



Low-consumption techniques in tropical climates for energy and water savings in buildings: A review on experimental studies

Técnicas de bajo consumo en climas tropicales para el ahorro de energía y agua en la edificación: Una revisión de estudios experimentales

Katherine Chung-Camargo¹ , Mariana Bencid¹ , Dafni Mora^{1,2,3} , Miguel Chen-Austin^{1,2,3*} 

¹ Universidad Tecnológica de Panamá, Facultad de Ingeniería Mecánica, Grupo de Investigación Energética y Confort en Edificaciones Bioclimáticas (ECEB), Panamá

² Centro de Estudios Multidisciplinarios en Ciencias, Ingeniería y Tecnología AIP (CEMCIT AIP), Panamá

³ Sistema Nacional de Investigación (SNI), Panamá

katherine.chung@utp.ac.pa; mariana.bencid@utp.ac.pa; dafni.mora@utp.ac.pa; miguel.chen@utp.ac.pa

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***Autor de correspondencia:** Miguel Chen-Austin (miguel.chen@utp.ac.pa)

ABSTRACT. Different investigations have been developed over the years, and experimental research takes time to collect the information. Considering this, the objective of this research is to carry out a literature review of the strategies adopted by countries with tropical climates to achieve energy and water efficiency, as well as the comfort of the occupants to evaluate the performance of these techniques for each tropical climate type (i.e., tropical rainforest, tropical monsoon, tropical savanna, and subtropical). A methodology is presented using keywords and exclusion criteria for the best selection of articles. Time is saved by searching for information on low consumption strategies, types of buildings, and techniques implemented in each country. A summary of each experimental investigation is made. Results showed that it is possible to apply different techniques to the same type of building and have the savings of interest (water, energy, or comfort) without limiting it to a specific technique. Some tropical climates tend to use only one type of savings, such as comfort and others use energy and water. The experimental studies presented a relevant saving for passive design strategies in the following order: 1- 62.22% applying natural ventilation, water wall and stack flue, 2- 41% and 43% applying daylighting and glazing. 3- 35% applying wall insulation. For low consumption techniques: 1-14.31% and a 32.30% Remote Control extension device and 2-19% applying semitransparent photovoltaic glazing. This article is a resource that can be used by anyone interested in experimental studies in tropical climates.

Keywords. *Tropical climate, experimental research, low consumption techniques.*

RESUMEN. Se han desarrollado diferentes investigaciones a lo largo de los años, y la investigación experimental toma tiempo para recopilar la información. Considerando esto, el objetivo de esta investigación es realizar una revisión bibliográfica de las estrategias adoptadas por los países con climas tropicales para lograr la eficiencia energética e hídrica en edificaciones, así como el confort de los ocupantes con el fin de evaluar el desempeño de estas técnicas para cada tipo de clima tropical (es decir, selva tropical, monzón tropical, sabana tropical y subtropical). Se presenta una metodología utilizando palabras clave y criterios de exclusión para la mejor selección de los artículos. Se realiza un resumen de cada investigación experimental. Los resultados de esta investigación demostraron que es posible aplicar diferentes técnicas a un mismo tipo de edificación y tener el ahorro de interés (hídrico, energía o confort) sin limitar a una técnica específica. Algunos climas tropicales tienen una tendencia a usar solo un tipo de ahorro como confort y otros usan energía y agua. Los estudios experimentales presentaron un ahorro relevante para las estrategias de diseño pasivo en el siguiente orden: 1- 62.22% aplicando ventilación natural, muro de agua y chimenea, 2- 41% y 43% aplicando iluminación natural y acristalamiento. 3- 35% aplicando aislamiento de paredes. Para técnicas de bajo consumo: 1-14.31% y 32.30% dispositivo de extensión de Control Remoto y 2-19% aplicando acristalamiento fotovoltaico semitransparente Este artículo es un recurso que puede ser utilizado por cualquier persona interesada en estudios experimentales en clima tropical.

Palabras clave. *Clima tropical, investigación experimental, técnicas de bajo consumo.*

1. Introduction

Global warming and its effects on climate change have been a matter of deep concern over the years, leading experts to evaluate and integrate different measures to offset the repercussions of greenhouse emissions in the atmosphere. The building sector, as part of this problem, comprises over one-third of the global energy consumption and nearly 40% of total CO₂ emissions [1]. These numbers reflect the imminent need to redirect our actions towards low-consumption solutions as well as to the use of renewable energy sources with the aim to reduce the carbon footprint of the building sector and to ensure sustainable development through the entire buildings' life cycle.

Following this direction, many countries have recently included near-zero energy buildings (nZEB) and net zero energy buildings (NZEB) as part of their policies. These types of buildings operate by reducing at utmost the energy consumption of the building in a way that the final energy needs can be supplied by renewable sources [2]. Thus, the application of both passive and active strategies is crucial as the first step to achieving low energy consumption in buildings. Nevertheless, the selection of the strategies to be used is strongly connected to the necessities of each specific climatic condition.

In tropical countries, which are characterized by high temperatures and high levels of solar radiation, conventional methods are commonly used for cooling purposes, resulting in very high energy demands. Simulations and experimental research have been conducted on different low-consumption techniques in buildings in the tropics to assess the effectiveness of these strategies in reducing water and energy needs while maintaining a comfortable environment. India, Indonesia, Malaysia, Singapore, Ghana, and Trinidad and Tobago are among the tropical countries that have implemented this type of technique.

