Building Envelopes Toward Energy-Savings in Hot and Humid Climates: A Review

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Abstract

Energy-efficient measures are being increasingly implemented in the building sector to reduce the increasing energy consumption with the growing population and the rapid development of urban building layouts. In hot and humid climates, energy-saving measures for the building envelope elements have attracted increasing interest in research and practice due to their effectiveness in upgrading the building energy performance by reducing the amount of heat gain and solar glare to the building’s indoor environments. Accordingly, as evidenced by our review of the literature, an increasing number of publications on energy-saving measures for the building envelope are being published in peer-reviewed articles. However, a few literature overviews covering all possible energy-saving measures of building envelope elements, which can provide insight into determining the value of their effective parameters to achieve the best performance and evaluate the feasibility of energy efficiency improvements. This paper attempts to fill that

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gap by reviewing recent advances in energy-saving measures for building envelope elements and comparing their various parameters to suggest the best design options. This study summarised that applying individual measures to a certain degree is straightforward energy-saving potential. Otherwise, high energy-saving levels must incorporate an optimum combination of many energy-saving measures and balance their conflicting influences on energy performance criteria. This study may be handy for stakeholders responsible for decision-making during the design of new or retrofitting existing buildings.

Keywords: Hot-humid climate, energy-saving measures, building envelope elements, solar passive strategies, energy efficiency.

1 Introduction

Economic expansion and rapid urbanisation have led to metropolitan building layouts devoid of energy efficiency criteria, increasing global energy demand in recent years. As a result, buildings have a significant share of the total energy consumed globally [1]. According to the International Energy Agency, buildings consume about 40% of global energy demand [2]. Furthermore, it is the largest sector for the end-use of electricity to provide occupants with a high level of comfort and convenience [3, 4]. In addition, it is responsible for approximately 30% of greenhouse gas emissions, which are expected to double by 2050 if business continues as usual (United Nations Environmental Programme Industry and Environment) [5]. Although this is cause for concern, it does present an excellent opportunity for sustainable energy planning in the building sector. Buildings reflect the most significant unmet energy savings and carbon mitigation potential within the urban environment as current and future buildings can decide a significant part of global energy demand [6, 7]. Therefore, optimising a building’s energy efficiency is essential for sustainable energy management.

Energy-saving measures are essential in decreasing buildings’ energy use, reducing costs, and maintaining a comfortable environment [8, 9]. Therefore, energy conservation measures and management are inextricably linked to monitoring and controlling energy consumption in buildings [10]. Furthermore, with the current increase in global energy demand, the primary concern is how to produce the required energy and improve energy efficiency to ensure a sustainable energy supply and meet the required demand.
Several factors have contributed to the growth of energy usage in buildings: comfort conditions, building characteristics, climate factors, and the efficiency of the equipment [11, 12]. As a result, the energy consumed by buildings can vary significantly based on the prevailing climate [13]. In hot-humid climates, upgrading building energy efficiency is even more challenging due to the high gain of solar radiation from the building envelope [14] and high cooling needs, which account for 55% of the total energy use [15]. In addition, the glare caused by the penetration of high solar radiation into the transparent building envelope systems causes a heavy dependence on artificial lighting systems. Therefore, the building envelope has the most effect on providing thermal and visual comfort for building occupants and thus reducing energy demand. Because of that, most energy efficiency practices in hot-humid climate climates highlight building envelope elements (opaque and transparent) as the essential parts with high energy-saving opportunities.

The introductory part of this paper provided an overview of global energy demand, total energy usage in buildings, and factors influencing rising building energy consumption. Section 2 reviews the energy analysis tools used in building energy management studies. The standard and general concept of the building envelope have been reviewed in Section 3. In addition, Section 4 introduces the building energy improvement practices in hot-humid climates, which focus on building envelope components (opaque and transparent building envelope elements). Also, Tables 2–6 summarise the reviewed studies in their resultant subsections. Furthermore, Section 4 contains the main conclusion of this paper as well as suggestions for future research.

Although building energy-saving practices are the subject of inclusive research, the remainder of this introductory part first provides an overview of the other review papers that cover specific energy-saving measures in hot-humid climates to define the most important aspects that should be discussed to fill the gaps in the literature.

The energy-conscious designs for building façades for the potential of energy saving of buildings in dry and humid climates were reviewed by Halawa et al. [7], they review different elements of building façade components, such as double skin façades, ventilated walls, and glazed walls, thermal mass, photovoltaic façades, green facades, thermal insulation application, and phase-change materials.

Al-Masrani et al. [16] review the potential of different types of window shading that can reduce building energy demand. They investigated their
applications, mechanisms, and applied materials in tropical climates, positioned in a comprehensive approach to recognising the patterns and trends by description and comparison. This study employed obvious analysis to examine many types and patterns of shading systems.

Mirrahimi et al. [17] provide a technical review of the building envelope elements, their effects on thermal comfortability, and their ability to save energy in high-rise buildings. Selected parameters have been highlighted, such as building physics (including form, height, length, width, etc.), building location (including building orientation and surrounding context), external/internal walls and materials, and thermal insulation of façades.

Roslan et al. [18] provide an exhaustive technical review to improve the passive design strategies of the roofing system in an innovative house in a hot and humid climate. Different energy-saving measures have been discussed, such as roof material, the color of the roof surface, roof angle, and passive ventilation mechanisms.

Hee et al. [19] provide an exhaustive technical review to investigate the impact of various dynamic and innovative glazing techniques on building energy performance. Vital parameters to provide energy-saving and visual comfort have been reviewed in terms of glazing type, thickness, coating tint, the spacer between panes, the number of glass panes, and the thermal characteristics of the glass.

Aflaki et al. [20] review the underlying scientific basis for NV operation and the associated fitting of architectural components in buildings to understand better what components and procedures effectively increase air velocity indoors in hot humid climates. These criteria discussed suitable parameters for the building size, layout, location of openings, building positioning, and mode of balconies on the external surfaces, WWR, and WFR.

Valladares-Rendón et al. [21] review the research on the influence of passive solutions to reduce insolation and amplify the energy savings for cooling systems by keeping daylighting and visibility. They reviewed four principal classes (facade self-shading, shading appliances, WWR, and building positioning).

