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A CRITIQUE ON THERMAL PERFORMANCE AND ENERGY USAGE IN GOVERNMENT OFFICE BUILDINGS IN TRINCOMALEE AND THE NEED FOR SUSTAINABLE RETROFITTING - A TYPOLOGICAL ANALYSIS

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Abstract: Buildings use a large amount of energy during their lifetime and are identified as the main contributors to the increasing energy demand. A proper understanding of the Thermal Performance (TP) parameters can result in a climate-responsive design and reduce indoor overheating. In the construction field, sustainable retrofitting is identified as another important field of research, where new technologies can be introduced to the existing built environment and enhance their efficiency. This paper mainly focuses on how different building typologies of the existing public office buildings are contributing to inefficient TP and energy usage, and how sustainable retrofitting can help to improve their energy performances. 27 existing public office buildings in urban and suburban areas in Trincomalee, were selected for the typology analysis, and with special attention to plan form, one case study under spread-out plan form was selected. The TP of the building was investigated through an on-site Thermal Performance Investigation and Computational Simulation (CS) process. It is proposed that the energy required for cooling a building can be reduced if efficient sustainable retrofitting design strategies can be used to improve the TP. The outcome is beneficial in the formulation of design guidelines for new and existing buildings.

Keywords: *Energy efficiency, Sustainable retrofitting, Design Solution Set, Design Builder, Thermal Performance*

1. Introduction

Energy is considered a valuable resource as it is necessary for almost all aspects of human activity. The growth of the world's population along with technological advancement can be identified as the main reason behind the increasing demand for generation and the usage of energy (Wilberforce et al., 2021). It is unarguable that energy is crucial to the expansion and development of any country, developed or developing. Humans face major challenges in energy sources and climate change (Zhao et al., 2015). In comparison to other economic sectors, the construction sector consumes a significant amount of energy, which varies with the location and nation (Oguntona et al., 2019).

Across the world, the high demand for building construction with efficient energy usage remains the same. There is a need to modify the buildings, to satisfy the visual and thermal comfort of the users along with effective energy usage. According to Amecke (2012), a building can be constructed by responding to energy management strategies, or else the existing buildings can be retrofitted with effective sustainable strategies to reduce energy usage and wastage.

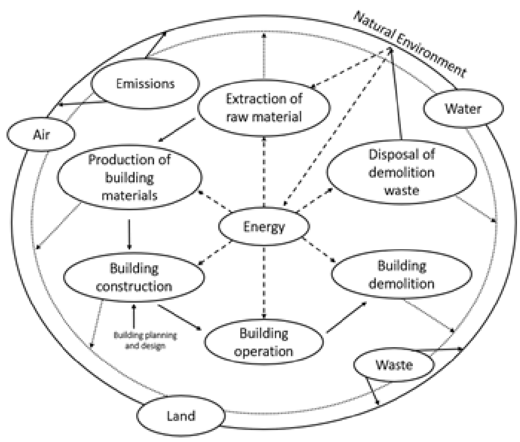

Figure 1: Resources and Energy involved in the Life Cycle of the Building (*Source: Praseeda, 2014*)

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The dry zone is one of the major climate zones identified in Sri Lanka. The climate context is a vital factor to be considered when designing buildings, particularly in an urban context, that are effective in thermal performance and energy conservation. The energy need of the building depends on heat removal or heat saving. Therefore, proper strategies should be followed to make efficient built environments. The context-specific building typologies pave the way for a sustainable built environment.

Trincomalee is a district in the Eastern Province that belongs to a hot dry climate. The major aim of the buildings here is to maintain internal thermal comfort by reducing the internal heat gain of the buildings. The existing public office building typologies are observed to be poorly responding to the climate, which has resulted in the excess use of energy to achieve thermal comfort inside the building. Most of these buildings were constructed during a period when there was a lack of knowledge of energy savings and energy efficiency. Also, the existing buildings fill up the land, creating an issue for the new and existing buildings. Therefore, applying new strategies that can help in efficient energy usage is unable to be implemented. An alternative strategy such as retrofitting is highly recommended that can benefit the existing buildings and facilitate the new buildings. Especially considering the current situation of our country, research, and analysis on effective energy savings methods will be much more helpful.

2. Literature Review

According to IPCC, (2007) buildings and building activities use above 40% of electrical consumption in the world, which increases energy demand and carbon dioxide emissions. Additionally, it is believed that the emissions of carbon dioxide linked to older buildings are rising, and this has made them a crucial topic for policy and architecture for all governments across the world. Concern is growing over rising energy consumption in existing commercial buildings and the potential negative effects on the environment because of the projected climate change effects associated with rising carbon dioxide in the atmosphere and the demand for indoor environments with raised comfortability (Rajapaksha & Hyde, 2013).

Same as other nations in the world, Sri Lanka is experiencing an energy crisis. It is stated by Attalage & Wijetunge (1997), that an 8% increase in energy demand can be observed each year. During the first half of 2019, a 1.9% increase can be observed in the energy demand. The maximum demand that was recorded during that period was 2,616W. 6,460 GWh units out of the generated 7,308 GWh have been consumed just within six months (Ceylon Electricity Board, 2020). Energy bills are considered to be the most significant part of any building. With the current economic crisis in Sri Lanka, the need for conserving energy can be well acknowledged and we are in a crucial situation to address this issue.

