architecture

Case Report

Analysis of Operational Energy between Adaptive Reuse Historic Buildings (ARHB) and Modern Office Buildings: A Case Study in Sri Lanka

Isuri Shanika Ariyarathna [1,*], Methsika Kariyakarawana [1], Wasudha Prabodhani Abeyrathna [1], Nina Danilina [2] and Rangika Umesh Halwatura [1]

[1] Department of Civil Engineering, University of Moratuwa, Bandaranayake Mawatha, Moratuwa 10400, Sri Lanka
[2] Urban Planning Department, Moscow State University of Civil Engineering, 129337 Moscow, Russia
[*] Correspondence: isurishanika@gmail.com

Abstract: Adaptive Reuse of Historic Buildings (ARHB) is a new concept in developing countries like Sri Lanka. One of the main concerns for the intendancy of decision makers to ARHB is the operational energy. This paper analyzes the research gap of reusing historical buildings as office spaces by utilizing their structural and architectural designs and preserving the buildings' authenticity for the future. It further aims to protect energy-efficient historical buildings from getting demolished and replaced with new modern buildings. A set of operational energy variables of modern office buildings and the potential historic buildings that can be reused as office spaces was established. During the early 1990s, old Dutch-era buildings in the country were mainly used as government office buildings. Three Dutch-era buildings in Galle Fort and three modern buildings in Colombo City have been selected as the case studies. Design-Builder (DB) software was used to comprehensively analyze sets of operational energy consumption variables. Selected historic buildings in Galle consumed 143.74 kWh/m^2, 156.34 kWh/m^2, and 209.39 kWh/m^2 while modern buildings consumed 337.29 kWh/m^2, 210.99 kWh/m^2, and 382.57 kWh/m^2 as operational energy, respectively. According to the analysis, the operational energy requirement of ARHB is comparatively lesser than that of modern buildings. This study, therefore, mainly concludes that the historical buildings saved more operational energy than the modern building envelopes while considerably reducing environmental impacts and saving the building energy cost.

Keywords: adaptive reuse of historic buildings; ARHB; energy; office buildings; modern buildings; energy-efficient buildings

Citation: Ariyarathna, I.S.; Kariyakarawana, M.; Abeyrathna, W.P.; Danilina, N.; Halwatura, R.U. Analysis of Operational Energy between Adaptive Reuse Historic Buildings (ARHB) and Modern Office Buildings: A Case Study in Sri Lanka. *Architecture* **2023**, *3*, 344–357. https://doi.org/10.3390/architecture3030019

Academic Editor: Hing-Wah Chau

Received: 15 May 2023
Revised: 30 May 2023
Accepted: 19 June 2023
Published: 22 June 2023

1. Introduction

The 2020 UN (United Nations) global status report for Building and Construction [1] stated that the building and construction sector is responsible for the world's largest energy usage and carbon dioxide emission. The building construction industry is currently searching for better solutions to overcome this global issue. Adaptive reuse of buildings has been identified as a sustainable solution to reduce the environmental footprint of the building construction sector [2]. When it comes to the adaptive reuse of buildings, historic buildings are more likely to be selected as they are bound to the people's cultural identity and personal identity [3]. Through the Adaptive Reuse of Historic Buildings (ARHB), material consumption, transport, and energy consumption can be reduced [3]. Even though the benefits of the ARHB have been widely espoused, many historic buildings have been disused or demolished as decision makers have had doubts over financial feasibility and operational and maintenance energy. This is mainly due to a lack of research on these concerns. Especially when it comes to developing countries like Sri Lanka, ARHB is a relatively new concept and research on this concept is very limited [2].

Research conducted by Bullen and Love [4] based on in-depth interviews with building owners and practitioners about ARHB found that the energy efficiency of many buildings in Perth was one of the main issues identified by all interviewees.

Operational and maintenance energy has the largest share in the life cycle energy use of buildings and it was calculated that this energy is 80–90% of the total energy [5]. In the modern building construction sector, major attention is given to operational and maintenance energy and energy efficiency. So, at the design stage of modern buildings, decisions are made on the building shape, orientation, materials, and other factors by considering the energy efficiency of the buildings. In historic buildings, most of them were designed based on the experience of the people, or when it comes to colonial buildings, these building features were mixed with the architecture of the governing country. In those early days, there were different assumptions concerning building properties. Hence, most of the building features in ARHB differ from modern-day buildings [6].

In recent decades, a significant transformation has taken place within the Galle Fort [7], where numerous historic townhouses have been acquired by expatriates, affluent Sri Lankans, and Indians. These individuals have undertaken extensive renovations, converting the properties into vacation homes, restaurants, hotels, and other establishments. It rapidly increases foreign occupants, a rapidly commercializing environment, and uncontrolled cultural tourism, which disrupts the authentic identity and sense of place of this living heritage site [8]. These living sites remain inhabited with active centers of commerce, networks of social connections, and continuity of cultural expressions. Rather than museumising the built fabric, preserving the Galle Fort as a "Living heritage" is important.

Moreover, the restoration of one heritage building, housing the Commercial Bank of Ceylon, stands out for its commendable eco-friendly features. In recognition of the restoration efforts, the building received the prestigious Platinum award from the Green Building Council of Sri Lanka in 2021. This accolade highlights the incorporation of environmentally conscious elements into the refurbishment process.

To preserve the living heritage characteristics of the area, it is crucial to maintain a variety of building types. In order to accommodate this diversity, the inclusion of office buildings is suggested. This study carefully examined the buildings from the Dutch era and selected three specific buildings for a quantitative analysis of their suitability and adaptability to be converted into office spaces. This study's conclusion can provide valuable guidance to decision makers regarding the conversion of these buildings into office spaces with minimal restoration activities. This approach aims to preserve the buildings' authenticity rather than undergoing extensive restoration and entirely transforming them into something else. Overall, by maintaining the original features and characteristics of these historic buildings, while repurposing them for office use, decision makers can ensure the preservation of the area's cultural heritage while meeting contemporary needs for functional spaces.

This study addresses the research gap related to a limited comparative analysis by examining historic and modern office buildings [9]. By comparing the operational energy consumption variables of both types of buildings, this research provides a valuable understanding of the energy performance differences. This analysis helps to fill the gap by offering empirical evidence and quantitative data to support the claim that the adaptive reuse of historic buildings can result in comparatively lower operational energy requirements. This study bridges the research gap by providing insights into the indoor conditions of low-rise buildings, indicating that they can maintain more consistent thermal and visual comfort levels throughout the building height.