1.1. Motivation and objectives

Along with high temperatures, tropical climates often face challenges such as high levels of relative humidity and, in some cases, considerable precipitation during the year. These characteristics make it difficult for the building to provide comfortable conditions to the occupants without relying on electrical lighting and mechanical cooling systems. To address this problem, it

is important to focus the building's design on passive strategies that enhance natural ventilation, take advantage of available daylight, and reduce heat gains through the envelope. Although the implementation of these strategies reduces dependency on conventional lighting and cooling systems, it creates a high dependency on climatic conditions that tend to be stochastic. This may represent an obstacle to the correct fulfillment of the passive solutions. Thereby, applying active strategies such as efficient lighting and air conditioning systems is fundamental to complement passive strategies in the reduction of energy consumption.

On the other hand, many of the countries located within the tropical regions are classified as developing countries (e.g., Malaysia, Oman, Ghana, Trinidad and Tobago, Tanzania, among others). As a consequence, most of them have few or no relevant policies regarding NZEB or nZEB [3]. The lack of policies makes it more difficult for the countries to have a realistic benchmark for their local conditions and therefore suppresses further investigation and planning for innovative strategies that change the course of the actual building sector in hot and humid climates. As a result, there are little experimental data on techniques that have been applied to buildings in the tropics that have reported a reduction in energy and water demand and/or an increase in thermal comfort. Nevertheless, these experimental results are worth reporting in a systematized way to provide a condensed bank of references for rapid identification regarding the type of tropical climate, building type, and energy and water reduction interest.

Hence, the aim of this research is to accomplish a literature review of the strategies adopted by countries with tropical climates to achieve energy and water efficiency as well as the comfort of the occupants with the purpose of reporting the techniques employed for each type of tropical climate (i.e., tropical rainforest, tropical monsoon, and tropical savanna).

1.2. Scope and Structure

This investigation comprises the experimental data of active and passive strategies adopted by tropical climate countries to reduce energy and water consumption and achieve thermal comfort in buildings.

The structure adopted for the research starts with section 1, with the introduction of the problematics faced by the building sector and the motivation to pursue

further investigation, specifically in the tropics. The methodology is then explained in section 2 regarding the searching strategy for the data collection and the filtering process. In sections 3 and 4, results and discussions on the analyzed techniques are presented. Ultimately section 5 includes the conclusions of the investigation.

2. Materials and methods

The methodology used for this research consists primarily of collecting data related to the objectives of the investigation. For this purpose, a research strategy following the next steps were implemented: (i) keyword generation, where specific words and their most relevant synonyms were selected, (ii) use of logical operators as OR, AND to combine and connect the keywords to make the research more efficient and (iii) selection of search engines that gather relevant information on the subject.

Regarding keyword generation, the words “Energy savings,” “Water savings,” “Low-consumption solutions,” and “Life Cycle” were connected through the logical operator AND to limit words as “buildings” and “tropical OR tropics.” The resulting combinations (square 2, figure 1) were introduced into the selected

engines (i.e., scholar google, ScienceDirect, and EBSCO) for preliminary research from which, manually, articles within the scope of the investigation were selected. The metadata of these articles was then analyzed to evaluate the most common words used by researchers to refer to strategies that achieve a reduction in water and energy consumption (square 4, Figure 1). From this analysis, words such as “Passive design strategies,” “Energy efficiency,” and “Water efficiency” were selected as new keywords and combined through logical operators obtaining the final combinations shown in square 5 of Figure 1. Thus, this time, the same procedure was applied for new research, including T&F, MDPI, and Emerald as search engines.

Once the final research was concluded, a manual filtration process was again conducted to ensure that only articles regarding experimental research on tropical countries and their application of low-consumption solutions to buildings were selected for this study. These articles were then thoroughly analyzed to review all the strategies found and their reported results.

