Fulfilling eco-needs with energy-efficient metrics in tropical-zone office buildings

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Abstract

Current office buildings in temperate climate zones may suffer from inefficient energy utilization that does not match the workers' demands. This research was inclined to detect the primary environmental need and determine energy-related metrics that help to sustain those environmental conditions. The study contained both qualitative and quantitative methods presented from other case studies due to the limitations we had. One of quantitative methods included surveys that helped us to comprehend the favorable environmental need to address from office occupants: indoor air quality. Another quantitative method involved analyzing energy records that served as a tool to define energy-efficiency metrics. Contrary, qualitative methods like interviews from experts were beneficial for understanding the specific problem with air quality systems, particularly regarding HVAC. To address the needs of refining air quality, we particularly found energy-efficient performance parameters-correlating metrics - containing such as HVAC consumption, outdoor temperature, and occupancy - and control systems strategies for air quality testing: BMS, VAV, and VFD. Altogether, this research found and promoted energy efficiency with occupants' needs in temperate climate office buildings, focusing on air quality improvement through refined control systems and performance metrics. Further research can potentially be conducted in office buildings located in more harsh climate zones. Moreover, due to research constraints, we were unable to conduct on-site visits to office buildings. Therefore, our future actions will focus on conducting in-person interviews during site visits to gain deeper insights into environmental requirements. We will also make efforts to obtain energy consumption records from the building administrations.

a) Keywords:

environmental needs, indoor air quality, energy consumption, performance metrics, energy management

b) Abbreviations:

LEED – Leadership in Energy and Environmental Design

BREEAM – Building Research Establishment Environmental Assessment Method

HVAC – Heating, Ventilation, and Air Conditioning

GHG – Greenhouse Gas

EER – Energy Efficiency Ratio

VAV – Variable Air Volume

VFD – Variable Frequency Drive

BMS – Building Management System

I. Introduction

Climate change is a globally recognized problem and is known for its existence for a long period of time. Extensive efforts were and are being exerted to find effective solutions to this problem. One of the most contributing sides to this problem is energy consumption, as to cover the massive energy demands the world relies on non-renewable energy resources, which produce large amounts of greenhouse gases like Carbon Dioxide, methane, and nitrous oxide. Therefore, constructing sustainable and energy-efficient buildings has become essential to meet the large energy demands of today's world. These buildings are known as green buildings, they are known for their sustainability and energy independence, as they use renewable resources to cover a large percentage of energy needs or even their whole demand. The purpose of this study is to dive deeper into the evaluation of green building projects, which are known as energy efficiency benchmarks, specifically for office buildings located in temperature climate zones, as these types of buildings consume tremendous amounts of energy and are located broadly over the globe. Among commercial buildings, office buildings have the largest number and have the highest total energy consumption (about 14% of the energy consumed by all commercial buildings) [1]. In a study about the energy consumption of green buildings, it was found that heating consumption in certified buildings, from building certification programs (e.g., LEED, BREEAM), was 26% lower than the consumption in uncertified buildings [2]. With that being said, it's concluded that constructing energy-efficient green buildings would contribute greatly to energy consumption quantities. This study provides an extensive comprehensive review of the most efficient energy metricizes and benchmarking methods to contribute to the success of green buildings, and meeting the demands of occupants. The aim of this study is to gather information and data related to this topic and analyze them in a critical scientific way to make the study of this topic easy and accessible by engineers to assess the success of green buildings. The purpose of this study will be fulfilled by gathering data from scholarly sources and analyzing them due to the lack of access to the experimental field.

II. Literature review

This literature review aims to explore the extensive field of benchmarks and measures related to energy efficiency. The primary focus is on how these benchmarks and metrics are applied to evaluate the effectiveness of green building initiatives in office buildings located in tropical climates. By analyzing diverse scholarly sources, this review aims to provide a comprehensive understanding of viewpoints, approaches, and terminology related to energy efficiency assessment. Certain researchers have made significant contributions in this area by proposing blueprints for the construction of sustainable, energy-efficient structures [3], whereas others have innovatively improved energy efficiency in office buildings [4]. However, there exists a research void when it comes to assessing the energy efficiency of operational buildings (office buildings that run) with a focus on sustainability objectives.