This research compared operational energy (OE) between ARHB and modern buildings in Sri Lanka. For this, three modern office buildings were selected along with three Dutch-era historical buildings that can be reused as office buildings. All six buildings were modelled using the Design-Builder software version 6.0 (DBS), assuming all of them are typical office buildings. Then the OE of the six buildings was compared to identify whether there was a significant difference between these two types of buildings. Modern buildings were further analyzed for their energy efficiency concerning baseline models. By emphasizing the significance of designing with natural lighting and enhancing visual comfort, this study offers practical guidance for architects, designers, and decision makers. This study sheds light on the energy efficiency potential of historic buildings, highlights the trade-offs between visual comfort and thermal comfort, and recommends a combined design approach for achieving energy-efficient office building design.

2. Literature Review

2.1. Building Sector and Energy Consumption

Building construction is a major sector that affects the environment mainly through raw material consumption and waste generation. It is also recognized as a prominent user of non-renewable energy and an emitter of greenhouse gases (GHG) and other gaseous wastes [10]. It is estimated through many types of research that buildings in the member states of the European Union consume approximately 50% of the final energy consumption through their construction, use, and demolition stages. They contribute almost 50% of the carbon dioxide (CO_2) emission, the most basic gas responsible for the greenhouse effect [11]. Building occupancy and operations is a crucial stage of a life cycle of a building that detrimentally impacts the environment. Approximately 40% of global energy is consumed by residential and commercial buildings, as found in [12]. Energy is mostly required to provide comfortable conditions and continue the functions of the building during its operational stage.

2.2. Correlation between Building Design and the Energy Efficiency

According to statistical studies conducted by researchers, the potential 20–40% energy savings in the building sector could be achieved by improving the energy efficiency of the building [13]. Thus, the energy efficiency of building design has attracted increasing attention. In the current building construction sector, energy efficiency has become a vital concern that may be put forward as early as possible, which is during the design stage. Building design itself has been identified as a crucial concern of the construction of sustainable buildings. The energy-efficient building design has become imperative for energy conservation, emission reduction, and life quality enhancement of occupants [14]. The architectural decisions that are taken in this stage are particularly important in reducing the future energy demand of the building [15]. Professionals' most challenging task is designing and promoting low- or zero-energy buildings in an environmentally responsive and cost-effective way [16]. In modern commercial or public buildings, high attention is paid to the glazing, which reflects a significant influence on the building's energy demand [17]. The building shape, orientation, influence of optimum fenestration, and other factors that affect the building's energy consumption have been analyzed by many researchers [18]. Statistical correlations have been found between the embodied energy of the building and cost performance over different stages of the building's life cycle. In [19], 30 recently completed residential and commercial buildings were examined and a positive correlation between the capital cost investment and the building embodied energy was revealed. Also, in [20], the relationship between the costs and embodied energy of a building was analyzed and a strong and positive correlation was found. This correlation was, however, weak at the material level.

2.3. Operational Energy Aspects of Modern Office Buildings

The operational energy of an office building is the energy that is required for the comfort conditions, maintenance of the occupants, and day-to-day maintenance of the building. Day-to-day maintenance energy is the energy that is used for HVAC (heating, ventilation, and air conditioning), domestic hot water, lighting, office equipment, and other running appliances. Operational energy largely depends on the comfort level required for the occupants, office functions, climatic conditions, and operating schedules [21]. In the Sri Lankan context, the energy cost is 20–60% of office buildings' annual operations and maintenance cost [20]. Similarly, in Sri Lanka, energy consumption of office buildings that is mainly electricity accounts for 20% of the total electricity consumption in Sri Lanka [22]. More than 75% of the electricity, energy balance in typical buildings in Sri Lanka is found to be accounted for by the energy consumption for the air conditioning systems. Office buildings in Colombo are recognized as having an annual energy consumption of around ~250 kWh/m^2/a [23].

Commercial buildings, primarily office buildings, are classified among the buildings with the highest energy consumption [24]. Office buildings consume a higher portion of energy per capita compared to residential energy use. This is mainly because office buildings are fully equipped with energy-intensive equipment functioning continuously during office hours and are also considered to have a high space cooling/heating demand [25]. The annual electricity consumption of a typical office building was identified to consist of 43% of energy for air conditioning, 17% for office equipment, 34% for lighting, and 6% for lifts and escalators [26].

In other words, the largest portion of office buildings' energy consumption is for the building's air conditioning. However, it is noteworthy that this demand is subject to increase with the continuous warming of the climate. Office buildings are mainly located within rapidly urbanized settings, and improving the energy efficiency of office buildings in response to climate change is one of the main methods of reducing the rising rate of energy consumption and carbon emissions [27]. Based on a per-unit floor basis, energy use of fully air-conditioned office buildings can be 10–20 times higher than residential buildings [28]. Yang, in 2022, established that around 78–89% of life cycle energy is attributed to the building operation during the life cycle energy of 10 high-rise office buildings in Hong Kong [29].

2.4. Operational Energy Aspects of Adaptive Reuse of Historic Buildings

Buildings have a long lifespan with proper maintenance and restoration. However, with time, buildings depreciate. One would not be able to save its original purpose with time due to obsolescence or changes in demand. Change in such a building's use while not damaging its structure and fabric can be considered as building adaptation [30]. Researchers stated that adaptive reuse is much more sustainable than demolition and rebuilding due to resource and energy usage reduction, the use of embodied energy for a longer period, and retaining cultural heritage for the next generations [4]. Maintenance issues, a lack of material availability and skilled tradespeople, and inaccuracy of information and drawings are some barriers to adaptive reuse projects [30]. Further, there are some debates over the financial feasibility of a building adaptation. Bullen [31] stated that even though adapted buildings' performances are not the same as new buildings' efficiency, they can be neglected due to social value gained through building reuse.

A questionnaire was conducted by Bullen and Love [31] to find the opinions of practitioners and researchers regarding adaptive reuse. They found that existing buildings' operational attributes and energy efficiency were the main reasons for building demolition over adaptive reuse. Higher-quality renovation, adapting better energy practices, and demand management help to achieve a better energy efficiency level for adaptive reuse buildings. Energy-efficient newer technologies for the majority of historic buildings cannot be introduced due to the buildings' historic status [32]. It is better to renovate these old buildings without damaging their passive features. Some researchers argue that even though these passive features were suited to earlier days, with the changing urban climate and the contempered building practices, passive features may not be effective [33]. It is important to investigate this deep-rooted perception of poor energy efficiency in reused buildings [34].

