IMPACT OF BUILDING MORPHOLOGY ON ENERGY EFFICIENCY IN DEVELOPING COUNTRIES: A STUDY OF OFFICE BUILDINGS IN SRI LANKA

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Abstract: The design phase of a building plays a significant role in implementing energy-efficient practices. This study explores how building morphology factors influence the energy efficiency of office buildings in Sri Lanka, focusing both on embodied and operational energy. This study was steered via a qualitative approach, conducting a series of expert interviews with professionals in architecture, engineering, and construction. This study highlights the importance of adopting a morphologically sensitive design approach in the early design stages of office buildings. It was found that key morphological factors such as building shape, size, height, storey height, circulation space, wall-to-floor ratio, building orientation, and the envelope were critical to energy performance in office buildings. The study highlights that beyond selecting energy-efficient equipment or adopting renewable technologies, a paradigm shift towards considering energy efficiency through design philosophy could help yield better results in making energy-efficient buildings in the future. This study contributes new knowledge by being the first to explore how design morphology affects building energy performance, within a developing tropical context like Sri Lanka. Finally, it offers a new interpretation of the traditional saying *"form follows function"*, arguing that form should not only follow function, but also that *"form follows energy".*

Keywords: *building morphology, operational energy, embodied energy, office buildings, Sri Lanka*

1. Introduction

The rapid urbanisation has significantly influenced global energy consumption, posing serious challenges to sustainable development. This increase in energy demand has raised concerns over energy resource depletion, supply constraints, and harmful environmental consequences such as ozone layer depletion and climate change (Huo and Peng, 2023). In urbanised contexts, the building sector consumes nearly 151 EJ of energy, which is approximately 36% of total global energy use (Santamouris and Vasilakopoulou, 2021). Of this, around 30% (or 130 EJ) is consumed by building operations, with the remainder attributed to construction-related services. Due to the substantial energy demand during the building's operation phase and the likelihood of it further increasing with the continued urbanisation, there is an urgent need to adopt effective energy conservation strategies and enhance building efficiency worldwide.

During recent decades, substantial efforts have been made to reduce building energy consumption and improve energy efficiency by examining the various factors that influence energy performance. For instance, Santamouris and Vasilakopoulou (2021) identified six factors that influence the energy consumption of buildings: (i) demographic factors; (ii) economic factors; (iii) climatic factors; (iv) social drivers; (v) morphological factors, and (vi) technological drivers. Among these, research indicates that building morphology has a significant influence on the operational energy and embodied energy demand of buildings (Xu et al., 2023; Zhou et al., 2025). In simple terms, building morphology is defined as the study of shapes and forms of buildings and architectural plans (Abdallah, Kamel and Mohamed, 2021). The energy performance of a building highly relies on the building's shape and form, which are determined in the pre-planning and design phase of a building (Leng et al., 2020). Therefore, architectural decisions made at the design stage can significantly influence a building's energy efficiency over its lifecycle. In this vein, building morphology is well-recognised as a practical and impactful approach to reducing energy consumption (Xu et al., 2023).

Many previous studies have explored the relationship between building morphology and energy consumption patterns in various geographical contexts (Heeren and Hellweg, 2018; Leng et al., 2020; Pauliuk, Sjöstrand and Müller, 2013). For example, Heeren and Hellweg (2018) found that in Switzerland, an expansion of floor area by 20% increased energy consumption, which in turn led to an 8% rise in greenhouse gas emissions. Similarly, a study in Norway revealed that reducing the floor area of buildings can significantly reduce their climatic impact by as much as 50% (Pauliuk, Sjöstrand and Müller, 2013). While many previous studies have focused on developed countries, limited attention has been given to developing contexts. According to Berardi (2017), the energy consumption patterns influenced by morphological factors in buildings vary significantly between developed and developing countries. The author further explained that buildings in developing countries tend to be smaller and low-rise, while in developed countries, most buildings are larger and taller,

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requiring more energy consumption. Therefore, how morphological factors affect buildings and what practices can be undertaken to optimise energy efficiency, differ between developing to developed contexts.

In developing contexts, a few studies have investigated the influence of building morphological factors on energy demand in different types of buildings. For example, Geekiyanage and Ramachandra (2018) developed an early-stage model for predicting operational energy demand of condominiums in Sri Lanka, focusing primarily on residential high-rise settings. Similarly, Weerasinghe, Ramachandra and Rotimi (2022) explored morphological impacts in commercial buildings, focusing on a few selected parameters and without integrating embodied energy considerations. Rajapaksha (2019) examined office buildings, identifying certain morphological factors such as building orientation and form; however, the study was restricted to operational energy and did not comprehensively address multiple morphological variables or their combined effects. Therefore, a key limitation of these existing studies is that they remain fragmented, focusing either on a specific building morphological factor or on operational energy alone, without incorporating embodied energy considerations. To date, no study has comprehensively assessed how a range of morphological factors collectively influence both operational and embodied energy consumption in office buildings in a developing context like Sri Lanka.