S. Chen et al. [22] review external and internal factors that affect building energy performance. Three groups of internal and external influencing factors were summarised to reduce the energy demand for the building, such as improving the building geometry and thermal insulation, the application of energy-saving apparatus and technologies, such as thermal storage, heating recapture, evaporative cooling as well as raising the level of control and the behaviors of occupants.
Thermal insulation is a promising method for conserving buildings’ energy [23] provide exhaustive technical reviews mainly focused on commercial heat insulators and their potential for building energy saving. In addition, the authors clarified various insulation materials based on thermal material properties (specific heat, density, and thermal conductivity) by classifying them based on their approachable application on walls, roofs and ceilings, windows, and floors.

Despite these efforts, the reviewed articles highlighted energy-efficiency measures that have been, or could be, implemented in buildings for energy savings. However, they present different and, in some cases, conflicting views of their effective options. In addition, a few structured literature reviews cover all possible energy-saving measures of building envelope elements in hot and humid climates. Thus, a sufficiently full understanding of their options and effective parameter values is crucial for developing methods to improve buildings’ energy performance. This paper attempts to fill that gap by reviewing recent advances in energy-saving measures for building envelope elements, which can provide insight into determining the value of their effective parameters and evaluating the feasibility of energy efficiency improvements.

2 Building Energy Analysis Tools

Over the past few decades, there has been extreme attention in the field of energy conservation, as energy efficiency projects have evolved from using traditional practices to efficient practices involving new technologies. Building energy analysis is an initial step in developing solutions for energy efficiency; the purpose of the building-energy analysis is to investigate energy consumption performance, perform system comparison and identify improvement alternatives [24, 25]. Simulation tools are increasingly being used to analyse building energy efficiency, predicting the energy performance of a given building and the thermal comfort of its occupants. Updating equipment and systems increase building energy performance, but there is no guarantee that these practices will result in long-term energy savings. On the other hand, more specific tools will be required for comprehensive energy analysis of each building energy system subsystem and life cycle cost analysis.

Furthermore, they support understanding how a specific building works according to certain criteria and enables comparisons between various optimisation alternatives. There is an increasing number of energy simulation programs on the market today. According to the Building Energy Software
Tools Directory, there may be over 400 tools offered by the US DOE in 2017.

Accurate simulation results depend on the input data, which primarily consists of building geometry, internal loads, HVAC systems and components, weather data, operating strategies and schedules, and simulation-specific parameters [26]. All energy simulation tools depend on thermodynamic equations, concepts, and assumptions. Due to a building’s thermal processes being complex and not completely understood, so energy simulation programs use qualified equations and methods to estimate their predictions [27]. Hence, if those assumptions are not met in the simulation or matched in real life, the results can be arbitrarily incorrect.

Building performance simulation tools are categorised based on various parameters, including calculation methods, modelling levels, and application area. According to Clarke [28], simulation tools can be classified into two categories according to calculation methods: simplified (static) and detailed (dynamic). The majority of simulation tools in use today employ dynamic numerical methods. Dynamic tools with high accuracy use finite or boundary element methods to quantify building energy loads and thermal system interactions, which typically quantify on an hourly and zone-by-zone basis to account for dynamic interactions between all thermally dependent building components associated with comfort and energy consumption (i.e., building envelope, HVAC system, lighting, and control systems) [29].

Many comparatives of building simulation tools surveys have been published, which the reader can refer to [29–31]. Furthermore, based on the criteria adopted by Solmaz [29], a shortlist of the most popular BEM resources among all reviewed papers has been developed, as the analyses and comparisons of the tools were conducted in accordance with:

- The general properties of the program include its main capabilities, programming language/platform, license, and developer/company.
- Tool integration during the design stage, simulation engine, interoperability/data exchange, performance criteria, applications/functions.
- The primary benefits and drawbacks of input and output file formats, weather data, and validation.

Although, most building simulation tools can evaluate building performance in common domains such as energy, thermal comfort, and environmental emissions. However, selecting a suitable tool is a critical issue for a specific project since they vary in many respects, including their thermodynamic models, graphical user interfaces, intended use, life-cycle applicability,
and ability to share data with other software applications. The graphical user interface is considered among the critical aspects of these tools, which can simplify input generation and output analysis while exposing the engine's features to the user. However, simple interfaces do not make energy analysis accessible to everyone. Therefore, knowledge of program limitations and understanding of thermal processes is critical to generating practical and accurate simulation results.

3 Standards and Components of Building Envelopes

A building envelope separates a building’s indoor and outdoor environments, which considers the most important part of the building system affecting indoor climate regardless of the changing external environment [32]. The building envelope’s fundamental and most important duties are to provide definition and shelter. Furthermore, it contributes to the comfort of built environment spaces by offering daylight, thermal, acoustic, solar, indoor air quality, fire resistance, and moisture control and contributing to the building quality [33].

Properly designed envelopes aim to reduce summer heat gain and winter heat loss in the building envelope to minimise the resultant heating and cooling conditions [34]. Generally, there are two primary building envelope elements: opaque and transparent. As shown in Figure 1, opaque envelope elements consist of walls, roofs, floors, and insulation, whereas transparent envelope elements consist of windows, skylights, and glass doors [17]. Different climates have unique building envelope designs to suit the local prevalent climatic situations [35]. Universally, two types of building

![Figure 1 Building envelope elements.](image-url)
standards are popularly employed to measure a building envelope’s thermal performance. The first one is the standards for thermal insulation used in cold climates in which the envelope material’s thermal transmittance values (U-values) are calculated. The second is the overall building regulations for thermal transfer value (OTTV), which are applied to hot climates regions like Southeast Asia to minimise the external heat associated with the building envelope and the demand for energy from the air conditioning system [36]. Thus, the OTTV stander is only applied to mechanically cooled buildings [7, 37]. Several countries have established compulsory standards for building energy efficiency and have employed the OTTV stander as a component of the requirements; Table 1 shows the OTTVs standard for residential and non-residential buildings in some hot-humid climates.

4 Effect of the Building Envelope on Energy Performance

Building envelope components (opaque and transparent elements) and the operation period of the HVAC system are the factors that impact the buildings’ total energy consumption [47]. In addition, envelope elements determine interior climate conditions and, consequently, the additional energy demand for HVAC and lighting systems. Energy-saving measures applied to building envelope elements can positively impact some energy requirements while adversely affecting others [48]. Consequently, it is essential to evaluate the overall performance of the building as a whole [49]. The energy-saving measures can be applied to retrofit or new building projects, while some are exclusive to the latter as they must be planned early in the design process, e.g., building orientation and floor layout [50]. The following section reviews energy-saving measures for building envelope elements commonly used in hot-humid climates to improve the building’s energy efficiency by reducing energy consumption and improving indoor comfort levels.

