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Thermal Impacts of the Internal Courtyards in Compound Houses: The Case of Tamale Metropolis

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ABSTRACT

The research seeks to understand the effects of internal courtyards on thermal comfort conditions in compound houses in Ghana's Tamale Metropolitan area. Internal courtyards are an integral part of the design of compound houses in this location.

Their inclusion in building designs is largely as a point of domestic activity such as cooking and cleaning and also for social interaction. However, a lot of interchanges in thermal conditions between structures and the outdoors take place within these internal courtyards. Various design details of the building will engender different thermal responses of the internal courtyard. This paper assesses thermal comfort in compound houses as against bungalow type houses in the Tamale Metropolis, Ghana by the application of the Predicted Percentage of Dissatisfied Persons (PPD) and Predicted Mean Votes (PMV) model. This prototype compares with the International Standards Organization (ISO) 7730 and American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 55 (estimated values between 23˚C - 26˚C seen as the allowable temperatures). Ambient indoor conditions (dry bulb temperature and relative humidity) of five (5) buildings each from the two building typologies from were recorded over a period of ten calendar months. These ambient conditions were analyzed, consequently generating the Predicted Percentage of Dissatisfied Persons (PPD) and Predicted Mean Votes (PMV) recordings. The investigations uncovered relatively high PPD - PMV recordings relating to the Bungalow type buildings while the compound houses attune to the comfort zone. The Actual Mean Votes (AMV) of residents suggests the two building typologies are all rated comfortable however; the compound houses are rated above the bungalow type houses.

1. Introduction

Global climate change has heightened awareness on the need to minimize the use of CO_2 emitting energy sources. The need therefore for the usage of passive tactics for the mitigation interior environments as a way of improving comfort conditions is pertinent [1]. The Guinea Savannah climate is noted for high daily mean temperatures leading

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to building interiors heating up to uncomfortable levels due to solar penetration. Compound houses as one of the most common typologies of domestic dwellings in Tamale are not spared of this menace. The use of unsuitable building materials coupled with design and fenestration issues render these houses thermally uncomfortable. Bioclimatic design strategies have been studied and practiced widely [2]. Amongst these strategies are the inclusion of courtyards within houses so as to introduce outdoor conditions into the core of these structures to optimize climatic conditions. Incident radiation from the sun hitting walls and planes in the courtyard will influence the effective heat capacity of these structures particularly in spaces that adjoin the courtyard. Factors such as weather conditions, seasons and the courtyard's disposition of buildings with internal courtyards have been widely studied. Examples can be found in [3,4]. However most studies usually evaluate different building typologies other than the compound house.

It is the stated intention of this work to examine the effects and efficacy of internal courtyards on the effective heat capacity of compound houses in Tamale, Ghana. The research will also contribute significantly to the effective utilization of internal courtyards in building design to ensure thermal comfort with minimal energy consumption and hence reduced CO_2 emissions mostly from the fossil fuel sources used to power these buildings.

2. The Area of Study

The Tamale Metropolitan Area is Ghana denotes the geographical and administrative boundaries of the provincial capital of the Northern region. It has a total population of 371,351 and 922 km^2 land area [5].

The region comprises of twenty seven (27) districts. Situated centrally in the region, the Tamale metropolis shares borders with to the south-west by Central Gonja, to the east by Mion, to the south by East Gonja and to the west and north by the Sagnarigu districts. The Metropolis has total estimated land size of 64,690,180 sqkm. The area strides longitudes 0º 36 and 0º 57 west and latitude 9º16 and 9º 34 north [6].

Amidst an equatorial climate, the Metropolis stands at 195m above sea level. There are two seasons in a year: the rainy (from April to September) and the dry seasons (from October to March). In the course of the latter season, (Mid November to end of January) dry winds from the Sahara blow across the region. In Tamale, the average annual temperature is 27.9 °C / 82.2 °F. Annual precipitation records about 1111 mm / 43.7 inches. The month of September usually records the most the humidity, while the least humid month is December. A recorded percentage of 47.0% represents the mean annual relative humidity. The windiest portions of the year spans eight months, from December to August, with speeds of averaging higher than 6.1 miles per hour [7].

