi.org/https://doi.org/10.1016/j.enbuild.2006.03.003

Lojuntin, S. A. (2022). Zero Energy Building (ZEB) Development Guide (Voluntary) For Building Sector in Malaysia. Zero Energy Building Development Guide Seminar

Malay Mail. (2023). More Malaysians transitioning to solar power to reduce electricity bills. *Malay Mail*. https://www.malaymail.com/news/malaysia/2023/07/06/more-malaysians-transitioning-to-solar-power-to-reduce-electricity-bills/78144

Mann, G., & Becerik-Gerber, B. (2012). *Understanding the Influence of Occupant Behavior on Energy Consumption Patterns in Commercial Buildings*. https://doi.org/10.1061/9780784412343.0072

Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I., & Napolitano, A. (2011). Zero Energy Building – A review of definitions and calculation methodologies. *Energy and Buildings*, *43*(4), 971-979. https://doi.org/https://doi.org/10.1016/j.enbuild.2010.12.022

Masoso, O. T., & Grobler, L. (2010). The dark side of occupants' behaviour on building energy use. *Energy and Buildings*, *42*, 173-177. https://doi.org/10.1016/j.enbuild.2009.08.009

Meddage, D. P. P., Chadee, A., Jayasinghe, M. T. R., & Rathnayake, U. (2022). Exploring the applicability of expanded polystyrene (EPS) based concrete panels as roof slab insulation in the tropics. *Case Studies in Construction Materials*, *17*, e01361. https://doi.org/https://doi.org/10.1016/j.cscm.2022.e01361

Ministry of Energy Green Technology and Water Malaysia. (2017). *Green Technology Master Plan Malaysia 2017-2030*.

Mlecnik, E., Attia, S., & Loon, S. (2011). *Net Zero Energy Building: a review of current definitions and definition development in Belgium*.

Musall, E., Weiss, T., Voss, K., Lenoir, A., Donn, M., Cory, S., & Garde, F. (2010). Net Zero Energy Solar Buildings: An Overview and Analysis on Worldwide Building Projects. https://doi.org/10.18086/eurosun.2010.06.16

Nicol, F., Humphreys, M., & Roaf, S. (2012). *Adaptive Thermal Comfort: Principles and Practice* (1st Edition ed.). Routledge. https://doi.org/https://doi.org/10.4324/9780203123010

Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building: A review. *Renewable and Sustainable Energy Reviews*, *16*(6), 3559-3573. https://doi.org/https://doi.org/10.1016/j.rser.2012.03.045

Palermo, S. A., & Turco, M. (2020). Green Wall systems: where do we stand? *IOP Conference Series: Earth and Environmental Science*, *410*(1), 012013. https://doi.org/10.1088/1755-1315/410/1/012013

Pan, S., Wang, X., Wei, S., Xu, C., Zhang, X., Xie, J., Tindall, J., & de Wilde, P. (2017). Energy Waste in Buildings Due to Occupant Behaviour. *Energy Procedia*, *105*, 2233-2238. https://doi.org/https://doi.org/10.1016/j.egypro.2017.03.636

Panicker, K., Anand, P., & George, A. (2023). Assessment of building energy performance integrated with solar PV: Towards a net zero energy residential campus in India. *Energy and Buildings*, *281*, 112736. https://doi.org/https://doi.org/10.1016/j.enbuild.2022.112736

Pettit, B., Gates, C., Fanney, A., & Healy, W. (2015). Design challenges of the NIST net zero energy residential test facility (NIST TN 1847).

Pless, S., & Torcellini, P. (2010). *Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options*. https://www.nrel.gov/docs/fy10osti/44586.pdf

Pirouz, B., Turco, M., & Palermo, S. A. (2020). A Novel Idea for Improving the Efficiency of Green Walls in Urban Environment (an Innovative Design and Technique). *Water*, *12*(12), 3524. https://www.mdpi.com/2073-4441/12/12/3524

Ran, J., Tang, M., Jiang, L., & Zheng, X. (2017). Effect of Building Roof Insulation Measures on Indoor Cooling and Energy Saving in Rural Areas in Chongqing. *Procedia Engineering*, *180*, 669-675. https://doi.org/https://doi.org/10.1016/j.proeng.2017.04.226

Robertson, K. (2003). *Daylighting guide for Buildings*. Canada Mortgage and Housing Corporation.

Röck, M., Saade, M. R. M., Balouktsi, M., Rasmussen, F. N., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., & Passer, A. (2020). Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation. *Applied Energy*, *258*, 114107. https://doi.org/https://doi.org/10.1016/j.apenergy.2019.114107

Rossi, F., Cardinali, M., Di Giuseppe, A., Castellani, B., & Nicolini, A. (2022). Outdoor thermal comfort improvement with advanced solar awnings: Subjective and objective survey. *Building and Environment*, *215*, 108967. https://doi.org/https://doi.org/10.1016/j.buildenv.2022.108967

Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews*, *15*(8), 3617-3631. https://doi.org/https://doi.org/10.1016/j.rser.2011.07.014

Sarasook, J. (2020). A Using of Solar Roof Top for Electrical Energy Conservation in Educational Organization. *IOP Conference Series: Materials Science and Engineering*, *811*(1), 012038. https://doi.org/10.1088/1757-899X/811/1/012038

SEDA Malaysia. (2019). Zero Energy Building Facilitation Program In S. E. D. A. S. Malaysia (Ed.).

