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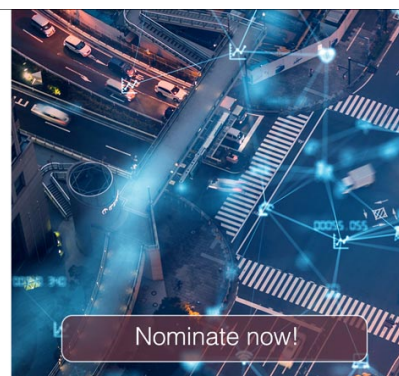


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# Impact of Passive Energy Strategies on Workers Productivity in Tropical Climate

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## Abstract-

Passive building strategies in tropical climates are believed to create thermal comfort, thereby enhancing the productivity of the workforce in office buildings. Very little study, however, exists on the impact of these passive design strategies on the productivity of workers in office buildings. This study presents the results of the study on the impact of passive design strategies on the productivity of workers, taking samples from office buildings in Lagos, Nigeria. Copies of questionnaires were administered to gather the required data. Observation guides were also utilised to document passive design features in the buildings studies. Passive design strategies such as; building orientation and the optimisation of solar and ventilation by the use of shading devices were significant strategies in predicting workers' productivity.

**Keywords:** Design Strategies, Operational Energy, Passive Design, Workers' Productivity, Tropical Climate

## 1. Introduction

Before the advent of active/mechanical cooling and heating technologies, passive or natural methods were used to achieve desired thermal comforts in work environments for higher productivity. However, today more people opt for energy-driven mechanical devices which depend heavily on high energy input in ensuring thermal comfort. These devices generate heat, leading to a rise in atmospheric temperature, especially in tropical climates; increasing the risk of climate change and global warming [1]. This is with the attendant heat radiation from sunlight permeating indoor spaces through openings in the roofs and walls, which causes overheating and gross discomfort in the indoor area. For office buildings, this can be a major cause of low productivity. Globally, research records that 40%-50% of all primary energy usage is in buildings. This is because the housing/building sector is the major user of electricity [2]. Buildings also contribute significantly to the emissions of carbon dioxide [3]. Therefore architects and builders have a big part to play in influencing energy saving in societies since energy usage is fundamentally determined by building orientation, the density of layout, etcetera.

Many countries located within tropical climates often experience daily daytime temperature varying from 24 to 36 degrees as the case may be [4]. Therefore, the installation of mechanical ventilation or air conditioning becomes a necessity to maintain a comfortable indoor space. Conversely, these mechanical appliances, particularly the air conditioning systems, often demands a significant amount of energy (mainly electricity) to operate. The



use of operative energy in cooling houses, specifically air conditioning system is on a consistent rise and most residences leave these systems running all through the night. Indoor thermal discomfort at night happens when buildings are poorly designed and they trap solar gain and heat indoors at day times, leading to heat radiation at night times [5]. As at 2015, 90% of all carbon emissions came from the residential sector in low-income countries and most of these countries are in the tropical climate [3]. Building designs in general, are not responsive to the tropical climate requirements. Offices and buildings are designed in ways that increase dependence on artificial lighting and ventilation for comfort. Furthermore, there is a dramatic increase in energy use in the workplace due to the constantly improving standard of living and also; the hot and humid climatic conditions.

Physiological factors such hot or cold environment affects bodily functions and overall performance. The feeling of discomfort leads to loss of performance due to time taken off tasks to adjust to discomforting situations [3]. For instance, when workers experience the extreme effect of working in hot or cold environments, there would be a physiological strain as individuals exert efforts to maintain productivity. Over time, these environmental conditions would cause excessive pressure resulting in decreased performance in the workplace.

This paper aims at investigating the influence of passive design strategies on the productivity levels of workers. The study is justified on the need to improve building strategies in workplaces in for internal comfort and to improve productivity in the workplace.