Dutch-era buildings at Galle Fort were selected for this research. Galle Fort is the largest Dutch colonial city, surviving outside Europe. Dutch-era buildings have both authentic Dutch architecture and Sri Lankan architecture influence [35]. Generally, all the houses have the same characteristics, such as a front veranda, one or two private spaces, courtyards, and large doors and windows with decorative fanlights. The thickness of the walls of these buildings is higher than modern wall thicknesses, and some buildings even have 1 m thick walls as well. Locally available materials like clay, sand, coral, and granite have been used as main construction materials. Roof structures are created using timber and half-round clay tiles. These historic buildings' architectural and construction features differ from modern-day building construction practices.

2.5. Energy Simulation of Buildings

The building design directly affects the energy performance of a building [14]. Studies on energy-efficient designs have attracted a center of attention in building construction by researchers and practitioners. Many researchers have identified that energy simulation is the best way to test ideas for improvement, and optimization is the best way to select the best idea. It is recognized that such efficient designs benefit economically, socially, and environmentally as well. The development of simulation models for buildings has been an essential factor in studying the design and control of thermally activated building systems. Thermally activated building systems is a technology with the potential to significantly reduce buildings' energy use [36]. How a building has been designed for energy efficiency and how well system integration issues have been addressed are the two factors that decide the energy performance of that building. Even though this emerging and innovative technique looks promising, it is not yet widely adopted by the building construction sector. DBS is a prominent software used for energy simulations of buildings. This requires data related to building construction, HVAC, lighting, openings, and indoor activity functions under separate tabs available with a range of standard values and factors. By providing a detailed overview, this software assists in analysisng energy utilization of the building through energy simulations and it can be conducted for any building that even facilitates a range of building operations [37].

3. Research Gap and Objective

It was identified that there is a minimal number of studies conducted on the operational energy consumption of Sri Lankan office buildings, even though office buildings were recognized to be one of the highest electricity-consuming building sectors in the country. This factor is such a critical concern that global attention has been put in minimizing the energy consumption of office buildings by improving the building architectural and structural designs.

However, historical buildings in Sri Lanka have gained insufficient attention in their building designs, and such buildings have been identified to be neglected without considering their potential to offer spaces for offices with further improvements. It is commonly seen in Sri Lanka that many historic buildings are being demolished and low-rise buildings are being reconstructed to offer more space area in a limited building footprint, but at the same time they are recognized to be inefficient in energy utilization.

By conserving the architectural and archeological value of these historical buildings, this research addresses reusing these spaces by modifying them with minimal alterations or harm to the unique design of the buildings. Therefore, this study addresses this research gap in the significance of historic building designs in terms of energy efficiency during the life cycle of the building, and the analyses further extend to the performance of ARHB in functioning them as office buildings, and their energy utilization.

The main focus of this research is on the comparison of energy consumption and energy simulation of modern office buildings and ARHB in Sri Lanka, to minimize the Building Energy Index (BEI) of novel constructions/buildings with adapted energy-efficient features for the functions of office buildings. We expect it to encourage building designers and architects to adapt such significant features of both modern and historic buildings in order to design an energy-efficient office building in the Sri Lankan context.

4. Methodology

4.1. Selecting Modern Office Buildings

Colombo City is the commercial capital of Sri Lanka and has the highest population density in the country. Due to rapid urbanization, it is identified that there is a high density of office buildings in Colombo. Most of the office buildings in Sri Lanka are recognized as low-rise buildings [20] with or below four floors. For this study, six low-rise office buildings with modern designs were initially simulated using the Design-Builder software (DBS). Out of these six simulated buildings, three buildings were selected based on a preliminary survey on rectangular, low-rise buildings regarding the shape, occupant density of less than 25 m^2/person, type of office functions carried out in the building, total floor area, and number of floors that can be categorized as a low-rise office building. The DBS simulated the buildings according to the main activity of the building.

During the selection of buildings, the occupancy density, number of floors, and function of the buildings were closely concerned while neutralizing the variations of the design features of buildings. Other than the structural properties of the building, the main functional properties such as the occupancy density, working profile, metabolic factor, Clo value, and floor area of the buildings were considered to be comparably similar when selecting the buildings to create baseline energy variables (Table 1), which are the factors to be fed in the activity tab of DBS. Other than these factors, the energy efficiency of the simulated buildings was considered to be comparatively similar. The average value of each factor was calculated to adapt the simulations of the historical buildings as fixed variables. Modern office buildings are notated as M1, M2, and M3.

Table 1. Main factors required to feed in the activity tab (administration).

Building	Main Function	Working Profile (Days a Week)	No. of Floors	Clo Value	Metabolic Factor	Occupancy Density (m^2/Person)	HVAC	Lux Level
M1	Administration	5	6	0.665	0.925	22.7	VRF (air-cooled), Heat Recovery, DOAS	300
M2	Administration	5	3	0.665	0.925	23.47	VRF (air-cooled), Heat Recovery, DOAS	400
M3	Administration	5	5	0.665	0.925	21.35	VRF (air-cooled), Heat Recovery, DOAS	400
Average	Administration	5	N/A	0.665	0.925	18.5	VRF (air-cooled), Heat Recovery, DOAS	350

The energy efficiencies of the selected DBS-simulated modern office buildings were M1 = 19.81%, M2 = 26.59%, and M3 = 26.51%. The floor areas of the selected buildings were M1 = 636 m^2, M2 = 798 m^2, and M3 = 1901 m^2.

Finally, the energy consumption of the top floor and the bottom floor of each building were simulated separately to test the difference in the BEI between the floors in order to differentiate the energy consumption on the top and bottom floors of the building.

4.2. Adaptive Reuse of Historic Buildings (ARHB)

Three adaptive reuse historic buildings, considered to be Dutch-era buildings from the 17th century located in Galle, Sri Lanka, were selected for this study. Initially, these buildings were built as residential buildings especially for Dutch governors and officers but they are currently used for tourist attractions, using them as private residences, restaurants, or homestay places for tourists. In the early 1990s, some Dutch-era buildings located in the country were used as government offices. Required data for this analysis were collected from available building plans, observations from site visits, and interviews with authorized archaeological professionals. These Dutch-era buildings are located at the center of the city of Galle. Today, the functional purposes of the three identified historical buildings are mainly as residents and restaurants. The building architecture was altered and improved to serve these purposes, but the alterations to the architectural design of such buildings are irrevocable. Hence, ARHB was used to conserve these buildings and utilize them efficiently with minimal damage to the building structure.

The climatic and geographical conditions of Galle are almost similar to Colombo, where modern buildings are located. So, the use of these two building types in different districts of the country did not critically affect the simulation criteria. The selected historical buildings are single-story buildings and they are notated as H1, H2, and H3.