Firstly, within this research domain, numerous academics concentrated on sustainable strategies applicable to office structures, establishing criteria to define a building as 'sustainable'. Previous studies extended their exploration beyond conventional LEED criteria and investigated additional crucial factors that contribute to the well-being of occupants in green buildings, such as natural illumination, climate regulation, and indoor air quality [4]. Secondly, certain researchers examined the allocation of energy within office buildings situated in tropical climate zones, devising personalized approaches to enhance the efficiency of energy systems. In their scrutiny of energy distribution, a consensus emerged among most scholars that a significant portion of energy is consumed by HVAC systems (approximately 68%) [5], which serves as a primary impediment to achieving energy-efficient operations. To address this challenge, numerous academics opted to integrate new technologies, particularly wireless sensor networks, to optimize cooling systems and achieve high scores on the COP metric [6]. Additionally, other scholars extended their investigation beyond HVAC systems, proposing strategies to minimize lighting consumption in office buildings, particularly in regions where environmental conditions permit such measures [7].

In summary, the current body of research offers valuable perspectives on recognizing beneficial attributes of green buildings and improving energy distribution. Nevertheless, there is a distinct lack of thorough exploration concerning the integration of energy optimization with the environmental inclinations of occupants in office buildings. This study seeks to bridge this gap by developing energy-efficient metrics that resonate with the eco-friendly inclinations of individuals working in office buildings located in tropical climate zones.

III. Methods

The results reported in this research paper were conducted using both qualitative and quantitative methods for a stronger and more integral approach to the required results with a net persuasive conclusion for the entire procedure, so this research is basically mixed-method research.

i. Quantitative methods

The quantitative methods were conducted mainly using two techniques: Surveys and energy records.

The surveys were used to configure the most impactful environmental aspect for the occupants that they wish to be more eco-friendly and energy-efficient, this aspect also contributed to occupants' comfort inside the building. The type of surveys used in our study is called post-occupancy evaluation (POE) surveys which basically obtain feedback on a building's performance based on surveys, spanning the amount of approximately 300 participants. These surveys (no access to background data or any other methodological data) were conducted by previous scholars in two office buildings in Australia, specifically in Sydney, which is a country known for its temperate temperature. Implementing surveys was a crucial step in our study because identifying the workers' environmental preferences and improving them will result in green and energy-efficient institutes in addition to increasing the workers' comfort level inside their working space, which will result in a more productive community. The energy records used in this research were made by scholars from Texas through observing the energy consumption of office buildings during a period of 24 hours; the observation records were analyzed using machine learning and algorithms techniques and used to build up graphs on three attributes: HVAC consumption, occupancy of the building, and outside temperature. These graphs shed light on some issues that can be potentially fixed for better energy performance metrics of these buildings.

ii. Qualitative methods

The qualitative methods used in this research are only in the form of interviews done with experts due to the ecological consequences of inefficient energy consumption regarding over-specification in cooling systems, which clarified the causes of these issues. The information collected from experts in these interviews helped eventually in the success of green buildings.

IV. Results

In Malaysia, a country characterized by a tropical climate, previous scholars conducted a case study. They employed a qualitative analysis through interviews (conducted by Razlin Mansor, Low Sheau-Ting) to ascertain occupants' preferences for well-being within office buildings [8]. Among the various findings, one discovery that resonates with our research question pertaining to energy-related matters involves occupants' preferences concerning their health and comfort. This aspect strongly influences the ecological considerations within office buildings, specifically addressing factors like thermal comfort, indoor air quality, and indoor lighting (Figure 1).

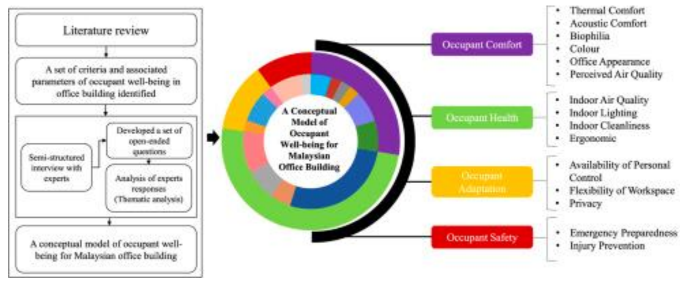


Figure 1. A Conceptual Model of Occupant Well-being for Malaysian Office Buildings.

