

Thermal Comfort Survey of Buildings at the Faculty of Sciences, Yobe State University, Damaturu, Nigeria

Idriss Saidu & Ahmed Ibrahim

Department of Architectural Technology, Mai Aloomo Polytechnic, Geidam

Abubakar Abdullahi & Mohammed H. Mukhtar

Department of Architecture, Ahmadu Bello University, Zaria

ABSTRACT

Three buildings within the Yobe State University (Lecture Hall building, Classroom building and Laboratory building) were assessed on their relationship in being bioclimatic responsive. Bioclimatic design checks building orientations, shading devices, thermal massing, correct number and sizes of openings etc. The buildings were selected according to applying the principles and also to their repeated usage by students and lecturers. The objective is to analyse occupants' subjective feelings about prevailing indoor conditions, a philosophy for which the study needed to be established. The researcher begins by correlating the various conditions that could be manipulated to tame the penetrating influence of thermal discomfort effects to the indoor conditions in hot and dry regions (indoor air temperature, air relative humidity and indoor air velocity). Moreover, the researcher is convinced that truth is not dependent on belief alone but on statements that can be verified through examination and observation of external occurrences. Based on the records of about 40% highest use of **adequately applied principles** (AAP) in design of the three field study buildings, the indoor thermal discomfort in the area were such. It was clearly indicated that the comfort votes was not up to the 80% standard required to be observed in the indoor conditions of all the buildings over the three consecutive days of the survey. Discomfort levels was therefore related to the percentage of missing **adequately applied principles** (AAP) in design of the three field study buildings.

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Corresponding Author's Contact:

Idriss Saidu/08037746544

Email: arcsadcons84@yahoo.com

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1.1 INTRODUCTION

Architecturally, designers take into account the problem of heat in unique ways in order to provide the adequate indoor temperature for buildings. The use of active instruments of thermal control was already discouraged among sustainable designers; therefore the only way is to encourage a design with an in-built 'passive thermal control'. Climate responsive designers dwelt greatly on the use of passive instruments of thermal comfort control to regulate temperature within the building. The factors that determine thermal comfort are the environmental parameters and personal factors. Such designs although have their limitations, and possibly requiring an extra cost at the construction stage,

they turn to use little energy in the overall life span of the building.

According to the American Society Heating Refrigerating and Air Conditioning Engineers Standard Number 55 (ASHRAE) Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment." While the comfort zone is defined as "those indoor conditions that most people in the society feel comfortable." However, the thermal comfort and the comfort zone are both subjective parameters and not absolute values for everyone. Indoor thermal comfort requires regulating heat entry from place to place into the building through conduction, radiation and convection. Hence designers considered the

following correctness: thermal conductivity of building materials as walls, floors and roofs, building orientation, sizes and positions of openings, surface treatments on different building parts and other parameters in order to respond to the issues of thermal comforts since the beginning of 21st century.

Many existing buildings within the Yobe State University Campus like the library, Office Blocks, etc were not designed in favour of passive thermal control measures hence; the conditions of such buildings tend to be negatively affecting the purpose of its design, which is effective and efficient learning. The assessment of thermal

comfort was designed through evaluation of Bioclimatic design principles using checklist to help supplement the auxiliary efforts of active control measures, so that the energy used for cooling and ventilating these buildings is established. The increases on generator fuel price recently due to subsidy removal and coupled with the current instability of electricity in the state.

The ASHRAE research conducted over many years on large numbers of people concluded that there is a range of combined temperatures and humidity that provides comfort to most people (80%). See Figure 1.1.

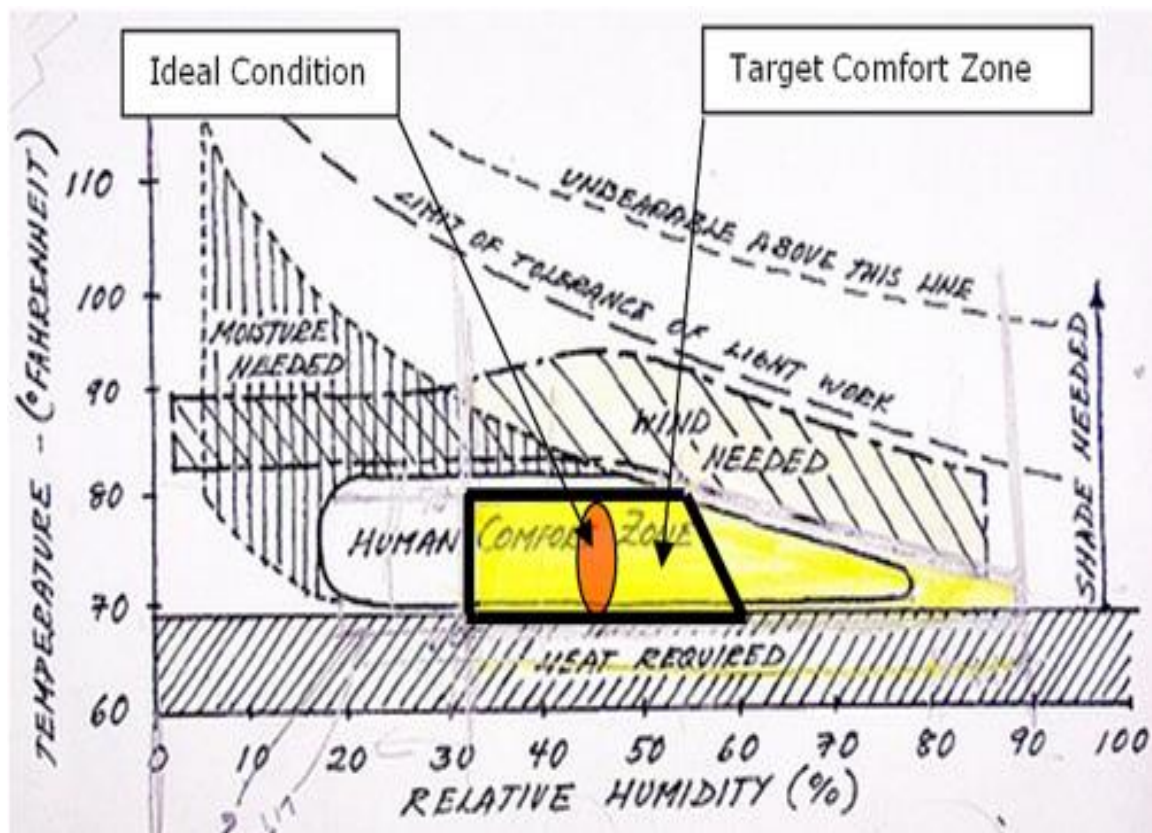


Figure 1.1: An ideal human comfort zone in any climate

Source: ANSI/ASHRAE Standard 55, 2010

Occupational Safety and Health Service (1997) provided a thermal comfort standard for sedentary occupations applicable in any climatic

zone. According to the standard, most people will be thermally comfortable for the following conditions as shown Table 1.1.

Table 1: Standard Conditions for Sedentary Occupations by OSHS - New Zealand, 1997

Conditions	Values	
	Summer/ Rainy Season	Winter/ Dry Cold Season
Air temperature	19-24°C	18-22°C
Relative humidity	(0.12) 40-70%	
Air speed	0.1-0.2 m/s, without creating a draught	
Radiant heat	No direct exposure to a radiant heat source	
Clothing	Light clothing (0.5clo)	Winter clothing (1.0clo)

Based on the above reviews, passive design elements could be assessed as applied differently on the selected buildings in order to attain an acceptable indoor thermal comfort. The research, however, assumes the following conditions to hold in as much as most people (80%) of respondents in the study irrespective of any other differences to be tolerant to the hot dry weather conditions (ANSI/ASHRAE Standard 55 – 2010).

- (27 – 34) °C Indoor Air Temperature
- (25 - 40) % Indoor Air Relative Humidity
- (0.4 – 0.7) m/s Indoor Air Velocity
- Cloth Constant (all wear universal type and culture guided type)
- Metabolic rate (Sedentary Activity)
- Age (18 – 40) years
- Gender (majority are male respondents)
- State of Health (all of them are Normal)
- Cultural expectation to clothing (is generally uniform among respondents)

2.1 The Concept of Thermal Comfort

Buildings located in hot dry areas must adapt the extreme conditions of heat or cold to achieve a-balanced for user comfort with indoor climates (Academia, 2014). The climatic condition of Yobe State (the site) is hot and dry for 6 -8 months of the year. And that the mean temperature for most meteorological stations in the state is about 37°C. The maximum daytime temperature of about 45°C is normally experienced in April, while minimum daytime temperatures of about 30°C are usually recorded in December (Community Portal of Nigeria, 2012). In all the hot dry climates, relative humidity is low, as it drops to about 20RH%

during the day time in these periods. And then there is a marked high wind velocity that drives the heated outdoor air into the indoor. And so remain the dry air moving rapidly enough to create drought conditions (Fislisbach and Zollikon, 1993).

Thermal comfort in school buildings is one of the problems attracting great attention when potential links between building performance, general sustainability, and the benefits of a healthy, productive and comfortable environment are considered. Schools are major energy consumers, due to significant demands for heating and cooling to provide acceptable thermal comfort conditions for inhabitants (Haddad, 2014). A comfortable classroom keeps students focused and alert (American Modular Systems, 2014). The relationship between indoor environmental conditions in general and student achievement is well established.

The study is imperative considering the place of indoor thermal comfort on learning conditions in school setup and the energy implications of maintaining a building by mechanical means. Regulating indoor conditions by mechanical means tends to make maintenance expenditure untenably high as the fuel prices rise coupled with the recent subsidy removal and the current instability of electricity in hot dry area.

2.2 Conceptual Model of Bioclimatic Design

Eventually, the adopted models referenced on the checklist were provided in Handbook on Energy Conscious Buildings by Kumar (2010). The

practical applications of bioclimatic design for the hot dry climate are:

1. Site
 - i. Landform
 - ii. Water bodies
 - iii. Street width and orientation
 - iv. Open spaces and built form
2. Orientation and plan form
3. Building envelope
 - v. Roof
 - vi. Walls
 - vii. Fenestration
 - viii. Colour and textures
 - ix. Special Considerations

2.3 Summary of Reviews and the Gaps

Previous works have been summarised as follows:

1. The principles of bioclimatic design is aimed at achieving the least possible energy consumption concurrently with the provision of thermal and visual comfort for the user of the building (Energy Design Partnership, E.D.P. energy solutions, 2013).
2. In hot-dry region, the objectives of bioclimatic design are the lowering of both daytime and night-time temperatures in and around the buildings as much as possible to the comfort conditions (The Ministry of New and Renewable Energy, MNRE, 2010).
3. Studies were made on the use of six primary factors affecting thermal sensation as either environmental or personal parameters on thermal comfort. These factors are air temperature, mean radiant temperature, air velocity, humidity, metabolic rate and clothing (American Society of Heating Refrigerating and Air Conditioning Engineers, ASHRAE 2007). Research has also shown that other contributing

parameters affect thermal comfort; these include climate change with time, building and its services, and occupants' perception (Nicol and Humphreys 2002, Evans 2003 and Hellwig *et al.* 2006).