4.3. Simulation of the Modern and Historical Office Buildings

For the building energy simulation, the construction materials of the buildings were considered an important input for the DBS. These data were collected during site visits, during architectural drawings and assessments, and through authorized persons. The selected modern buildings have a common building design and structures, which were constructed with concrete foundations, cement block/brick walls, concrete columns, doors/windows constructed with aluminum and glass, cement and sand plasters, and tiled and plastered reinforced concrete slab floors and concrete tiled staircases. All the buildings have a t roof terrace.

Moreover, historical buildings have random rubble foundations; clay, limestone, and granite mixed walls; clay, limestone, and granite columns; and doors/windows constructed with timber, clay, sand, and lime plasters. All the buildings' roofs were constructed with timber plus Sinhala roofs.

Table 2 shows a summary of the construction materials that were used for the different structural elements in both modern and historical buildings.

Table 2. Construction materials for the different structural elements.

	Construction Materials					
	M1	**M2**	**M3**	**H1**	**H2**	**H3**
Foundation	Concrete	Concrete	Concrete	Random Rubble	Random Rubble	Random Rubble
Walls	Cement Block wall, 150 mm + Plasters	Brick wall, 225 mm + Plasters	Brick wall, 225 mm + Plasters	Clay, Limestone, Granite mix, 450/250 mm	Clay, Limestone, Granite mix, 600/350 mm	Clay, Limestone, Granite mix, 800/600 mm
Columns	Concrete	Concrete	Concrete	Clay, Limestone, Granite	Clay, Limestone, Granite	N/A
Doors/windows	Aluminum + Glass	Aluminum + Glass	Aluminum + Glass	Timber	Timber	Timber
Wall plaster	Cement/Sand Plaster	Cement/Sand Plaster	Cement/Sand Plaster	Clay, Sand, Lime	Clay, Sand, Lime	Clay, Sand, Lime
Floor	RC slab, 5 in + Plaster + Tile	RC slab, 4 in + Plaster + Tile	RC slab, 4 in + Plaster + Tile	Granite	Granite	Granite
Staircase	Concrete + Tile	Concrete + Tile	Concrete + Tile	N/A	N/A	N/A
Roof	Roof terrace	Roof terrace + Clay tile roof	Roof terrace + Amano sheets	Timber + Sinhala clay tiles	Timber + Sinhala clay tiles	Timber + Sinhala clay tiles

The simulations were conducted for the buildings using material and design properties of actual buildings as shown in Table 3, in order to achieve energy-efficient building modelling. The buildings were considered for the influence of the size and direction/orientation, building envelope, ventilation, window type, and infiltration rate during the energy simulation. The real data of the building materials and designs of each building case were used to simulate the buildings using DBS.

Table 3. Building materials and designs of the building components.

Building	M1	M2	M3	H1	H2	H3
Building shape	Rectangle	Rectangle	Rectangle	"L" shape	"U" Shape	Rectangle
Orientation	North	South–west	South–east	East	South	South
Number of floors	5	2	4	1	1	1
Gross floor area (m^2)	636 m^2	798 m^2	1901 m^2	251 m^2	349 m^2	724 m^2
Building volume	2305.2 m^3	2120.1 m^3	6083.2 m^3	1581.3 m^3	2751.9 m^3	6081.6 m^3
Material (layers)	Cement Brick, Cement Plaster	Brick Wall, Cement Plaster	Cement Brick, Cement Plaster	Clay, Limestone, Granite Mix	Clay, Limestone, Granite Mix	Clay, Limestone, Granite Mix
Thickness (m)	150 mm	225 mm	150 mm	450/250 mm	600/350 mm	800/600 mm
Window area	111 m^2	103 m^2	368 m^2	6.1 m^2	23.4 m^2	27 m^2
Window type	Single-glazed windows (both open and closed)	Tinted single-glazed windows (closed)	Tinted single-glazed windows (closed)	Double-sash wooden windows (both open and closed)	Double-sash wooden windows (open)	Double-sash wooden windows (both open and closed)
U-value of the window	5.72 W/m^2.K	0.32 W/m^2.K	0.32 W/m^2.K	0.64 W/m^2.K	0.64 W/m^2.K	0.64 W/m^2.K
Ceiling	Concrete Slab	Concrete Slab	Concrete Slab	Timber Ceiling	Timber Ceiling	Timber Ceiling
Internal partitions	Plywood and Glass	Plywood and Glass	Gypsum Boards	N/A	Timber	N/A
Window shading	No	No	No	No	No	No

The modern office buildings are rectangular in shape and the main envelope elements are a brick wall/cement brick walls with cement plaster. The wall thickness varies from 150 mm to 225 mm. Windows are single-glazed or tinted glazed and all the buildings are multi-story (low-rise) with concrete slabs. Internal partitions of the buildings were made from plywood, gypsum boards, and glass.

The selected historical buildings are different in shape (L, U, and rectangular) and the main envelope elements are a mix of clay, limestone, and granite. Double-sash wooden windows are mainly used in the Dutch-era buildings.

The DBS is a user-friendly energy modelling environment used for these buildings' energy simulation process using the guideline of ASHRAE 90.1 and EnergyPlus. The data in Tables 2 and 3 were fed to the software and it was the simulation's base. During the simulation, the DBS simulated the modelled building design based on the climatic conditions of Sri Lanka—data that was chosen in the software, subject to all four orientations. This process of the DBS helps to generate a baseline building to compare it with the subjective case. Moreover, building a footprint is justifiable with the fact that this software provides energy performances in kilo Whatts per square meter (kWh/m^2). Hence, it further validates the analytical criteria of buildings with various building typologies and climatic conditions.

The setback cooling temperature was kept at the value of the buildings' indoor temperature, which is 26 °C for all six buildings.

5. Results and Discussion

The historical buildings are currently used for different functional purposes. Therefore, actual energy consumption of the buildings was initially simulated. The adaptability of converting from the current function into administration (office building) was conducted using the average values of the activity factors of an office building as shown in Table 1.

The actual functional factors of historic buildings and the average factors that were to be used in the adapted case are distinguished in Table 4. It clearly states the existing values and the values that this study was based on for the hypothetical adapted situation of the buildings. These factors created an environment of a general functioning office for the simulation purposes of this study. Therefore, all three historical buildings shared the same functional factors by keeping them constant.