4.1 Window-to-Wall Ratio (WWR)

Windows, as one of the most important building components, positively impact the occupants’ comfort and health [51]. Additionally, it plays a significant role in providing daylight [52], and reducing buildings’ energy demand [53, 54]. However, it is generally known that big windows increase the thermal load without considering the window’s position [55]. Hence, the profound solution to this challenge is to balance unnecessary solar heat and appropriate daylight, which determines the amount of solar radiation falling
<table>
<thead>
<tr>
<th>Location</th>
<th>Year Released</th>
<th>Standard</th>
<th>Maximum Wall OTTV (W/m^2)</th>
<th>Maximum Roof OTTV (W/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore 2008</td>
<td>Building and Construction Authority (BCA)</td>
<td>≤50</td>
<td>≤25</td>
<td>≤50</td>
</tr>
<tr>
<td>Thailand 2015</td>
<td>Building Energy Code (BEC)</td>
<td>≤50 for Offices and schools. ≤40 for stores, supermarkets, and restaurants. ≤30 for hospitals and hotels.</td>
<td>N/A</td>
<td>≤15 for Offices and schools. ≤12 for stores, supermarkets, and restaurants. ≤10 for hospitals and hotels.</td>
</tr>
<tr>
<td>Hong Kong 2016</td>
<td>Building (Energy Efficiency) Regulation. B(EE)R</td>
<td>≤21 for building tower. ≤50 for a podium.</td>
<td>≤14</td>
<td>≤24, ≤56</td>
</tr>
<tr>
<td>Malaysia 2016</td>
<td>Green Building Index. (GBI), MS1525,</td>
<td>≤50</td>
<td>≤50</td>
<td>≤25</td>
</tr>
<tr>
<td>Philippines 2013</td>
<td>Building for Ecologically Responsive Design Excellence (BERDE)</td>
<td>≤45</td>
<td>≤45</td>
<td>≤45</td>
</tr>
<tr>
<td>Indonesia 2011</td>
<td>Indonesian National Standard. SNI 03-6389-2011</td>
<td>≤35</td>
<td>N/A</td>
<td>≤35</td>
</tr>
</tbody>
</table>
inward and considers an isolation point between the building’s internal and external environment [56].

Ghosh and Neogi [57] investigate the effect of the WWR and window orientation on the energy consumption in terms of lighting, heating, and cooling of the building facade facing the South. Energy Plus simulation tool was used to investigate three considered values of WWR 53.33%, 26.67%, and 13.33%. The results showed an increase in energy consumption for cooling and a decrease in energy consumption for heating and lighting for the first situation. The reduction in WWR reduced the overall energy consumption in the second and third situations by 1.48% and 2.70%, respectively. Shaeri et al. [58] investigated the optimal values of WWR for all building orientations based on minimising the total energy demand for heating, cooling, and lighting using the Design Builder simulation tool. Three different climates have been considered (hot or dry climate, hot/humid climate, and cold climate). The simulation results showed that the optimum WWR for the north building facade for all climates is 20–30%. For the south facade, the value of WWR is 20–30%, 10–30%, and 20–50%, respectively. The optimum WWR for the eastern and western building facades are 30–50%, 40–70%, and 20–60%, respectively. X. Chen et al. [59] provided a relative sensitivity and design optimisation analysis to investigate the impacts of main design variables and their effect on building energy performance in different combinations of urban design factors.

The sensitivity results showed the WWR has the most important influence on decreasing building energy demand, contributing 35% of the cooling demand and 1% of the lighting energy demand.

4.2 Thermal Insulation

Insulating building envelope elements with thermal materials is a simple and cost-effective way to reduce the heat involved in the interior and exterior of the building during all climatic conditions. Also, thermal insulation reduces energy demand for HVAC in all climatic conditions [7]. In this context, suitable insulation means selecting insulation materials, optimum locations for the installation, and the required thickness for the walls and ceilings of buildings [65].