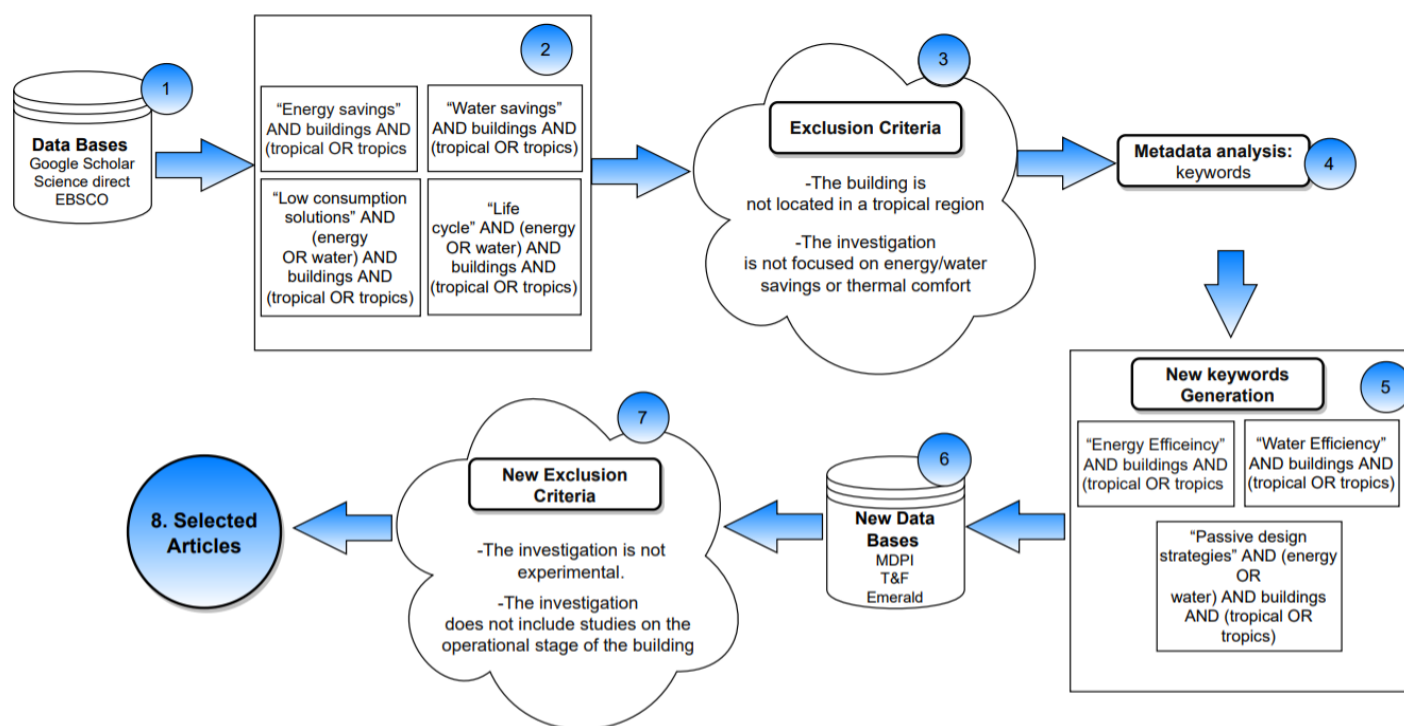


Figure 1. Search procedure for the inspection of the literature.

3. Results and discussion

The following section summarizes each selected article according to the chosen parameters. Also, Table 1 gathers the countries with a tropical climate that have applied experimental studies, type of building, and the saving strategy applied in each experimental research.

3.1. Results of Energy Savings

3.1.1. Passive design strategies

Different passive strategies have been studied and implemented to buildings in the tropics to address high energy consumption and thermal comfort issues. Among these, passive cooling is a widely studied technique that has been applied to new buildings [4-7], atriums [8], as well as to already existing buildings as a retrofit [9]. Passive cooling can be achieved through different strategies such as enhancing natural ventilation with the aim of reducing dependency on Air-conditioning systems (ACS). One of the most basic strategies used to accomplish successful natural ventilation is to orientate the building in a way that ensures comfortable airflow throughout the day. This technique has been adopted by the ENERPOS building, a net zero energy building (NZEB) located in the Sant Pierre Campus at the University of Reunion, where the main facades are north and south oriented, that being perpendicular to the thermal breezes, optimizing this way the natural ventilation of the building [4].

Besides building orientation, windows, and openings play an important role in natural ventilation. A prototype of a residential zero energy building in Muscat, Oman, named SQU eco-house, implemented in its design long vertical windows with lower and upper openings in parallel walls that create a wind pressure differential and allows the air to flow from the lower openings to the upper ones, ensuring natural ventilation at daytime and nighttime [5].

Other strategies are also commonly implemented, such as adjustable louvers that control the direction of air flow. An example of this is the case of an energy-efficient university building located in Singapore that opted for an open design concept with louvered sunscreens that allow free flow of air in the canteen area [6]. A similar strategy was employed by the ENERPOS building in which cross natural ventilation was provided through manually

adjustable louvers with a window to wall ratio (WWR) of 30% on parallel sides of the classrooms, avoiding the necessity for ACS. This passive cooling technique proved to be efficient at providing temperature comfort to students as the building scored 5.73 points in the BUS (building use studies) survey, that is, better than the average score of buildings surveyed [4]. Cross ventilation also proved to be effective for residential buildings such as the Golconde Dormitories in South India, where a north corridor was built with adjustable cement louvers. The corridor blocks direct solar radiation and rain and acts as a buffer zone, managing to lower inside room temperature by 0.5°C regarding the corridor's temperature. The temperature difference provides air flow and thus ventilates the area between the corridor and the adjacent room [7].

Furthermore, additional passive cooling techniques were studied at Golconde Dormitories, such as a ventilated double roof made of reinforced concrete (RCC) covered with a precast concrete shell that forms a ventilated air gap of approximately 10-30cm. Monitoring showed that the ventilated double roof managed to lower temperature damping by 18°C, maintaining thermal comfort without the need for mechanical ventilation. Additional to the ventilated roof, the Golconde Dormitories count with two gardens located at each North and South facades, respectively. The purpose of these gardens, along with preventing hot air from entering the building, is to create a temperature difference that allows air to flow constantly through the building and the semi-basement, making this latter area the coolest area in the building, maintaining a stable surface temperature between 30-34°C [7].