Therefore, as a step toward addressing this gap, this study aims to identify key building morphological factors influencing energy efficiency in office buildings located in hot climate developing countries, using Sri Lanka as the case study. The choice of Sri Lanka is based on its status as a developing nation with a hot, humid tropical climate, which contributes to extensive energy consumption in buildings (Li et al., 2024). Office buildings in Sri Lanka account for a significant share of national energy demand, with air conditioning, lighting, and office equipment being the primary contributors to high electricity usage (Ariyaratne, Karunathilake and Punchihewa, 2022). Moreover, these buildings demonstrate considerable embodied carbon emissions, largely due to components such as sub-structures, structural frames, upper floors, and external walls (Kumanayake, Luo and Paulusz, 2018). Therefore, conducting a study within this context is justified to precisely identify which key morphological factors affect the energy efficiency of office buildings in developing countries.

2. Literature Review

This section presents the findings of the literature review on operational energy consumption in buildings and the influence of building morphology on energy efficiency.

2.1. KEY DETERMINANTS OF OPERATIONAL ENERGY CONSUMPTION IN BUILDINGS

The building industry consumes energy in various forms and, in turn, contributes to environmental impacts and sustainability challenges. Therefore, understanding the distinct categories of energy consumption in a building is important to decide which strategies to undertake in reducing overall energy use and carbon emissions. Accordingly, the total life cycle energy of a building can be categorised into two types as follows (Kamazani, Dixit and Shanbhag, 2025):

1. Embodied Energy – Total energy sequestered in building materials from the point of production to on-site construction and finally to demolition and disposal.
2. Operational Energy – Total energy used to operate the building, including heating, cooling, lighting and powering appliances.

Of the two categories of energy consumption in the building industry, operational energy contributes the largest share over a building's life cycle. Generally, operational energy consumption happens continuously throughout the building's occupancy phase, and it often constitutes 80-90% of the total energy consumption of a building (Kusi et al., 2025).

Many operational systems and behavioural factors influence the operational energy consumption of a building. For instance, operational systems such as **heating, ventilation and air conditioning (HVAC)** are among the largest energy consumers in building (Bae et al., 2021). Energy efficiency of HVAC systems can be improved by using high-performance HVAC systems, well-designed and sealed ductwork and smart control systems to respond to occupancy and environmental conditions (Bae et al., 2021). Similarly, **lighting systems** also substantially contribute to the operational energy demand. The lighting energy consumption can be improved through strategies such as installing LED fixtures, incorporating automated controls, and using maximum natural daylight (Kurian et al., 2008). Besides, **water systems,** which include plumbing and heating for hot water, impact both water use and energy efficiency. To enhance the energy efficiency of these water systems, strategies such as using low-flow fixtures and high-efficiency water heaters (e.g., tankless or solar systems) can be used (Pomianowski et al., 2020). Furthermore, integrating **building automation systems** can help further improve efficiency in HVAC, lighting and security functions of a building using real-time data, even if their implementation can result in high installation and maintenance costs (Aste, Manfren and Marenzi, 2017). In addition, **incorporating renewable energy** sources such as solar panels further helps to reduce energy consumption in buildings (Abolhosseini, Heshmati and Altmann, 2024).

Similar to operational systems, the **behavioural factors** of the occupants also play a crucial role in steering the energy efficiency of buildings. For instance, encouraging the adoption of energy-conscious practices such as turning off lights and equipment when not in use, and conducting awareness and structured behavioural change programs can make a significant reduction in energy consumption in buildings (Chen et al., 2021).

Most of the above-mentioned operational systems and associated approaches that determine energy efficiency would be more effective if building morphology factors were favourably considered during the planning and design phase of a building. Therefore, it is important to understand how these building morphology factors impact energy efficiency by influencing the operational systems that determine overall performance. This relationship is discussed in the next section.

2.2. THE IMPACT OF BUILDING MORPHOLOGY ON THE ENERGY EFFICIENCY OF BUILDINGS

Building morphology refers to the study of the physical characteristics of a building, including building structure and design, building geometry, and intensity driver use (Weerasekara et al., 2021). The concept stems from the broader discipline of morphology, which originated in biological and linguistic studies to describe the form and structure of organisms and language (Devlin, 2004). In architectural design, building morphology focuses on the configuration of a building's physical shape, the spatial arrangement of its elements, and its relationship to its surroundings, particularly in terms of energy efficiency and environmental impact (Xu, 2023).