Lei et al. [66], investigated the effects of incorporating PCMs materials into building envelopes on cooling load reduction using numerical simulations. The results revealed that PCMs could efficiently minimise heat gains via the envelopes of buildings, ranging from 21–32% annually. The efficiency
<table>
<thead>
<tr>
<th>Case Study Location</th>
<th>ASHRAE Simulation Project</th>
<th>Method/Tools</th>
<th>Design Aim</th>
<th>Design Variables</th>
<th>Major Findings</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran 2A,2B,6A</td>
<td>Design-Builder</td>
<td>Energy-saving for HVAC, and lighting.</td>
<td>Window orientation &amp; WWR.</td>
<td>WWR values for hot-humid &amp; hot-dry climates are between 20–40% for the north and 20–30% for the South. In contrast, the WWR value for the cold climate is between 20–30% for the north facade and 20–60% for the south facade, which provides the best energy reduction.</td>
<td>[58]</td>
<td></td>
</tr>
<tr>
<td>Singapore 1A</td>
<td>JEPlus + EA</td>
<td>NZEB</td>
<td>The thickness of insulation for wall &amp; roof, WWR, window opening time, overhang depth, and glass properties.</td>
<td>WWR is the most influential variable in balancing natural cooling and daylighting. Hence, it contributes significantly to the improvement of energy efficiency and cost-effectiveness.</td>
<td>[60]</td>
<td></td>
</tr>
<tr>
<td>Panama 2A</td>
<td>Design-builder NZEB</td>
<td>The occupancy rate, window opening time, insulation material for walls &amp; roof, WWR, and building orientation.</td>
<td>Minimising the WWR could substantially reduce energy consumption by adjusting window positions or only reducing the Sun-oriented windows’ size.</td>
<td>[61]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyprus 3A</td>
<td>EDSL Tas</td>
<td>Energy-saving and thermal comfort</td>
<td>Window opening ratio, WWR, U-value of the walls, roof, ceiling, ground, and U-value of glazing.</td>
<td>Thermal comfort can be achieved when the WWR is 10%, and the window opening ratio is between 0.1–0.9.</td>
<td>[62]</td>
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<tr>
<th>Case Study Location</th>
<th>ASHRAE Climate Zone</th>
<th>Simulation Method/Tools</th>
<th>Project Aim</th>
<th>Design Variables</th>
<th>Major Findings</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>3A</td>
<td>EnergyPlus</td>
<td>Energy-saving for lighting and Thermal comfort</td>
<td>Window positions, WWR, and shading type.</td>
<td>Cooling load is considered extremely sensitive to WWR &amp; window position by relating it to the heating load &amp; lighting energy demand.</td>
<td>[57]</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2A</td>
<td>EnergyPlus</td>
<td>Energy-saving</td>
<td>Building orientation, WWR, window U-value, depth of window, visible transmittance, solar reflectance of walls and windows.</td>
<td>For most energy and indoor climate efficiency metrics, window properties such as WWR, visible transmittance &amp; overhang project fraction are required design parameters.</td>
<td>[59]</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2A</td>
<td>EnergyPlus</td>
<td>Energy-saving</td>
<td>Building orientation, WWR, window U-value, window visible transmittance rate, wall thermal resistance &amp; overhang depth.</td>
<td>The most significant aspects of the PV envelope design are window shape and thermal &amp; optical properties. WWR makes the most considerable contribution due to the influence of the HVAC efficiency, lighting &amp; PV energy simultaneously.</td>
<td>[63]</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>2A</td>
<td>Design-builder</td>
<td>Energy-saving for lighting and Thermal comfort</td>
<td>WWR, building orientation, building shape, and zone sizes &amp; locations.</td>
<td>Thermal comfort and energy saving for different shapes of naturally ventilated buildings depend on WWRs and the zone sizes, and their locations.</td>
<td>[64]</td>
</tr>
</tbody>
</table>
of PCMs materials on the exterior wall surfaces was higher than PCMs on the interior wall surfaces. As the amount of PCM increases, the heat gain of the envelope decreases. However, this energy use can still be controlled and minimised by factors such as the positioning of insulation materials. In this respect, the insulation layer is placed in the outer layers during hot summers. In comparison, the insulation layer in the center of the wall does better in winter [67]. Mora et al. [61], developed a test model for envelope composition established on generic construction materials, using Design Builder software to evaluate the thermal performance of the building envelope to reduce energy consumption and promote NZEB in Panama. Simulation results showed that insulation materials applied to the roof and exterior walls lowered the energy demand by 14.90%. Hay and Ostertag [68] propose a double-skin façade (DSF) system to reduce energy consumption for heating and cooling. Modelling for energy and effect cost analyses was implemented for a representative practical unit set, the simulation results showed that the energy for the operation and emission of carbon dioxide could be reduced annually to 9.2% by the DSF system; besides, the cost and total energy could be recuperated within the first two 8.2 years of continuous operation. In the same vein, the investigation was carried out by Wong and Baldwin [69], revealed the ability of DSGF to minimise the energy consumption for refrigeration in high-rise apartment buildings in the subtropics. Rehman [70], evaluate the retrofit impact on the concrete walls and innovative insulation methods of the buildings aimed at determining the reduction of heat flux and the energy savings of the buildings.

The results showed that by using a dry insulation material for walls like an exterior insulation finishing system (EIFS), energy could be saved on average up to 7.6–25.3% due to the decrease in heat flux in the range of 22–75% at the south walls.

4.3 Glazing Technologies

Glazing units are one of the weakest thermal control points in exterior building envelope elements. Window glazing used in modern and traditional buildings, such as windows, glazed building facades, and glass roofs, is an essential part of the building. They provide many benefits and advantages to the building’s occupants, such as visibility, daylight, air ventilation, and passive solar gain [75, 76].

The glazing modules and windows provide a weak barrier to heat entry. Therefore a high amount of overall energy consumption of any conditioned
<table>
<thead>
<tr>
<th>Case Study Location</th>
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<th>Design Variables</th>
<th>Major Findings</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran</td>
<td>2A</td>
<td>Design-builder</td>
<td>Energy-saving and thermal comfort.</td>
<td>Thermal properties of walls, internal gains, heating, cooling &amp; ventilation set point, and wall insulation.</td>
<td>The incorporation of insulation with local building materials has significant potential for energy conservation and thermal comfort enhancement, but it has raised the risk of condensation</td>
<td>[71]</td>
</tr>
<tr>
<td>Chicago</td>
<td>–</td>
<td>Design-builder</td>
<td>Energy-saving and thermal comfort.</td>
<td>HVAC setpoint, building shape, the solar reflection of an envelope, and bio-PCM insulation.</td>
<td>Integrating a bio-PCM layer, the high whiteness of the surface, and hydrogels to remove moisture from the inlet air has significant results in saving energy when the outside temperature is high.</td>
<td>[72]</td>
</tr>
<tr>
<td>Singapore</td>
<td>1A</td>
<td>COMFEN</td>
<td>Energy-saving for HVAC, reducing CO₂ emission</td>
<td>Insulation materials, Façade orientation, U-factors for wall components, U-factor for the SG and WWR.</td>
<td>DSF system produced with high-performance fiber-reinforced concrete (HP-G-HyFRC) has excellent potential to improve reduced energy consumption.</td>
<td>[68]</td>
</tr>
<tr>
<td>Singapore</td>
<td>1A</td>
<td>EnergyPlus</td>
<td>Cooling load reduction</td>
<td>PCM thermal properties, PCM thickness &amp; amount, PCM location, and temperature range of PCM.</td>
<td>PCMs used for the exterior wall surfaces performed better in reducing the cooling load than those used for the interior wall surfaces. They minimise heat gains effectively by building envelopes during the whole year.</td>
<td>[66]</td>
</tr>
<tr>
<td>Location</td>
<td>Region</td>
<td>Building Simulation Tool</td>
<td>Building Envelope Characteristics</td>
<td>Energy-Saving and Thermal Comfort Measures</td>
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<tr>
<td>Panama</td>
<td>–</td>
<td>Design-builder NZEB</td>
<td>Insulation thickness, U-values of envelope components, Thermal properties of Insulation material.</td>
<td>The inclusion of expanded polystyrene insulation layers in the roof and external walls’ composition to a reduction resulted in a U-value of 0.23 W/m²K and 0.362 watt-m²K, respectively.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2A</td>
<td>–</td>
<td>Cooling load reduction, Building orientation, Solar resistance of DSGF.</td>
<td>The selection of facade plants depends on the location of the building façade and the presence of adjacent buildings. Green roofs are more suitable for retrofitting existing non-or partially insulated buildings than well-insulated modern buildings.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madagascar</td>
<td>2A</td>
<td>Design-builder NZEB</td>
<td>Energy-saving and thermal comfort, The thickness of PCM, external Shading, and Insulation Material.</td>
<td>PCM materials have more influence on cooling energy saving in hot climates than in mild climates.</td>
<td></td>
<td></td>
</tr>
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</table>
As shown in Figure 2 [83, 84], the energy-saving glazing can be classified as:

- **Heat-absorbing glass**
  - Phosphate glass
  - Soda lime silica glass
  - Aluminosilicate glass
  - Borosilicate glass

- **Heat-reflecting glass**
  - Super silver glass
  - Opal glass
  - Sunshield glass
  - Ecosense glass

- **Low emissivity glass**
  - Passive low-E coatings
  - Solar control low-E coatings

Figure 2  Classification of energy-saving glass.