Monitoring procedure was also conducted to a low energy office building, KeTHA, located in Malaysia. The aim of the study was to investigate the effects of natural ventilation and other passive cooling techniques (i.e., stack flue and water wall evaporative cooling) on the thermal performance of the building's atrium. The atrium was built with four large windows and doors that supply fresh airflow already precooled by the trees on the street. It also counts with a water wall that works as an evaporative cooling system since the airflow passes through the humid surface of the wall and some of the water turns into vapor, in this way, the continuous flow of the water extracts heat from the air. Another feature of the atrium is the stack flue installed at the top of the roof

that supplies a pressure difference between inside and outside air that naturally drives the cool fresh air from outside into the building. Results showed that a high percentage of thermal comfort was achieved (62.22%) when the water wall remained open and the stack flue semi-open, providing cross ventilation in different levels. These configurations of the openings resulted in an average temperature of 27.12°C during working hours [8].

Similar to the stack flue, four solar chimneys were installed on the roof of an already existing university building in Singapore as part of a set of retrofits. The mechanism of this chimney is to expel hot air out of the building through the buoyancy effect while permitting the entrance of outdoor ambient air. Energy savings due to the operation of the chimneys accounted for 832kWh annually [9].

Moreover, among the passive cooling techniques, thermal insulation has been implemented in buildings in the tropics with the purpose of reducing heat gains through the envelope. It is the case of the ENERPOS building in which a 10cm layer of polystyrene was installed over the roof as an insulation material [4]. Along with this building, other studies on thermal insulation have been conducted in the tropics such as an experimental monitoring at Trinidad and Tobago evaluating the energy performance of three equal-sized small prototypes that were equipped with different types of wall and roof materials, making different models to be tested. The study was conducted in two phases, phase 1 for the building envelope insulation and phase 2 for the roof system insulation. In Phase 1, three models were constructed with (A): 100mm concrete block envelope and red clay tile roof, (B): 100mm clay block envelope with corrugated standing steam ceiling, and (C): 150mm concrete block envelope with galvanized iron roof system. These three models were thermally insulated with 38.1mm of fiber glass on the envelope and roof. From this study, it was found that model B showed the lowest energy consumption in the peak hours (an average of 0.3420kWh from 10:00am to 4:00pm) and recorded the lowest indoor temperature and relative humidity (60%) regarding the other models, proving to be the most efficient. Phase 2 tested five different models, in which model #2 with corrugated galvanized sheeting and fiber glass insulation had the lowest energy consumption when compared to the other models; a recording consumption of 1.74kWh through the daytime and 0.754kWh during

nighttime [10]. Moreover, in Trinidad and Tobago, another study was conducted using coconut fiber as insulating material. In this case, two identical small-scale models were tested, models 1 and 2 were constructed with concrete and clay blocks, respectively. To correctly assess the performance of the materials, both models were first tested without insulation to develop a benchmark. Then, the models were tested using the coconut fiber and fiberglass insulation under the local climatic conditions. For model 1, coconut fiber insulation proved being the most efficient material, maintaining an average temperature of 27.8°C with a temperature difference of 5.6°C regarding outside temperature. On the other hand, the most efficient material for model 2 was the fiberglass insulation since it managed to maintain relative humidity values inside the acceptable range (40-70%) for the longest number of hours (9:00-21:00). Related to energy efficiency, the model with fiber glass insulation showed the lowest energy consumption, reducing up to more than 35% when compared to the no-insulation model. [11].

Vegetation is also part of the passive cooling techniques studied in the tropics, it is commonly applied to buildings as a part of their envelope (i.e, walls and roofs) or as a shading strategy to protect the building from solar exposure. As an example of this, the QSU building in Oman included, along with date palm wood screens and vertical canvas strips, climber plants that could grow up to the height of one floor, creating a bio-wall system that provided shading through the year [5]. Moreover, a case of a study of two similar houses (with and without vegetation) was conducted in Malaysia with the purpose of evaluating the thermal performance of the shading. According to the measured data, the temperature difference between the vegetated and non-vegetated building was of 5.3°C and 2.8°C for indoor and outdoor temperatures, respectively; concluding that the outdoor and indoor temperatures can be significantly reduced by implementing vegetation as a shading strategy [12].

Vegetation can also be applied to already existing buildings as a retrofit technique, that is the case of the NZEB in Singapore that installed three different types of vertical and roof green systems (panel, planter and cage type) in order to reduce heat transmissions. Results of a year-round monitoring showed that the most efficient type of vegetation was the planter type, achieving an annual saving of 5.72kWh/m². As for the total energy savings of the three types of greenery, including the green

roof, the building registered 82.9kWh per year. For further cooling in the building, the low emissivity glazing was coated with UV film to reduce solar heat gains. The glazing retrofits achieved annual energy savings of 1,250kWh [9].

Additionally, University of Sebelas Maret in Indonesia carried out a field study testing three different types of green roofs named A, made with concrete, B, made with corrugated zinc, and C made with the same criteria as B with the difference that this last one was not covered with vegetation. For this study, a significant reduction on indoor temperature was found when comparing corrugated zinc roof with plants and without plants (types B and C). The indoor temperature difference between both was of 25.6°C at the peak hour (12:00 pm). Also, the vegetated zinc roof reached a maximum indoor temperature of 27.7°C, while maintaining the indoor temperature within the range of 24.8°C to 32.4°C through the rainy season. On the other hand, the heat flow of concrete roof with plants was the lowest of the three types, reaching its peak at 5:00pm at a rate of 10.5W/m², more than three times less than the corrugated zinc with plants [13].