There are several building morphology factors related to the physical form and structure of a building that influence its performance in terms of energy consumption, thermal comfort, and environmental impact. Herein, building morphology factors affect energy efficiency by influencing the operation systems that determine the overall energy performance of a building. Table 1 presents significant morphological factors and describes how each factor contributes to the energy efficiency of a building.

Table 1: Influence of key morphology factors on energy efficiency

	Building Morphology Factors	***How the factor affects the building energy efficiency***	***References***
1	*Building shape*	*Simple building shapes are more energy efficient than complicated ones as they are easier to insulate, cool and ventilate.*	*Chen et al. (2020)*
2	*Building orientation*	*Impacts solar heat gain and daylight penetration, affecting heating, cooling and lighting energy needs.*	*Valladares et al. (2017)*
3	*Building height*	*Impacts vertical air distribution and temperature stratification, affecting HVAC system zoning and efficiency*	*Chen et al. (2020)*
4	*Internal layout*	*Depending upon the open and compartmentalised plans, ventilation requirements and zoning strategies would differ.*	*Xu et al. (2023)*
5	*Fenestration*	*Effective fenestration reduces the need for artificial lighting and HVAC as it enables daylighting, solar gain, heat loss and ventilation*	*Feng et al. (2021)*
6	*Façade Geometry*	*Affect shading, and daylight input, influencing lighting and thermal comfort*	*Liu et al. (2023)*
7	*Skylights/ Light Wells*	*Enhance the daylight penetration and reduce the reliance on artificial lighting*	*Pilechiha et al. (2020)*
8	*Courtyards / Open Spaces*	*Enhance natural ventilation and thermal comfort*	*Loo et al. (2021)*
9	*Roof Design*	*Possible to use solar panels to improve energy efficiency*	*Baleta et al. (2019)*
10	*Circulation areas*	*An effective circular layout promotes energy-saving behaviors such as using natural light and ventilation*	*Delzendeh et al. (2017)*

As shown in Table 1, building morphology factors significantly determine how energy is consumed within a building. Previous studies have highlighted that building energy efficiency can vary significantly between developing and developed contexts. Since limited studies have been done on how the building morphology impacts the energy efficiency of buildings in developing countries, this study is a progression toward filling this gap, taking Sri Lanka as a case study. Further details about how the study was carried out are explained in the following section.

3. Methodology

Tuckerman, Kaufman and Danchin (2020) stated that the qualitative research approach focuses on exploring a specific group's opinions, experiences, beliefs, and attitudes, making it effective for investigating emerging ideas through detailed analysis. It is particularly suitable for gathering insights from individuals based on their behaviours and experiences. Since gathering the opinions of industry experts was essential to achieve the aim of this study, which is exploratory in nature, a qualitative approach was followed.

In this study, the qualitative approach was implemented through conducting a total of 15 semi-structured interviews with professionals in the construction industry who are aware of the morphology concept and who have prior experience in energy-efficient practices of office buildings in Sri Lanka. During the analysis, no new themes, categories, or insights emerged after the 12th interview. The final three interviews served only to confirm and reinforce the previously identified patterns, indicating that additional interviews would not yield significant new information. Both purposive sampling and snowball sampling techniques were used to recruit the interviewees for the study. Table 2 presents the profile of the study's interviewees.

Table 2: Profile of interviewees

Interviewee	***Profession***	***Experience in the industry***		***Interviewee***	***Profession***	***Experience in the industry***
1 (E1)	*Civil Engineer*	*12 Years*		*9 (E9)*	*Civil Engineer*	*10+ Years*
2 (E2)	*Architect*	*11 Years*		*10 (E10)*	*Civil Engineer*	*7 Years*
3 (E3)	*Mechanical Engineer*	*14 Years*		*11 (E11)*	*Architect*	*17 Years*
4 (E4)	*Facilities Manager*	*22 Years*		*12 (E12)*	*Architect*	*12 Years*
5 (E5)	*Mechanical Engineer*	*8 Years*		*13 (E13)*	*Architect*	*18 Years*
6 (E6)	*Facility Manager*	*19 Years*		*14 (E14)*	*Architect*	*16 Years*
7 (E7)	*Facility Manager*	*17 Years*		*15 (E15)*	*Civil Engineer*	*31 Years*
8 (E8)	*Architect*	*12 Years*				

The interviews were conducted from September 2024 to December 2024. Each interview lasted for one hour, and the interviews were audio-recorded with the consent of the interviewees. The qualitative data collected through semi-structured interviews were analysed using content analysis. Through content analysis, the data were systematically categorised and interpreted to identify key themes and insights relevant to achieving the aim of the study (Kleinheksel et al., 2020). This analysis consisted of three phases. First, the data were transcribed and scrutinised to identify preliminary themes known as open codes. Second, the developed open codes were combined, refined, and categorised to form the axial codes, which were further refined in the third step to form the final themes of the study, known as selective codes. To support this process, 'Taguette', which is free, open-source software, was used to facilitate the organisation of data and coding.