Certainly, aspects such as how occupants adapt to their workspace, ensuring flexibility and privacy, as well as safety measures like emergency readiness and injury prevention, are vital for overall well-being. However, it is important to highlight the significance of ecological concerns because they impact not only individuals but also the broader natural environment. Moreover, it is worth noting that ecological preferences that occupants need for their well-being are zial reflections of their environmental beliefs, which are determined in a quantitative approach.

In Australia, in 2 office buildings in Sydney, researchers utilized post-occupancy evaluation (POE) surveys to conduct quantitative analysis in two academic office buildings. Generally, POE is the process of obtaining feedback on a building's performance based on surveys (conducted by Richard de Dear, Max Deuble), spanning the amount of approximately 300 participants. In our case, the outcomes revealed a noteworthy correlation between occupant satisfaction levels in POE and their environmental beliefs [9]. Given that addressing indoor air quality consumes a significant portion of total energy usage (about 61.2%) and accounts for an estimated 27% of the total greenhouse gas (GHG) emissions, occupants exhibited greater leniency toward their buildings, particularly favoring those incorporating green design elements like operable windows for natural ventilation [9]. On top of the great amount of energy usage, some scholars from the tropical zone of China noted health issues that might occur because of the components of indoor air quality [15]. Specifically, questionnaires (conducted by Zhu Cheng, Nuoa Lei and other scholars) were utilized to study how people perceive indoor air quality and its connection to sick building syndrome. Additionally, cancer risk assessments for these office buildings were conducted using on-site air quality data of Chinese office buildings. The results highlighted a significant correlation between indoor and outdoor pollutant concentrations, with fluctuations throughout the day. Having said that, indoor conditions were found to be less favorable during the morning and afternoon. While the risk assessment indicated that health problems could exist even though the pollutant concentration levels in the indoor environment were within the standard limits.

Moving on to energy consumption again, in Malaysia, other scholars noted the ecological consequences from inefficient energy consumption regarding over-specification in cooling systems [10]. They employed experts' interviews (conducted by Nurul Zahirah, Nazirah Zainul and other scholars) to clarify the causes of over-specification issues (Figure 2).

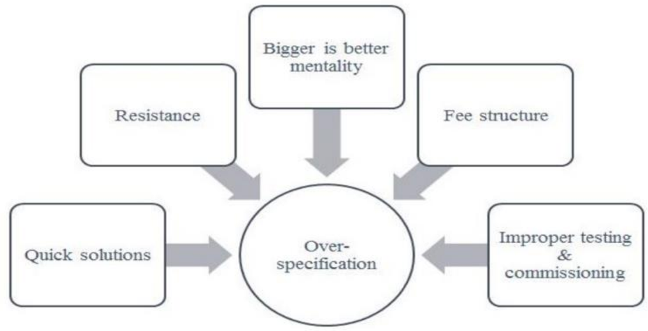


Figure 2. Causes of over-specification in experts' opinion

It can reasonably be inferred that those issues can be classified into 2 categories of drawbacks: imprudence during building (non-calculated resistance, searching for quick solutions, size-dependent mentality) and careless maintenance (stingy fee structures, inaccurate testing). Therefore, the research later will propose a specific metric that is responsible for building and controlling new systems in office buildings.

In general, scholars attributed to green buildings' success by acknowledging efficient HVAC systems and eliminating harmful causes to those systems.

Among outdoor causes, radon, formaldehyde, asbestos, dust, and lead paint can enter through poorly located air intake vents and other openings [11]. Apart from over-specification, some scholars pointed out specific technical causes through inspections of office buildings: placement of refrigerators in front of a thermostat, broken dampers, leaking valves, etc [12].

There is much research done on devising effective HVAC systems to satisfy occupants' needs. Beyond basic EER metrics (a way of evaluating an air-conditioning unit's efficiency), academics established new metrics by analyzing energy consumption records for office buildings and implementing machine learning algorithms.

For instance, scholars from Texas were able to track the energy performance of buildings through various scaling methods [13] (Table 1).

Scaling Method	Description	Mathematical Formula
Min-Max Scaler	Used to normalize data in the range of [0,1] For each value in the feature, the minimum value is subtracted and then divided by difference between the original maximum and original minimum [42]	$\frac{X-min}{max-min}$
Standard Scaler	Used to rescale the distribution of the data by subtracting the mean and then dividing by the standard deviation [43]	$\frac{X-\mu}{\sigma}$
Robust Scaler	Primary used to remove the effect of outliers as the centering and scaling of this scaler are based on percentiles [44]	$\frac{x-Q_1}{Q_3-Q_1}$

Table 1. Data Scaling methods.