2.1. RETROFITTING FOR SUSTAINABLE ENERGY

Since most people spend most of their time indoors, we must think about ways that buildings may conserve energy (Dong et al., 2022). This has resulted in the implementation of many new practices to reduce the usage and wastage of energy in buildings. Many nations are putting different plans into action to stop energy loss and work toward energy-efficient processes.

In recent years “Sustainability” has turned out to be a famous field of research. This has become popular as it has specific goals concerning development. This area of discussion is broad and difficult and can be useful in design initiatives. Using effective strategies in the built environment is known as sustainable architecture (Oguntona et al., 2019). The efficiency of energy usage in buildings can be affected by many factors such as orientation, material usage, plan forms, sectional forms, roof structure, arrangement of windows, etc. The energy requirement of each building varies according to its typology. A specific template of design can be used to make the buildings more energy-efficient and context-specific. Since the lifespan of a building's fabric and structure is significantly longer than that of the installed components, retrofitting is frequently connected with buildings (Khodeir et al., 2016). Sustainable retrofitting of buildings can assist in the process of reducing the energy usage of buildings.

To lessen environmental energy exhaustion, older buildings that require new technology or have gotten worse over time must be renovated. Based on the research, retrofitting existing building structures is one of the key approaches to significantly reducing the emission of greenhouse gases and energy consumption. Due to the significance of building retrofitting, professionals in the construction industry and other relevant parties must overcome many obstacles. It is noteworthy that decisions made in the early design stage and stages of construction have a big impact on whether to decide the success of the project (González et al., 2015).

It is necessary to complete proper demand management at the location in a shorter period. For instance, improved thermal performance, better building rules, building technology, consumer behavior changes, legislation quantifying building plant performance, and new, efficient home appliances in terms of energy systems and materials, there are several technological solutions available to enhance the building's energy performance. By utilizing cutting-edge renewable technologies, building energy consumption may be reduced. It may have a favorable effect on climate change too (Da Silva & Sekulima, 2015).

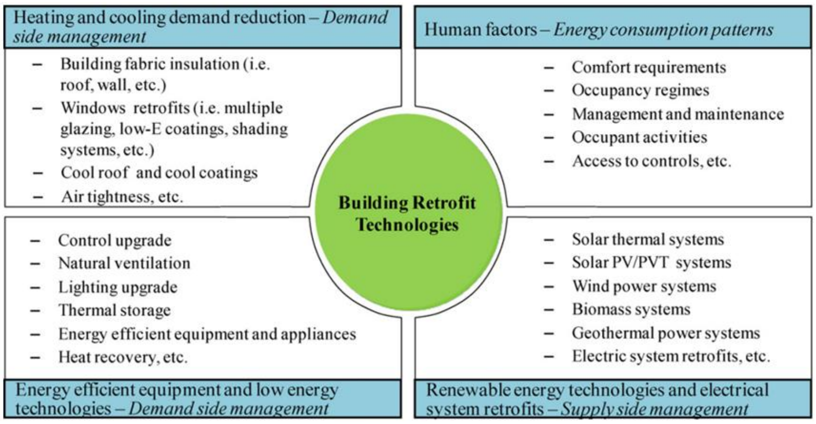


Figure 2: Main categories of Building Retrofit Technologies (*Source: Z. Ma et. al., 2012*)

2.2. BIOCLIMATIC DESIGN AND THERMAL COMFORT

The interaction between occupants, climate, and the building is the primary focus of the bioclimatic design. The approach developed by Olgyay, which considers the way buildings modify and filter the exterior environment for users, is seen as an appropriate way to deal with energy-efficiency opportunities in retrofitting existing commercial buildings (Olgyay, 1963). Part of the problem comes from the process of building designs for the past 50 years, which has moved away from this approach and hence has led to buildings that rely on high-energy use systems to provide occupant comfort.

Bioclimatic design involves four equally important interlocking variables, i.e., climate, biology, technology, and architecture. Promoting thermal mass and night ventilation, usage of external shading devices, including the internal atrium and cavity wall, and introducing a double skin façade are some of the most effective bioclimatic design strategies that can result in increasing indoor thermal comfort.

Thermal comfort is the mind's condition of expressing satisfaction with the indoor environment. The experienced thermal comfort inside a building plays an important role and indoor overheating is identified as a major problem in impacting it. As in Auliciems & Szokolay (1997), the factors that affect the dissipation of heat from the human body and affect thermal comfort can be divided into 03 main groups: environmental parameters, personal parameters, and other contributing factors such as body weight and shape, age, gender, state of health etc.

Constructing buildings by responding to climate can create a comfortable living environment. According to Huntington's theory from 1951, all human circumstances and capacities will typically peak at the most agreeable times of the year and decline during unfavorable ones. The satisfaction of man's need for thermal comfort and the enhancement of human performance (intellectual, manual, and perceptual performance) are further justifications offered by Fanger [1970]. Givoni (1998) stated that "design principles aim at maximizing comfort and minimizing the use of energy for heating and cooling".