4. Thermal comfort in buildings is defined as the state of mind for the building occupants to be satisfied with their indoor thermal environment having desire for neither a warmer nor a cooler condition (Fanger 1970).
5. Studies have also shown that the occupants in the tropic environment have a higher heat tolerance and can adapt to the environment that they are used to (Hussein I., and Rahman M. H. A., 2009).

The gaps are emerging from the following areas:

1. Bioclimatic design assessments were aimed at low energy design, thermal and visual comfort through the use of visual survey and photographing techniques alone without the use of measuring instruments.
2. Thermal comfort assessments previously conducted were not related to bioclimatic designing: Nicol, 1995 in Hussein, 2009 postulated that the best representation of how thermally comfortable a building is depend on the occupant' predictions derived from field studies with questionnaires.
2. Building design was not cognizance of user tolerance to the hot dry weather conditions.
3. The following instruments (visual survey checklist on bioclimatic principles, photographs, measuring instruments and questionnaires) generate bioclimatic response – thermal comfort relationship.

4. The technique of using multiple instruments generate additional data which was not previously presented in the reviews.

3.1 METHODS

The researcher begins by correlating the various conditions attached to all roof forms as the alternatives that could be manipulated to tame the penetrative influence of thermal discomfort to the indoor conditions in hot and dry regions. The objective is to analyze peoples' subjective feelings about prevailing indoor conditions, a philosophy for the study needed to be established. Therefore, the research philosophy adopted was positivism. Positivism recognizes working with an observable social reality and that the end product of such research can be law-like generalizations similar to those produced by the physical and natural scientists. Moreover, the researcher is convinced that truth is not dependent on belief alone but on statements that can be verified through examination and observation of external occurrences.

3.1.1 Research Design

The bioclimatic design studies includes checking orientations, shading devices, thermal massing, correct number and sizes of openings etc.

As the research focuses on establishing a relationship between the Indoor thermal comfort conditions and the applied Bioclimatic Responses on buildings in the study area, it is then important to conduct the study on buildings considered bioclimatic responsive during the driest period where the users find the weather condition to be thermally most uncomfortable.

The field study buildings within the university (Lecture Hall building, Classroom building and Laboratory building) are assessed for the relationship between the bioclimatic responsiveness of buildings and the indoor thermal conditions in the area.

The field studies were carried out on Wednesday, 1st May 2019 – (Day 1), Thursday 2nd May 2019 – (Day 2) and Friday, 3rd May. 2019 – (Day 3). The period of the study is considered the driest and hottest period in the area (Desert Research Center – Damaturu, 2019).

Samples are manageable units drawn from the wider population of the study. The following criteria presented the reason for their selection:

Case study Selection - buildings' selection was based on the following Sampling Criteria:

1. The occupants of the building must be science oriented for easy responses to the thermal comfort questionnaire survey;
2. The buildings must be of the highest occupancy rates within the campus.

Hence, the following buildings were selected according to the above criteria:-

- i. Lecture Hall building (100 seats)
- ii. Classroom building (50 seats)
- iii. Laboratory building (50 seats)

3.2 Data Collection Techniques

In the collection of data for this study, bioclimatic design data in form of checklist is first conducted on each of the three buildings on Day 1 and used in subsequently in conjunction with synchronised surveys throughout Day 1, Day 2 and Day 3. The checklist output is then compared to the synchronized field measurements (with measurements with instruments as well as with questionnaires surveys) conducted simultaneously for up to 3 working days on each of the three buildings.

3.3 Bioclimatic design studies

Appropriate bioclimatic responses for hot-dry climate are coded (P_n) and tabulated from (P₁) up to (P₂₂) numbers. The listing of these principles from 1 - 22 is known as the checklist. There were three assessing scales on each row as were: *Adequately Applied Principles, Inadequately Applied*

Principles and Not Applied Principles and abbreviated cumulatively as (AAPn), (IAPn) and (NAPn). The codes are then interpreted and formed into percentages on a pie chart according to applications. Photographs were graphically an additional data here. (See appendix I for sampled checklist).

3.4 Thermal comfort studies

3.4.1 Field measurement

This is termed as the *Physical measurements* (pM) in this study; morning session is coded (pMm) and afternoon session as (pMa). The field measurement focuses on measuring the three thermal comfort parameters. The equipment used are ANEMOMETER (Model AM-4812) with accuracy of $\pm (2\%+1d)$, 0.1 resolution as well as range of 0.4-30m/s for measuring wind velocity, HYGROMETER (wet and dry bulb) for measuring air relative humidity and THERMOMETER for measuring air temperature respectively. Indoor space was measured each case after calibrating the instruments to the referenced units for the purpose of reliability and

accuracy of read-off values. The average values of the total points of measurements were recorded in the morning and afternoon sessions according to (pMm and pMa) respectively.

Due to the distribution of the effects of thermal variables in the indoor space, six numbers of points were marked within comfort zone for measurement taking at the Chemistry Lab. and Classroom buildings. While eight numbers of points were marked within the occupied zone for measurement taking at the Lecture Hall building. All the readings were taken at a height of 1.0 m above floor level, which represents the height of an occupant at seated level. The maintenance section of the faculty of science building operates between 9 am until 5 pm. It takes about (30 to 40 minutes) to trek between the three measuring points or case study buildings. And therefore readings were taken from 10 am to 5pm daily. The samples were recorded at every 1 hour interval, alternately repeated for all three locations for a total period of 3 days.



Plate I: Measuring instruments (Hygrometer, Anemometer and Thermometer)

Source: Researcher's field studies, 2019

3.4.2 Thermal Comfort Questionnaire Survey

This is termed as *Subjective Assessments* (sM) in the study; morning data are coded sMm and afternoon (sMa). In this, the Faculty Building is occupied by a total of 582 occupants (539 students and 43 staff) as confirmed from the Dean. The faculty management granted permit to the researcher to conduct the study two weeks in advance of the study and consent was obtained for their staff to be involved voluntarily and participate in the survey. Staff participation was encouraging in the study because the needed number took part in the study.

All students who were present on the research days took part. The list of staff and students in the faculty building made up the sampling frame. In light of the time and financial constraints, a 17.2% sample size ($n=100$) out of the population size ($N=582$) was used. However, taking into consideration the possibility of non-response, the study increased the sample size to 117 (20%). All participants' respondents answered the questionnaires within each building at the time of measurements. The survey was conducted at the respective occupied spaces of the respondents as follows (Lecture hall, Laboratory and Classroom). Although the respondents were free to decide if they wanted to participate in the study or not. A total of 100 successful questionnaire surveys were completed yielding a response rate of 100%.

The thermal comfort questionnaire survey was adapted and edited by the researcher for the purpose of this study from: SURVEYMONKEY platform. It covered 4 sections. Its first section focuses on user's demographic information such as age, gender, background and designation. The second section deals with users' perceptions about the thermal environment in terms of the three thermal comfort parameters. The measures include air temperature (ranging from very warm to very cold), wind velocity (ranging from very windy to no wind), and humidity (ranging from very damp to very dry). The third and final section covers preferences to the bioclimatic

design features (such as use of shading device, changing sizes of windows, repositioning of windows, etc. as well as opinions on the provision of comfort within buildings.

The subjective assessments basically treated for the research were respondents' vote (thermal comfort votes) in the occupied zone on the following: -

- i.) *Thermal Preference Scale* was designed to assess how the perceived indoor thermal condition was preferred to change: 1(warmer), 0(no change), -1(cooler)
- ii.) *Assessment of relative humidity Scale* assessed responses on how dry or wet the indoor condition was perceived: 1(air is wet), 0(air is just right), -1(air is dry)
- iii.) *Assessment of air movement Scale*: 3 (much too still), -2 (too still), -1 (slightly still), 0(just right), 1 (slightly breezy), 2 (too breezy) and 3 (much too breezy).

The data collection followed the Morning (9-10am) and Afternoon (12-1pm) sessions. The plan for two-sessions and three-day activities were necessary to capture the different conditions and environmental changes at different hours of the day. Respondents' votes was based on the ASHRAE Standard (ANSI/ASHRAE) 55 – 2010 which specified an acceptable thermal environment to record 80% of occupants' vote as the *central three categories* (-1, 0, 1) of any subjective measurement.

3.5 Data Analysis and Interpretation

3.5.1 Bioclimatic design studies (BDS)

The relevant bioclimatic responses for hot-dry climate are coded (Pn) and tabulated from (P_1) up to (P_{22}) numbers. There were three assessment scales on each row as the: *Adequately Applied Principles* (AAP), *Inadequately Applied Principles* (IAP) and *Not Applied Principles* (NAP) are provided as options on the checklist.

The listing of these principles from 1 - 22 (appendix I) known as the checklist. The number

of times an option is applied marked by ticking (×) cumulatively against the relevant principle as (AAPn), (IAPn) and (NAPn). It is used in the survey to determine the ratio of how the principles were variously applied on each building. The codes are then interpreted and formed into percentages on a pie chart according to applications. The survey data is illustrated in the following figures (1, 2 and 3) about each building showing the percentages of (AAPn%), (IAPn%) and (NAPn%) respectively. The *photographs* were graphically an additional data here.

3.5.2 Thermal comfort studies (TCS)

Physical measurements: The physical measurements (pM) were numerical values directly recorded as the readings on the instruments; {temperature (°C), relative humidity (Constant) and wind speed (m/s) respectively}. It is recorded as the indoor conditions when the thermal comfort questionnaire survey is administered to the indoor users. The morning session is coded (pMm) and afternoon session as (pMa) respectively.

Subjective Parameter Assessments: The subjective measurements (sM) are finally recorded and converted into percentages (%) of different levels of user comfort votes about the perceived indoor thermal variables as indicated on relevant question. The morning data are coded sMm while sMa referred to the data collected in the afternoon.

Analysis was finally made, in form of summary by the subjective measurements (sM) and physical measurements (pM) and then relating it to checklist data and hence bioclimatic design in a hot dry climate is assessed according to thermal

comfort. Additional data was in form of tables, charts, figures/plates, description, explanations and etcetera. Refer to Chapter Four.