Building, especially in a hot-humid climate, is due to window glazing used because cooling is the largest major energy consumer in this climate (Qahtan, 2019). The heat loss from the windows represents about 30% of the building’s energy consumption in cold climates [79, 80]. In contrast, excessive gain is also a significant problem, leading to the enormous energy usage of cooling-dominated buildings in hot environments [81, 82]. Consequently, glazing units play a vital role in the energy demand of buildings and provide indoor thermal and visual comfort. The energy-saving glazing can be classified as shown in Figure 2 [83, 84].

Many researchers have investigated the effectiveness of glazing material in improving building energy performance. Yousefi et al. [85] investigated the glazing variables in three different climates for energy saving. Several aspects were verified: glass type, gas filling, the thickness of the glass, interior shading, and frame portion under different climatic conditions.

The simulation results showed that low-E glass is the most efficient type that could be used in cold and hot climates for thermal energy demand reduction of the building. Also, using argon gas can reduce a load of thermal energy in the building by up to 2%. The effect of using argon gas is more apparent in a cold climate compared to a hot one. A double transparent glazing system can minimise the thermal energy demand in the building by up to 8.5% in the cold and 2.5% in hot climates. Any glazing with low SHGC and U values could reduce energy consumption in buildings in hot climates [86].
Energy efficiency, visual and thermal were investigated for the suggested retrofit double glazing by Somasundaram, Chong, et al. [65]. According to the findings, the retrofit hard-coat Low-E double glazing can save around 9% of the cooling energy demand daily, increasing energy savings on hotter days. However, there is a possibility of negative effects due to the low temperatures during rainy or cloudy days and reducing the visible transmission of light by 75%. Therefore, it could be suitable when daylight is required to lessen the glare and get the Lux level down to desired levels.

Edeisy and Cecere [87], examine the influence of retrofit glazing on the cooling load and carbon emissions. They discovered that replacing the single transparent glass with double grey low-E glazing reduces the cooling load by up to 14% and that using triple low-E glazing reduces the cooling load by 31%. Furthermore, the effect of solar film installation and Low-E coated glass incorporated into retrofit double glazing was examined to maximise the energy savings of existing buildings [88]. The results indicated the lighting and HVAC have opposing requirements regarding the transmissivity of the glass. However, it showed that an optimal tint of the solar film would lead to minimum total power consumption (HVAC + lighting). Different types of glazing have been evaluated by Taleb and Antony [89] to reduce energy consumption and improve the lighting performance of office buildings in the UAE. Simulation results concluded that single glazing provides a lux of 300 to 500 value that is visually suitable in the UAE. In addition, the Mashrabiya application, as tinted glazing, can lower the cooling load by up to 23%.

4.4 Solar Passive Strategies

Passive energy efficiency measures are technologies capable of achieving the lowest energy demand by striking a balance between heat losses and heat gain of a building envelope with the climatic conditions of the building’s site [90]. These technologies naturally utilise the sun’s energy for free heating, ventilation, and daylighting to minimise the need to consume energy from other sources and provide a comfortable indoor environment [91]. The following sections summarise the main types of solar passive strategies that have been investigated for their potential for energy savings in hot and humid climates.

4.4.1 Shading on buildings

A shading system is a common method to control the amount of solar radiation the building receives. It limits the penetration of direct sunlight and allows daylight to penetrate the interior space of the building. It is
<table>
<thead>
<tr>
<th>Case Study Location</th>
<th>ASHRAE Simulation Project Design Major Variables</th>
<th>Findings</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran 2B EnergyPlus</td>
<td>Energy saving Climate zone, glass types, filling material, glass thickness, and interior shading.</td>
<td>A double transparent glazing system minimises thermal energy consumption up to 8.5% (cold) and 2.5% (hot) climates. The efficiency of argon gas in a cold climate is greater than that of a hot one. Low-e glass is suitable for minimising thermal energy demands in hot &amp; cold districts.</td>
<td>[85]</td>
</tr>
<tr>
<td>KSA 1A EnergyPlus</td>
<td>Energy saving Glass types, SHGC for glazing, and U-value of glass.</td>
<td>The best energy savings glazing is a double-pane argon-filled specific Low-E glazing characterised by low SHGC and U values to minimise solar heat gain in hot areas.</td>
<td>[86]</td>
</tr>
<tr>
<td>Singapore 1A Radiance</td>
<td>Cooling energy saving Glass types, climate zone, and solar azimuthal angle.</td>
<td>Low-g-value glass is more useful in reducing cooling load than low-U-value glass in the tropics. It can reduce significantly up to 26 to 43 percent of the cooling load.</td>
<td>[92]</td>
</tr>
<tr>
<td>Singapore 1A EnergyPlus</td>
<td>Cooling energy saving Façade orientation, transmittance, and reflectance of glass, air gap size, WWR &amp; ACH.</td>
<td>The retrofit hard-coat Low-E double glazing hoards about 9 percent of the cooling energy demand daily installed on all three wings (SE, NW, and NW). It minimises visible light transmittance by 75 percent.</td>
<td>[65]</td>
</tr>
<tr>
<td>Location</td>
<td>Region</td>
<td>Simulation Tool</td>
<td>Energy Saving</td>
</tr>
<tr>
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<td>---------------</td>
</tr>
<tr>
<td>Singapore</td>
<td>1A</td>
<td>DIVA-for-Rhino</td>
<td>Cooling energy saving.</td>
</tr>
<tr>
<td>Singapore</td>
<td>1A</td>
<td>EnergyPlus</td>
<td>Energy-saving</td>
</tr>
<tr>
<td>UAE</td>
<td>1A</td>
<td>IES</td>
<td>Lighting</td>
</tr>
<tr>
<td>Singapore</td>
<td>1A</td>
<td>Design-builder for HVAC</td>
<td>Energy-saving for HVAC</td>
</tr>
</tbody>
</table>
designed for a variety of applications, including overheating prevention and mitigation, reducing lighting and cooling loads [92, 95], and improving the visual environment (such as glare, color, contrast, light, and view) [98, 99]. Hence, shading systems are essential to enhancing the building’s energy efficiency, especially for cooling loads in hot climate areas.