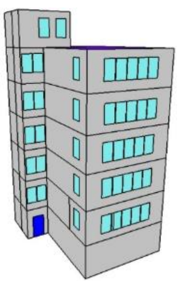
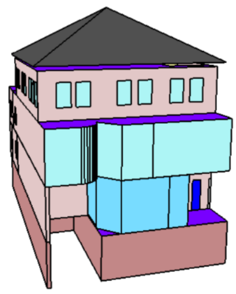
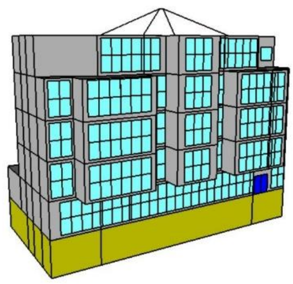
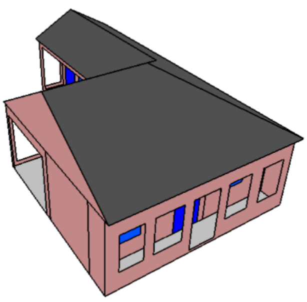
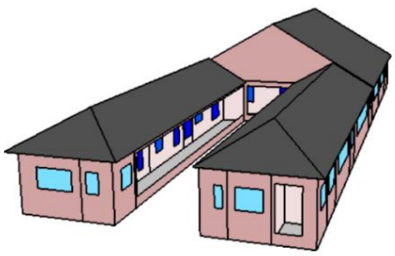
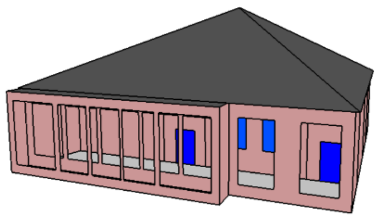
Table 4. Actual and adapted functional factors in the historical buildings.

Actual/Adapted	Building	Main Function	Working Profile (Days a Week)	Clo Value	Metabolic Factor	Occupancy Density (m^2/Person)	HVAC	Required Lux Level
Actual	H1	Residential	7	0.665	0.925	83.6	-	150
	H2	Restaurant	7	0.665	0.925	34.97	-	150
	H3	Residential	7	0.665	0.925	183.5	-	150
Adapted	H1/H2/H3	Office	5	0.665	0.925	18.5	VRF (air-cooled), Heat Recovery, DOAS	300

The Clo values and metabolic factors are equal to the average value of the modern buildings, while here there were no HVAC systems implemented in the adapted historical buildings, and the VRF system was introduced to adapt the building to an administrative office building. According to the ASHRAE 55, the lux level threshold in an office building is considered to be 300–500 lux. Therefore, the historical buildings were set to a 300 lux illumination level for the simulation [38].

Table 5 depicts the graphical representations of the models of all six buildings, developed with DBS. It is clear that historic buildings are of different shapes and office buildings are mainly rectangular-shaped low-rise buildings, but with different building architecture and structural variations. With such designs, the buildings cover the land efficiently in a highly urbanized area. These models further illustrate that modern buildings feature transparent glazing more than historic buildings, allowing a higher utilization of daylight. On the other hand, historic buildings have open passages unlike modern buildings, which activates a proper indoor ventilation system to facilitate the thermal comfort of them.

Table 5. Six buildings modelled using Design-Builder software.

M1	M2	M3
		
H1	**H2**	**H3**
		

Based on the DBS simulation results, breakdowns of electricity consumption, which is the main mode of energy supply of these buildings, were obtained for each building case. It was identified that electricity is consumed by four main categories: cooling, interior lighting, interior equipment, and fans.

The BEI of the top floor and ground floor of the low-rise modern buildings is shown in Figure 1. According to the simulations, it is recognized that the BEI values are not considerably changed with the height or number of floors of a low-rise building. The differences are negligible. It illustrates that, even though the low-rise modern office buildings consist of 1–4 floors, the building energy utilization does not vary significantly within the floors. Therefore, it neutralizes the concern of comparing low-rise buildings with single-story historic buildings.

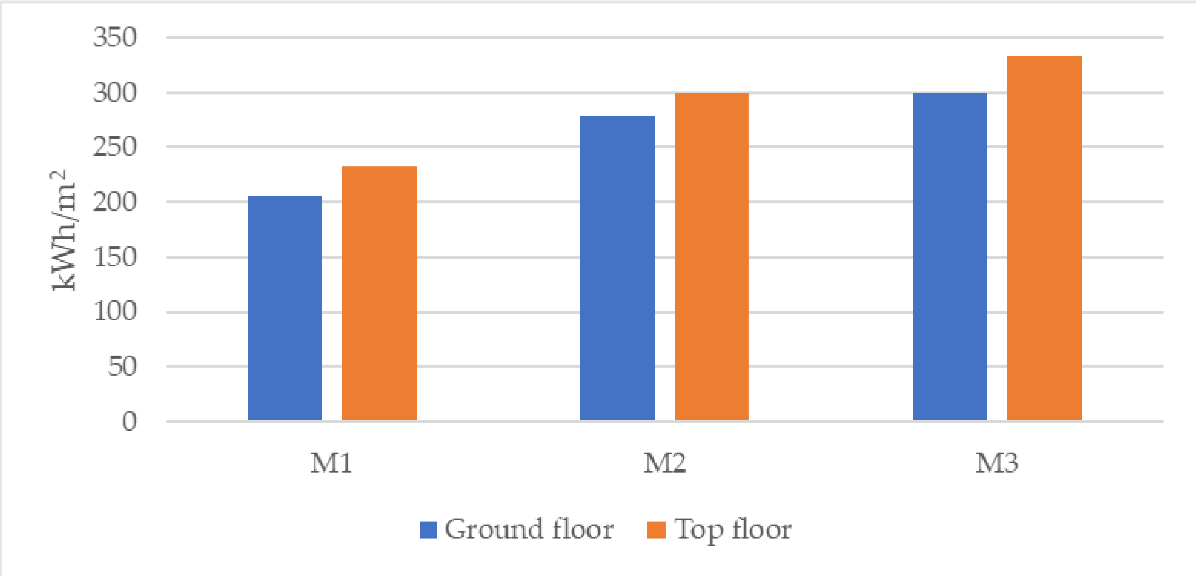


Figure 1. BEI of the top floor and the ground floor of modern buildings.

The total energy consumption of the building per square meter (m^2) was obtained through the software simulation and it is summarized in Table 6 and Figure 1. Accordingly, Table 6 reflects that there is a contrasting difference between these two building types in terms of the BEI. The BEI of the historic buildings varies between 140 and 200 kWh/m^2. The BEI of the modern buildings varies between 210 and 380 kWh/m^2. These values are significantly different as an average and show a BEI in the modern buildings 2–3 times that of the historic buildings.

Table 6. BEI for the modern and historical buildings.

Historical Buildings		Modern Buildings	
Building	**Building Energy Index (kWh/m^2)**	**Building**	**Building Energy Index (kWh/m^2)**
H1	143.74 kWh/m^2	M1	337.29 kWh/m^2
H2	156.34 kWh/m^2	M2	210.99 kWh/m^2
H3	209.39 kWh/m^2	M3	382.57 kWh/m^2

Figure 2 resembles a graphical representation of building energy consumption, which depicts a higher rate of consumption by the modern buildings. Comparatively, the simulations identified lower energy consumption in the historical buildings.