3.6 Reliability and Validity of Research

The instruments were fully tested on previous researches. Prior to the actual survey, a pilot study was conducted at the Architecture department, ABU Zaria to examine the respondents' understanding to gauge thermal comfort questionnaires. Research assumptions were tested by pilot studies at the Classrooms of Yobe State University where the respondents comprised of science students. The final research respondents were ensured science oriented students already at 400 level who are believed to be exposed to general environmental studies and at least spent like three (3) years staying in the faculty building ever ready to provide relevant information in the thermal comfort questionnaire surveys.

4.1 RESULT AND DISCUSSION

4.1.1 Field Studies

To establish a relationship between the Indoor thermal conditions and the adequacy of Bioclimatic Responses on buildings located in the study area, Faculty of Sciences, Yobe State University Damaturu was selected as the case study within the hot dry climate of north-eastern states of Nigeria. Within this faculty building, three other case study buildings were selected for field studies: Lecture Hall building (100 seats), Classroom building (50 seats) and Laboratory building (50 seats) respectively. The three field study buildings within the faculty of sciences in Yobe State University are shown in Figure 4.5 below.

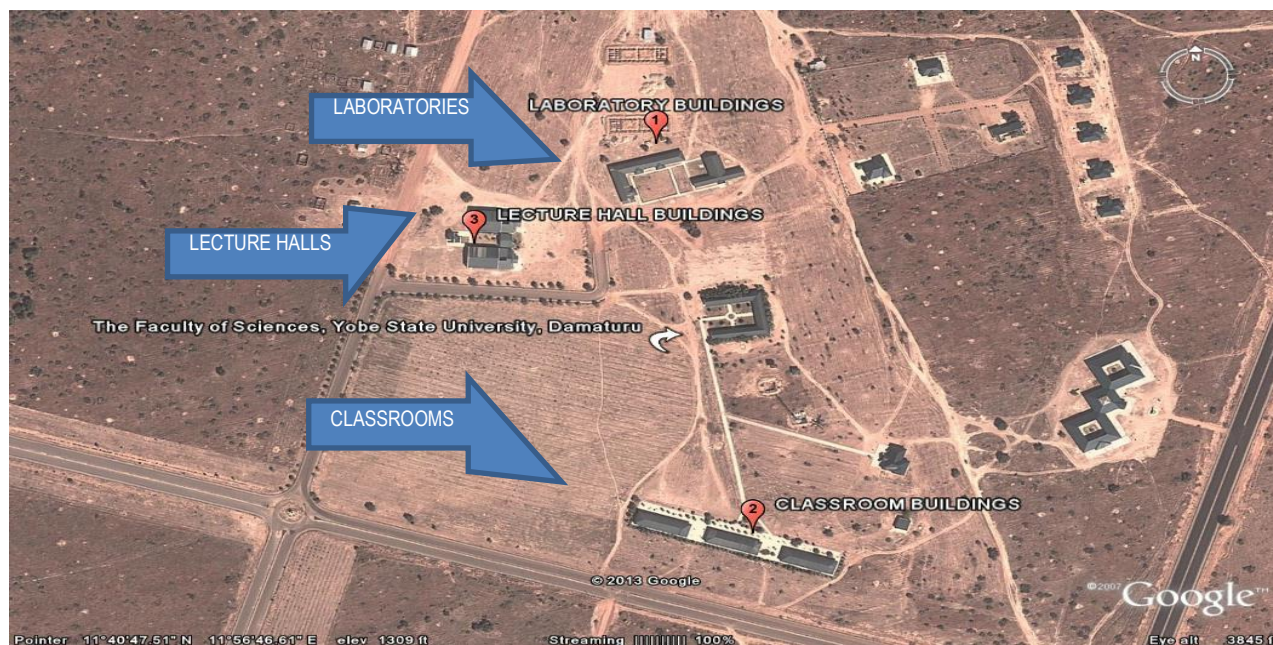


Figure 4.1: Field study buildings in the Faculty of Sciences YSU, Damaturu.

Source: Google earth, 2019

4.1.2 Laboratory building complex

A. Bioclimatic response in design of laboratory (Day 1)

The principles of bioclimatic design for the area were applied such that out of the 22 numbers of

applicable: there were 4 (AAP), 10 (IAP) and 8 (NAP) respectively (see sample checklist on Appendix I). Building is shown in Plate XI while the rates of implementation of principles on Fig 4.2.

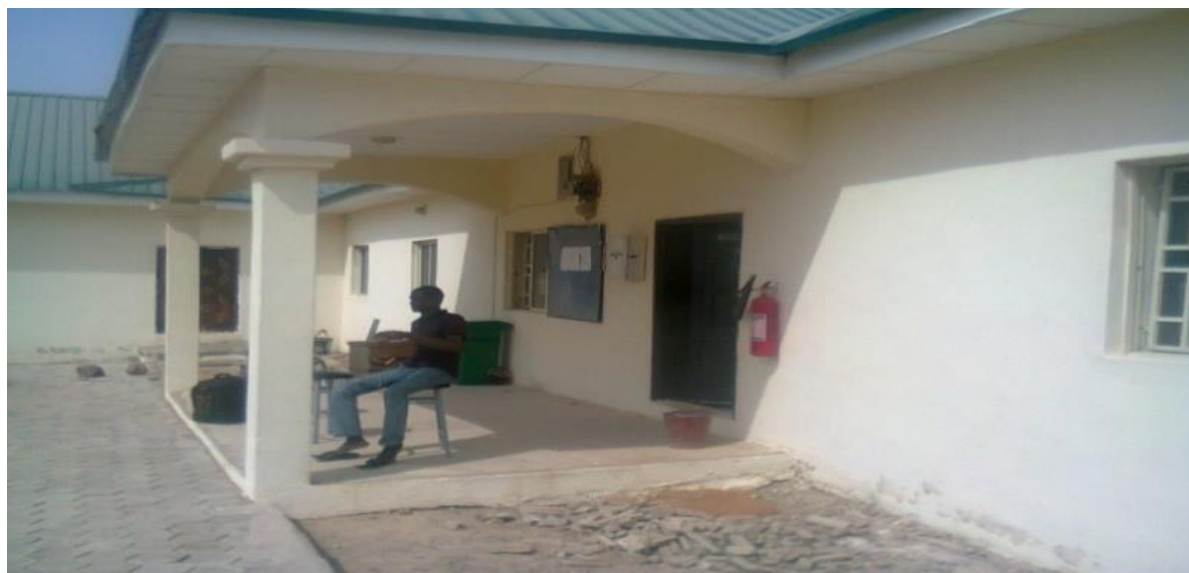


Plate I: Laboratory Building Complex (Chemistry Lab.)

Source: Researcher's Field Studies, 2019

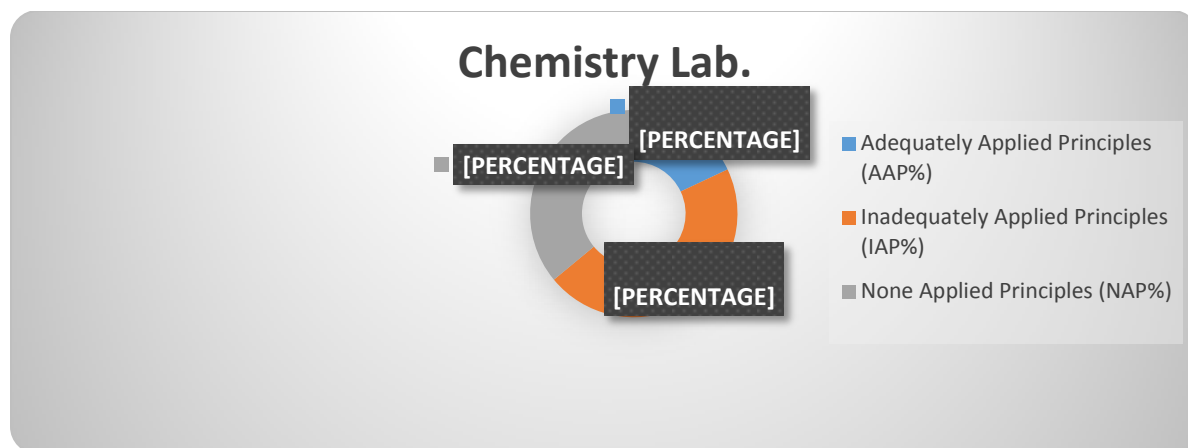


Figure 4.2: Bioclimatic Responses in Laboratory Building.

Source: Researcher's Field Studies, 2019

Figure 4.2 above presents the rates of bioclimatic responses with respect to the laboratory building: The percentage of adequately applied principles (AAP%) was 18%; the percentage of inadequately applied principles (IAP%) was 46% and the percentage of none applied principles (NAP%) was 36% respectively. This explains how only four (4) of the twenty-two (22) principles are adequately applied (minimised surface volume, insulative ceilings, white/light

colours, and reflective surfaces) were used in the design of Laboratory building complex.

B. Physical Measurements on Indoor Thermal Variables (Day 1)

At the Laboratory building complex (Chemistry Lab.), the average values of thermal variables were obtained by instruments at the measuring points as shown on Figure 4.3 below.

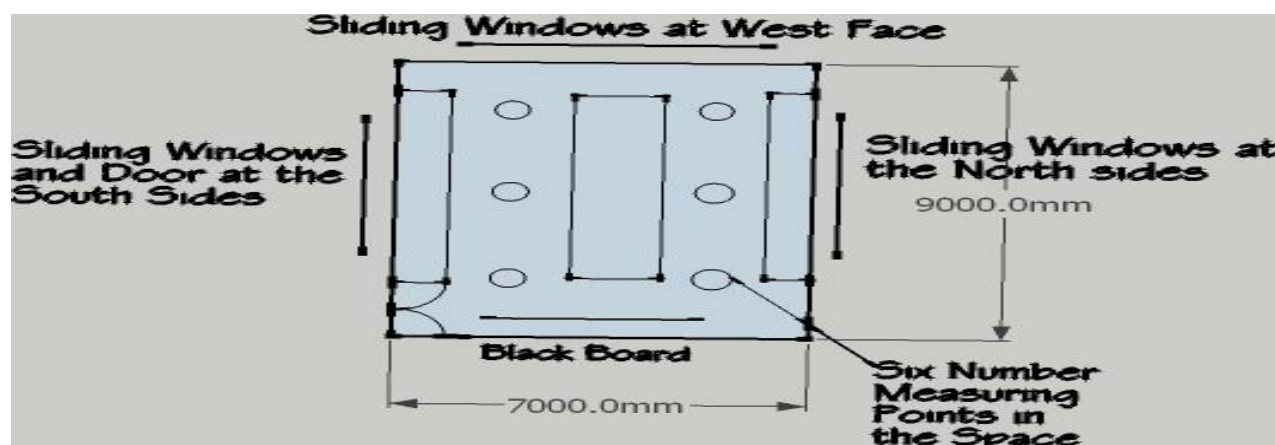


Figure 4.3: Six measuring points at the Chemistry Lab.