Alhuwayil et al. [100] investigate the impacts of overhang shading on the overall energy demand and minimise the heat gain in a multi-story hotel building in hot-humid climates. The simulation results showed the anticipated passive shading strategy could decrease energy consumption annually by 20.5%, and it is possible to recover expenses incurred in 2 years. Along the same lines, Nematchoua et al. [74] conducted a statistical study to weigh the application of passive strategic techniques in coastal tropical areas. The results indicate that using overhang shading devices can reduce the building’s average internal temperature by 0.3°C and save about 4% of the total energy consumption. Shahdan et al. [101] investigated the potential of shading devices to reduce cooling energy demand for Malaysian buildings. Three shading devices have been simulated, including vertical and horizontal shadings and egg crates shading devices using IES (VE) software. The results indicated that the egg crate shading systems could achieve the largest annual savings in cooling energy compared to vertical and horizontal shading. Figure 3 shows the energy reduction potential for the three shading types with different orientations. On the other hand, Arifin and Denan [102], examined the efficacy of vertical shading devices, horizontal shading devices, and egg-crate shading devices to determine the most appropriate shading

![Figure 3](image-url)
Table 5  Influences of solar shading for several case studies

<table>
<thead>
<tr>
<th>Case Study Location</th>
<th>ASHRAE Simulation Project Method/Tools</th>
<th>Design Aim</th>
<th>Energy-saving Variables</th>
<th>Major Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saudi Arabia</td>
<td>1A Design-builder</td>
<td>Energy-saving</td>
<td>Shading type, fins-width, length of shading device, and shading orientation.</td>
<td>The choice of a building’s proper shading strategy relies primarily on the climatic position. By introducing the vertical fins and overhangs on NW, NE, SW, and SE screens, annual energy consumption can be decreased by 20.5%. [100]</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1A IES (VE)</td>
<td>Cooling load</td>
<td>Type of external shading devices, facade orientations, and glazing type.</td>
<td>Applying different shading devices on the lower double-glazed facades saved energy for cooling 1.0 to 3.4 percent per year; this depends on the categories of shading devices &amp; the directions of the façades. [103]</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1A Autodesk Revit</td>
<td>Cooling load</td>
<td>Building orientation, type of external shading devices, climate condition, glazing type, and internal loads.</td>
<td>Egg crate shading is the best efficient shading technology for hot and humid climates because it can blend horizontal and vertical shading solutions. [101]</td>
</tr>
<tr>
<td>India</td>
<td>3A EnergyPlus</td>
<td>energy-saving</td>
<td>Type of external shading devices, WWR, overhang depth, dimensions, and deflection angle for shading devices.</td>
<td>The proposed shading brought about the lowest overall energy demand, which decreased by 4.62% relative to other shading types. Moreover, it is the most effective in regions that have warm climates. [57]</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Case Study Location</th>
<th>ASHRAE Climate Zone</th>
<th>Method/Tools</th>
<th>Project Aim</th>
<th>Design Variables</th>
<th>Major Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uganda</td>
<td>2A</td>
<td>EnergyPlus</td>
<td>Thermal comfort</td>
<td>Physical properties of the building envelope, type of shading devices, solar heat gain for walls and roof, and reflection paint.</td>
<td>Shading strategies are less influential in achieving thermal comfort requirements on their own. Thus, they should use them in combination with other passive techniques as it reduces solar heat gain and glare through windows by 76%.</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2A</td>
<td>Design-builder</td>
<td>Cooling load</td>
<td>Façade’s orientation, external shading types, length and width of shading devices, and angle.</td>
<td>Opaque façades facing west have a lot of correlation with the rate of energy-saving and the length, the number, and the angle of the shading panels. The energy-saving from using ideal shade panels can be up to around 8%.</td>
</tr>
<tr>
<td>Jordan</td>
<td>2B</td>
<td>Radiance IES-VE</td>
<td>Visual and thermal comfort</td>
<td>External shading types, length and width of shading devices, shading devices angle, and spacing between the shading panels.</td>
<td>Shading devices improve the visual environment by controlling the illumination level, improving uniformity, eliminating glare, and lowering the temperature but not reaching a thermal comfort level.</td>
</tr>
</tbody>
</table>
4.4.2 Daylighting

Daylight is one of the essential components of the building’s indoor environment that must be considered; it provides a suitable indoor climate, energy efficiency, and other sustainable results [107, 108]. In addition, Daylighting has a high luminous efficacy of 110–130 lm/watt compared with artificial lighting, which has a luminous efficacy of 70–100 lm/watt [109], reducing reliance on artificial lighting, and therefore reducing the energy consumption of the building.

The appropriate consideration of envelope components while designing the building, such as orientation, interior positions, facade layouts, shading devices, windows, and skylight glazing, can provide as much natural daylight to internal building spaces [110, 111]. For existing buildings, the skylights, window glazing, and window-to-wall ratio are considered to improve the amount of daylight and reduce energy consumption. However, it is essential to consider the necessity of shading devices (reflectors) to minimise the possible impact of annoying glare from direct solar radiation [112, 113].

Many studies investigated the influence of passive technologies on improving the amount of natural daylighting in the building and their potential to reduce lighting energy demand. Lapisa et al. [114] studied the effects of the skylight area design on the lighting level and its impact on thermal discomfort. Numerical simulation results indicated that the skylights planned for 2.5% to 5% of the entire roof would offer more than 50% energy efficiency of lighting in the tropics during the day with a mild rise in thermal discomfort. Fasi and Budaiwi [115], investigated the effects of energy efficiency and
## Table 6  Influences of passive measures on daylighting performance for several case studies