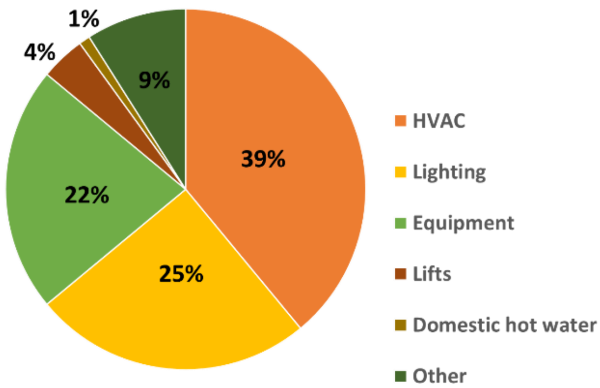


Figure 3: Typical energy consumption breakdown in an office building (*Source: Z. Ma et. al., 2012*)

To maintain thermal comfort, in comparison to other industries, the commercial sector is experiencing a faster increase in energy demand due to the expansion of HVAC systems in new buildings (Pérez-Lombard et al., 2008). Environmental Protection Agency (EPA) (2008) has revealed that typical office buildings use 55% of their total energy consumption on HVAC systems. Therefore, the application of efficient design strategies in the construction process is the universally accepted method to save the cost on energy usage.

3. Research Methodology and Data Collection

The whole process was divided into 06 different stages, and each stage contained several sub-stages. As a preliminary study, 27 existing office buildings in Trincomalee district were classified based on their plan form, materials, orientation, buildings integrated atrium, mode of ventilation, etc. Within the 27 case studies, one office building was selected for further research.

The building was subjected to an on-site thermal performance investigation process using highly sensitive types of equipment. The collected data along with the ambient temperature data from the Meteorological Department of Colombo were summarized and input on the CS process using DesignBuilder (DB) software. The model was validated by testing the actual measurement, and the calibrated model was used to propose Sustainable Retrofitting Strategies.

Each strategy was introduced as Design Solution Sets (DSS) and the TP of each DSS was tested with parameters such as indoor temperature and ambient temperature and the DSS with a higher reduction of temperature was identified. The analysis of the CS was used to identify the relationship between TP and energy efficiency of the office building in the dry zone, Trincomalee. The findings were discussed further on their application in new buildings and sustainable retrofitting of existing buildings.

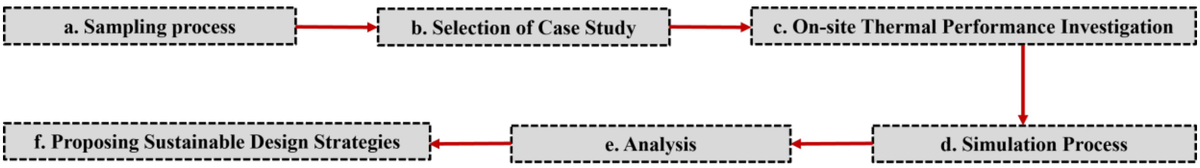
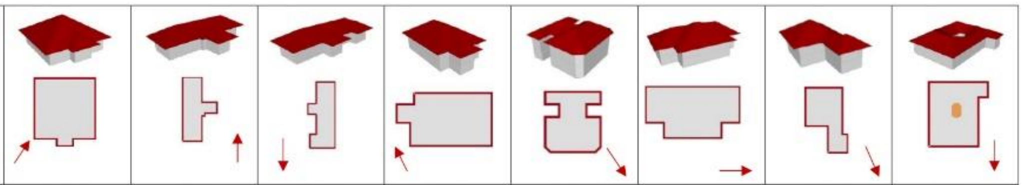


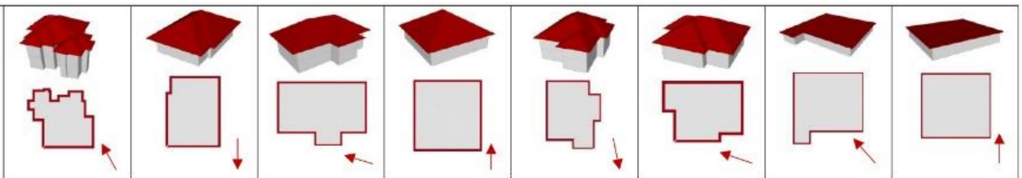
Figure 4: Overall methodology used in data collection and analysis

3.1 SAMPLING PROCESS

27 public office buildings from the Trincomalee district were selected to represent the existing office typologies. The necessary architectural drawings were drafted and a SketchUp model to show the building forms was created. The sample buildings were classified under plan form, material usage, orientation, and mode of ventilation. The necessary data for plan form classification was derived through a literature study and a similar method of the preliminary method can also be seen in other research papers (Rajapaksha, 2020).