Source: Researcher's Sketches, 2019

As in Fig 4.3, all measurements were taken at the points or positions of holding the instruments as shown.

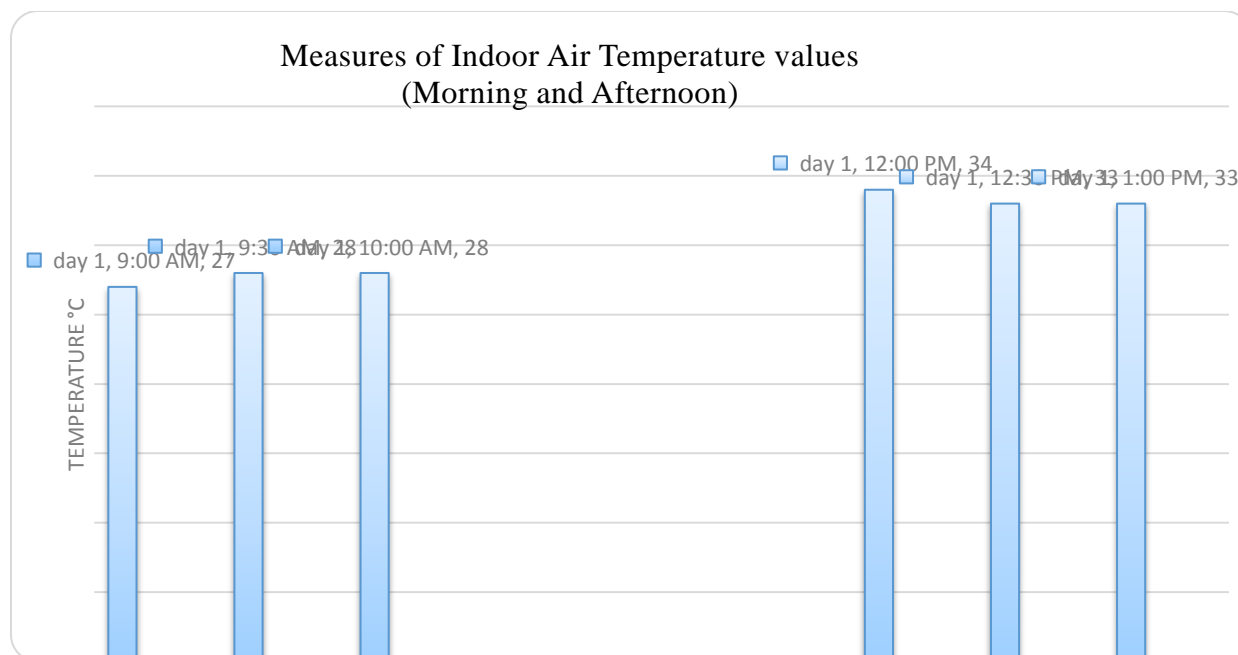


Figure 4.4: Indoor Air Temperature Measurements according to (pMm and pMa) at the Chemistry Lab. Day 1

Source: Researcher's Sketches, 2019

Fig 4.4 presents the values of measurements on air temperature: there was a gradual increase in

the values in the morning session (27 – 28) °C while there was a gradual decrease in the values in the afternoon session (34 – 33) °C.

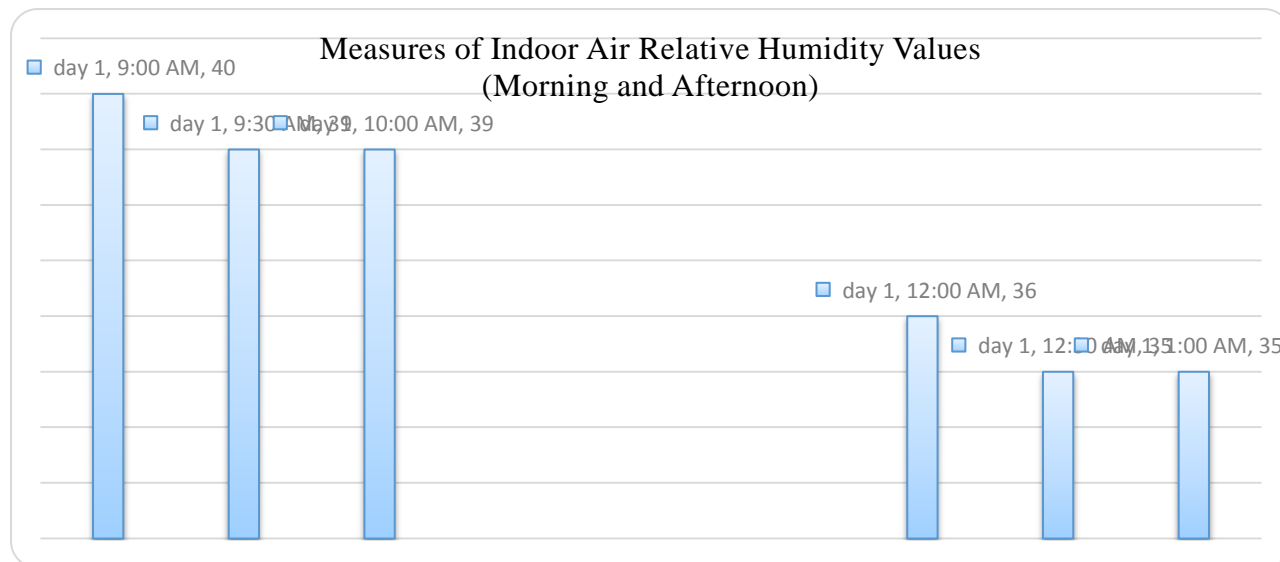


Figure 4.5: Indoor Air Relative Humidity Measurements according to (pMm and pMa) at the Chemistry Lab. Day 1

Source: Researcher's Sketches, 2019

Fig 4.5 presents the values of measurements on air relative humidity: there was a gradual

decrease in the morning session (40 – 39) RH% as well as in the afternoon session (36 – 35) RH%.

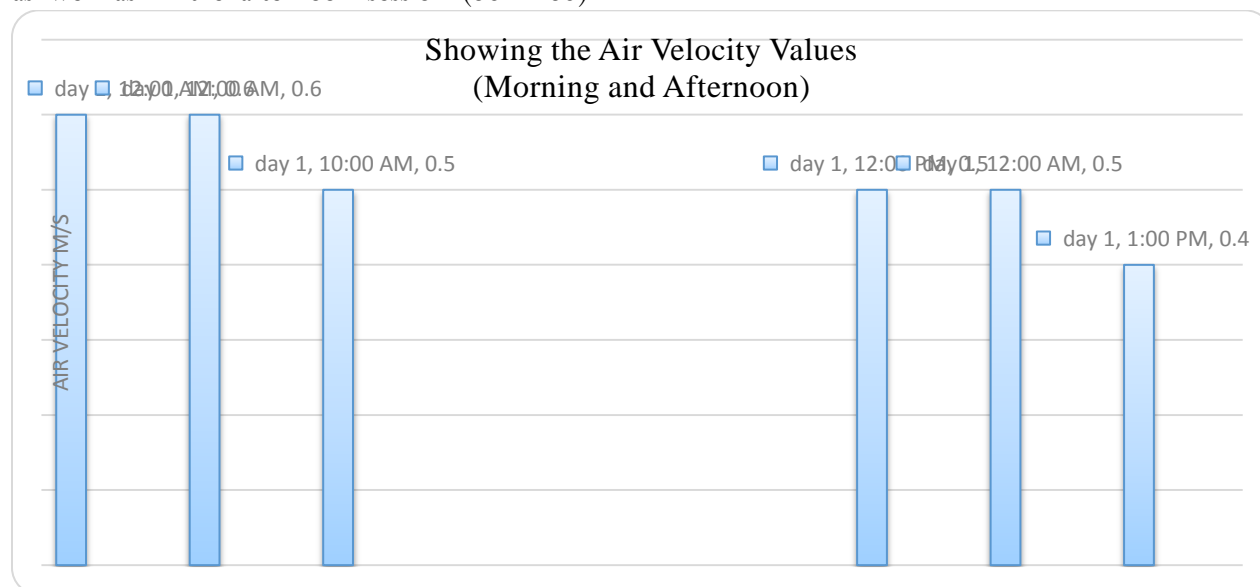


Figure 4.6: Indoor Air Velocity Measurements according to (pMm and pMa) at the Chemistry Lab. Day 1

Source: Researcher's Sketches, 2019

Fig 4.6 presents the values of measurements on air velocity: there was a negligible increase in the values in the morning session (0.6 – 0.5) m/s as well as in the afternoon session (0.5 – 0.4) m/s.

4.1.1.3 Subjective Assessments on Indoor Thermal Variables (Day 1)

The subjective assessments on thermal variables at the Chemistry Lab. were administered to the building occupants as shown in Plate XII.



Plate II: Questionnaire survey conducted at Chemistry Lab., Day 1.

Source: Researcher's Field Studies, 2019

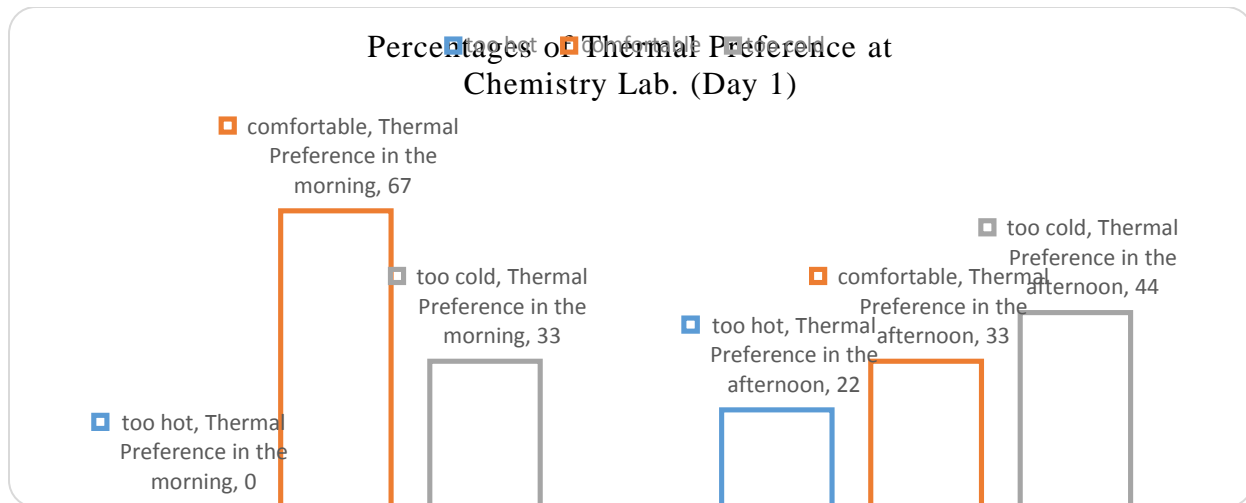


Figure 4.7: Thermal preferences (*sMm* and *sMa*) at Chemistry Lab.