4. Findings

This section presents the empirical findings of the study, highlighting how various building morphology factors influence the energy efficiency of office buildings in Sri Lanka.

4.1. THE IMPACT OF BUILDING SHAPE ON THE ENERGY EFFICIENCY OF BUILDINGS

Building shape plays an important role in both embodied and operational energy consumption. The interviewees agreed that complex and irregular buildings tend to increase embodied energy due to the need for more materials and the resulting waste. For instance, Interviewee E3 noted *that "odd-shaped buildings lead to significant material wastage"* due to the need for various types of formworks. Similarly, irregular roofs are another concern, as Interviewee E5 mentioned they "demand more materials and result in higher embodied energy."

In terms of operational energy, the irregular buildings also negatively affect lighting, cooling and mechanical system efficiency. Herein, the Interviewee E2 noted, *"Buildings with odd shapes require more light fixtures".* The reason for this, according to the Interviewee, is that the overly complex shape of the building results in unequal distribution of natural light in that space and requires additional artificial lighting. Similarly, the interviewees explained the effect of shape on heat transfer. For instance, Interviewee E4 mentioned that *"If the exposed area of a building increases, more heat is transferred into the building, which makes the cooling load higher."* Additionally, the Interviewee E7 highlighted that irregular shapes also affect HVAC efficiency: *"Buildings not in rectangular forms are more expensive in terms of energy."* For the same reason, Interviewee E9 added, "Odd shapes may lead to a complex piping layout."

Another commonly noted factor was the contribution of roof constructions to energy use. E12 said that *"If the roof is flat, we can place solar panels for electricity generation, which aids in reducing reliance on electricity from the grid and improves the operational energy use of the building."* This emphasises the need for design features that enhance the application of solar energy, which is not always possible for extremely irregularly shaped buildings.

Overall, the findings indicate that basic-shaped buildings contribute to significant energy efficiency benefits. These simple buildings help reduce embodied energy by improving material efficiency and minimising waste, while reducing operational energy by improving natural lighting, reducing cooling loads, optimising HVAC system efficiency, and facilitating renewable energy integration.

4.2. THE IMPACT OF BUILDING SIZE ON THE ENERGY EFFICIENCY OF BUILDINGS

Building size is a key determinant of both embodied and operational energy consumption. Therefore, in the context of high-energy-consuming office buildings, especially in tropical climates like Sri Lanka, understanding how size influences energy demand is essential.

With respect to embodied energy, larger buildings, compared to smaller ones, undoubtedly require more materials, leading to increased energy use and carbon emissions. These buildings always require more structural components like deep foundations, reinforced concrete cores, and steel frameworks, further increasing embodied energy. Interviewee E1 explained this as, *"Reducing the size of a building and adopting more compact designs consistently decrease material usage, leading to lower embodied energy and reduced carbon emissions."* Since larger volumes of materials are required, the increasing number of transportation rounds to procure them is another concern that augments embodied energy. Herein, the Interviewee E12 pointed out that "*smaller and more compact building designs require fewer materials, thereby reducing transportation-related energy consumption."* Additionally, large buildings often use cranes and concrete pumps to handle, move, and procure materials, increasing the overall energy footprint.

From an operational energy perspective, too, the larger buildings require more artificial lighting, cooling, and mechanical systems. As Interviewee E3 explained, *"Larger buildings necessitate extensive artificial lighting systems, especially in areas with limited access to natural light."* Similarly, the Interviewee E6 cautioned that *"maximising natural lighting may also lead to increased heat gain,"* resulting in higher demand for cooling. As explained by Interviewee E7, with an increase in building size, there is a greater need for energy-intensive HVAC systems, including a larger number of Air Handling Units (AHUs). When buildings have many storeys, it also becomes necessary to incorporate larger water distribution systems, which consume more energy to pump water to higher floors.

In a context like Sri Lanka, where land is scarce, large-sized buildings are often unavoidable. Therefore, the interviewees pointed out practical solutions, such as implementing the concept of 'grouping buildings'. Interviewee E9 noted that *"grouping buildings contributes to reduced energy costs."* This design strategy helps minimise inefficiencies in lighting, cooling, and mechanical systems, making it a valuable approach for promoting sustainable design in Sri Lanka's office sector.