Likewise, a study on living walls (LW) was conducted in Naresuan University, Thailand with three experimental boxes of which Box 1 was a reference box with no vegetation, and Box 2 and 3 were covered with 6mm of thick felt and 0.10x0.1 m pockets for plants. In this study, twelve different plant species with different leave sizes (small, medium, and large) were installed on the LWs. When compared to the reference box, LWs showed a lower temperature during the daytime but a higher temperature during the nighttime. Furthermore, LWs accommodated with medium-sized leaves proved to be more efficient at reducing temperature, managing to reduce the peak indoor temperature from 50.6°C to 44.9°C. The study concluded, through a correlation analysis, that the leaf area index (LAI) is a key factor in the achieving cooling efficiency for LWs [14].

In addition to the strategies previously mentioned, daylighting is a passive approach that seeks to take advantage of natural light in a way that minimizes electricity consumption. Daylighting was achieved in the ENERPOS building by adequate orientation and glazing. In this way, total artificial lighting was reduced and even avoided in two of the classrooms [4]. As another example, the QSU eco-house at Oman enabled sunlight by installing clear glass windows and glass doors with

adjustable drapes that were distributed in all zones [5]. Glass doors were also installed, along skylights in the energy efficient NIE building in Singapore, to enhance daylighting. The linear design of the building provided a floor depth of less than 12.2 meters from walls or windows, which also maximized natural light inside the lecture rooms and staff offices [6].

In order to incorporate daylighting as a retrofit, the ZEB building in Singapore installed mirror ducts and light shelves with reflective materials to redirect zenith light into deeper spaces of the building, along with light pipes in which mirrors would rotate with the sun's trajectory. The annual energy savings for the ducts, light shelves and light pipes was of 50kWh, 180kWh and 550kWh respectively [9].

A full-scale study conducted in Malaysia evaluated the performance of an innovative roofing system (IRS) that integrates both daylight and passive cooling techniques. In this study, top-lighting system and skylight with double polycarbonate were implemented into an attic in order to provide natural light. The chosen passive technique for cooling was reflective and radiative cooling. The IRS showed the lowest indoor temperatures relative to outdoor temperatures when compared to other systems, managing to reduce indoor temperature up to 2.01°C under daylight conditions [15].

In Tanzania, daylighting was studied through a field experiment using building integrated semi-transparent photovoltaic modules on a classroom at the Nelson Mandela Institute of Science and Technology. The purpose of this study was to measure air temperature, relative humidity, and solar irradiance under weather conditions as clear sky, cloudy sky, and normal sky. Measurement was carried from May to August 2019 in an hour range from 8:00 to 18:00hr. The results of this study showed a significant dependency of the PV module efficiency on solar irradiance, achieving the highest electrical efficiency of 8.89% at 1100W/m². The system also proved to provide visual comfort during the mentioned hours and thus saving up to 19% of the energy of the room [16].

Daylight plays an important role on visual appraisal as it contributes to the occupant's comfort and reduction of energy consumption. A survey was carried in two different green buildings in Malaysia, i.e., the Energy Commission Building (ECB) and the Public Works Department (PWD), with the purpose of evaluating the performance of daylighting techniques on the visual

appraisal of the occupants. Results showed that more than 80% of users in ECB and 65% of users in PWD preferred having daylight in their working spaces. Nevertheless, 21% and 24% of users of ECB and PWD respectively, stated to be dissatisfied with task brightness when working in the computers, and 28% and 25% when doing paperwork. On the other hand, daylighting techniques applied to both buildings, such as WWR adjustments, glazing, ceiling, wall and floor reflectance and adequately oriented openings, showed a reduction in energy consumption of 41% for ECB and 53% for PWD [17].

To address the problem of an excess of brightness and heat gains from the sunlight, shading devices are commonly used. The QSU eco-house in Oman implemented a double shell system to obstruct solar radiation and to prevent its thermal load from reaching indoor spaces. A shell was also applied to the building in a way that creates a 60cm cavity and provides shading to the roof [5].

3.1.2. Active strategies

Following the hierarchical design model for NZEBs proposed by Wells [18], once all the passive techniques have been fully considered for the building's design, the next step is to evaluate the implementation of energy-efficient systems. These are called active strategies and they include, but are not limited to, ACS, heat pumps, boilers, and electric lighting.

Countries with tropical climate are characterized by a high cooling demand due to the high temperatures and levels of irradiance. This has led to different studies on how to make mechanical systems such as air-conditioning more efficient in terms of energy consumption and reduction of GHG emissions. This is the case of a research conducted in Malaysia where a solar-assisted air conditioning system is proposed. The purpose of this cooling system is to convert the energy captured from the solar rays into electricity that powers the AC. The results indicated that the coefficient of performance (COP) for the solar-assisted AC ranged from 2.98 to 4.45 on the three days it was measured, proving to be energy efficient. When compared to an inverter AC unit, solar assisted AC proved to have considerably lower values of power usage on account of the PV panel [19].