Source: Researcher's Field Studies, 2019

Figure 4.7 presents the respondent's preference to indoor temperature (Day 1): In the morning, **67%** of respondents preferred the thermal condition of **27.7°C** temperature; whereas in the

afternoon, **44%** of respondents preferred **lower** temperature values than the measured **33.3°C**. This means that the majority of respondents could be thermally alright up to the temperature of **30°C** in this building.

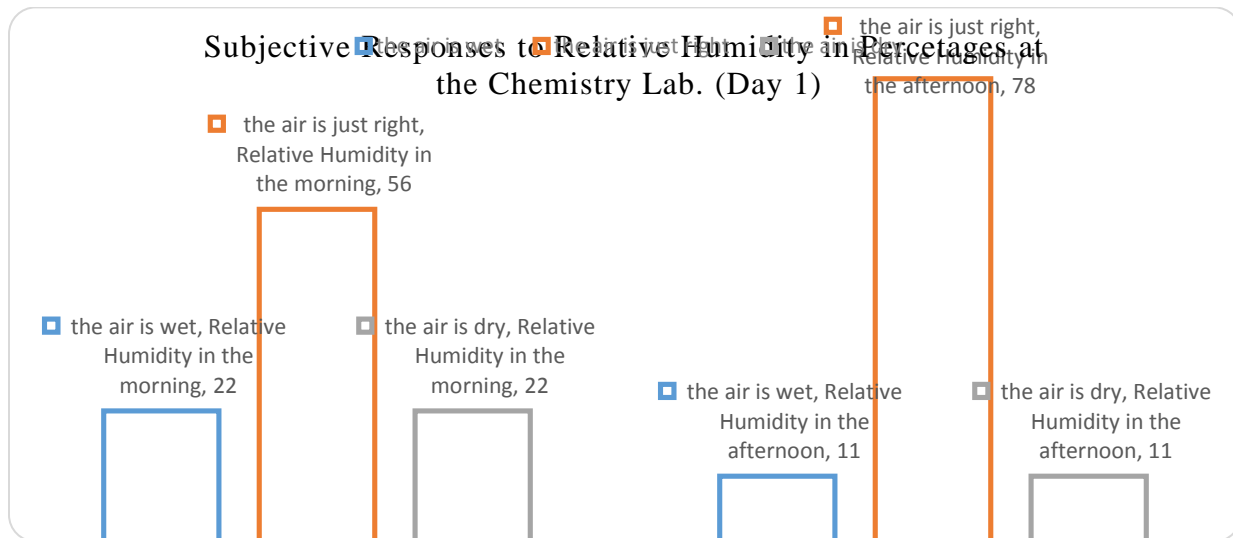


Figure 4.8: Subjective Responses to indoor relative humidity at Chemistry Lab.

Source: - Researcher's Field Studies, 2019

Figure 4.8 presents the respondent's votes to indoor relative humidity (RH) in Day 1 as follows: In the morning, **56%** of respondents preferred the measured RH value of **27.7%**; also

in the afternoon, **78%** of respondents preferred the measured RH value of **26%**; This means that the majority of the respondents were not comfortable with the RH values **higher than 27.7%** as measured in this building.

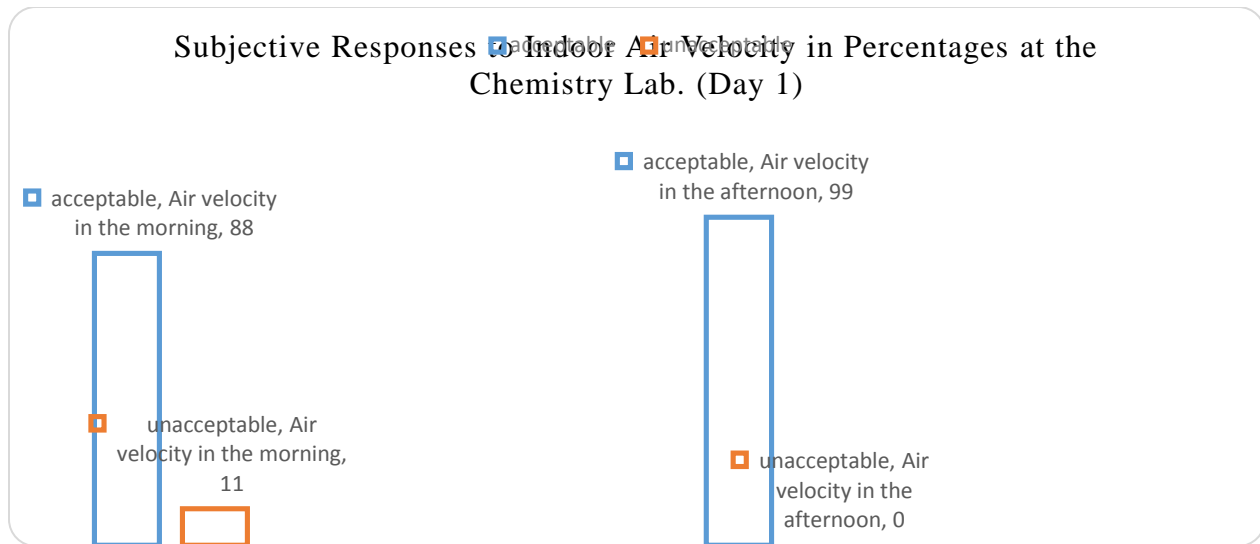


Figure 4.9: Subjective Responses on indoor air velocity at the Chemistry Lab.

Source: Researcher's Field Studies, 2019

Figure 4.9 presents the respondents' acceptability or unacceptability to indoor air velocity in Day 1: 88% of respondents were comfortable with the air velocity value of 0.57m/s as physically measured in the morning; where as 99% of respondents were comfortable with the air velocity value of 0.47m/s as physically measured in the afternoon. This means that the majority of the respondents were comfortable with the values of air velocity ranging from $\pm 0.47\text{m/s}$ to $\pm 0.57\text{m/s}$ as measured in this building.

4.1.3 Classroom building complex

A Bioclimatic response in design of classroom (Day 2)

The principles of bioclimatic design for the area were applied such that out of the 22 numbers of applicable: there were 6 (AAP), 7 (IAP) and 9 (NAP) respectively (see sample checklist on Appendix I). Building is shown in Plate XIII while the rates of implementation of principles on Fig 4.10.



Plate III: Classroom Building Complex (Physics Class)

Source: Researcher's Field Studies, 2019

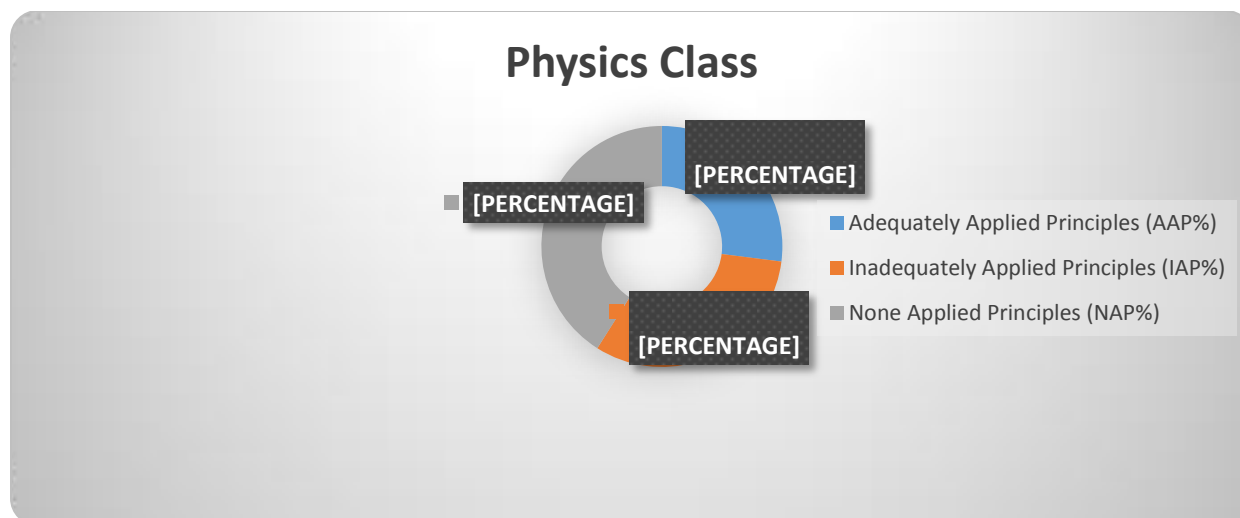


Figure 4.10: Bioclimatic Responses in Classroom Building.

Source: Researcher's Field Studies, 2019

Figure 4.10 above presented the rates of bioclimatic responses with respect to the laboratory building is such that: The percentage of adequately applied principles (AAP%) was 27%; the percentage of inadequately applied principles (IAP%) was 32% and the percentage of none applied principles (NAP%) was 41% respectively. This explains how only four (6) of the twenty-two (22) principles are adequately applied (minimised surface volume, insulative

ceilings, correct orientations, more openings on NS directions, white/light colours, and reflective surfaces) were used in the design of Laboratory building complex.

B. Physical Measurements on Indoor Thermal Variables (Day 2)

At the Classroom building complex (Physics Class), the average values of thermal variables were obtained by instruments at the measuring points as shown on Figure 4.15 below.