Over a 24-hour time interval, the performance metric was established by integrating values of HVAC Consumption (in Kilowatts per Hour), Outdoor Temperature, and Number of Users in the building (Figure 3).

The objective of performance metrics is to detect elevated average power usage during

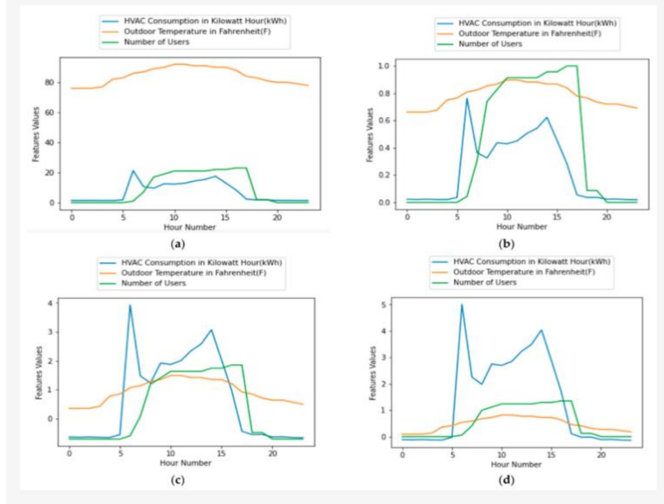


Figure 3. Effect of data scaling: (a) original data, (b) min-max scaler, (c) standard scaler, (d) robust scaler.

periods of low outdoor temperatures and reduced occupancy (Table 2).

Clusters Content	Min Max Scaler			Standard Scaler			Robust Scaler		
	HVAC kWh	Outdoor Temperature (F)	N_Users	HVAC kWh	Outdoor Temperature (F)	N_Users	HVAC kWh	Outdoor Temperature (F)	N_Users
Cluster 0	2.92041	79.321325	0.79497	1.98926	79.047934	0.625069	13.87707	83.121461	15.52785
Cluster 1	7.96495	74.409836	20.4754	8.98954	76.07863	18.82016	1.774806	70.057293	0.747598
Cluster 2	2.35077	55.230648	0.8503	2.39227	54.342054	1.759859	5.714216	66.734021	17.44433

Table 2. Clustering the values of performance metrics

This signal prompts building managers to adjust these conditions to a more energy-efficient state, such as decreasing the thermostat's setpoint [13]. In general, researchers mentioned the lack of control systems within office buildings, stating that the HVAC system needs to respond to the building's dynamic load or dry and wet bulb temperatures, leading to inefficiencies. To solve the issue, packaging air conditioning with metrics like variable air volume (VAV) and variable frequency drives (VFD) along with control and building management systems (BMS) could respond to the changes in the building's internal loads and ambient variations [14].

V. Discussion

The primary goal for this research paper was to find the essential environmental needs and determine the energy-related metrics that are most efficient for the environment, these goals were described in detail earlier in the abstract and introduction, The objectives of this research were fulfilled using both qualitative (Experts' interviews) and quantitative (Surveys and energy records) approaches. These data focused on the needs of the building occupants when it comes to their environment and their environmental beliefs (POE Surveys), the energy consumption of the building based on three attributes: HVAC consumption, occupancy, and the outdoor temperature (Energy records), and how to fix problems related to the cooling system of the building (Expert's Interviews). After gathering these data and analyzing them, it was found that the most important environmental factor to the workers is the indoor air quality Also the energy records showed the lack of controlling systems within office buildings. These findings showed solutions to the objectives of our study like improving the indoor air quality using natural ventilation systems, using efficient control systems for the HVAC consumption so that the building could respond to the extensive load on specific day periods and solutions to the problems related to the cooling systems. The quantitative data used in this paper (Surveys and energy records) were analyzed using descriptive statistics, which is a way of describing a dataset statistically. The findings of this research will contribute significantly to the development of green buildings as the data was collected from different sources and analyzed to come up with efficient solutions that will shorten the way for engineers to build a green office building that is totally green and totally self-dependent in energy consumption. During the process of conducting this research, we weren't able to access the experimental field, so we had to rely on datasets collected by other scholars, this obviously was a significant limitation to our work as it might have affected the accuracy of our results with a small percentage, it's also unlikely for any future obstacles to face our study as green buildings is increasing wildly and similar topics related to green buildings is currently being researched by many other scholars. For efforts willing to continue the work done in this study we would recommend having a larger set of data for better precision in the results, in addition, having access to experimental fields and on-site location would contribute greatly to the accuracy of the results.