Analysing the climate scenario of countries in tropical climates, or having an understanding of the typical thermal behaviour of buildings in this climates is of great importance. To control the amount of heat that permeates a building space; it becomes crucial to know the thermal behaviour of tropical climates. Tropical climates are characterised by high temperatures and high humidity most of the year and peculiarly marked seasonal differences in precipitation [5]. Most of the seasons in tropical climates are generally sunny and hot. Elements that influence the productivity of users include the open-space air temperature, relative airflow and outdoor humidity [4]. Therefore, various building design strategies need to be adopted to facilitate airflow and minimise heat radiation for users' indoor comfort.

Passive design is an architectural term used in describing building designs that are responsive to local climatic conditions to ensure indoor thermal comfort through natural means to last the lengthiest of times [6]. The terminology 'passive' is expressed to reflect a protective or defensive approach of housing designed to shield occupants from local unconducive climate elements. Architecture as a profession has committed in the hands of the architect; the responsibility of creating good building designs to suit fundamental climatic needs [7]. Primarily, countries with hot and humid tropics like those in Africa, are encouraged to adopt passive building designs to avoid indoor heat radiation from the sun; stimulate natural ventilation from dominant wind; and give room for daylight into buildings. Over the years, experts have deliberated on the necessity of passive building design strategies for modern buildings in tropical climates.

From the preceding, it evident that passive building design strategies are essential for various reasons. Having established the importance of energy-efficient building, it is also necessary to examine the basic passive design strategies that can bring about energy efficiency in tropical climates. From an in-depth review of literature, the following has been established as the basic passive design strategies:

*a) Building Orientation*

In making passive building designs, the building orientation is the first criterion to help the developer and architect examine and take advantage of thermal factors such as the sun and prevailing winds. Large fenestration on the west and east should be avoided because the east and the west receive twice the amount of sun irradiation as compared to the north and south sides [8]. The entire building envelope will gain minimum solar heat when the longer axis of the building lies along the east-west direction [5]. However, the amount of possible energy savings in a home through such planning should be stipulated. Figure 1 shows the orientation of solar radiation received from the east, west and south sides of a building.

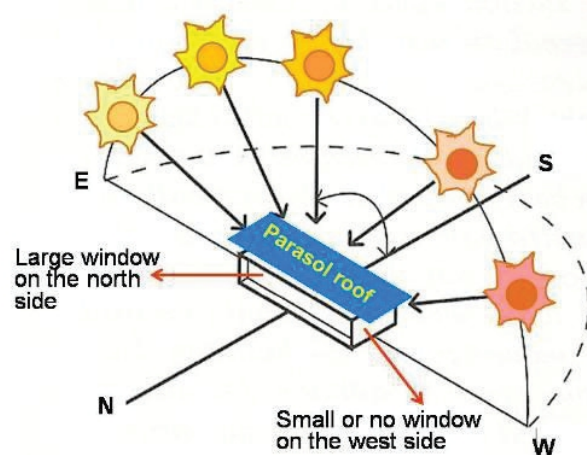


Figure 1. Passive Building Design Strategies for Houses in tropical climates [9]

*b) Windows and Openings for Ventilation*

For cross ventilation in a hot and humid climate, rooms ought to be arranged in a single bank and large windows installed to absorb breeze from prevailing wind [9]. Additionally, small openings could be made near the ceiling level to ensure adequate air circulation and considerably minimise heat gain [9]. Air movement in the indoor area of a building is mostly influenced by the design strategies adopted for a building. The natural airflow in a building increases the rate of the evaporation of bodily heat loss, exchange cool outdoor air for hotter indoor air while satisfying the occupants' needs of fresh air [10].