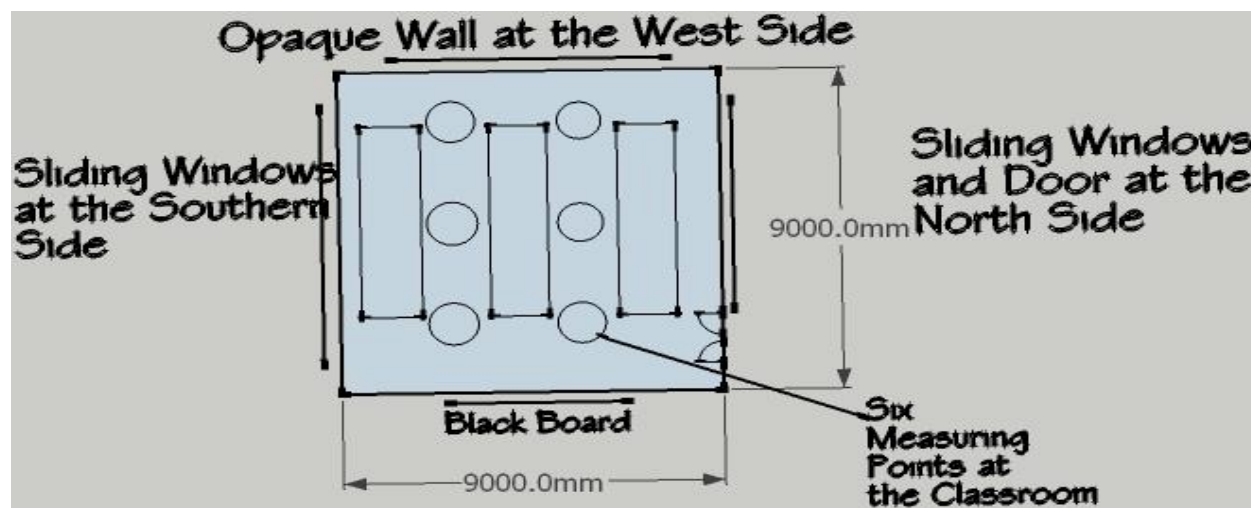


Figure 4.11: Six measuring points at the Physic Class.

Source: Researcher's Sketches, 2019

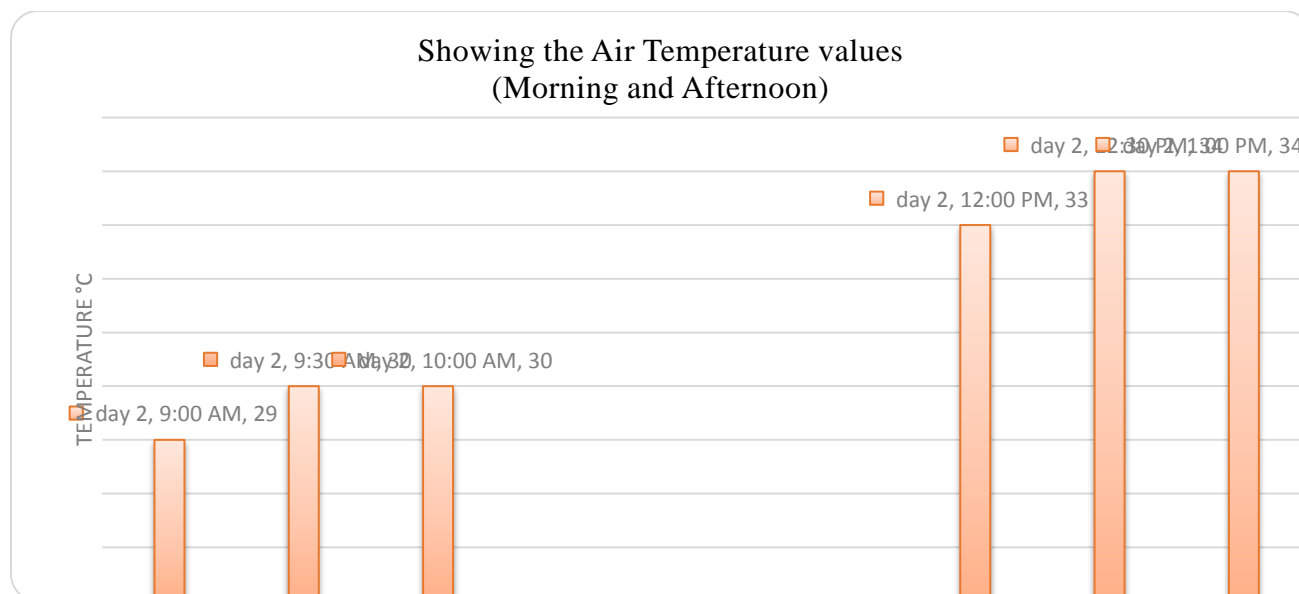


Figure 4.12: Indoor Air Temperature Measurements according to (pMm and pMa)) at the Physic Class. Day 2

Source: Researcher's Sketches, 2019

Fig 4.12 presents the values of measurements on air temperature: there was a gradual increase in

the values in the morning session (29 – 30) °C as well in the afternoon session (33 – 34) °C.

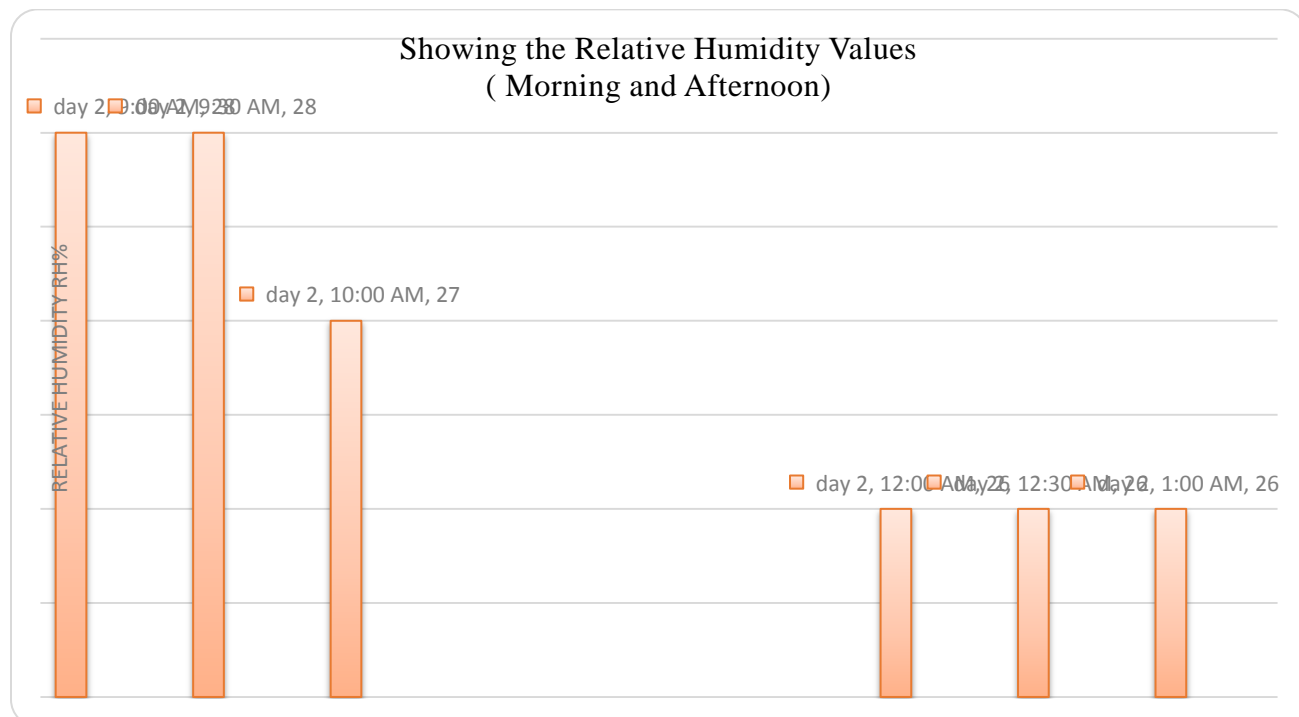


Figure 4.13: Indoor Air Relative Humidity Measurements according to (pMm and pMa) at the Physic Class. Day 2

Source: Researcher's Sketches, 2019

Fig 4.13 presents the values of measurements on air relative humidity: there was a gradual decrease in the morning session (28 – 27) RH%

while there was a relatively uniform values in the afternoon session (26 – 26) RH%.

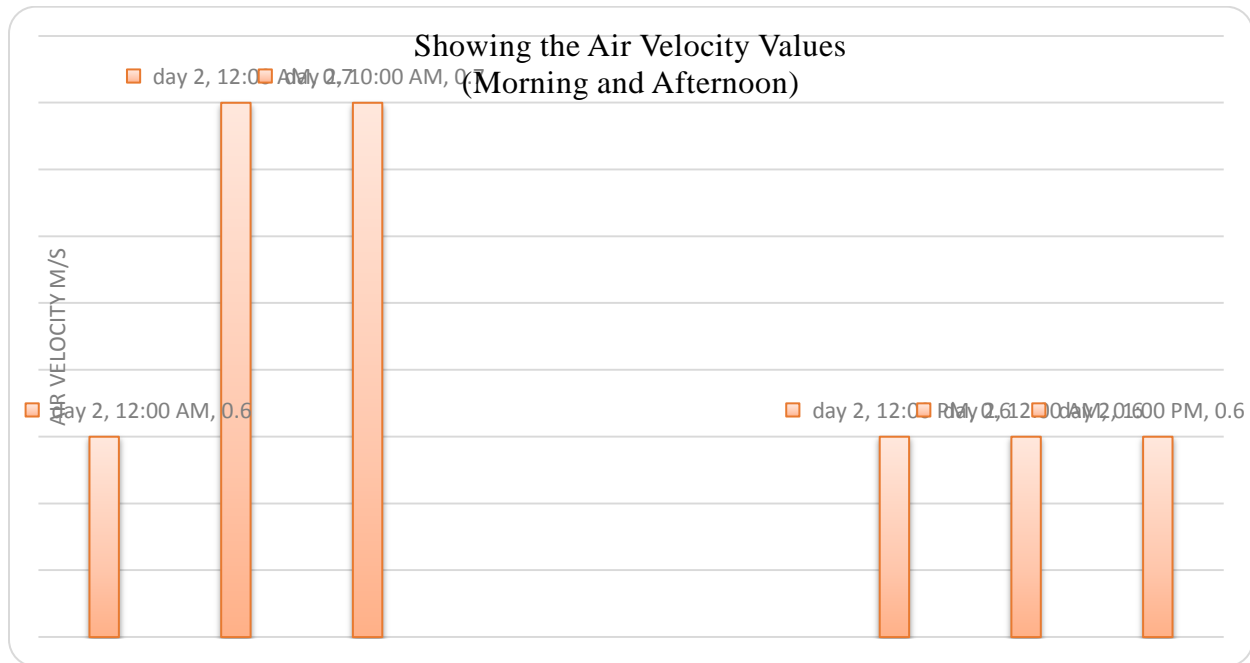


Figure 4.14: Indoor Air Velocity Measurements according to (pMm and pMa) at the Physic Class. Day 2

Source: Researcher's Sketches, 2019

Fig 4.14 presents the values of measurements on air velocity: there was a slight increase in the values in the morning session (0.6 – 0.7) m/s while there was a relatively uniform speed in the afternoon session (0.6 – 0.6) m/s.