SEDA Malaysia. (2021). *Voluntary Sustainable Energy Low Carbon Building Assessment Greenpass* https://www.seda.gov.my/energy-demand-management-edm/sustainable-low-carbon-building-assessment/

Shaik, S., Maduru, V. R., Kontoleon, K. J., Arıcı, M., Gorantla, K., & Afzal, A. (2022). Building glass retrofitting strategies in hot and dry climates: Cost savings on cooling, diurnal lighting, color rendering, and payback timeframes. *Energy*, *243*, 123106. https://doi.org/https://doi.org/10.1016/j.energy.2022.123106

Shamseldin, A. (2023). Adaptation opportunities for balconies to achieve continuity of their environmental functions. *Alexandria Engineering Journal*, *67*, 287-299. https://doi.org/https://doi.org/10.1016/j.aej.2022.12.037

Silva, S. M., Mateus, R., Marques, L., Ramos, M., & Almeida, M. (2016). Contribution of the solar systems to the nZEB and ZEB design concept in Portugal – Energy, economics and environmental life cycle analysis. *Solar Energy Materials and Solar Cells*, *156*, 59-74. https://doi.org/https://doi.org/10.1016/j.solmat.2016.04.053

Somasundaram, S., Chong, A., Wei, Z., & Thangavelu, S. R. (2020). Energy saving potential of low-e coating based retrofit double glazing for tropical climate. *Energy and Buildings*, *206*, 109570. https://doi.org/https://doi.org/10.1016/j.enbuild.2019.109570

Suratman, R., Samsudin, S., Ibrahim, H., & Ahli, N. (2018). Energy Saving in Residential Buildings: Resident's Effort and Awareness. *International Journal of Real Estate Studies*, *12*(2), 43-60. https://builtsurvey.utm.my/intrest/files/2018/11/ENERGY-SAVING-IN-RESIDENTIAL-BUILDINGS-RESIDENT%e2%80%99S-EFFORT-AND-AWARENESS.pdf

Suruhanjaya Tenaga (2025). "Energy Efficiency and Conservation Act (EECA) 2024." from https://www.st.gov.my/eng/microsites/index/19/106.

Tahir, M., Mohd Nawi, M. N., & Rajemi, M. (2015). Building Energy Index: A Case Study of Three Government Office Buildings in Malaysia. *Advanced Science Letters*, *21*, 1798-1801. https://doi.org/10.1166/asl.2015.6239

Taib, N. S. M., Ahmad Zaki, S., Rijal, H. B., Razak, A. A., Hagishima, A., Khalid, W., & Ali, M. S. M. (2022). Associating thermal comfort and preference in Malaysian universities' air-conditioned office rooms under various set-point temperatures. *Journal of Building Engineering*, *54*, 104575. https://doi.org/https://doi.org/10.1016/j.jobe.2022.104575

Torcellini, P., Pless, S., & Deru, M. (2006). *Zero Energy Buildings: A Critical Look at the Definition* ACEEE Summer Study Pacific Grove, California.

UNDP. (2023). *Malaysia's NDC Status*. https://climatepromise.undp.org/what-we-do/where-we-work/malaysia

UNEP-SBCI. (2010). *Common Carbon Metric: Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations Draft For Pilot Testing* U. N. E. P.-S. B. C. I. (UNEP-SBCI).

Volder, A., & Dvorak, B. (2014). Event size, substrate water content and vegetation affect storm water retention efficiency of an un-irrigated extensive green roof system in Central Texas. *Sustainable Cities and Society*, *10*, 59-64. https://doi.org/https://doi.org/10.1016/j.scs.2013.05.005

Widiastuti, R., Zaini, J., & Caesarendra, W. (2020). Field measurement on the model of green facade systems and its effect to building indoor thermal comfort. *Measurement*, *166*, 108212. https://doi.org/https://doi.org/10.1016/j.measurement.2020.108212

Wu, W., & Skye, H. M. (2021). Residential net-zero energy buildings: Review and perspective. *Renewable and Sustainable Energy Reviews*, *142*, 110859. https://doi.org/https://doi.org/10.1016/j.rser.2021.110859

Xiang, C., & Matusiak, B. S. (2022). Façade Integrated Photovoltaics design for high-rise buildings with balconies, balancing daylight, aesthetic and energy productivity performance. *Journal of Building Engineering*, *57*, 104950. https://doi.org/https://doi.org/10.1016/j.jobe.2022.104950

Yim, S. Y., Ng, S. T., Hossain, M., & Wong, J. M. (2018). Comprehensive evaluation of carbon emissions for the development of high-rise residential building. *Buildings*, *8*(11), 147.

Yu, Z., Fung, B. C. M., Haghighat, F., Yoshino, H., & Morofsky, E. (2011). A systematic procedure to study the influence of occupant behavior on building energy consumption. *Energy and Buildings*, *43*(6), 1409-1417. https://doi.org/https://doi.org/10.1016/j.enbuild.2011.02.002

Zaki, S. A., Damiati, S. A., Rijal, H. B., Hagishima, A., & Abd Razak, A. (2017). Adaptive thermal comfort in university classrooms in Malaysia and Japan. *Building and Environment*, *122*, 294-306. https://doi.org/https://doi.org/10.1016/j.buildenv.2017.06.016