The Tamale Metropolis has an aggregate housing stock of 19,387. This takes up 7.5% of the whole count of dwellings in the region while 35,408 is the total sum of households. On the average a 6.3 household size pertains in the metropolis, this is below the 7.8 recorded for the region. The compound house constitutes the highest portion of residential buildings in the area at 80.6% of the total. The next is the detached house type which stands at 7.5% followed by semi-detached houses at 3.4%. Traditional huts comprising a number of small units made into a compound stands at 4.3% while Apartments or Flats comprise 2.1%. Kith and kin own approximately 55% of residential dwellings in the area. This individual proprietorship of houses recorded at 57.1% is greater in houses with male heads compared to 47.1% houses headed by females. The least value of 2.9% is owned by Government and Public institutions [5].

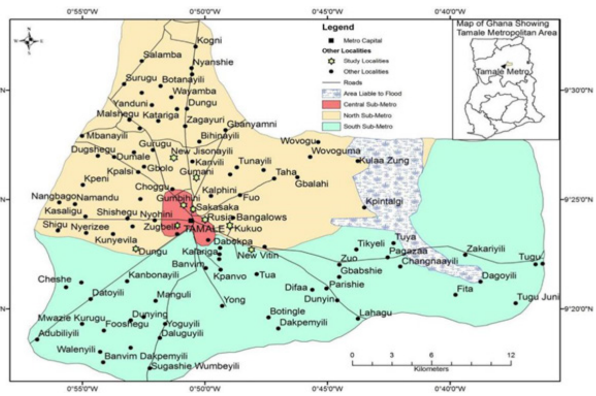

Figure 1. Delineation of the Tamale Metropolis.

Source: [8]

3. Statement of Problem

Recently, majority of buildings in Tamale and Ghana in general have increasingly adopted the use of glass for openings such as doors and windows. This exposes the facades to the high day time temperatures contributing to uncomfortable ambient conditions inside the interiors. With the purpose to reduce the undesirable effects of this vulnerability, builders and users of facilities have resorted to the application of mostly mechanical ventilation and air conditioning systems. The attendant problems such as high energy consumption and greater emission of Carbon dioxide (CO_2) from mostly fossil fuel sources. It is therefore imperative to engage alternative means including passive design to ameliorate this situation.

4. Purpose of Study

The purpose of this study includes:

•Appraisal of the internal and external thermal comfort conditions of some chosen compound and bungalow type residential dwellings;

•To analogize the Actual Mean Votes (AMV) with the Predicted Mean Votes (PMV) among occupants of these chosen buildings.

5. Conceptual Framework and Literature Review

Energy efficiency is increasingly gaining priority as energy consumption from fossil fuel sources has become a serious concern [9]. Domestic buildings in the Tamale metropolitan area will record rising energy consumption as a consequence rising population and income. Consequently, this has generated increased momentum with regards to uncovering potent approaches and consciousness to low energy buildings. Generally, the use of artificial lighting in buildings is deemed to be a major source of consumption of total energy production as it leads to higher heating and cooling loads of buildings [10]. It is reckoned that artificial lighting takes up between 25% - 40% of total energy usage [11].

More research findings reveal that immense gains can be made in enhancing building energy efficiency by the addition of internal courtyards into buildings. They act not only as daylight- enhancers but also bring in ample ventilation into interior spaces consequently minimizing the need for HVAC systems. As a result of this, all dimensions of the courtyards in buildings (i.e. distribution, position, form and size, altitude, shading devices etc.) need to be thoroughly deliberated at the initial design stage. Inadequate design could result in difficulties in the control of ambient conditions such as temperature and glare.

Over the last decades, achievements have been made in creating conducive environments for all kinds of activities. The main ones being the creation of environment to sustain ambient comfort conditions for users of buildings because they directly impact health, productivity and morale.

Additionally, [9] posits that thermal comfort is realized when a thermal balance is attained: a condition whereby heat storage does not occur in the substance. Though it can be attained over a wide spectrum of parameters, it is also attributed to conditions to which substances easily adapt to. [12] describes thermal comfort as the state of the mind that expresses satisfaction with the surrounding environment. Criterion like the ASHRAE Standard 55 and ISO Standard 7730, [13] has formed the foundation for evaluation of thermal comfort conditions by a greater proportion of experts.

However, different climatic zones, present different comfort conditions for human beings: a situation which may differ vastly from this set global criterion.

Four key elements including relative humidity, mean radiant temperature, dry bulb temperature and air velocity exert immense influence on the determination of thermal comfort conditions. There are also two additional personal elements; (insulation/ clothing index and exercise).

The stipulations of the criterion of thermal comfort by ISO 7730 are among the pioneering works that have received worldwide attention [14]. This forms the basis of Fanger's investigations using Danish students in climate controlled chamber experiments. This later gave rise to the development PMV model.