C. Subjective Assessments on Indoor Thermal Variables (Day 2)

The subjective assessments questionnaires on thermal variables at the Physic Class Day 2 were administered to the building occupants as shown in Plate XIV.



Plate IV: Questionnaire survey conducted at Classroom, Day 2.

Source: - Researcher's Field Studies, 2019

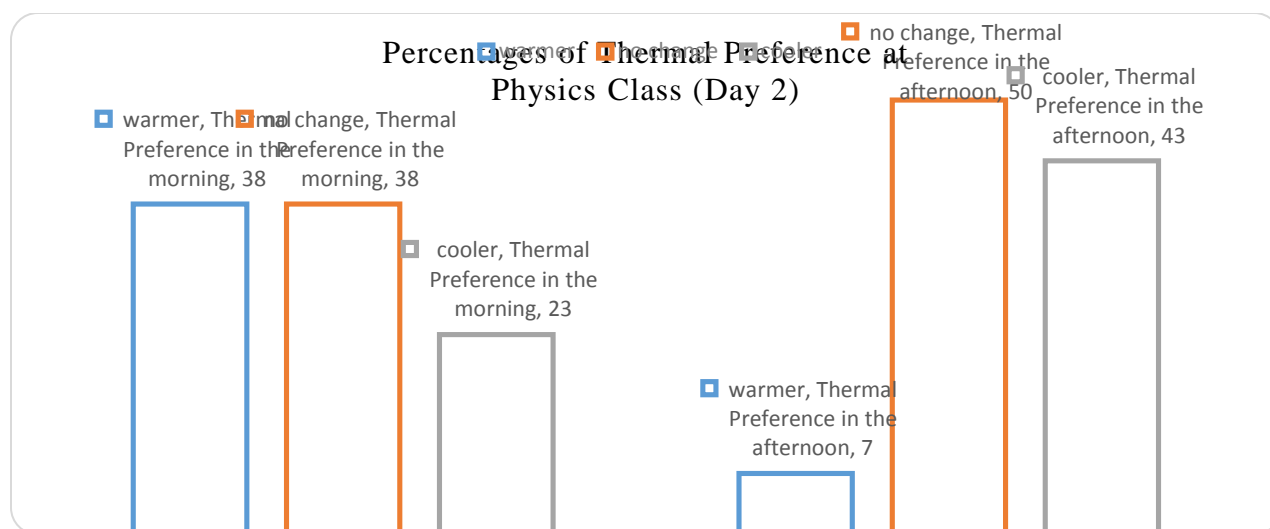


Figure 4.15: Subjective Responses to thermal preferences (*sMm* and *sMa*) at the Physics Class.

Source: Researcher's Field Studies, 2019

Figure 4.15 presents the respondent's preference to indoor temperature (Day 2): In the morning, 38% of respondents preferred the thermal condition of 29.7°C temperature, also 38% of respondents preferred **higher** temperature values than the measured 29.7°C; whereas in the

afternoon, 50% of respondents preferred the thermal conditions at 33.7°C. This means that the majority of respondents could be thermally alright up to the temperature of 33.7°C in this building.

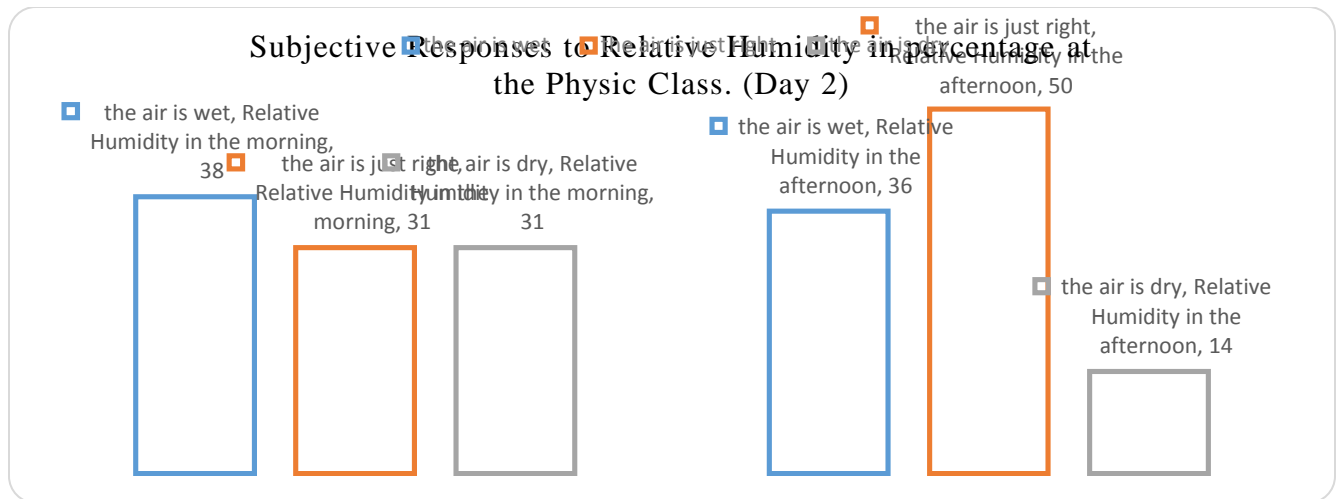


Figure 4.16: Subjective Responses to air relative humidity at Physics Class.

Source: Researcher's Field Studies, 2019

Figure 4.16 presents the respondent's votes to indoor relative humidity (RH) in Day 2 as follows: In the morning, 38% of respondents preferred **lower** RH value than the measured 39.3%; whereas in the afternoon, 50% of

respondents preferred the RH value of **35.3%** as measured; This means that the majority of the respondents were not comfortable with the RH values **higher than 35.3%** as measured in this building.

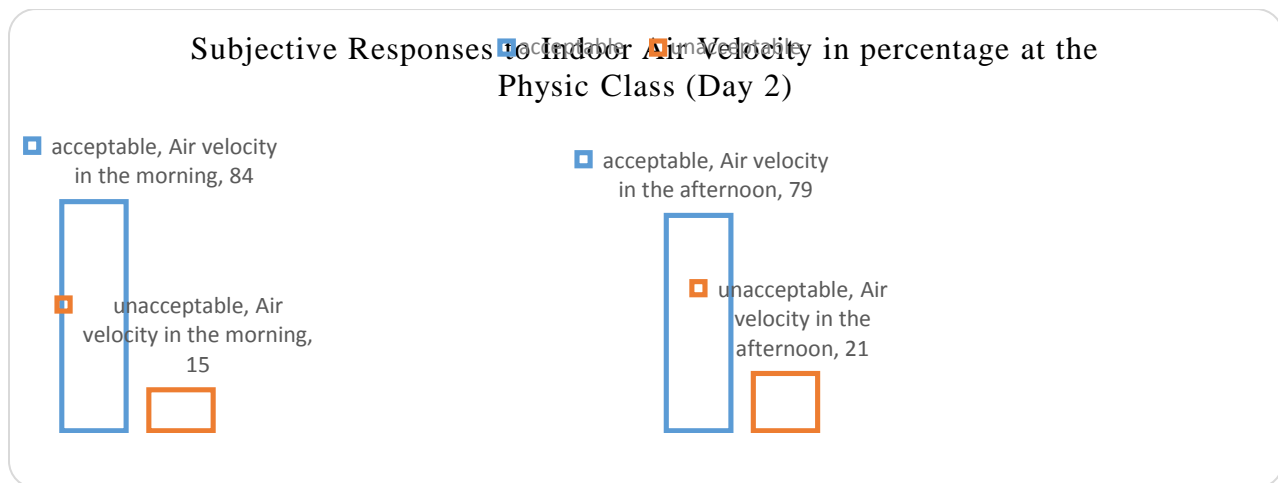


Figure 4.17: Subjective Responses on indoor air velocity at the Physics Class.

Source: Researcher's Field Studies, 2019

Figure 4.17 presents the respondents' acceptability or unacceptability to indoor air velocity in Day 2: 84% of respondents were comfortable with the air velocity value of **0.67m/s** as physically measured in the morning; whereas 79% of respondents were comfortable with the air velocity value of **0.6m/s** as

physically measured in the afternoon. This means that the majority of the respondents were comfortable with the values of air velocity ranging from $\pm 0.6\text{m/s}$ to $\pm 0.67\text{m/s}$ as measured in this building.

4.1.4 Lecture hall building complex

A. Bioclimatic response in design of lecture hall (Day 3)

The principles of bioclimatic design for the area were applied such that out of the 22 numbers of

applicable: there were 9 (AAP), 6 (IAP) and 7 (NAP) respectively (see sample checklist on Appendix I). Building is shown in Plate XV while the rates of implementation of principles on Fig 4.18.



Plate v: Lecture Hall building Complex (Hall A)

Source: – Researcher's Field Studies, 2019

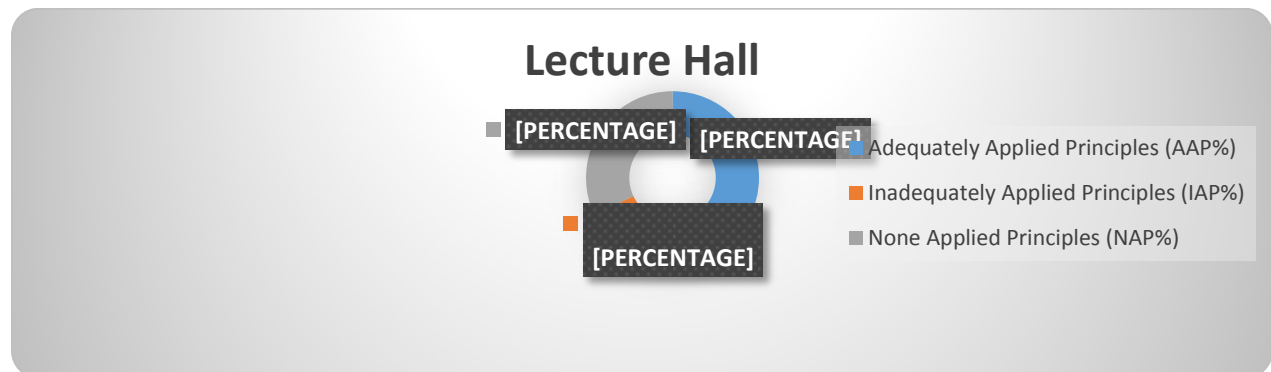


Figure 4.18: Bioclimatic Responses in Lecture Hall Building.