Following this line of studies, in Indonesia, a remote-control extension device was proposed to reduce the

energy consumption of already installed cooling units without recurring to expensive built-in automation. The purpose of the system is to detect human presence through a passive infrared sensor (PIR), activated by a push-button mechanism. The device is controlled by a Mini Arduino that activates a solenoid when the PIR detects heat energy from humans. The purpose of the solenoid is to produce an electromagnetic field that pushes the remote button and turns on the AC unit. The device can be programmed to turn off the machine after a period of undetected human presence. The study was conducted on a standard 1 hp AC unit and when compared to the performance of a built-in automated AC, the proposed system was able to reduce energy consumption a 14.31% and a 32.30% regarding standard AC without the extension device [20].

Other high efficiency systems have been implemented in nZEBs and NZEBs in the tropics. Such is the case of the National Institute of Education (NIE) in Singapore. This building uses a variable air volume system (VAV) which has proven to be effective in reducing energy consumption in tropical climates [21]. Along with the VAV, the fans installed through the building are controlled manually by variable speed drive (VSD) avoiding the fans to operate at full speed unless needed. Also, the building uses chillers with 0.6kW/ton of efficiency. In relation to electricity systems, the NIE is integrated with motion detectors in toilets, parking lots and internal corridors to limit the time the lights are switched on. Common areas are controlled by Integrated Building Management System (IBMS) and monitored throughout the year to measure energy consumption and to support decision-making when improvement is needed. The cooling and electrical efficiency measures mentioned above have significantly decreased energy consumption and cost of the NIE building regarding the original design [6].

The university ZEB building in Singapore considered the application of active strategies as well, in this case as retrofits. The main techniques were focused in making mechanical ventilation more efficient using variable speed fans, a single coil twin fan system, displacement ventilation system, under-floor cooling and personalized ventilation. Variable speed fan system (VSF) is designed to detect the levels of carbon dioxide (CO₂) in the room and adjust the speed of the fan according to the number of occupants. As a result, VSF showed to save 64,000kWh of energy annually. Single Coil Twin Fan

System is properly an invention of Singapore and consist of the separation of fresh and recirculated air inside the fan in order to reduce the amount of airflow that needs to be cooled, this system led to energy savings of 37,189.6kWh per year. Another technique used by the building is the displacement ventilation (DV) which can supply at low speed, and thus, reducing energy load. DV along with personalized ventilation (PV), which consists of desk fans (manually adjusted by the user), proved to save an annual amount of 3,410kWh [9].

Electrical retrofits for the Singapore's ZEB included replacing lights with LED bulbs equipped with a sensor grid to measure occupancy and consequently adjust lighting levels. Task light were also installed in personal desks to promote manual control of light according to personal preference. These electrical retrofits represented more than 40% of energy savings, with a total of 74,623kWh per year. Altogether, the combination of both passive and active strategies implemented as retrofit managed to reduce the building energy demand up to 183MWh. This value results low enough for the building to compensate that demand through renewable solar energy [9]. LED lightbulbs were also the selected lighting system for the QSU house in Oman since it proved to reduce the lighting load of the house from 4-7W/m² for conventional fluorescent lamps to 1.6-2.7W/m² using LEDs [5].

3.1.3. Occupant's behavior

In addition to passive and active strategies, it has been stated by different authors [22], [23] that occupant's practices have an important influence on the energy consumption of buildings. Consequently, researchers as Ahadzie [24] and Ohueri [25] have studied how can occupant's behavior impact on the energy efficiency of buildings in the tropical region. Ahadzie conducted a correlational research based on surveys and questionnaires to identify occupant's practices that lead to efficient use of energy regarding ACS. In this study, 172 users of three major institutional buildings in Ghana were surveyed through a questionnaire for a hypothesis-testing approach on the relationship between the efficient use of air conditioners (EUAC) and four behavioral attitudes (i.e switching off the AC when leaving the room, opening windows for natural ventilation, switching on fans as an alternative for ACs, and the use of light or heavy clothes). Results showed that all

behaviors have a positive impact on achieving EUAC. Nevertheless, the practice with more relation to it, with a coefficient path of 0.527, is switching on fans as an alternative to AC, followed by opening windows for natural ventilation (0.351), wearing light or heavy clothes (0.174) and switching off ACs when leaving the room (0.146) [24].

On this subject, Ohueri conducted a mixed quantitative and qualitative study which consisted of surveying 53 green building's occupants in Malaysia in order to determine energy efficient practices for green building occupants to reduce their consumed energy. The purpose of the questionnaires was to investigate how can occupants adjust heating and cooling units on their workspace and how many occupants apply this and other specific techniques, such as dressing to manage comfort, obey organizational polices, opt for natural light when possible, and turn off appliances when leaving the office to achieve energy efficiency in the building. The data collected from the questionnaires was then triangled with the results of an interview made to five experts with the purpose of investigating the influence of the occupant's behavior practices on the energy consumption in the building. The energy efficiency (EE) practices developed for occupants consisted in implementing and evaluating an action plan by individuals who are most likely to achieve energy conservation, monitor and control energy consumption through building energy monitor and advance sensor control systems and provide occupants with all the necessary information about EE practices including regular training, workshops and incentives since the experts concluded that the first obstacle to achieve energy efficiency in green buildings is the lack of information and training given to the occupants on how to use the sustainable features integrated in the building [25].