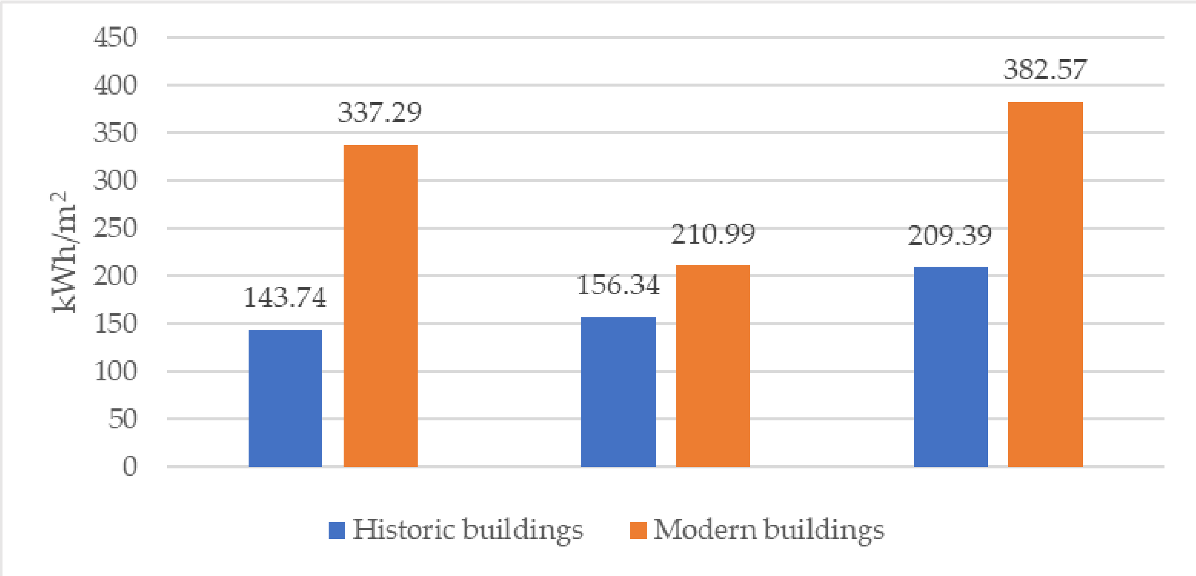


Figure 2. BEI of the modern office and historical buildings.

The change of fractions of energy consumed for lighting and cooling of the building with these two sectors (modern and historical buildings) has been stipulated in Figures 3 and 4. These values were gained for the office building activity model generated for the simulation purpose. This factor can be justified based on the building models created through the DBS as shown in Table 5. Their architectural designs have primarily encouraged a cooler environment in the historic buildings and a more lighted environment in the modern buildings. These two design variations are contrastingly placed in these historic and modern buildings. But the best approach in new building designs would be to combine both these strategies together and improve both visual and thermal comfort in the building, leading to more energy-efficient buildings in the future.

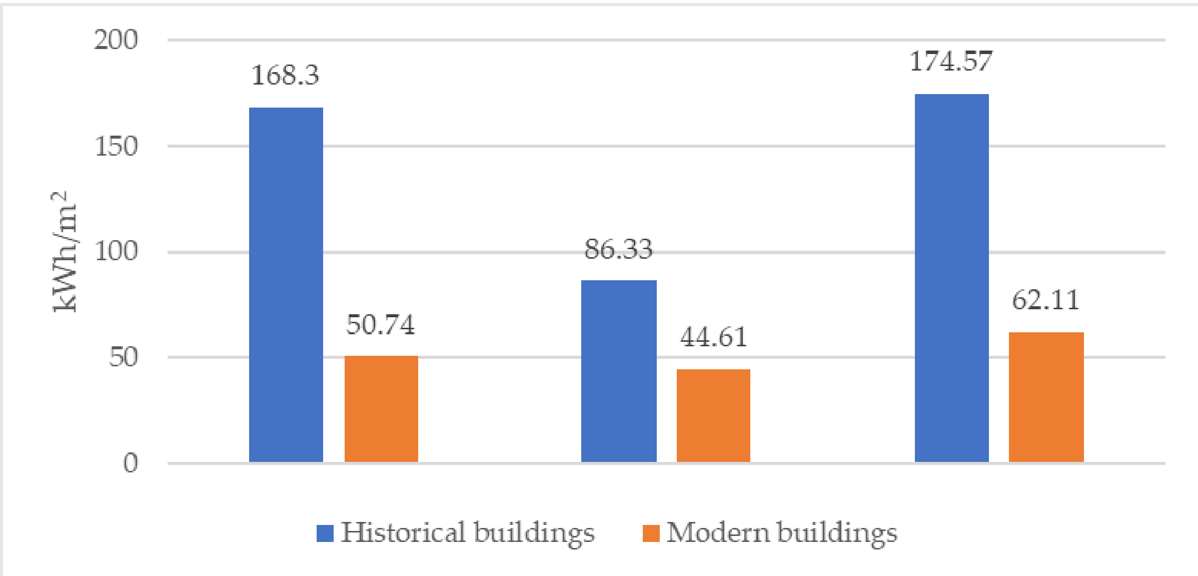


Figure 3. Energy consumption for interior lighting of office buildings and historical buildings.

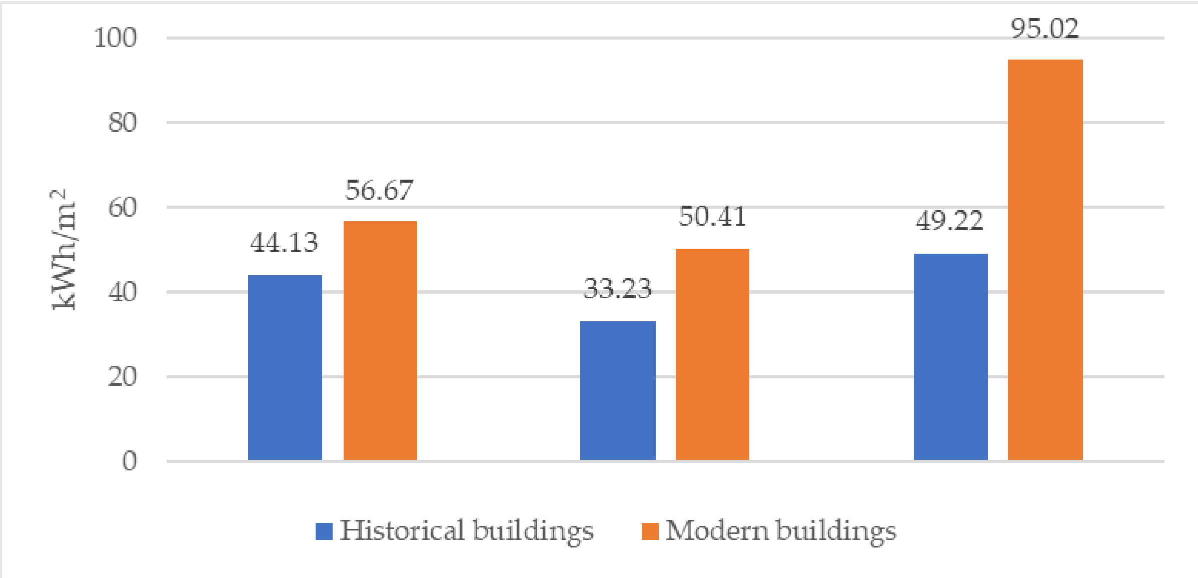


Figure 4. Energy consumption for cooling of office buildings and historical buildings.