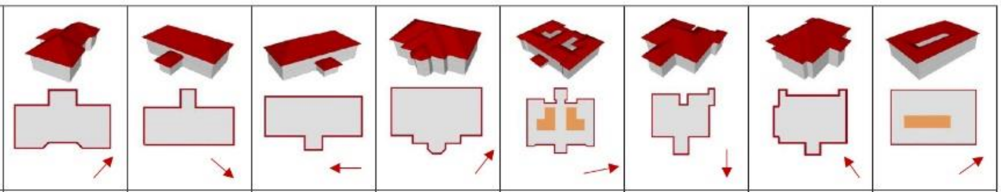


Building Code		CS-01	CS-02	CS-03	CS-04	CS-05	CS-06	CS-07	CS-08
Name		CS-01	CS-02	CS-03	CS-04	CS-05	CS-06	CS-07	CS-08
Year		1978	1982	1988	2003	2008	1996	1991	2000
Plan form		Compact	Compact	Compact	Compact	Compact	Compact	Compact	Compact
Orientation (Long façade)		E-W	N-S	N-S	NE-SW	NE-SW	N-S	NE-SW	N-S
No.of Storeys		1	1	1	2	3	2	3	2
Material	External wall	Brick	Brick	Brick	Concrete block	Concrete block	Brick	Brick	Concrete block
	Roof	Tile	Tile	Tile	Asbestos	Zn/Al sheet	Tile	Asbestos	Zn/Al sheet
	Window	Single pane, wood framed	Single pane, wood framed	Single pane, wood framed	Single pane, Al framed	Single pane, Al framed	Single pane, wood framed	Single pane, Al framed	Single pane, wood framed
Mode of Ventilation		Natural & A/C	A/C	Natural & A/C	Natural & A/C	Natural	Natural & A/C	Natural & A/C	Natural & A/C



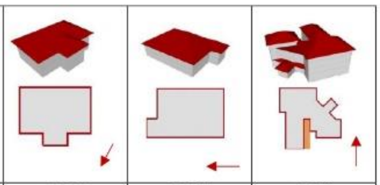
Building Code		CS-09	CS-10	CS-11	CS-12	CS-13	CS-14	CS-15	CS-16
Name		CS-09	CS-10	CS-11	CS-12	CS-13	CS-14	CS-15	CS-16
Year		2008	1983	2010	2006	2003	1973	2001	2009
Plan form		Compact	Compact	Compact	Compact	Compact	Compact	Compact	Compact
Orientation (Long façade)		NE-SW	N-S	NW-SE	N-S	N-S	NW-SE	NE-SW	N-S
No.of Storeys		4	1	3	1	3	2	1	1
Material	External wall	Concrete block	Brick	Concrete block	Concrete block	Brick	Brick	Concrete block	Concrete block
	Roof	Zn/Al sheet	Tile	Zn/Al sheet	Tile	Tile	Tile	Concrete Slab	Concrete Slab
	Window	Single pane, Al framed	Single pane, wood framed	Single pane, Al framed	Single pane, Al framed	Single pane, wood framed	Single pane, wood framed	Single pane, Al framed	Single pane, Al framed
Mode of Ventilation		A/C	Natural & A/C	Natural & A/C	Natural & A/C	Natural & A/C	Natural & A/C	A/C	A/C

Building Form								



Building Code		CS-17	CS-18	CS-19	CS-20	CS-21	CS-22	CS-23	CS-24
Year		1978	1983	2000	1993	1999	2001	2007	1888
Plan form		Compact	Compact	Compact	Compact	Compact	Compact	Compact	Compact
Orientation (Long façade)		NE-SW	NW-SE	N-S	NW-SE	N-S	N-S	NW-SE	NE-SW
No.of Storeys		2	2	2	3	3	3	4	4
Material	External wall	Brick	Concrete block	Concrete block	Concrete block	Brick	Concrete block	Brick	Brick
	Roof	Tile	Tile	Zn/Al sheet	Zn/Al sheet	Tile	tile	Zn/Al sheet	Asbestos
	Window	Single pane, Wood framed	Single pane, wood framed	Single pane, Al framed	Single pane, wood framed	Single pane, wood framed	Single pane, Al framed	Single pane, Al framed	Single pane, Al framed
Mode of Ventilation		Natural & A/C	Natural	Natural	Natural & A/C	Natural & A/C	Natural	Natural	Natural

Building Code				



Name		CS-25	CS-26	CS-27
Year		1997	1990	2012
Plan form		Compact	Compact	Spread-out
Orientation (Long façade)		NE-SW	N-S	N-S
No.of Storeys		3	2	4
Material	External wall	Brick	Brick	Concrete block
	Roof	Tile	Tile	Zn/Al sheet
	Window	Single pane, wood framed	Single pane, wood framed	Single pane, Al framed
Mode of Ventilation		Natural	Natural	Natural & A/C

CS-01: Provincial Survey Office
CS-02: Provincial Department of Education
CS-03: Admin Block at Trincomalee
CS-04: AMC at Trincomalee
CS-05: Department of Agriculture
CS-06: Provincial Planning Secretariat
CS-07: Provincial Public Administration
CS-08: Zonal Education Office at Muthur
CS-09: Forest Department at Trincomalee
CS-10: Department of Cultural Affairs
CS-11: Base Hospital at Mutur
CS-12: BME Unit at Trincomalee
CS-13: Department of Industries (VTC) at Trincomalee
CS-14: RDA at Muthur
CS-15: Herbal Garden Management Center at Trincomalee
CS-16: Ministry of Education, Eastern Province
CS-17: Building Department
CS-18: MOH Office at Echchilampathu
CS-19: MOH Office at Trincomalee
CS-20: Customs Office at Trincomalee
CS-21: Ministry of Agriculture Land and Irrigation at Trincomalee
CS-22: Pradeshiya Shaba at Kinniya
CS-23: Pradeshiya Shaba at Morawewa
CS-24: Pradeshiya Shaba at Mutur
CS-25: Pradeshiya Shaba at Verugal
CS-26: Unit office at Muthur
CS-27: District Secretariat at Trincomalee