Furthermore, two forces generate natural air [9]. The first is the difference between the indoors and outdoors temperature (otherwise known as thermal force). When the air in an

indoor space is heated, the air becomes smaller and less dense because it expands and rises. Therefore, if openings are made at varying heights of a building, there will be higher air pressure at the upper opening and lower at the bottom opening. The varying degrees of pressure will inevitably generate an inward flow of air at the lower opening, which releasing an outward flow from the upper openings. This process is called 'stack effect', that is. when there is a release of air from a building through 'thermal forces'. The second is the 'wind pressure force, which is basically the flow of wind against a building. The air in front of a building becomes compressed, creating a pressure zone whenever wind blows against the building. A suction zone is created as wind above the roof and next to the leeward expands, reducing air pressure in a building. The possibility for ventilation is determined when opening are made at the points of the wind driving force or whether air flows through the opening points with wind pressure through lower pressure zones.

Consecutively, through a comparative study carried out in Bangladesh, the quality of indoor air in a naturally ventilated rooms was overtly better than air-conditioned rooms in residential buildings [9]. The levels of carbon dioxide emitted in air-conditioned rooms was consistently higher than rooms with natural ventilation. Also, the study observed that it required forty-eight (48) hours of mechanical cooling to bring the indoor temperature of a contemporary terrace house, into a thermal comfort zone. In comparison, only eight (8) hours of mechanical cooling brought a passive designed building to a desirable thermal comfort zone [9]. The indices indicated a higher percentage of thermal comfort in naturally ventilated rooms with just fans in comparison with air-conditioned rooms which are often substantively over cooled; and leaving many users with sick building syndrome (SBS).

### *c) Shading Devices*

Many buildings in tropical climates suffer the prominent problem of overheating due to solar radiation, especially at day time. The best form of shading from the sun for countries in tropical climates; are projected canopies at the top of the east and west windows and extended fins for the windows on the north and south sides [5], [11]. Shading devices ought to be mounted parallel to the sun rays.

There are three categories of shading devices, namely; interior shading, exterior window shade and solar transmittance of finishing materials. Solar transmittance is basically the heat admitting or rejecting the ability of the glazing materials used. For tropical climates, scholars' advice against heat-absorbing glazing [12].

A simulation study was carried out to explore the effect of various alternatives on solar radiation, natural light penetration, solar transmitted heat and energy use [5]. The objective of the study was to evaluate and compare the effect of horizontal shading devices in the reduction of excessive solar heat gain and observe the level of natural light dissemination into office buildings in Malaysia. Figure 2 shows the dimensions of a single unit room with the following dimensions: height of 2.8 metres, length and depth of 6 metres and a window with the length and height of 4.4 and 1.82 metres respectively.

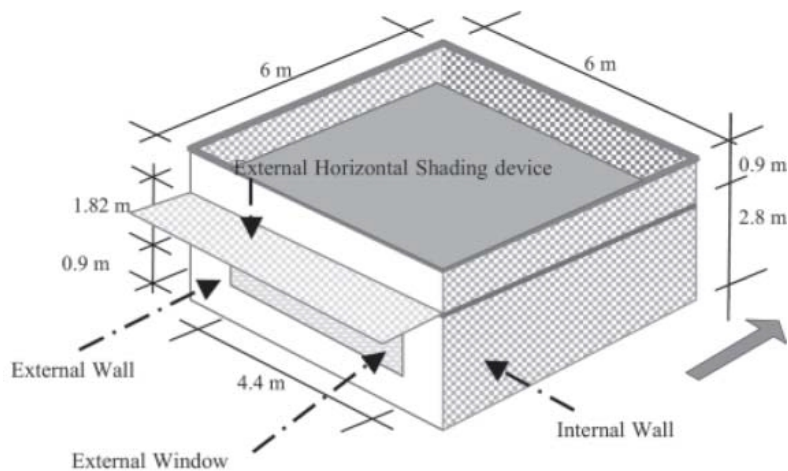


Figure 2. Overhang Design [9]

The main variable in this study was the depth of the external horizontal overhang and its ability to shade and prevent solar radiation and terminate solar heat gain [5]. It was established that in hot and humid climates; considering the trade-off between natural light penetration and solar heat gain, external solar shading gave optimum results for energy efficiency.