4.3. THE IMPACT OF BUILDING HEIGHT ON THE ENERGY EFFICIENCY OF BUILDINGS

Building height is also a crucial morphological factor affecting both embodied and operational energy consumption in office buildings. As buildings grow taller, several interrelated aspects contribute to increased energy consumption, including structural material requirements, HVAC demands, water supply systems, and vertical transportation.

Generally, taller buildings demand stronger structural elements to support the high loads and stresses produced by their height. This often leads to the requirement of higher quantities of reinforced concrete, structural steel, and other durable and stronger materials that have higher embodied energy as they are subjected to intensive manufacturing processes. Interviewee E9 confirmed this observation, mentioning, *"Taller structures require stronger construction materials, resulting in higher embodied energy."*

Operationally, building height immensely impacts HVAC performance. This was explained by Interviewee E2, who stated, *"When the height of a building increases, windows on the upper levels cannot be opened… HVAC systems remain necessary to maintain indoor comfort."* Similarly, water supply systems in high-rise buildings are also energy intensive. Interviewee E6 stated, *"Longer pipes are required… leading to higher energy costs for pumping water to the upper levels,"* including chilled water for HVAC. Vertical transportation is another factor that increases energy consumption in taller buildings. Interviewee R6 mentioned, *"Tall buildings require high-capacity, high-speed mortar elevators."* While uncovering the same fact, Interviewee E12 added that powerful pumps are also needed in high-rise buildings for water supply, fire protection systems, and HVAC systems.

However, the interviewees also noted that the increased heights offer benefits in terms of energy efficiency. For instance, Interviewees E8 and E9 pointed out that taller buildings are exposed to limited obstruction from other buildings, allowing more natural light and reducing the need for artificial lighting. In this context, Interviewee E5 confirmed, "*Designers should optimise the building's height,"* balancing land use, energy consumption, and sustainability. Therefore, an optimal building height can manage embodied and operational energy demands effectively.

4.4. THE IMPACT OF STOREY HEIGHT ON THE ENERGY EFFICIENCY OF BUILDINGS

Storey height is also a significant morphological factor that impacts both embodied and operational energy efficiencies in office buildings. Focusing on embodied energy, obviously, buildings with lower storey heights require fewer materials, directly reducing embodied energy. In contrast, Interviewee E8 mentioned, *"Unnecessarily increased storey height leads to high embodied energy,"* due to the higher demand for raw materials, structural reinforcements, and mechanical systems.

In terms of operational energy, when floor-to-ceiling heights increase, indoor air volume enlarges, requiring more energy for air conditioning. Even if there is a possibility of getting more natural light into buildings with taller storey heights, in the same manner, there is also a higher requirement for artificial lighting, especially during darker times. This indirectly increases the need to adopt smart lighting strategies. In the same vein, Interviewee E4 explained that *"Unnecessary storey height increases plumbing requirements, leading to higher energy consumption for pumping water to upper floors."* This suggests that increasing storey height leads to additional energy consumption for water pumping and distribution. Therefore, ensuring optimal storey height and spatial organisation can significantly reduce these inefficiencies.

Similarly, on one hand, heat gain from the roof significantly affects the upper floors of a building if there is a lower ceiling space. E5 highlighted that *"Ceiling space is critical on the topmost floor,"* where roof heat transfer increases cooling loads. Herein, approaches such as insulation, reflective roofing, and ventilation can be effective in mitigating this effect. On the other hand, increasing the service space above the ceiling raises overall energy consumption due to the increased building height. This includes higher requirements for piping and pumping energy, extended elevator shafts, and additional service components. Therefore, this emphasises the need to have an optimised storey height for an office building that helps reduce embodied energy and operational energy while contributing to more sustainable building design. In an attempt towards this, the Sri Lankan government has mandated, through regulatory standards, minimum heights required for office buildings. This information is important for designers to consider in order to create buildings that balance regulatory compliance with energy efficiency through passive design and careful planning.

4.5. THE IMPACT OF WALL-TO-FLOOR RATIO ON THE ENERGY EFFICIENCY OF BUILDINGS

The wall-to-floor ratio, another morphological factor, is significant in determining the embodied and operational energy efficiency of office buildings. Herein, unlike other factors, the wall-to-floor ratio is a plan efficiency measure that represents is the proportion of a building's external wall area compared to its internal floor area. A high wall-to-floor ratio means that the external wall area of the building is large compared to the floor area. This indirectly means that the amount of construction materials required, such as insulation and cladding, is high, leading to greater embodied energy.

From an operational energy perspective, the larger the exposed wall area, the greater the heat transfer will be, increasing the demand for cooling and operational HVAC energy. Therefore, from an architectural standpoint, optimising the wall-to-floor ratio is crucial for balancing aesthetics, cost, and energy performance. Interviewee E5 emphasised that *"Building designers are accountable for maintaining an optimised building ratio to avoid unnecessary operational energy consumption."* The interplay between form and function is evident in these considerations, where the challenge lies in achieving energy efficiency without compromising architectural integrity.