According to the DBS simulation results, the energy consumption for interior lighting, which mainly affects the occupants' visual comfort, is contrastingly higher in the historical buildings than in the modern buildings and the energy consumption for cooling, which affects occupants' thermal comfort, is higher in the modern buildings than in the historical buildings.

These results conclude that modern office buildings are more visually comfortable than historical buildings in design, while historical buildings are more thermally comfortable than modern office buildings.

6. Conclusions

Based on the simulation results generated using the DBS, there are three main conclusions this study drives to. According to the simulation results of the ground and top floors of all the modern buildings, it is seen that in low-rise buildings, the BEI varies slightly with the height of the building.

It is further established that indoor conditions of the low-rise buildings are consistent with the least variations with the height of the building. According to the literature and data, the efficiency of visual comfort and thermal comfort of these buildings have been acted contrarily to each other. Therefore, with the height of the building, visual comfort increases while thermal comfort decreases on the other hand.

Simulated BEI values of the buildings reflect that the historic buildings are more energy-efficient compared to the modern office buildings. Selected historic buildings in Galle consumed 143.74 kWh/m^2, 156.34 kWh/m^2, and 209.39 kWh/m^2 while selected modern buildings consumed 337.29 kWh/m^2, 210.99 kWh/m^2, and 382.57 kWh/m^2 as operational energy, respectively. However, as it was further elaborated, it was identified that a better thermal performance of the historical buildings led to the thermal comfort of the historic buildings by resulting in lower energy consumption for cooling. Even though the historic buildings performed better in the thermal performance of the buildings, the visual comfort was considerably lower, which then led to higher energy consumption for interior lighting.

Therefore, it is clear that the visual comfort of modern building designs and thermal comfort of historical building designs need keen attention in achieving the best suitable energy-efficient office building design. Concludingly, it is advisable to improve visual comfort of historic buildings when reusing them as office buildings. Also, a combined approach to designing future office buildings is encouraged to achieve energy-efficient, low-cost, and sustainable office building design.

This study utilizes simulation results generated by the Design-Builder (DB) software. While simulation models are commonly used and provide valuable insights, they rely on assumptions and simplifications. The accuracy and complexity of the simulation results may be limited. This study primarily focuses on operational energy consumption and the BEI as the main evaluation metric. Other important aspects, such as the embodied energy, life cycle assessment, and occupant comfort, are not extensively addressed. A more holistic evaluation considering these factors would provide a more comprehensive understanding of the sustainability and overall performance of the buildings.

Future studies can expand on this study's findings by conducting a more detailed analysis of the economic aspects of ARHB. This may include evaluating the upfront investments, life cycle costs, potential return on investment, and cost effectiveness. By examining the economic feasibility, researchers can offer valuable insights to decision makers, developers, and investors, bridging the research gap and encouraging wider adoption of ARHB practices. Also, through this study, future researchers can enhance the understanding of ARHB's energy efficiency potential, economic viability, and long-term sustainability, facilitating informed decision making and promoting sustainable architectural practices in developing countries like Sri Lanka.

Author Contributions: Conceptualization, R.U.H.; methodology, R.U.H. and N.D.; software, I.S.A. and M.K.; validation, R.U.H., I.S.A., W.P.A. and M.K.; formal analysis, I.S.A., W.P.A. and M.K.; investigation, I.S.A., W.P.A. and M.K.; writing—original draft preparation, I.S.A., W.P.A. and M.K.; writing—review and editing, R.U.H., N.D., I.S.A., M.K. and W.P.A.; supervision, R.U.H. and N.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is unavailable due to the Non-Disclosure agreements with the building managements.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. UN Environment Programme. *2020 Global Status Report for Buildings and Construction*; Global Alliance for Buildings and Construction: Bonn, Germany, 2020; pp. 20–24. Available online: https://www.iea.org (accessed on 14 May 2023).
2. Conejos, S.; Langston, C.; Smith, J. AdaptSTAR model: A climate-friendly strategy to promote built environment sustainability. *Habitat Int.* **2013**, *37*, 95–103. [CrossRef]
3. Vardopoulos, I. Adaptive Reuse for Sustainable Development and Land Use: A Multivariate Linear Regression Analysis Estimating Key Determinants of Public Perceptions. *Heritage* **2023**, *6*, 809–828. [CrossRef]
4. Bullen, P.A. Adaptive reuse and sustainability of commercial buildings. *Facilities* **2007**, *25*, 20–31. [CrossRef]
5. Udawattha, C.; Halwatura, R. Thermal performance and structural cooling analysis of brick, cement block, and mud concrete block. *Adv. Build. Energy Res.* **2018**, *12*, 150–163. [CrossRef]
6. Pachta, V.; Giourou, V. Comparative Life Cycle Assessment of a Historic and a Modern School Building, Located in the City of Naoussa, Greece. *Sustainability* **2022**, *14*, 4216. [CrossRef]
7. Kuruppu, I.; Wijesuriya, G. *The Conservation of the Galle Fort and Its Environs: A Special Volume to Mark the Occasion of the Completion of the Phase One of the Long Term Preservation Programme for the World Heritage City of Galle*; Department of Archaeology: Colombo, Sri Lanka, 1992.
8. Rajapakse, A.C. The Sense of Place and Diminishing Living Heritage in the World Heritage Site of Galle Fort. 2013. Available online: http://www.academia.edu/10826944/The_Sense_of_Place_and_diminishing_living_heritage_in_the_World_Heriage_site_of_Galle_Fort_Sri_Lanka (accessed on 14 May 2023).
9. Remøy, H.T.; Wilkinson, S.J. Office building conversion and sustainable adaptation: A comparative study. *Prop. Manag.* **2012**, *30*, 218–231. [CrossRef]
10. Thie, C.; Quallen, S.; Ibrahim, A.; Xing, T.; Johnson, B. Study of Energy Saving Using Silica Aerogel Insulation in a Residential Building. *Gels* **2023**, *9*, 86. [CrossRef]