#### *d) Roof and Wall Insulation*

Heat gain in tropical countries comes mostly from the top of the building therefore, it becomes essential to insulate the roof properly [9]. Air is the best insulator as in roofs pitched with raised ridges (jack roof); which has been known to cause stack effect [13]. Also, to encourage the release of hot air and cross-ventilation, roofs with air gaps (parasol roof) is recommended.

Many countries with tropical climates are third world countries which are plagued with constant power disruption and load shedding amid hot and humid climatic conditions [15]. This makes living conditions of people in highly populated cities very unbearable. Time used to manage this unbearable live-in condition cuts deep into the productive time of occupants/users. These conditions are getting worse over time due to the ever-increasing population, industrialisation, increased emission of carbon dioxide, leading to climate change. Due to the worsening load sharing situation, excessive heat radiation has driven many people to depend on operational energy for cooling and heating at homes and offices. The cost of energy has risen due to a rise in demand, and countries in the tropical region have been experiencing a shortfall in generating electricity [15], [16].

When various passive buildings strategies are adopted, it facilitates airflow and comfort which enhances productivity as it has been observed that when there is little or no airflow, productivity is barely at 44% in humid climates. Airflow of just about 0.7m/s can increase

users' productivity by a 100% [7], [16]. The benefits of passive building strategies cannot be overemphasised both to the users and architects. Improved energy efficacy through passive building design impact users in several ways but to mention a few:

- i. Minimal emissions of carbon dioxide emissions from operational energy usage
- ii. Improved thermal comfort for workers
- iii. Improved indoor air quality
- iv. Reduced cost of energy to users through reduced electricity bills
- v. Security of energy supply
- vi. Cheaper than operational energy
- vii. Positive contribution to climate change strategies through reduction of total societal energy usage.

Constant pressure from building owners to design multi-unit buildings that maximise space utilisation (that is, more rooms per unit/flat). The quest for excellent economic projects poses a significant limitation to the attainment passive building strategies [16], [18].

Energy-efficient buildings offer the best habitual environment for building occupants and minimises the cost of energy. Passive building strategies aim to improve the comfort levels of users and boost productivity while reducing energy use from electricity, natural gas, and other energy sources [20].

Human performance has been studied extensively. Particularly it has been noted that hot and cold environments affect physiological mechanisms. In an office environment, more extreme effects should be negated by the heating system, as some occupants will likely experience over-arousal and some level of discomfort when they feel either too warm or too cold [13]. This discomfort can result in a decline in performance due to the time wasted on adjusting the controls for heating, for instance. The same can happen in warm environments. Vasodilation allows for easy body movement when the human body is hot. However, sweating could compromise grip and distraction may result from physiological strain and over-arousal as the body temperature increases, especially in mostly inactive individuals. Mental and psychological stress may likewise be a factor if the individual applies exertion to keep up productivity regardless of natural conditions; after some time, this will cause exhaustion and result in a decrement in performance. The degree to which the above responses will affect movement and execution will rely on the errand being performed and the individual.

Following the foregoing discussion, it can be deduced that natural conditions can interfere with the activities of humans, increasing or reducing productivity and influencing the execution of tasks. In this regard, it is, therefore, an excellent option to build up a model of human performance that is rational and can be utilised in researching the impacts of various thermal conditions [21]. This would consolidate applicable and relevant factors and determine the impact they have on an individuals performance.

Studies provide substantial evidence to demonstrate that environmental factors affect the performance of workers [22]. The results gathered from the studies disclosed that the overall consensus is that prime conditions for comfort are very well suited for performance, even though short-term exposure to discomfort can cause improvement in the performance of

simple tasks. Relevant factors that were identified comprised: job satisfaction, motivation, engagement, perceived temperature, noise, lighting, and air quality and space layout. Motivation and the impact of space layout are psychological factors that can be hard to measure, but all the other factors can be measured and assessed based on their impact.

Numerous studies have linked environmental variables to productivity. Insight into the ways productivity might be affected by air temperature was provided by twenty-four (24) different studies, and this is based on the measurements of task performance at various activities [23]. Statistical investigation of the results of these studies yielded the following relationship between relative productivity and air temperature.