<table>
<thead>
<tr>
<th>Case Study Location</th>
<th>ASHRAE Climate Zone</th>
<th>Simulation Method/Tools</th>
<th>Project Design Aim</th>
<th>Major Variables</th>
<th>Findings</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia</td>
<td>1A</td>
<td>TRNSYS.</td>
<td>Energy-saving for lighting and thermal comfort.</td>
<td>Skylight to roof ratio, the distance between skylights and skylight surface area.</td>
<td>Determination of the skylights to roof ratio has a significant effect on providing lighting energy efficiency &amp; thermal comfort for buildings. In contrast, it can provide lighting energy savings for buildings by more than 50% with a moderate increase in thermal discomfort.</td>
<td>[114]</td>
</tr>
<tr>
<td>Singapore</td>
<td>1A</td>
<td>DAYSIM</td>
<td>Energy-saving for lighting and thermal comfort.</td>
<td>Interior reflectance of (ceiling–wall–floor), visual transmittance of glass, design variants of light shelves, and shading control.</td>
<td>The vital influences of glazing visual transmittance, interior surface reflectance &amp; shading control on DAcon and DAmax were identified.</td>
<td>[116]</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1A</td>
<td>DAYSIM</td>
<td>Energy saving WWR, windows orientations, and wall reflectance.</td>
<td></td>
<td>The study established that thirty percent of WWR, wall reflectance of 0.8 &amp; South window positioning stand as a promising option to balance the visual aspect and performance of lighting energy demand.</td>
<td>[117]</td>
</tr>
<tr>
<td>Location</td>
<td>Type</td>
<td>Software/Method</td>
<td>Focus</td>
<td>Details</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Malaysia</td>
<td>1A</td>
<td>IERS-VE</td>
<td>Lighting load and visual comfort</td>
<td>Sky conditions, shelf height, number of shelves, depth of the shelf, WWR, solar reflectance of walls, ceiling &amp; floor, and building orientation. The configurations of LS 6 with 2.77% and LS 4 with 2.82% were confirmed to be the best combination under an intermediate sky. The LS 2 indicated the best performance under an overcast sky, with 3.56% for optimising daylighting performance.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>1A</td>
<td>Radiance</td>
<td>Visual comfort</td>
<td>Solar shading device and glazing type. Light shelf with partial blinds inclined at an angle 45° improves performances of mean Guth visual comfort probability (VCP) and CIE Glare Index.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>1A</td>
<td>EnergyPlus and Holigilm</td>
<td>Energy-saving of lighting and cooling load</td>
<td>WWR, building orientation, glazing type, visual transmittance of glass, and light pipe dimensions. The maximum energy conserved by daylight is accomplished for the single-glazed south-oriented window with a 40% glazed area. DPF for the light pipe is low in the morning and evening time.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>1A</td>
<td>Design-builder</td>
<td>Energy-saving &amp; visual comfort</td>
<td>Glazing type and window orientations. Double-glazed windows with integrated daylight minimise 70% of lighting, 8% of cooling, and 14% of total energy consumption annually.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>1A</td>
<td>IES&lt;VE&gt;</td>
<td>Visual comfort</td>
<td>Building orientation, duct shape, and duct dimensions. ADS performs better in the South location than in any other orientation. ADS with a duct width of 3 meters in rectangular shape has a higher illuminance value under overcast and intermediate sky conditions.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
visual comfort for various glazing types (tinted, low-E, and clear glass). The simulation results indicate that annual lighting energy consumption decreased by 8% and 14% for tinted glass and clear class, respectively. In addition, low-E glass can decrease a significant amount of overall building energy demand by (16%) by offering a glare-free indoor environment.

4.4.3 Natural ventilation (NV)
The major functions of NV ideas are providing better indoor air quality (IAQ) without demanding electricity to convey the air and improving thermal comfort via ventilating the users. Natural ventilation is a procedure to distribute clean air to the indoor building environment and remove indoor air moist out, aided by thermal buoyancy, wind pressure, or their combination, to provide a pleasant and well-off living environment [119, 120]. Natural ventilation is a significant, sustainable way to reduce buildings’ energy use, improve thermal comfort, maintain a well indoor environment [121] and reduce the problems associated with air conditioning systems [122]. Directly, it is used when the cooling by the airflow or indirectly when the built mass is cooled by the night ventilation and pauses the thermal gains the next day [122, 123].

Utilising NV strategies depends significantly on the local climate, which differs considerably from region to region worldwide. In addition to exterior climate conditions as the primary driving factor, architectural design measures play a significant role in natural ventilation and indoor airflow efficiency. Design parameters that change the internal airflow into the building include the opening size and position, the internal layout of the building’s height and orientation, and the façade features such as the balconies [124, 125]. Studies on the possibility of using NV in hot-humid climates by Aflaki et al. and Al-Cheikh Mahmoud et al. [126, 127] have established that this strategy is unsuitable for tropical climates, due to the temperature consistency between the alternations of day and night, as well as cloud cover and the high humidity in the sky, minimising the heat transfer rate, which causes uncomfortable thermal conditions.

4.4.4 Solar chimney (SC)
Solar chimneys are a type of passive solar heating and cooling system that aims to regulate the temperature of a building to provide natural ventilation. They are considered one of the ways to achieve energy efficiency in a building [128, 129]. Solar chimneys depend on the movement of the natural air
convection resulting from the density variation of the internal air currents. Therefore, the solar chimney can serve as a passive heating technique, a device for thermal insulation, or a natural ventilation system. These depend on the distribution and opening of air vents, as presented in Figure 4 [83]. Solar chimneys’ efficiency is only based on the outside temperature and not the increase in the indoor temperature. The stack ventilation efficiency is limited by the distance between the chimney outlet and the inlet [130].

The working mechanism of the solar chimney is like the Trombe wall if it is connected to the wall. The hot, warm air received from the solar collector supplies passive heating. Natural ventilation depends on the temperature disparity between the indoor and the outdoor air [126]. A solar chimney gives passive ventilation when the inside temperature is greater than that of the outside one. However, it is inefficient in tropical climates since the internal temperature differential usually is less than 5°C, with the outside temperature increasing by more than 30°C [131, 132]. Besides, a study conducted by Tan and Wong [133] showed that, in tropical climate situations, high solar irradiance is more than 700 W/m², the ambient airspeed is less than 2.00 m/s, and cross ventilation acts better than the solar chimney. However, tropical countries where the sky is always overcast act as thermal insulation to minimise the building’s heat gain [134].

5 Conclusion
Buildings are among the essential energy use sectors worldwide due to the upward trend of the world’s population and the urgent need for increased
development. Various proposals have been suggested in recent decades to resolve this problem, as various policies are being implemented alongside the development of new technologies to monitor the growing increase in energy consumption in the building sector. Using energy-saving measures for the building envelope elements is one of these approaches due to their efficiency in improving building performance in terms of minimising energy consumption and providing daylighting and thermal comfort by balancing heat loss and heat gain in prevailing climatic conditions. This statement can be supported by the findings of the studies reviewed, suggesting improvements in energy and environmental emissions accomplished using these strategies.