Figure 5: Analysis of the existing 27 public office buildings in the Trincomalee district

It was visible that most of the buildings were designed to be in a compact form. It can be observed that the long facade of most of the buildings was constructed facing East-West. Therefore, the internal heat is higher because of solar radiation. The usage of building external wall materials is comparatively similar, whereas the buildings that were built within the last 20 years have used concrete blocks. The majority of the buildings have pitch roofs, which can impact positively on the hot dry climate. All the buildings have single-pane windows, which can transmit the heat directly indoors. Most of the buildings use passive ventilation in general areas and Air Conditioning systems in higher official units. This analysis is subjective and to make detailed comments on each building, a detailed analysis is needed. The analysis can include both physical and thermal performance characteristics.

3.2 SELECTION OF CASE STUDY

Based on the typological analysis, most of the public office buildings have compact plan forms, which is not suitable for the dry climate, and there existed one with spread out plan form. As spread-out plan forms are identified as suitable for dry climates (OH Koenigsberger et al., 2013), the Author decided to test the thermal performance of the building.

The District Secretariat Office, the administration body of Trincomalee district, is selected as the case study and the reasons for the selection are mentioned below:

I. Spread-out plan form, situated at dry zone.
II. The building was constructed within 10 years.
III. It has spaces with both HVAC and natural ventilation.

This is a 4-story office building and consists of several subdivisions that are arranged in different orientations within the building. The walls are constructed of concrete block with 200mm thickness, and the roof is of Zn/Al sheets. The windows are single glazed with a clear glass pane of 3mm thickness. The internal partitions are made of aluminium framed glass partitions.

Specifically, the District Samurdhi Division, located at the second-floor level of the building was selected for the TP analysis. This division uses both natural and mechanical ventilation through stand fans and is lit naturally. The windows are operable and orientated for cross-ventilation. The total area of the selected office space was 274.m^2 and the finished floor-to-ceiling height is 2.9m. The office hours are 8.25 hours starting at 8.00 a.m. to 4.15 p.m. The observed wind direction was from the West.

Figure 6: Photograph of the case study building

Figure 7: Plan and Section drawings of the District Samurdhi Division

3.3 ON-SITE THERMAL PERFORMANCE INVESTIGATION

A proper thermal investigation needs months and continuous monitoring of instruments is important to justify the measurements. This requires the consideration of several points along horizontal and vertical levels, that can provide accurate data. But with the certain limitations of the academic duration, and with the availability of the number of instruments, the investigation was shortened. The case study was restricted to one, regarding limited time and the existing unfavorable weather conditions. The investigation days were restricted to 04, as it was difficult to find hot days during rainy days. The hottest days within the week of the investigation were considered typical hot days.

A pre-meeting was held with the District Secretary, District Engineer, District Samurdhi Director, and the staff from District Samurdhi Division, and a brief introduction was given on the research purpose. This ensured the minimization of human errors. The office space was used as it was, without changing any functions or doing modifications.

The Thermal Performance Investigation process was divided into a pilot study and a spot measurement study. The pilot study was mainly to justify the observed pattern of the measurements. The Pilot study was conducted for continuous 2.3 days from the 17th of October at 8.00 a.m. to the 19th of October at 4.00 p.m. The air velocity was measured on the 19th of October from 8.00 a.m. to 4.00 p.m. All measurements were taken at a height of 7m above the ground level. The investigation was carried out during the weekdays with natural ventilation conditions.

Environmental variable measurements such as indoor air temperature, outdoor air temperature, air velocity, outdoor relative humidity, indoor relative humidity, and internal surface temperature were measured using high-accuracy instruments. Corresponding ambient measurements were taken from the Meteorological Department of Colombo and set as an indicator to compare the heat stress.

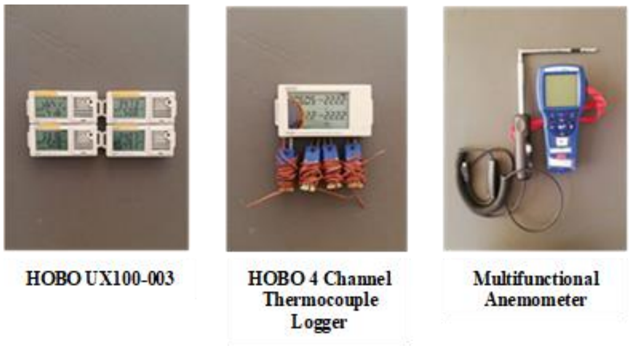


Figure 8: Photographs of the instruments used in the field study

An efficient section along the East-West direction was taken for the pilot study. The HOBO Loggers and Thermocouple Logger were launched at time intervals of 5 minutes. The Multifunctional Anemometer was launched at 10s intervals and the instruments were marked with safety notes to avoid any accidental errors. During the pilot study, the Thermocouple was fixed near the window on the East façade and three external probes were used to measure the surface temperatures of the internal wall surface, external wall surface, and the floor surface. The ends of the wires were sealed with blue-tac adhesive to avoid contact with the air temperature, which increases the accuracy.