11. Campagna, L.M.; Fiorito, F. On the Impact of Climate Change on Building Energy Consumptions: A Meta-Analysis. *Energies* **2022**, *15*, 354. [CrossRef]
12. Ding, Z.; Zhu, H.; Wang, Y.; Ge, X. Study and analysis of office building energy consumption performance in severe cold and cold region, China. *Adv. Mech. Eng.* **2017**, *9*, 1–21. [CrossRef]
13. Amiri, A.; Ottelin, J.; Sorvari, J. Are LEED-certified buildings energy-efficient in practice? *Sustainability* **2019**, *11*, 1672. [CrossRef]
14. Ngo, N.T. Early predicting cooling loads for energy-efficient design in office buildings by machine learning. *Energy Build.* **2019**, *182*, 264–273. [CrossRef]
15. Udawattha, C.; Halwatura, R. Life cycle cost of different Walling material used for affordable housing in tropics. *Case Stud. Constr. Mater.* **2017**, *7*, 15–29. [CrossRef]
16. Wang, J.; Yu, C.; Pan, W. Relationship between operational energy and life cycle cost performance of high-rise office buildings. *J. Clean. Prod.* **2020**, *262*, 121300. [CrossRef]
17. Mann, D.; Yeung, C.; Habets, R.; Vroon, Z.; Buskens, P. Static and Thermochromically Adaptive Energy-Efficient Glazing in Various Climate Regions. *Energies* **2020**, *13*, 2842. [CrossRef]
18. Phillips, R.; Troup, L.; Fannon, D.; Eckelman, M.J. Triple bottom line sustainability assessment of window-to-wall ratio in US office buildings. *Build. Environ.* **2020**, *182*, 107057. [CrossRef]
19. Li, Q.; Long, R.; Chen, H.; Chen, F.; Wang, J. Visualized analysis of global green buildings: Development, barriers and future directions. *J. Clean. Prod.* **2020**, *245*, 118775. [CrossRef]
20. Dixit, M.K. Embodied energy and cost of building materials: Correlation analysis. *Build. Res. Inf.* **2017**, *45*, 508–523. [CrossRef]
21. He, Q.; Ng, S.T.; Hossain, M.U.; Skitmore, M. Energy-efficient window retrofit for high-rise residential buildings in different climatic zones of China. *Sustainability* **2019**, *11*, 6473. [CrossRef]
22. Miranville, A. Sri Lanka Sustainable Energy Authority. Annual report 2019. *AIMS Math.* **2020**, *5*, i–v. [CrossRef]
23. Rajapaksha, U. Heat stress pattern in conditioned office buildings with shallow plan forms in Metropolitan Colombo. *Buildings* **2019**, *9*, 35. [CrossRef]
24. He, Y.; Chen, Y.; Chen, Z.; Deng, Z.; Yuan, Y. Impacts of Occupant Behavior on Building Energy Consumption and Energy Savings Analysis of Upgrading ASHRAE 90.1 Energy Efficiency Standards. *Buildings* **2022**, *12*, 1108. [CrossRef]
25. Deb, C.; Lee, S.E. Determining key variables influencing energy consumption in office buildings through cluster analysis of pre- and post-retrofit building data. *Energy Build.* **2018**, *159*, 228–245. [CrossRef]
26. Weerasinghe, A.S.; Ramachandra, T.; Rotimi, J.O.B. Towards sustainable commercial buildings: An analysis of operation and maintenance (O&M) costs in Sri Lanka. *Smart Sustain. Built Environ.* **2020**, *11*, 454–468. [CrossRef]
27. Ferdyn-Grygierek, J.; Sarna, I.; Grygierek, K. Effects of climate change on thermal comfort and energy demand in a single-family house in Poland. *Buildings* **2021**, *11*, 595. [CrossRef]
28. Wan, K.K.W.; Li, D.H.W.; Liu, D.; Lam, J.C. Future trends of building heating and cooling loads and energy consumption in different climates. *Build. Environ.* **2011**, *46*, 223–234. [CrossRef]
29. Yang, B.; Lv, Z.; Wang, F. Digital Twins for Intelligent Green Buildings. *Buildings* **2022**, *12*, 856. [CrossRef]
30. De Silva, G.D.R.; Perera, B.A.K.S.; Rodrigo, M.N.N. Adaptive reuse of buildings: The case of Sri Lanka. *J. Financ. Manag. Prop. Constr.* **2019**, *24*, 79–96. [CrossRef]
31. Bullen, P.A.; Love, P.E.D. The rhetoric of adaptive reuse or reality of demolition: Views from the field. *Cities* **2010**, *27*, 215–224. [CrossRef]
32. Coles, T.; Dinan, C.; Warren, N. Climate change mitigation and the age of tourism accommodation buildings: A UK perspective. *J. Sustain. Tour.* **2015**, *23*, 900–921. [CrossRef]
33. Emmanuel, R.; Rathnayake, G. Indoor thermal comfort in contemporary Sri Lankan urban houses: A simulation study. *Built Environ. Sri Lanka* **2016**, *2*, 22. [CrossRef]
34. Akande, O.K.; Odeleye, D.; Coday, A.; JimenezBescos, C. Performance evaluation of operational energy use in refurbishment, reuse, and conservation of heritage buildings for optimum sustainability. *Front. Archit. Res.* **2016**, *5*, 371–382. [CrossRef]
35. Bohingamuwa, W. The Galle Fort World Heritage Site: A Nature-Culture Approach to the Conservation of Cultural Heritage along the Southern Coast of Sri Lanka. *J. World Herit. Stud.* **2019**, *2019*, 29–37.
36. Romaní, J.; De Gracia, A.; Cabeza, L.F. Simulation and control of thermally activated building systems (TABS). *Energy Build.* **2016**, *127*, 22–42. [CrossRef]
37. Stasiak-Betlejewska, R.; Potkány, M. Construction Costs Analysis and its Importance to the Economy. *Procedia Econ. Financ.* **2015**, *34*, 35–42. [CrossRef]
38. Abdou, Y.; Kim, Y.K.; Bande, L. Indoor environmental quality evaluation in a hot and arid climate: A case study of a higher education office building. In Proceedings of the E3S Web of Conferences, 2020 11th International Conference on Environmental Science and Development, Barcelona, Spain, 10–12 February 2020; EDP Sciences: Yu Lisi, France, 2020; Volume 167, p. 04004. [CrossRef]