VI. Conclusion

Throughout the work, the research played an integral part in identifying energy consumption metrics with two purposes: performance-measuring, managing. It determined specific performance metrics, such as linking HVAC consumption, outdoor temperature, and building occupancy, as well as effective control system strategies like VAV, VFD, and BMS. These were utilized to optimize energy utilization in office buildings, aligning with occupants' primary environmental needs. Throughout the study, energy records taken into consideration by other scholars were handy in defining those metrics. Although the initial anticipation was to formulate highly specific HVAC usage metrics, the study revealed that external factors facilitate a vast role in shaping the ultimate metrics. Having said that, as we align with occupants' ecological preferences, it became essential to establish metrics for indoor air quality, considering that many occupants prioritize it as a primary concern. This step had not met any previous expectations prior to the onset of this research. All in all, the findings from this research were successful to bridge the gap between pointing out momentous energy-related metrics that primarily address the occupants' needs regarding indoor air quality in temperate office buildings located in temperate climate zones (like Malaysia, Australia, and Southern United States). The further research can potentially investigate other environmental needs of occupants: for example, both eco-friendly and energy-efficient lighting. On top of that, there is potential for further research in more challenging climate conditions, such as extreme cold or high humidity environments.

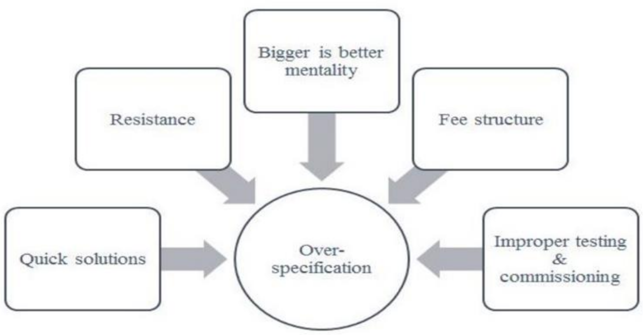
VII. Acknowledgement

First, we would like to praise God for helping us and guiding us during this journey to yield this research paper. Secondly, we would like to give our huge thanks and gratitude to our biggest supporters for their invaluable help, as without their support this work would never have been possible:

First, to Ziad Ahmed, our respectful and patient mentor; his feedback was the biggest contributor to our paper, and he was available all the time for our urgent inquiries. Second, to the Youth Science Journal management board, they were our number one supporter throughout this entire journey; they helped us with our biggest challenges and provided us with useful materials that clarified many questionable things in our research. Third, to the researchers who conducted the papers mentioned in the references list; these scholarly resources were our main source of information. Finally, to our family and friends for giving us emotional support and keeping us motivated during this process.

VIII. Tables & Figures

Figure 1. A Conceptual Model of Occupant Well-being for Malaysian Office Buildings



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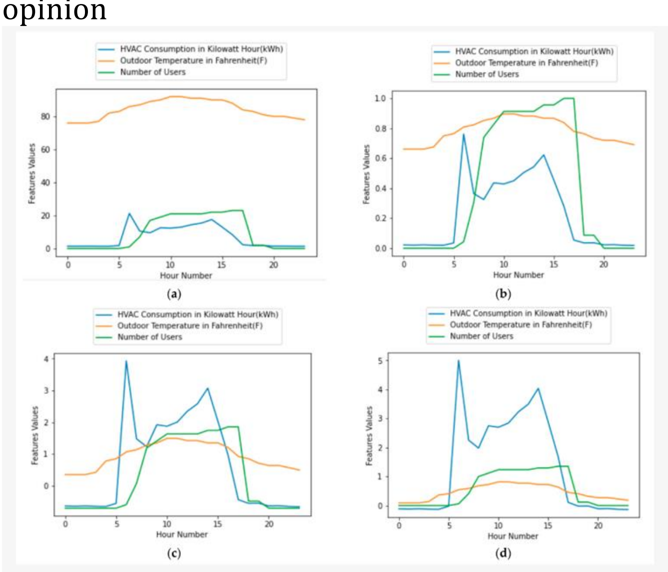

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