4.6. THE IMPACT OF CIRCULATION SPACES ON THE ENERGY EFFICIENCY OF BUILDINGS

Circulation spaces, including corridors, lobbies, stairwells, and lift lobbies, play a crucial role in determining the overall energy efficiency of office buildings. While these areas are essential for movement within buildings, their design and spatial configuration significantly influence both embodied and operational energy consumption. Inefficient planning of circulation paths can lead to unnecessary energy wastage, making it imperative for architects to optimise their layouts. One of the primary concerns with circulation spaces is their contribution to embodied energy. Interviewee E1 noted, *"Corridors and lobbies require additional finishing materials, adding to embodied energy; this remains the architect's responsibility".* Architects, therefore, play a fundamental role in ensuring that these spaces are designed efficiently, minimising excessive material use without compromising functionality.

The operational energy demand of circulation spaces is another critical factor. While traditional office layouts often allocate significant space to corridors and lobbies, Interviewee E2 noted that *"Unnecessarily increasing building circulation areas, such as corridors, lobbies, and lift lobbies, always leads to higher energy consumption."* This is particularly relevant in office buildings, where excessive circulation areas not only demand additional lighting and ventilation but also contribute to higher cooling loads. On the contrary, Interviewee E3 claimed that *"Placing corridors along the perimeter of the building helps minimise heat transfer into the office area and reduce cooling demands".* However, this contradicts another argument, as improper connectivity between circulation paths and external environments, especially in a tropical context like Sri Lanka, can lead to increased HVAC energy consumption. Interviewee E4 mentioned, *"Energy wastage through corridors and other circulation areas is considerably lower in high-rise buildings due to fewer openings."* These arguments emphasise that if circulation paths directly connect to the external environment, significant energy loss can occur through HVAC systems. This underscores the importance of designing enclosed circulation areas that prevent excessive heat exchange while maintaining sufficient ventilation.

4.7. THE IMPACT OF BUILDING ORIENTATION ON THE ENERGY EFFICIENCY OF BUILDINGS

Building orientation plays a fundamental role in determining the operational energy efficiency of office buildings in Sri Lanka, where solar radiation remains relatively consistent throughout the year, making heat gain a persistent challenge. Several interviewees emphasised that optimising building orientation can significantly reduce the energy demand of HVAC systems, thereby lowering cooling loads. Herein, a common concern raised was the impact of east-west-oriented buildings on thermal performance. Since east- and west-facing walls receive the most intense sunlight during mornings and afternoons, they contribute to excessive indoor heat accumulation. In response to this issue, Interviewee E4 stated, *"In Sri Lanka, [....] orienting longer facades towards the north and south minimises direct solar exposure of a building."* This underscores the importance of strategic orientation in reducing direct heat gain, as improperly oriented buildings tend to absorb excessive solar radiation, leading to higher cooling requirements.

As an important part of the building orientation, the interviewees highlighted the importance of careful planning in window placement and cladding selection. For example, Interviewee E11 noted, *"A poor selection of window and cladding arrangements highly influences a building's energy consumption [...] it is important to select glass with the correct U-value to be compatible with the orientation and climate of the region."* This emphasises that when selecting materials for the building, their specifications must align with building orientation to achieve optimal energy performance.

One of the most frequently discussed strategies for improving orientation-related energy performance is the incorporation of shading devices and morphological elements. Several experts pointed out that architectural features, such as fin walls and external shading systems, play a crucial role in blocking direct sunlight. For example, Interviewee E6 noted, *"In the World Trade Centre building, the east-west-facing walls incorporate a mix of glass and concrete to reduce heat transfer, while other orientations feature a cladding system. Additionally, the two towers are positioned so that one tower provides shade to the other, helping to mitigate solar heat gain."* These insights demonstrate that not only material selection, but also the overall building layout can influence energy efficiency. The deliberate use of shading between structures further supports the argument that orientation must be considered alongside other design factors.

4.8. THE IMPACT OF BUILDING ENVELOPES ON THE ENERGY EFFICIENCY OF BUILDINGS

The building envelope is a critical morphological factor influencing the energy efficiency of office buildings in Sri Lanka. The choice of materials in the building envelope plays a vital role in determining both the embodied energy and operational energy efficiency. For instance, Interviewee E3 noted, *"the materials used in the building envelope significantly impact carbon emissions and the lifecycle cost of the building, including energy expenses".* Similarly, the insulation properties of the building envelope also affect energy efficiency by determining the level of heat gain and loss, which in turn affects cooling and heating requirements. Here, a few innovative solutions, such as reflective coatings, have been identified as cost-effective insulation methods. Interviewee E5 highlighted that *"Applying white-coloured insulation paint on the roof surface can significantly reduce heat transfer into the building."* Besides, windows and shading devices are crucial elements that influence thermal efficiency. Interviewees stressed the importance of optimising window placement and shading systems to minimise heat gain. This approach aligns with passive design strategies that integrate shading features such as fin walls and overhangs.