3.1.4. Water savings

Water is a vital natural resource for the survival of species. Nevertheless, factor such as human intervention, climate change, population growth, etc., threaten the abundance of water available for consumption [26]. This has led to research on how to reduce water demand in different sectors, including construction and building sectors. One of the most common strategies to minimize

water consumption in buildings is to recycle water from bathroom sinks and shower. This is the case of a Positive Energy House (PEH) in Queensland, Australia, which manages to recycle 197 liters of water per day and use it for flushing and gardening purposes. This PEH also replaced conventional dishwashers and washing machines for water-efficient ones. These are usually equipped with sensors and controllers in a way that the quantity of the water used and/or the washing cycle duration can be adjusted according to the numbers of

dishes or the washing load. Applying the mentioned techniques, the housed managed to achieve an energy reduction of 220Wh/day on sewage treatment and reticulation of water [27]. Similar to the PEH, the ZEB in Singapore also implemented water-saving strategies such as efficient water systems, which were monitored through water sub-meters, achieving a total amount of 3,620,000 liters of water per year [9].

Table 1. Tropical climate countries with experience in experimental studies

Country	Year	Climate type	Type of building	Life cycle phase	Savings interest	Techniques studied	Details of Savings
France	2012 [4]	Aw: Tropical Savanna	University Building	Operation	Energy and Comfort	-Roof insulation -Vegetation surroundings -Natural ventilation -Building orientation -High performance ceiling fans -Solar shading -Efficient lighting and ACS	-
Ghana	2020 [24]	Aw: Tropical Savanna	Office buildings	Operation	Energy	Occupant's behavior	-
India	2017 [7]		Residential building	Operation	Comfort	-Building orientation -Natural ventilation	-
Indonesia	2019 [20]	Af: tropical rainforest		Operation	Energy	-Remote Control extension device	14.31% and a 32.30% regarding standard AC without the extension device
	2020 [13]		Residential Building		Comfort	-Green Roof	-
Malaysia	2014 [15]	Af: tropical rainforest	University Building	Operation	Comfort	-Daylighting	-
	2015 [8]		Office Building		Comfort	-Natural Ventilation -Water Wall -Stack flue	62.22% Thermal comfort
	2017 [19]				Energy	-Solar assisted AC	-
	2017 [17]				Comfort	-Daylighting -Glazing	41% for ECB and 53% for PWD
	2018				Energy	Occupant's behavior	-

	[25]						
	2019 [12]		Residential building		Comfort	-Vegetation Shading	-
Omán	2019 [5]	Bwh tropical and subtropical		Operation	Energy	-Water irrigation -form geometry and natural vent -envelope and shading	-
Singapore	2006 [6]	Af: tropical rainforest	University Building	Operation and Maintenance	Energy	-Daylighting -Natural ventilation -IBMS -Efficient Maintenance Practice	-
	2017 [28]			Energy and Water	-Shading -Low WWR -Low-e glazing -BIPV -Heat and sun pipes -LED lights - Water Efficiency Labelling Scheme	-	
	2018 [9]			Energy and Water	-Green walls and roofs -low-emissivity glass -solar film coating -Shading devices - solar assisted natural ventilation -Energy-efficient Air conditioning and mechanical ventilation -Energy-efficient Lighting -Intelligent BMS (Building management system) -low-emissivity glass -solar film coating -Shading devices - solar assisted natural ventilation -Energy-efficient Air conditioning and mechanical ventilation -Energy-efficient	832kWh chimneys 50kWh, 180kWh and 550kWh respectively ducts and lights 1,250kWh glazing retrofits 64,000kWh Variable speed fan 37,189.6kWh Single coil twin fan 3,410kWh Displacement ventilation Total: passive and active up to 183MWh 3,620,000 liters of water	

						Lighting -Intelligent BMS (Building management system)	
	2019 [29]		Various	Maintenance	-	Green walls	-
Tanzania	2019 [16]	Aw: Tropical Savanna	Institutional Building	Operation	Energy	-Semi-Transparent Photovoltaic Glazing	19% energy
Thailand	2019 [14]	Aw: Tropical Savanna	University Building	Operation	Comfort	-Living walls	-
Trinidad and Tobago	2019 [10]	Am: tropical monsoon	University building	Operation	Energy	-Insulated building envelope and roof system insulation	1.74kWh daytime and 0.754kWh nighttime
	2019 [11]					Wall insulation	35% energy

3.2. Discussion on saving interest and building type according to climate type.

First, a classification of the type of climate has been implemented according to the Köppen climate classification. Af, Aw, and Bwh are the common classification presented in a tropical climate with experimental research experience.

Climate classification is a reference to compare with other countries their experience applying energy-saving, experience, and type of building

in which their experiments were realized. In this sentence, Indonesia, Malaysia, Singapore can be compared. The same applies to France, Ghana, Tanzania, and Thailand. Trinidad and Tobago, Oman, and India presented different classifications which could not be compared.