This article provides an overview of energy-saving measures for building envelope elements that have more efficient for reducing energy demand and optimising the indoor environmental aspects of buildings in hot-humid climates. Six energy-saving measures were examined: the window-to-wall ratio, thermal insulation of walls and roofs, glazing units, solar shading, natural ventilation, and solar chimneys. Based on the study, the following conclusions are drawn:

1. It is found that the WWR is the most significant variable for balancing daylighting and natural cooling, and it depends primarily on climatic conditions and facade orientation. Its suitable percentage for hot-humid and hot-dry climates range from 20–40% for north facades and 20–30% for south facades.

2. The variety of glass provides more options for the building’s visual and energy performance aspects. However, all glass types can conflict with some properties, such as U value, SHGC, and light transmittance. Thus, choosing glazing to minimise energy use in buildings requires concessions in some respects to open up possibilities for other aspects and provide an ideal compromise between the features being considered while minimising the contradictions between them. Low-E glass in hot & humid climates is more effective for reducing the cooling load than low-U-value glass, which can drastically reduce up to 26% and 43% of the cooling load.

3. Incorporating insulation materials with domestic building materials have greater potential for energy efficiency and improved thermal comfort, as it can minimise heat gains effectively via building envelopes ranging from 21–32% annually. However, this energy saving can nonetheless be controlled and improved by considering the thickness of insulation
material and placement. In this respect, in hot climates, the application of insulation layers to the surfaces of the exterior walls serves better for reducing cooling load than the ones applied to the interior wall surfaces.

4. The proper shading technology for a building is determined primarily by its climatic location and façade direction. Shading technology with an Egg-crate is the perfect choice to reduce cooling energy, minimise indoor air temperatures and the number of uncomfortable hours, and improve the daylight level, where it can blend horizontal and vertical shading techniques simultaneously.

5. Natural ventilation depends on architectural design features that significantly affect natural ventilation efficiency, indoor airflow, and the local climate. High humidity and cloud cover minimise the heat transfer rate because of the lack of temperature variations between day and night. As in hot and humid climates, its effectiveness is limited.

6. The performance of the solar chimney depends on the outside temperature and ambient airspeed. A solar chimney offers passive cooling when the temperature outside is lower than the inside and the ambient airspeed is higher than 2.00 m/s. It renders it inefficient under tropical weather conditions, whereas high solar irradiance is more than 700 W/m² and the speed of the ambient air is less than 2.00 m/s. It can, however, be used as thermal insulation to reduce heat gain in the indoor environment.

The studies mentioned above dealt with energy-saving measures for building envelope elements that have been investigated for energy-savings in hot and humid climates. These measures have been investigated individually to improve building energy performance by providing daylight, minimising heat gain for a building envelope, or reducing energy use for cooling, lighting, etc. Even though energy-saving measures have varying potentials to reduce a building’s energy consumption and improve thermal and visual comfort, high levels of energy efficiency require the integration of several of them simultaneously. One of the future trends is to investigate the effect of interrelationships and interactions when incorporating a set of energy-saving measures derived from an integrated approach on a building’s energy performance. This paper could promote the development of building energy efficiency in hot & humid climates and a better understanding of energy-saving measures of building envelope elements and their potential to improve energy performance. In addition, providing stakeholders with insight into the most efficient measures and evaluates the feasibility of energy efficiency improvements during the design of new or retrofitting existing buildings.
Nomenclature/Abbreviation

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ACH</td>
<td>Air change rate</td>
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<tr>
<td>ADS</td>
<td>Anidolic Daylighting System</td>
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<tr>
<td>AIW</td>
<td>ATTOCH Inner Window</td>
</tr>
<tr>
<td>BCA</td>
<td>Building and Construction Authority</td>
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<tr>
<td>BEC</td>
<td>Building Energy Code</td>
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<tr>
<td>BERDE</td>
<td>Building for Ecologically Responsive Design Excellence</td>
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<tr>
<td>B(EE)R</td>
<td>Building (Energy Efficiency) Regulation</td>
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<tr>
<td>CIE</td>
<td>International Commission on Illumination</td>
</tr>
<tr>
<td>DA</td>
<td>Daylight autonomy</td>
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<tr>
<td>DSGF</td>
<td>Double skin green façade</td>
</tr>
<tr>
<td>DSF</td>
<td>double-skin façade</td>
</tr>
<tr>
<td>DPF</td>
<td>Daylight penetration factor</td>
</tr>
<tr>
<td>ETTV</td>
<td>Envelope thermal transfer value</td>
</tr>
<tr>
<td>GBI</td>
<td>Green Building Index</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heat ventilation and air condition</td>
</tr>
<tr>
<td>IAQ</td>
<td>Indoor air quality</td>
</tr>
<tr>
<td>LCC</td>
<td>Life cycle cost</td>
</tr>
<tr>
<td>MFOM</td>
<td>Multi-factor optimisation model</td>
</tr>
<tr>
<td>NV</td>
<td>Natural ventilation</td>
</tr>
<tr>
<td>NZEB</td>
<td>Net Zero Energy Building</td>
</tr>
<tr>
<td>nZEB</td>
<td>Nearly Zero-energy building</td>
</tr>
<tr>
<td>OTTV</td>
<td>Overall Thermal Transfer Value</td>
</tr>
<tr>
<td>PCM</td>
<td>Phase change material</td>
</tr>
<tr>
<td>PRH</td>
<td>Public rental housing</td>
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<tr>
<td>Sc</td>
<td>Solar coefficient of glass</td>
</tr>
<tr>
<td>SC</td>
<td>Solar chimney</td>
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<tr>
<td>SHGC</td>
<td>Solar heat gain coefficient</td>
</tr>
<tr>
<td>SNI</td>
<td>Indonesian National Standard</td>
</tr>
<tr>
<td>U-value</td>
<td>Thermal transmittance value</td>
</tr>
<tr>
<td>VCP</td>
<td>Visual Comfort Probability</td>
</tr>
<tr>
<td>WFR</td>
<td>Window-to-floor ratio</td>
</tr>
<tr>
<td>WWR</td>
<td>Window-to-wall ratio</td>
</tr>
</tbody>
</table>

References


[34] Y. Kharbouch, A. Mimet, M. El Ganaoui, and L. Ouhsaine, “Thermal energy and economic analysis of a PCM-enhanced household


Biographies

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