The hot and dry guinea savannah region of Tamale can be classified into the most challenging climate to mould through design. This is as a result of high outdoor temperatures and fluctuating humidity conditions. Indoor temperatures can rise very high above the ASHRAE comfort ceiling of 26˚C in summer. The desired result for comfort is that which enables up to 90% of residents/users feel ambient comfort for most part of the year [15].

The Fanger-based criterion, which is otherwise referred to as the heat-balance method, was initiated through investigations in climate controlled enclosures later resulting into the PPD – PMV prototype. It was first mooted by Fanger in the 1970s.Working together with 1296 student participants' draped in systemized clothing. These participants were made to go through regulated tasks comparable to metabolic rates of around 1.2 Mets or 70 W/m^2.

This criterion (Predicted Mean Vote PMV) has since been used as part of global standards in the prediction of comfort conditions of residents/users of buildings. It is said to be extensively applied by architectural scientist and researchers to assess indoor comfort conditions [25]. The PMV criterion employs the four comfort conditions of relative humidity (%), air velocity (m/s), mean radiant temperature (˚C), air temperature (˚C). Another pair of personal variables i.e. clothing index (Clo) and metabolic rate (Met) are also applied. The computation of these parameters forms an index that is useful in the prediction of comfort conditions in spaces. This index furnishes scores that align with the ASHRAE 'thermal sensation scale'. It constitutes the average thermal sensation experienced by users [16].

Table 1 shows the seven point 'ASHRAE thermal sensation scale'. On the whole, field studies in comfort conditions [16] have reckoned the PMV template does inadequately forecast real thermal sensation of occupants from time to time. Errors in mensuration and circumstantial suppositions mostly account for the variance.

Table 1. ASHRAE Thermal sensation scale

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

Source: [12]

Thermal comfort researchers have cited factors that can lead to skewed results of the PMV model. These include, mensuration of the physical variables with dependable equipment, clothing indices, exercise, contrasts in individuals, variations in buildings, outdoor conditions, adjustments relating to behavior and psychology adaptation all account for this. The PMV template is considered by most studies as the preferred means of prediction in buildings ventilated by mechanical means [10]. Inconsistences have also been noted between thermal feelings recorded from occupants and the PMV template in naturally ventilated buildings, [28]. Research indicates that thermal sensation of residents or users tends to be either under or over estimated by the PMV. The major criterion of design for thermal comfort is often considered to be air temperature; hence it is essential for occupants' efficacy and welfare [18].

Consequences related to ambient conditions on sensations of thermal comfort have been widely investigated by. Solar ingress by way of external windows makes up to 25% - 28% of the total solar heat gain. The relative positioning and plan formation of buildings have an effect on their ventilation and the radiation bearing potential [19]. To optimize heat gain from the sun and ventilation conditions, buildings need to be positioned such that their elongated ends face the prevailing wind direction to enable them catch these winds, while the short ends are towards incident solar ingress. The desirable effects shading mechanisms on comfort conditions have also been noted by [20].

[24] in Germany have investigated comfort conditions and the satisfaction of users of low energy consumption offices. Their findings indicate that "just right" and "slightly warm" votes falls in line with the baseline temperature of above 27˚C. Also, it was observed that PMV is quite extensive but varied marginally on the sensation scale, contingent on factors such as the nature of the subjective responses of ("slightly warm" "very warm" or "just right"). Other related research undertaken by [20] during the summer season in the United Kingdom observed a 23.9˚C average temperature with 21.6˚C to 26˚C span. −0.25 average PMV recording consistent with a span of −1.6 to 0.5. [11]. Findings from investigations of domestic buildings in London also established temperatures averaging around 23.8˚C.

On the contrary, not enough thermal comfort research has been carried out in Ghana [22-24].

The need therefore to build incrementally on literature in this subject area is pertinent. The impact of thermal comfort and indoor ambient conditions exert significant impact on morale, productiveness and well-being. Consequently the objective of this research to examine the extent of thermal comfort in residential buildings (i.e. compound houses and bungalow type houses) using the PMV-PPD model. In the end, researchers and practitioners in the industry will benefit from the findings and best practices found by the study. This can also help to improve thermal comfort conditions in the buildings under study.

6. Research Methodology

Thermal comfort of residential buildings (i.e. compound houses and bungalow type house) was investigated through quantitative research coupled with questionnaires for the residents of these building. The thermal comfort index (PMV), the foundation of this research is widely accepted to be useable in a particular environmental setting for reasons as follows:

Fanger's investigation is founded on a broad spectrum of climatic parameters, such as a recording of greater than 30˚C for air temperature and a value of up to 70% for relative humidity. PMV values ranging from recordings of −3 noted as cold to +3 noted as hot are acceptable as a moderate thermal environment.