The major experimental experience has been in Af: tropical rainforest; 12 research has been presented. Three saving strategies were presented in this type of climate.

For office building, experimental research applied energy-saving strategies [19], [25] and comfort assuring strategies [8], [17]. In the case of university, different saving strategies for comfort [15], energy [6], energy and water [9], [28], being University building the only type of building applying two saving strategies together.

Residential buildings showed comfort assuring strategies [12], [13].

According to tropical climate Am: tropical monsoon, two experimental research in university buildings was implemented, both focusing on energy saving [10], [11]. Aw: tropical Savanna applied energy-saving strategies Institutional Building [16] and office [24]. The comfort assuring strategies in this type of climate was applied only in university [14].

Finally, the Bwh: tropical and subtropical presented studies in energy-saving strategies [5].

The comfort assuring strategies are the most common in Af climate. In the case of Am, Aw, and Bwh, they implement energy-saving strategies, as is presented in Figure 2.

3.3. Discussion on saving interest and techniques studies according to building type.

The saving strategies for low consumption have been classified as comfort, energy, and water, for the analysis of this research.

For residential buildings to have comfort savings, even though it is the same type of building, different techniques were applied as a green roof [13], vegetation shading [12], building orientation, and natural ventilation [7]. In the case of university a

daylighting [15] and living walls [14] were used to get comfort savings.

Office building used solar-assisted AC [19], daylighting, and glazing [17], and for occupant behavior [24], [25] proved to use the same technique to reduce the energy consumption.

It appears that energy and comfort [4] or energy and water [9], [28], the combination of the two saving strategies, were only present in University buildings.

According to saving interest (energy, comfort, and water), this research proved that it is possible to apply different techniques to the same type of building and have the saving in which is the interest.

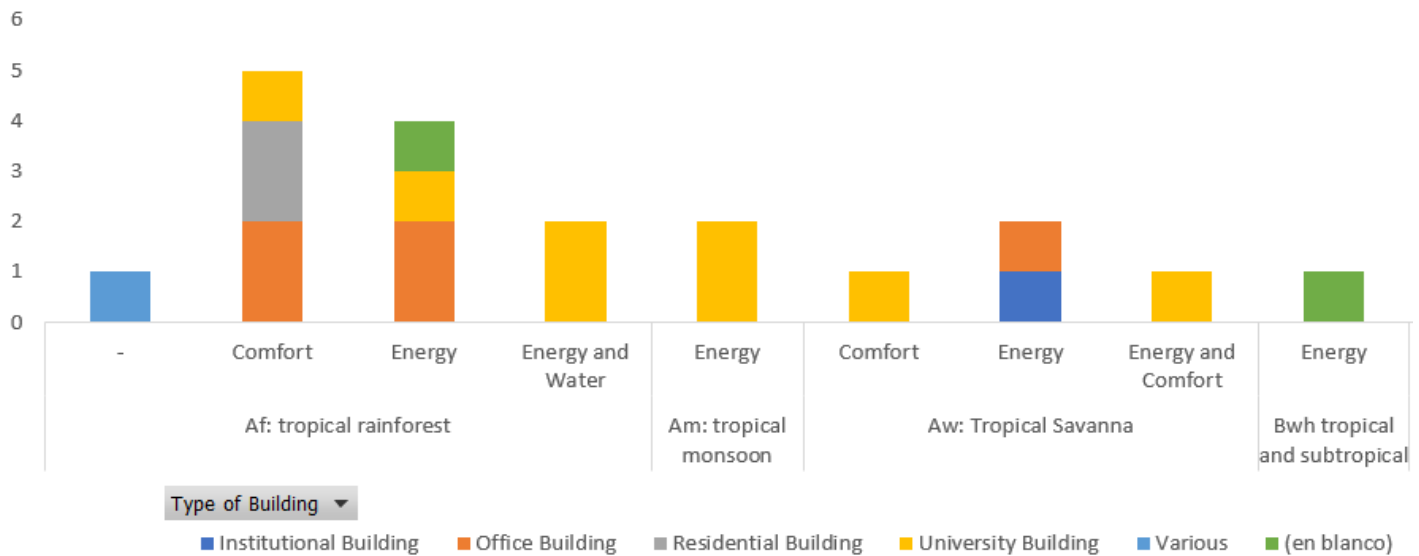


Figure 2. Saving interest and building type according to climate type.

4. Conclusions

Experimental studies are important to validate the information that has been studied. This article gathers the tropical climate countries with experimental experience in buildings. The different techniques applied in tropical climates give a better understanding of the type of building and saving strategies. The advantage of this article is to have in one place the necessary information to compare or to use in future works.

The energy savings values were analyzed, and passive solutions strategies presented the highest percentage of savings in the experimental studies that reported results.

The impact in the scientific community is a resource that can be used for any person interested in experimental studies in a tropical climate, which saves time on looking for the information for low consumption strategies, type of building, and techniques implemented in each country.

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CONFLICTS OF INTEREST

The authors would declare no conflict of interests.

AUTHOR CONTRIBUTIONS AND APPROVAL

Introduction, figures and writing of most of the manuscript by K.C. and M.B. Original concept, formal analysis, and editing by K.C. and M.B. Methodology by K.C. and M.C.A. Supervision and funding by M.C.A. and D.M.

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