The spot measurement study was conducted only during office hours and 2 effective sections were selected for the placement of the equipment. Two HOBO instruments were placed inside the office space and the other two HOBOs were used to take spot measurements in each cardinal direction at 15-minute intervals. For example, HOBO D will be placed in the East for 15 minutes and then will be changed to the South. This process continued until the end of the investigation time. The Thermocouple instrument was placed on the West façade and the surface temperatures of the internal wall surface, external wall surface, and floor surface were measured.

3.4 SIMULATION PROCESS

The physical data were collected by taking manual measurements of the space and observations. The building envelope system data were collected through the conversation with District Engineer, Trincomalee. The base case model was created with the collected data. Field observations and photographic studies were also used for further data collection. The selected office space was used to develop the simulation model by drafting the plans using Autodesk Revit 2018, and the BIM model was exported to Design Builder v6.1.8.021 to calculate cooling data and internal and external temperatures. The base model has used actual SWERA data from the Meteorological department, and the validation process was run on both the 26th and the 18th of October 2022 to justify the pattern. The ASHRAE standard data was used during the simulation to increase the accuracy. The measurements from the on-site thermal performance investigation were used to validate the base model and to continue with further procedures.

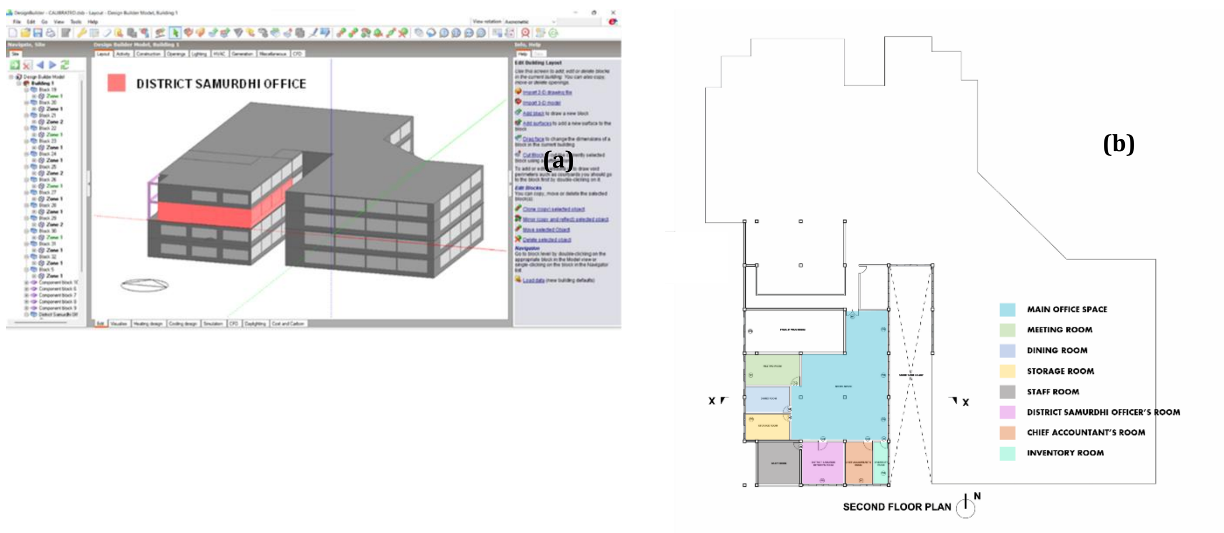


Figure 9: (a)- DesignBuilder's user interface with a 3D view of the office division
(b)- Floor plan of the office space with internal partitions

Architecture and building construction data, engineering and mechanical data, and non-technical data were recorded to improve the accuracy of the research. The input data are mentioned below:

ARCHITECTURE AND BUILDING CONSTRUCTION DATA		
Characteristics/ Component	**Attributes**	**Details**
Location	• Trincomalee, Eastern Province, Sri Lanka	• Latitude 8.59° S and Longitude 81.22° E • ASHRAE climate zone = 0A
Type of building & shape	• District Secretariat Office Building	• Four stories, Spread-out plan
Division Chosen for Simulation	• District Secretariat Office Building	• Located at second floor level
Finished floor to ceiling height	• 2.9 m	
Gross floor area	• 274.2 m^2	
Roof	• Area of the Upper Floor Slab : 274m² • Slab Thickness : 300mm • Description : Reinforced Concrete Slab, Internal surface finished with 15mm Cement/lime plaster, External surface finished 6 mm with Porcelain tiles, No thermal insulation	• 200mm Reinforced Concrete Slab
External Walls	• Area of the external walls: 149 m2 • Thickness of the wall: 200 mm • Description : Medium-weight concrete block wall, No thermal insulation	• Solid concrete blocks 170 mm. • 15 mm cement plaster. • Light colored (U) = 2.005 W/m^2 K
Floor	• Area of the Floor Slab : 274m² • Slab Thickness : 300mm • Description : Reinforced Concrete Slab, Internal surface finished with 4mm Porcelain tiles, External surface finished with 15mm Cement/lime plaster, No thermal insulation	• 200mm Reinforced Concrete Slab
Windows	• Total no. of windows:08 • Area of single window: 9.2m² • Description: Single glazed window • WWR: 64% • Horizontal overhangs over the East facade	• Single-glazed (3 mm) windows. • Aluminum frame (no air tightness). • No shading • (U) = 6.121 W/m2 K, total solar transmission(SHGC) = 0.81, direct solar transmission 0.775, light transmission = 0.881
Internal Partition	• The area of each partition walls varies	• Single-glazed (3 mm) windows • Aluminum frame (no air tightness) • Gypsum Board Partition

NON-TECHNICAL DATA	
Characteristics/ Component	**Details**
No. of people	32
Floor area/ person	8.3 m^2/ person
Time of operation	8.00 a.m. - 4.15 p.m.
Surrounding landscape	• The immediate surrounding has taller trees up to 10m on the Northern side. • The intermediate courtyard has few vegetable crops.