Ten buildings (five compound houses and five bungalow type houses as shown in Table 2) at different locations within the Tamale Metropolis were selected for studies. The selected buildings represent a crossection of recent residential design and building trends within the metropolis.

There were 150 occupants selected from all 10 buildings to participate in the study. All the participants were residents in these buildings. Most of them had lived in the selected houses between time periods ranging from six months to fifteen years. The respondents were made up of 73 females and 77males. The age demographics of respondents were as follows: forty-six (46) persons were in the 25 – 35 age bracket, thirty-nine (39) were below 25 years, forty (40) persons between the ages 36 - 45 years and twenty-five (25) persons over the age of forty-five (45).

Experimental Design

Field investigations were undertaken from the 30th March, 2018 to 28th February, 2019, spanning both the rainy and the dry seasons in the Tamale metropolis.

The respondents' subjective data were gathered through thermal comfort questionnaires. Objective data on the other hand were gathered through HOBO data loggers placed at various points in the living and bedrooms of the buildings to measure ambient conditions. Parameters such as relative humidity levels and indoor temperature were recorded at 30 minute cycles. A sum total of 486,452 datum points was collected and used in the research. The seven stage thermal sensation ranking by ASHRAE was employed to find out respondents' thermal sensation otherwise referred to as Actual Mean Votes (AMV) from them. Subsequently their Actual Mean Votes AMVs are analogized with their Predicted Mean Votes (PMV). Questionnaires also considered how occupants usually dressed around the house (clothing index). Added to this is a thermal insulation of furniture index of (0.1) to the clothing index of each participant.

Lastly, a rate of metabolism of up to 1.2 mets stated in [13] was adopted for occupants for living and bedroom activities.

Onset hobo sensors were employed to record Relative Humidity (R.H) and air temperature (T). The hot wire anemometer was engaged in the measurement of air velocity (A.V). These ambient parameters were recorded from about 1.1 m above the floor level. This aligns with the anthropometric dimension of an occupant in a sitting position. Reliability limits of these instruments used are illustrated in (Table 3).

Table 3. Reliability of measuring instrument

Comfort parameter	Range of measurement	Reliability limit
Relative Humidity (R.H)	From 5% to 95%	± 3%
Air Velocity (AV)	From 0.1 to 25.0 m/s	±5% ±0.1 m/s
Air Temperature (T)	From -20˚C to 70˚C	± 0.4˚C

The Predicted Percentage of Dissatisfied occupants (PPD) as well as the Predicted Mean Vote (PMV) was computed through the (PMV CALC V2) operating system. The processes involved the capture of aggregate values of items including, relative humidity, air velocity and temperatures, clothing index and metabolic rate recordings were loaded onto the operating system.

Subsequently, the outcomes were analyzed and presented in tabular form.

7. Data Analysis

The use of greenline operating system was employed to set up and download data from the instruments used to collect data from the various spaces. Sorting and export of the readings to Microsoft Excel document format constituted the next step. Data files were again sorted and constructed into tables showing month on month readings. Formulae sheets were effectuated to provide mean hourly recordings. The periods of high occupancy in the various houses i.e. from 5:0 am to 9:00 am and from 3:00pm

Table 2. Summary of selected buildings.

Building code	Floor area (m^2)	Location	Orientation	Spaces monitored	Thermal controls	Window type	Usage
CH1	420	Kanvili	North-South	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
CH2	435	Agric. Ridge	North-South	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
CH3	506	Kalpohin	East-West	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
CH4	412	Changli	East- West	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
CH5	409	Nyohini	South-East	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
B1	104	Kanvili	North-South	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
B2	138	Agric Ridge	North-South	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
B3	113	Kalpohin	East-West	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
B4	146	Changli	East-West	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping
B5	129	Nyohini	South-East	Bedrooms, Living rooms	Internal, Manually controlled	Timber framed louvred	Living, dining, sleeping

to 10pm. Descriptive statistics were then employed to analyze generated values.

8. Discussion

The research results are as presented below. They provide insights into the thermal comfort levels of the buildings under study.