Daylighting has also been reported to increase productivity, although a quantitative effect has not been discovered[24]. Daylight results in higher indoor illuminance than is achieved typically with artificial lighting. Even though higher illuminance may enhance productivity, there seem to be added advantages of daylight over mechanical or artificial light. A close relationship exists between productivity and indoor environmental quality (heat, cold, noise, light, etc.). Workers can maintain their performance by exerting more effort when there's an increase in workload demand when experiencing thermal discomfort [25]. This, however, calls for conscious effort and can allow for lower motivation to tasks and work. Motivation is a known factor in improving productivity. Workers who are dissatisfied with the working environment might exhibit reduced productivity for psychological reasons rather than physiological ones. These factors all influence the performance of individuals, although a number of them are not easily quantifiable

## **2. Methodology**

As earlier stated, the main objectives of this study were to assess the extent to which passive energy strategies are adopted in office buildings and evaluate the influence they have on workers productivity. To achieve this goal, this study adopted the mixed research method; therefore, the data used in this study were both qualitative and quantitative. Descriptive statistics were used to analyse the quantitative data. These analyses were presented using tables, and photographic content from the cases studied, to accurately describe the strategies adopted. Four workplace environments (sample size) were visited and observed according to a guide based on the research focus. Copies of questionnaires were administered personally as the research instrument and data were collated to survey workers' productivity in Lagos, Nigeria between November and December 2019. The respondents were required to answer questions that were related to their productivity in their workplace on a five point likert scale. Data on passive design strategies were obtained through observation guides.

## **3. Results and discussions**

The aim of this study was to examine the passive building designs adopted by these selected buildings to measure how these strategies impact on workers' productivity. The assessment



of workers' productivity was carried out by investigating the perception of users of four selected office buildings in Lagos, Nigeria.

The study found that more of the respondents indicated that they were satisfied with their work environment (63.8%) and job (68%). The case was however slight different with their perception of their motivation, with only 41.5% of the respondents indicating that they were motivated. Just about half of the respondents however indicated that they were productive on the overall.

**Table 1: Respondents' Job satisfaction**

	Frequency	Percent
Not satisfied	4	4.3
Undecided	23	24.5
Satisfied	46	48.9
Highly satisfied	18	19.1
Missing	3	3.2
	94	100.0

**Table 2: Respondents' motivation**

	Frequency	Percent
Not motivated	18	19.1
Undecided	32	34.0
Motivated	31	33.0
Highly motivated	8	8.5
Missing	5	5.3
	94	100.0

**Table 3: Respondents' work environment**

	Frequency	Percent
Not satisfied	8	8.5
Undecided	19	20.2
Satisfied	49	52.1
Highly satisfied	11	11.7
Missing	7	7.4
	94	100.0

**Table 4: Respondents' total productivity**

	Frequency	Percent
Not productive	5	5.3
Undecided	24	25.5

Productive	47	50.0
Highly productive	8	8.5
Missing	10	10.6
	94	100.0

As part of the objectives of this study, the extent to which passive energy strategies are adopted in these buildings were to be assessed. From the case studies observed, the strategies most considered include building orientation, building shape, building mass, considerations in landscaping, window choices, solar shading, planning of spaces, buffer spaces, and air and moisture tightness.

Four regression analyses were carried out to find out the passive design strategies that influenced the different dimensions of workers' productivity investigated. The dependent variables were job satisfaction, motivation, satisfaction with work environment and overall productivity. The independent variables were the passive energy strategies adopted in the office buildings.