5. Discussion

This study provides valuable insights into how morphological factors of office buildings affect embodied and operational energy consumption, especially within a tropical developing context of Sri Lanka. The findings of this study validated that building morphology factors, including building shape, size, height, storey height, wall-to-floor ratio, circulation space, orientation, and envelope, play a crucial role in determining the energy performance outcomes. Figure 1 presents a summary of practices that optimise the energy efficiency of office buildings in Sri Lanka.

Previous studies have found a noticeable trade-off between architectural features and the energy efficiency of residential buildings (Shadram et al., 2020). This study confirmed this finding and further elaborated that the contradictory situation is not only an issue inherent to residential buildings but also for office buildings. For instance, even if buildings with irregular and complex designs are aesthetically appealing, they tend to increase material consumption and, in turn, material waste, resulting in increased embodied energy.

This finding aligns with past studies (e.g., Kamal and Nasir, 2022; Shadram et al., 2020), which claim that architectural minimalism could foster resource efficiency and waste minimisation. Herein, it should be noted that simple shapes not only reduce material consumption and waste generation (thus reducing embodied energy) but also improve natural lighting and cooling efficiency, while contributing to a lower operational energy demand. Within this context, the study highlighted the need to adopt approaches such as compact designs and grouped building arrangements, which offer practical alternatives to large office buildings that are unsustainable in terms of energy efficiency.

Storey height is also a crucial building morphology factor that affects the energy efficiency of office buildings in Sri Lanka. When the floor-to-ceiling height is too high, even if it improves daylight penetration and ventilation, in a tropical country like Sri Lanka, this simultaneously will increase the volume inside the building which needs to be cooled, adding more energy burden. This trade-off is also a common issue that can be found in cold countries like the UK and Germany, where buildings are supposed to have lower ceiling heights to avoid requiring heating of unnecessary volume inside the building (Foster et al., 2016; Wong, 2008). However, in Sri Lanka, in regions like Kandy with mild weather conditions, higher ceilings could always be encouraged to maximise getting natural lighting and ventilation, while reducing the need for using artificial lighting. The study raised the importance of maintaining an optimal floor-to-ceiling ratio when designing office buildings, which allows sufficient thermal comfort and lighting while avoiding excessive height that wastes mechanical energy. Interestingly, the study found that local regulatory standards mandate minimum storey heights for office buildings, and these standards are always aligned with passive energy saving strategies, which is an approach also evident in most developed countries like Australia (Heffernan et al., 2017) and Sweden (Eriksson et al., 2020).