Mean outdoor temperature recorded the lowest reading of 25.6˚C (in November) matching with 28% Relative Humidity during the research period. The highest temperature of 36˚C was recorded in March with 56% Relative Humidity. Relative Humidity however peaked in September with a recording up to 70% while the month of December recorded the least value of up to18%. These recordings comprehensively cater for the two main climatic seasons in Tamale, Ghana. The Predicted Percentage of Dissatisfied Persons (PPD) as well as the Predicted Mean Votes (PMV) of residents and the associated is illustrated. The Actual Mean Votes (AMV) of participants was then decided.

The results show that Relative humidity readings average in the compound houses averaged around 58%, 65% and 67% compared to 69%, 73% and 75% in the bungalow type houses.

The subjective feeling of relative humidity is also analyzed. The respondents generally expressed satisfaction with the magnitude of humidity in the houses perhaps as a result of the known fact humidity levels within 6% - 90% show no significant influence on comfort conditions.

As Table 4 illustrates, the compound houses show average air temperatures of (23.4^{o}C- 25.6 ^{o}C) lower than that for the bungalow type houses (27 ^{o}C -30 ^{o}C). The recordings for the former is in tandem with ASHRAE's allowable temperature limits of between 23˚C - 26˚C [12], the latter has higher reading.

However, many studies have stated that the tropics exhibit high comfort temperatures while humans also have the capacity to adapt to different climatic conditions [25]. It has also been reported that a 23.6˚C - 28.6˚C comfort spectrum in Malaysia (an example of Tropical climate) for all typologies of buildings [23].

Table 4 again shows that air velocity for Bungalow type houses falls between 0.2 – 0.48 m/s and 0.9 -1.32 for the compound house type. The average of 0.65 m/s for bungalow type and 1.0m/s for compound houses illustrates better air flow in the compound houses due to the presence of internal courtyards.

In the bungalow type houses, average Predicted Mean Votes recorded up to 1.65 (noted to be warm) which carries 55% Predicted Percentage of Dissatisfied Persons. Meanwhile, the indoor temperature ranged from 27 - 30˚C. These readings are at variance with other studies. Readings of 21.6˚C - 26˚C thus averaging up to 23.9˚C for indoor temperature were recorded in that investigation. The Predicted Mean Votes recorded (−0.25) rendering the bungalow houses hotter (PMV of 1.65).

Conversely, compound houses recorded an average PMV of 0.7 (closer to "just right") which matched up to 39% PPD. At the same time, recorded the indoor temperature were between 2 3.4-25 ˚C.

Factors such as form and orientation, courtyards to enhance cross ventilation, proportions of eaves in the direction of the prevailing winds, lateral walls etc. need to be into account especially for buildings that rely on natural ventilation [23]. Fitting of ceiling and/or wall fans within the buildings can also enable up to a 2˚C

Table 4. Summary of indoor measurements.

Comfort parameter	Unit	CH1	CH2	CH3	CH4	CH5	B1	B2	B3	B4	B5
Average Air temperature (min-max)	˚C	23.9 (24to27.5)	25.6 (23to26.8)	23.4 (23to28)	24 (23.7-28)	23.8 (24to28.6)	27 (24to28.6)	29 (24to30)	30 (26 to32)	29 (25to31)	29.7 (26to32)
Average Relative humidity (min-max)	%	58 (56 to 60)	63 (57 to 66)	59 (58 to 64)	65 (60 to 66)	66 (58 to 67)	67 (58 to 70)	69 (65 to 70)	61(59 to 68)	69 (58 to 70)	68 (64 to 72)
Average Air velocity (min-max)	m/s	1.2 (0.5 to 1.8)	0.9 (0.7 to 1.8)	1.0 (0.85 to 1.9)	1.15 (0.5 to 1.9)	1.32 (0.75 to 2.0)	0.25 (0.2 to 0.75)	0.3 (0.2 to 0.7)	0.2 (0.2 to 0.80)	0.4 (0.3 to 0.85)	0.48 (0.4 to 0.9)
Clothing index	clo	T-shirt, shorts sports clothing and light trousers. Clothing insulation index used (0.57clo).									
Average PMV (min-max	-	0.5(-0.3 to 0.85)	0.65 (0.5 to 1.0)	0.89 (-0.5 to 0.9)	0.8 (0.7 to 1.2)	0.6 (1.0 to 1.9)	1.75 (-0.5 to 1.9)	1.5 (1.0 to 1.8)	1.65 (0.3to1.9)	1.7 (-0.5 to 1.8)	1.65 (-0.5to1.8)
Average PPD (min-max	%	38 (25to45)	44 (55to70)	40 (35-50)	35 (30to50)	39 (45to65)	55 (60to75)	58(50to65)	57(24to40)	49 (40to65)	58 (50to70)
Average AMV(min-max)		-0.85 (-2.5to3)	-0.6 (to2-3)	0.45 (-3-2)	0.65 (-2to1.5)	-0.5 (-3to2.5)	-0.7 (-3to2)	-1.2 (-2to0)	-1.5 (-3to0)	-0.5 (-3to2)	-1.35 (-3to 0)

temperature reduction [23].