The results in Table 5 show that passive design strategies were significant in predicting job satisfaction ( $F=1.849$ , Sig change=0.020,  $R^2=0.524$ ), satisfaction with work environment ( $F=2.338$ , Sig change=0.002,  $R^2=0.582$ ) and total productivity ( $F=2.889$ , Sig change=0.000,  $R^2=0.633$ ). These strategies were however not significant in predicting motivation ( $F=1.608$ , Sig change=0.056,  $R^2=0.490$ ) of the respondents. Building massing was the strongest predictor of both job satisfaction ( $\beta = 0.852$ ) and total productivity ( $\beta = 0.688$ ). A closer look at the data revealed that respondents who worked in offices with thick building mass were less satisfied with their jobs and less productive than their counterparts who worked in offices with slender mass. Other passive strategy variables that predicted job satisfaction were solar shading ( $\beta = 0.624$ ), site orientation ( $\beta = 0.567$ ), building shape ( $\beta = 0.526$ ), and provision of buffer spaces ( $\beta = -0.493$ ). In particular, while respondents who worked in offices with curved shapes ( $\beta = 0.526$ ), where the longest side of the building faced the south axis ( $\beta = 0.567$ ), and solar shading ( $\beta = 0.624$ ) and buffer spaces ( $\beta = -0.493$ ) were available were more satisfied with their jobs than those without these provisions. Similarly, respondents who indicated that their offices has solar shading ( $\beta = 0.488$ ) and buffer spaces ( $\beta = -0.468$ ) also indicated higher overall productivity than those whose office buildings did not have these provisions. The only variable that predicted satisfaction with work environment was availability of buffer spaces ( $\beta = -0.294$ ) in the office buildings in the sample.

**Table 5: Coefficients for dependent variable**

	Job satisfaction (Standardised Beta)	Motivation (Standardised Beta)	Work environment (Standardised Beta)	Total productivity (Standardised Beta)
<b>F</b>	1.849	1.608	2.338	2.889
<b>Sig</b>	0.020	0.056	0.002	0.000
<b>R<sup>2</sup></b>	0.524	0.490	0.582	0.633
Number of floors	.055	-.186	.215	.031

Site Orientation	.567*	.064	.123	.209
Building Shape	.526*	.148	.121	.207
Building Massing	.852*	.669	.237	.688*
Provision of Buffer Spaces	-.493*	-.332	-.294*	-.468*
Windows	.067	.300	-.008	.167
Provision of Solar shading	.624*	.464	.110	.488*
Passive Heating [Spaces such as water containers are used to collect and store heat]	.075	.139	.215	.221
Passive Heating [Glazed windows are used to collect solar energy]	-.125	.149	-.179	-.058
Passive Heating [Thermal(Concrete) walls are used to absorb and store heat]	.087	.113	-.078	-.046
Passive Heating [The floors used (such as concrete or brick) are able to absorb and store heat]	-.104	-.013	.158	.143
Passive Heating [Roof pond systems (Water collector) are used to absorb and transfer heat]	-.089	-.284	-.252	-.212
Passive Heating [There are thermal collectors on the building facade]	-.054	.141	-.021	.058
Passive Heating [Are there openable vents in the wall for convection of heat?]	-.069	-.209	-.215	-.236*
Passive Heating [Fans are used to transmit heat]	.262	.068	-.048	.070
Passive Heating [Ducts are used to transmit heat]	.019	.099	.291	.199

Passive Heating [Blowers are used to transmit heat]	-.021	.045	-.033	.109
Passive Cooling [The site design encourages passive cooling in the building]	-.189	-.185	-.058	-.169
Passive Cooling [The site orientation encourages passive cooling]	.203	-.094	-.025	-.007
Passive Cooling [The placement of openings encourages passive cooling]	-.149	-.157	.085	-.086
Passive Cooling [The building form and layout encourages passive cooling]	.210	.093	-.162	.046
Passive Cooling [Green roofs is a strategy used to enhance passive cooling]	-.076	-.065	.258	-.096
Passive Cooling [Double glazing is a strategy used to enhance passive cooling]	-.215	.368	-.004	.157
Daylighting [Daylighting is optimized in this building]	.228	-.041	.157	.109
Daylighting [I have control over the amount of natural light that enters the space]	.108	-.118	.206	-.030
Daylighting [The building receives sufficient natural light]	-.031	.192	.054	.064
Daylighting [There is adequate solar shading provided for the building]	-.072	.125	.077	.070
Daylighting [The	.000	-.179	.038	-.054