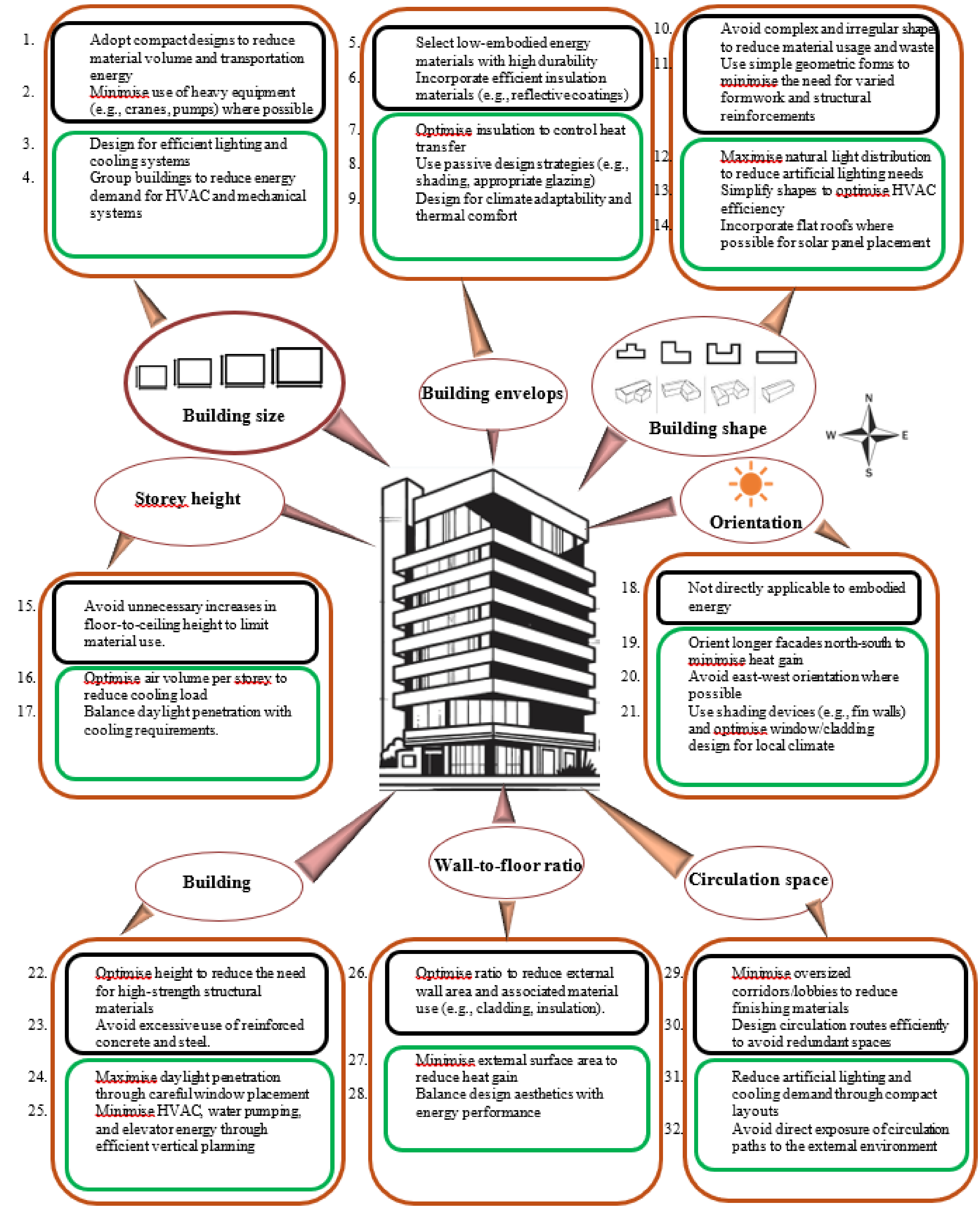

Figure 1: Practices for the optimisation of embodied energy efficiency

The study also emphasised the significance of the wall-to-floor ratio and circulation spaces for energy-efficient office buildings, particularly from a layout efficiency perspective. A higher wall-to-floor ratio correlates with increased heat transfer and greater material use, both of which undermine energy performance. Similarly, the circulation spaces that have been designed ineffectively also contribute to immense embodied and operational energy demands. Besides, the study found a context-specific, but universally relevant finding that is the critical role that the building envelope and orientation play in deciding the energy efficiency of office buildings. Herein, orienting buildings to minimise solar gain was highlighted as an essential strategy for passive cooling. Moreover, the role of building envelopes in terms of material choice, insulation performance, and the integration of reflecting coatings or shading devices was repeatedly mentioned as low-cost, high-impact strategies for improving operational energy efficiency.

To sum up, the findings of the study indicate that a morphologically sensitive approach is required for making energy-efficient office buildings in Sri Lanka. These insights, which derive from the study, reiterate the importance of optimising shape, size, plan efficiency, alongside planning climatically responsive building envelopes and orientation, especially during early design phases. Finally, this study offers a new interpretation of the traditional saying in the literature, *'form follows function'* (Ntieni, 2024), by emphasising that form should not only follow function, but also *'form follows energy'.*

6. Conclusion

The study explored how key morphological factors influence the energy performance of office buildings in Sri Lanka, considering both embodied and operational energy consumption. The findings of the study confirmed that the building's morphological factors, such as shape, size, height, storey height, wall-to-floor ratio, circulation spaces, orientation and envelopes play interconnected roles in deciding the building's energy performance. This study highlights the importance of adopting a morphologically sensitive design approach in the early design stages of office buildings. These energy-cautious decisions in early stages provide better opportunities to build more sustainable, cost-effective and regulation-compliant buildings.

As contributions to the practice, the study highlights that beyond selecting energy-efficient equipment or adopting renewable technologies, a paradigm shift towards considering energy efficiency through design philosophy could help in yielding better results in making energy-efficient buildings in future. These considerations must be incorporated into local design regulations and architectural education to ensure long-term sustainability in the construction industry. In terms of research, this study contributes to the new knowledge by being, to the authors' best knowledge, the first to explore how design morphology affects building energy performance, considering a developing tropical context like Sri Lanka. While the findings of the study are based on expert interviews in Sri Lanka, the underlying principles and concepts could be broadly applied to other tropical or developing countries that are encountering similar energy and urbanisation challenges.

7. References

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