The recorded average indoor temperature of the compound houses could also be associated with orientation of the buildings (north-south), wide overhangs, courtyards and in some cases trees as shading.

The slightly warm PMV for the bungalows, is as a result of orientation (in some cases east-west) and the lack of shading, no internal courtyards, some amount of glazing in the fenestration.

PMV computation for the two building types as shown in Table 4 reveals that residents of compound houses reported more desirable comfort conditions. Readings align with the major categories classification of the thermal sensation scale.

Inconsistencies between the PMV and the average AMV in both compound and bungalow type also exist. (Table 4).

It is pertinent to state also that over-prediction of PMV was recorded in the indoor thermal comfort in the both building typologies by around 1.5 scale units. These results are consistent with the findings of other studies [25]. The study noted a divergence of 1.3units in Predicted Mean Votes and Actual Mean Votes. Excesses in the forecast of PMV have also been found by other researchers in related studies [26].

Major causes that could be assigned to the over-prediction of PMV in the present research can be outlined as:

Respondents had the flexibility of use of appliances, building elements and nature itself. These include the use operable louvered windows, standing, wall and ceiling fans, trees and shrubs for shading.

Additionally, the respondents in the buildings mostly go to work during the mornings when temperatures are known to be tolerable Majority of respondents about (78%) remaining at home in the afternoons would usually sit outside in the shade when recorded temperatures are very high.

The other case for the over prediction could also be attributed to respondents acclimatization to the ambient temperature and humidity recordings hence the feedback.

Significant differences inside the internal spaces could have also led to the high value of the PMV compared to Fanger's situation during the climate controlled enclosure investigations. These include use of gadgets for cooking, ironing etc. Individual configuration of spaces and human activity within also plays a critical role. Some respondents who are at locations astride openings may report more comfortable conditions especially in the early hours of the day when openings are not shut. (58.7%) meanwhile respondents located deeper within the spaces reported less comfortable (15.4%).

9. Conclusions

Data analysis and results from the assessment of comfort parameters in compound houses as well as bungalow type buildings presented by this investigation. The purpose of this endeavor was to evaluate thermal comfort levels of in these building typologies juxtaposed against the ASHRAE 55 and ISO 7730 criterion. Fanger's PMV-PPD model was harnessed to investigate ambient comfort levels in the compound and bungalow type houses.

The synthesis of results and further deliberations explicitly shows that the Predicted Percentage of Dissatisfied Persons (PPD) as well as the Predicted Mean Vote framework ably forecasts ambient comfort parameters in these building typologies. Therefore, ambient comfort conditions recorded in these buildings identify properly with the ASHRAE and ISO standards. However some over-prediction issues acknowledged earlier also exist. The compound houses average temperature record of 24.5˚C and 27.5 ˚C bungalow type houses (though higher) conforms to the ASHRAE's 23˚C - 26˚C summer tolerable temperature.

Furthermore, the average of satisfied users/occupants for compound houses of around 88.7% can also be said to align favorably with the International Standards Organization 7730's limits 75%. It is also 90% close to the American Society of Heating Refrigeration and Air conditioning Engineers' recommendation rate of satisfied respondents. This is noted to be at variance with conditions of the bungalow type of 59.8%.

In conclusion, it is imperative to state the limitations of this study; errors in mensuration such as measurement of physical variables with dependable equipment and circumstantial suppositions e.g. clothing indices, exercise, individual idiosyncrasies, variations in buildings, outdoor conditions, adjustments relating to behavior and psychological adaptation could all contribute to some margin of error.

10. Recommendations

It is recommended that adaptive measures should be employed to improve ambient thermal comfort in these buildings. Some of the recommended measures include the incorporation of internal courtyards, shading devices (both natural e.g. trees, shrubs etc. and built forms), orientation to catch prevailing winds and reduce solar ingress and increase size of windows.

Lastly, more research is recommended to establish the dependability of the PMV-PPD in the prediction of ambient thermal sensation within the building typologies used in this study. This will facilitate the development of best practices consequently resulting to efficient design, construction and use of these buildings.

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