ENGINEERING AND MECHANICAL SYSTEM DATA	
Characteristics/ Component	**Details**
No. of lightings	• Luminaire - Recessed Lighting Louvre full set with 3 tubes (Fluorescent) • 33 Nos.
Capacity of lightings	15 W/m^2
Type of lightings	T5 Fluorescent lamps
No. of switch points	10
No. of fans	15
No. of fan points	09
No. of Air Conditioners	02
Capacity of Air Conditioners	12BTU & 18 BTU - Not used during the office hours
Equipment	15 W/m^2
Ventilation rate	10.0 L/s/person
Infiltration rate	0.5 ACH

Figure 10: Details of data used in the Computational Simulation (CS)

A calibrated model was created after the validation process. This paper uses hourly data on the 26th of October 2022 and the 18th of October 2022 as the simulation dates for validation. As per Kalpan and Canner (2008), a 15% difference in daily basis data is recommended as the allowable difference between the simulated and actual values.

In this paper, 02 parameters are considered for the validation of the base model during the CS process. Those are:

1. Internal average hourly temperature
2. Ambient hourly temperature

Once the changes were made to the base model and the simulated results were found with similar readings, the validated/ calibrated model was used for the next phase, proposing retrofitting strategies. A similar type of methodology is used in (Chapter2.2-Hyde, et. al., 2013. Sustainable retrofitting of commercial buildings.), through which, the whole process can be validated.

4. Analysis and Results

The measurements from the on-site thermal performance investigation of both the pilot and spot measurement study were graphed and overheating conditions were observed in both investigations. It was visible that, even though the internal temperature was less than the outdoor microclimate temperature, it was higher than the ambient temperature in both stages of thermal performance investigation.

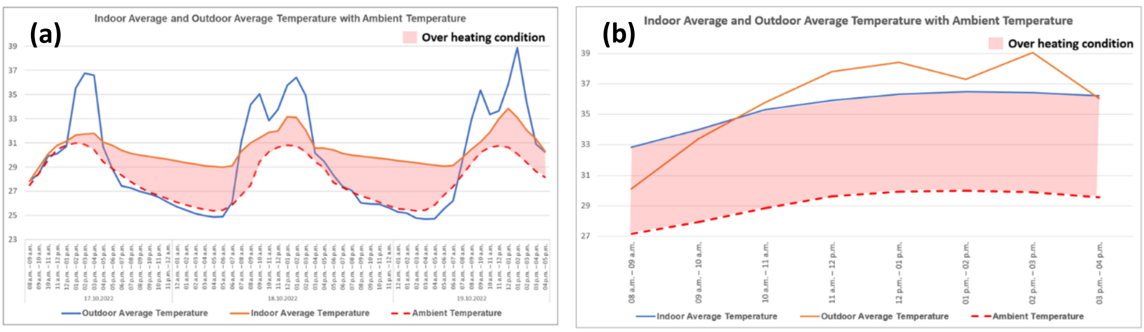


Figure 11: (a)- Indoor overheating condition during the Pilot Study
(b)- Indoor overheating condition during Spot Measurement Study

Based on the collected data the base model showed different thermal parameters. Therefore, the model was again adjusted with the actual measurements and the model was calibrated and validated again. This process ensured that the measurements from the on-site thermal performance investigation and the calibrated model showed similar thermal patterns and the model can be used to test the sustainable retrofitting strategies. Since the data on the 26th of October 2022 showed maximum similarity to the 18th of October, the computational process for sustainable retrofitting was tested on the 26th of October 2022.

4.1 PERFORMANCE BEHAVIOR WITH PROPOSED DESIGN SOLUTIONS

Once every data was analysed and the calibrated model was created, the model was ready for the proposal of design strategies. 05 different sustainable retrofitting solutions were proposed to the calibrated model and simulated to find the changes in internal temperature and the effectiveness of those strategies was discussed. Finally, passive design strategies were proposed to create an energy-efficient office building that is suitable, especially for the dry zone.

The strategies were included as DSS, to check the appropriateness of the possible retrofitting strategies. The temperature differences were observed at 3 points A, B, and C respectively at 11 a.m., 12 p.m., and 1 p.m. Taking different points into consideration can increase the accuracy of the findings. And finally, the overall temperature reduction was observed.