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building doesn't get uncomfortable when there is no artificial energy supply]				
Daylighting [Space planning in the building takes advantage of the buildings natural thermal response]	.169	.166	.148	.182
Daylighting [There are buffer spaces provided to reduce heat loss between the exterior and interior spaces]	-.206	-.093	.191	-.114
Daylighting [There are circulation spaces such as corridors and entryways that act as sunspaces and trap solar heat]	.074	-.184	.016	.009
Ventilation [The movement of air allows for sufficient ventilation in the building]	.237	.111	.133	.212
Ventilation [There are enough openings that enhance ventilation]	-.197	.128	.130	.156
Ventilation [The ventilation affects thermal comfort and the indoor air quality in the space]	.155	-.026	-.150	-.001

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- Significant at  $p < 0.05$

The findings suggest that building orientation and window types are influential in the productivity of workers as discussed in the literature but the most influential strategies on the productivity of workers are the building mass, provision of buffer spaces, orientation of building on the site and the provision of solar shading.

The orientation of the building is very key especially in the tropics as a building's orientation affects the amount of sunlight it can receive. South-facing windows capture desirable sunlight when the sun angle is low, which is ideal for passive solar heating during the. Care should be taken when windows are placed at the east and west facades since they receive the second largest amount of solar radiation. The orientation of a building can affect

other factors like solar shading choice, window to wall ratio, positioning of window, performance of window and exterior color choice.

Solar shading could be on the exterior, interior or in the transmittance properties of materials. The most popular in the topics is projected canopies at the top of the east and west windows due to the extent of heat gain and extended fins on the windows facing the north and south axis. Shading devices ought to be mounted parallel to the sun rays [5].

Buffer spaces, located around a building's perimeter help to improve a building's energy performance by increasing the external temperature range in which thermal comfort can be maintained while being energy efficient. South and west buffer spaces act as solar collectors or sunspaces and trap solar heat gain. The careful and conscious design of sunspaces such as circulation spaces, corridors, and entryways is crucial

Building mass which is revealed from the findings to be the most significant factor on productivity have the greatest potential to reduce a building's energy consumption. Thin-high towers with high area to volume are usually preferred to a compact shapes as they affect the space planning and allow spaces receive more natural light, allowing for an advantage due to their slender nature.

#### 4. Conclusions

Passive design strategies, when appropriately designed, have positive impressions on the psychological and physiological health of occupants'. For instance, better access to natural daylight has been reported to cause a decrease in eye-strain, fatigue and headaches, and an increase in general well-being. There are numerous benefits to natural light and access to views which include enhanced mood, reduced stress, improved morale, and a reduction in symptoms from Seasonal Affective Disorder (SAD) [15].

Active energy designed houses do not respond adequately with tropical climates. Hence, this pattern of housing designs has continued to inflict severe thermal discomfort to occupants; pushing them toward adaption through dependence high-cost operational energy for ventilation and cooling. This has impaired the productivity of many nations workforce.

This paper recommends the enforcements and adoption of passive building design strategies for workplaces by builders in tropical climates for the sake of workers' comfort and productivity. Passive building orientation is proven to be an exceptional tool in the improvement of indoor thermal comfort and increasing productivity. The findings show that environmental conditions affect workers' activities, interferes with their ability to accomplish task and influences the overall level of productivity. Also, this study recommends establishing a rational model of human performance that can investigate the impact on different thermal climate, which would be relevant in determining their effect on human performance.

The energy-saving benefit offered by passive building strategies is at a significant rate of 80%, clearly demonstrating the environmental perspective of passive design strategies on

workers, in comparison to conventional active building designs. However, further studies should be done to assess the marketability of passive design buildings to assert its effectiveness. Until then, this paper projects the direct and indirect environmental and economic benefits of passive building designs on workers' productivity.

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