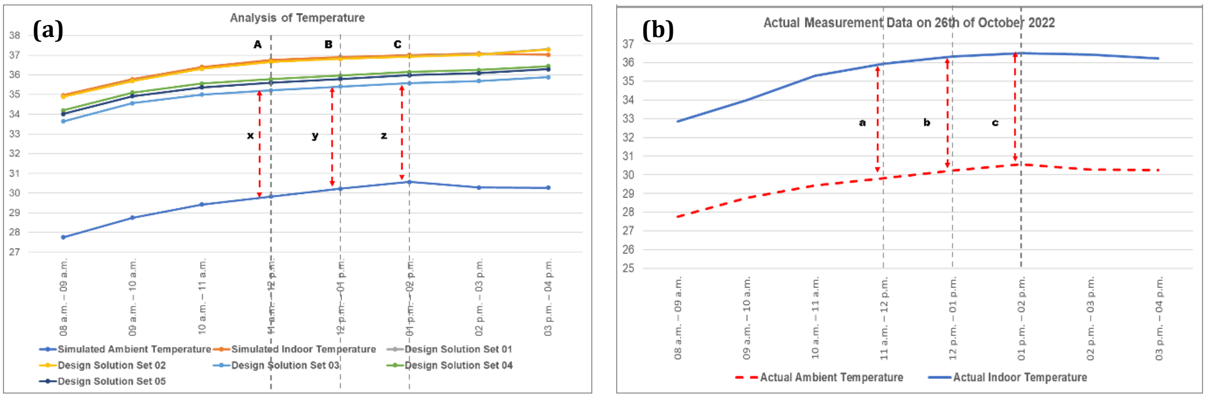
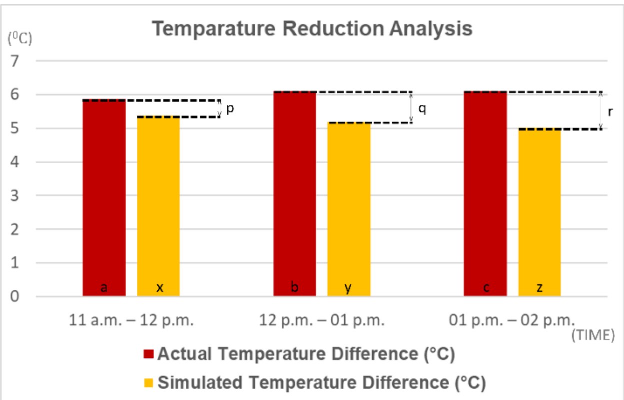


Figure 13: (a) - Temperature value for all DSS
(b) – Temperature value for actual on-site data

The findings showed that there was a significant reduction in the internal temperature when the model was proposed with DSS. Even though the internal temperature wasn't reduced below the ambient temperature, it was visible that sustainable retrofitting can reduce internal overheating.

The CS process has identified that there is a visible reduction in indoor temperature. Even though not all the design solution sets have resulted effectively, a visible reduction in the indoor temperature was visible. As per the observation in Fig. 14, on the 26th of October, the indoor temperature has been reduced up to 1^{0}C. It is apparent that proposing shading structures in buildings can contribute to a major reduction of indoor overheating. This reduction of indoor temperature can result in reduced energy usage for cooling.



Time	Actual Temperature Difference (°C)	Simulated Temperature Difference (°C)	Effective Temperature Difference (°C)
11 a.m. – 12 p.m.	a = 5.876667	x = 5.39046	p = 0.486207
12 p.m. – 01 p.m.	b = 6.106667	y = 5.18131	q = 0.925367
01 p.m. – 02 p.m.	c = 6.106667	z = 5.01622	r = 1.090447

Figure 14: Comparative analysis of the effectiveness of sustainable retrofitting

5. Discussion and Conclusion

The demand for energy and the need to reduce the extensive usage of energy are key points of discussion around the world. As the construction industry is consuming more energy, it is vital to research the background and propose effective solutions. The private and public sectors have more responsibilities in working together to implement effective strategies for energy usage. Therefore, the research has also attempted to contribute to this high-priority mission.

Energy is an essential factor for attaining almost all of the Sustainable Development Goals. The development of sustainable retrofit approaches through a proper understanding of thermal load sources, economic feasibility, and their effectiveness toward climate change can help to lead the nation towards achieving the SDGs and reducing the energy demand. Even though it is suggested to think of them at the initial stages of the design process, there are still opportunities to enhance the energy and TP of the building after construction. Implementation of sustainable strategies is more feasible when constructing new buildings, but improving the existing buildings is also equally important.

The research has analyzed 27 existing office buildings in Trincomalee, and the importance of appropriate plan forms is discussed. Especially concerning dry zones, improper plan form can increase the chances of indoor overheating. It was also identified that, even though spread-out plan forms are considered effective in a hot dry climate, they too need proper climatic knowledge to increase their effectiveness.

The paper has presented a framework for sustainable retrofitting through onsite TP investigation and CS process. The onsite TP investigation has identified the selected case study as overheating and the DSS were proposed to mitigate these conditions. The proposed strategies were tested using computer software and the results have ensured the positive impact of sustainable retrofitting. Even though the strategies were unable to reduce the indoor temperature below the ambient temperature, a visible reduction from the existing indoor temperature can be seen.

The study has revealed that sustainable retrofitting can be effectively applied to hot dry climates where it can reduce the energy used for cooling. This research also highlights that retrofitting is more efficient in economic and environmental aspects that can aid architects, energy policymakers, researchers, and engineers. The methodology used in the assessment is efficient and can act as a potential tool in the process of decision-making. The recommended design strategies have a high potential of being included in the building regulations that can improve the existing ones and make them more versatile and comprehensive.

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