Source: Researcher's Field Studies, 2019

Figure 4.18 above presented the rates of bioclimatic responses with respect to the laboratory building is such that: The percentage of adequately applied principles (AAP%) was 41%; the percentage of inadequately applied principles (IAP%) was 27% and the percentage of none applied principles (NAP%) was 32% respectively. This explains how only nine (9) of the twenty-two (22) principles are adequately applied (mutual shades, facades protections, open

space as heat sink, correct orientations, flat/vaulted roofing, more openings on NS directions, use of white/light colours, reflective surfaces and landscape plants) were used in the design of Laboratory building complex.

B. Physical Measurements on Indoor Thermal Variables (Day 3)

at the Lecture Hall building complex (Hall A), the average values of thermal variables were

obtained by instruments at the measuring points as shown on Figure 4.23 below.

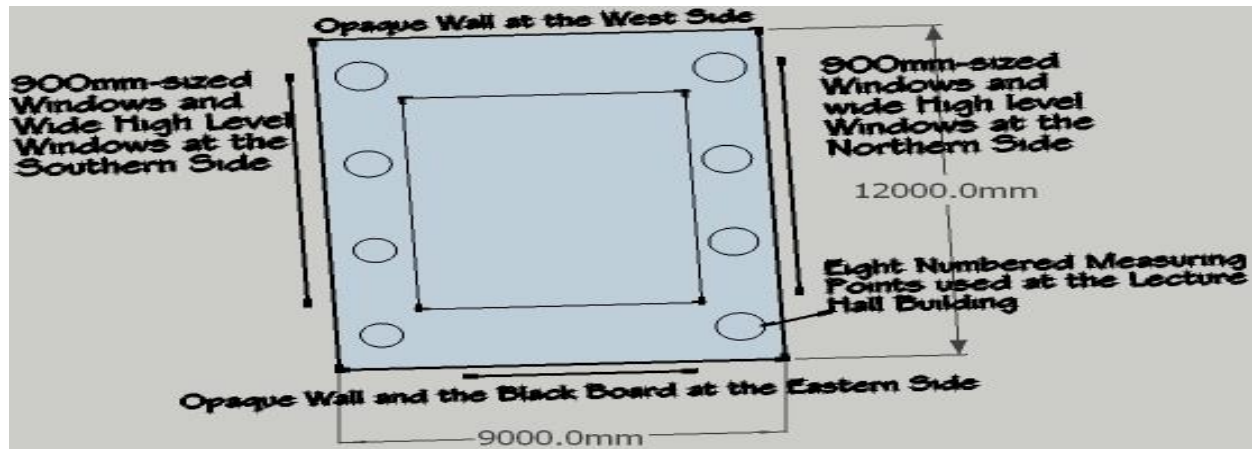


Figure 4.19: Eight measuring points at the Lecture Hall A.

Source: Researcher's Sketches, 2019

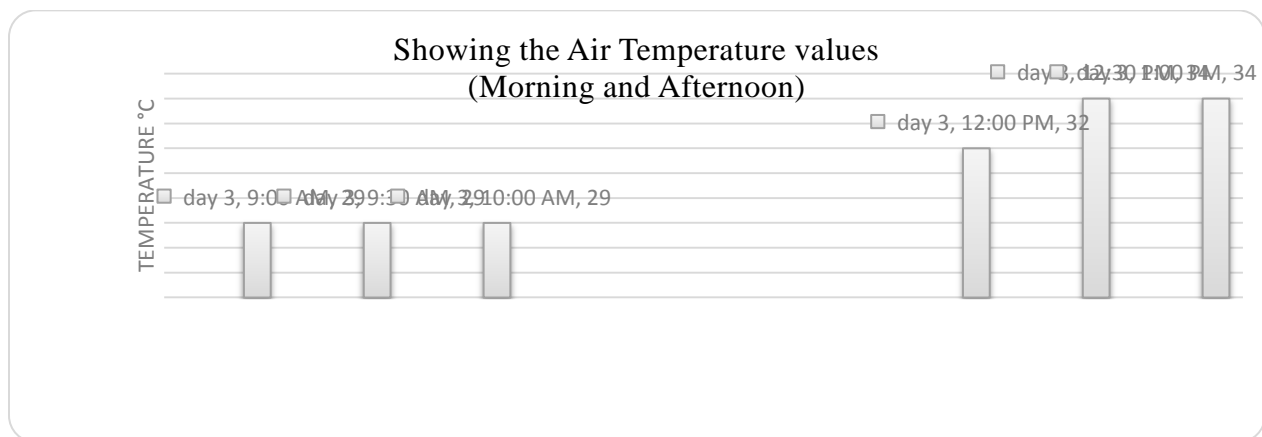


Figure 4.20: Indoor Air Temperature Measurements according to (pMm and pMa) at the Lecture Hall A. Day 3

Source: Researcher's Sketches, 2019

Fig 4.20 presents the values of measurements on air temperature: there was no change in values in the morning session (29 – 29) °C while there was

a gradual increase in values in the afternoon session (32 – 34) °C.

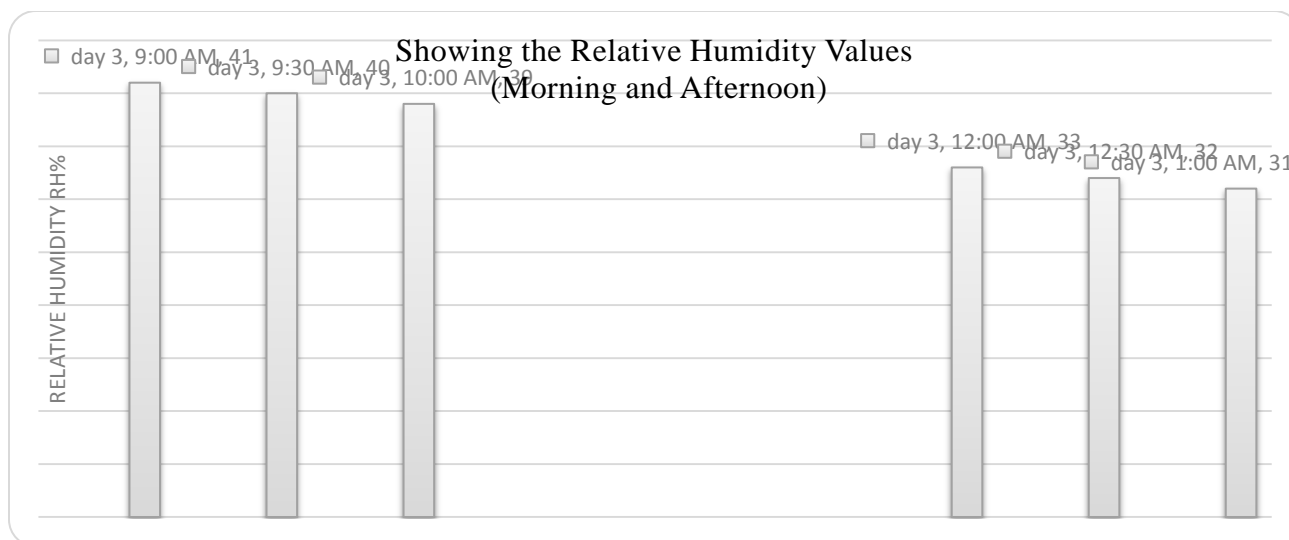


Figure 4.21: Indoor Air Relative Humidity Measurements according to (pMm and pMa) at the Lecture Hall A. Day 3

Source: Researcher's Sketches, 2019

Fig 4.21 presents the values of measurements on air relative humidity: there was a gradual decrease in the morning session (41 – 39) RH%

as well as in the afternoon session (33 – 31) RH%.

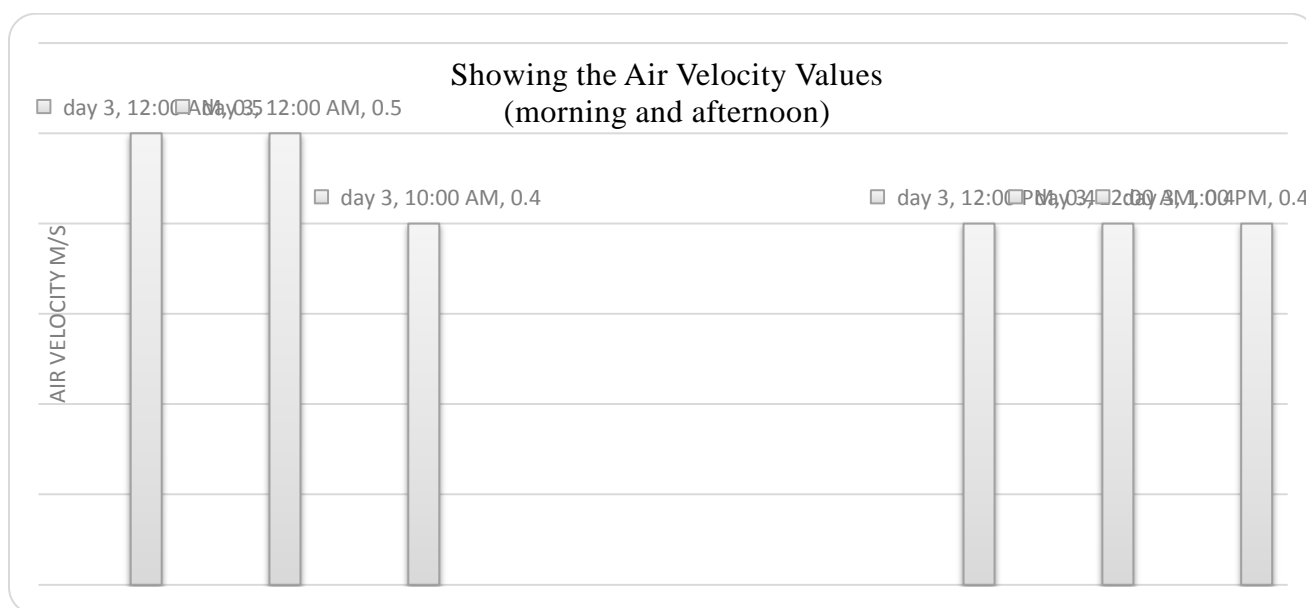


Figure 4.22: Indoor Air Velocity Measurements according to (pMm and pMa) at the Lecture Hall A. Day 3

Source: Researcher's Sketches, 2019

Fig 4.22 presents the values of measurements on air velocity: there was a slight increase in the values in the morning session (0.5 – 0.4) m/s

while there was a relatively uniform speed in the afternoon session (0.64– 0.4) m/s.

C. Subjective Assessments on Indoor Thermal Variables (Day 3)

The subjective assessments questionnaires on thermal variables at the Lecture Hall A were

administered to the building users as shown in Plate to the building occupants as shown in Plate v.



Plate VI: Questionnaire survey conducted at Lecture hall, Day 3.

Source: Researcher's Field Studies, 2019

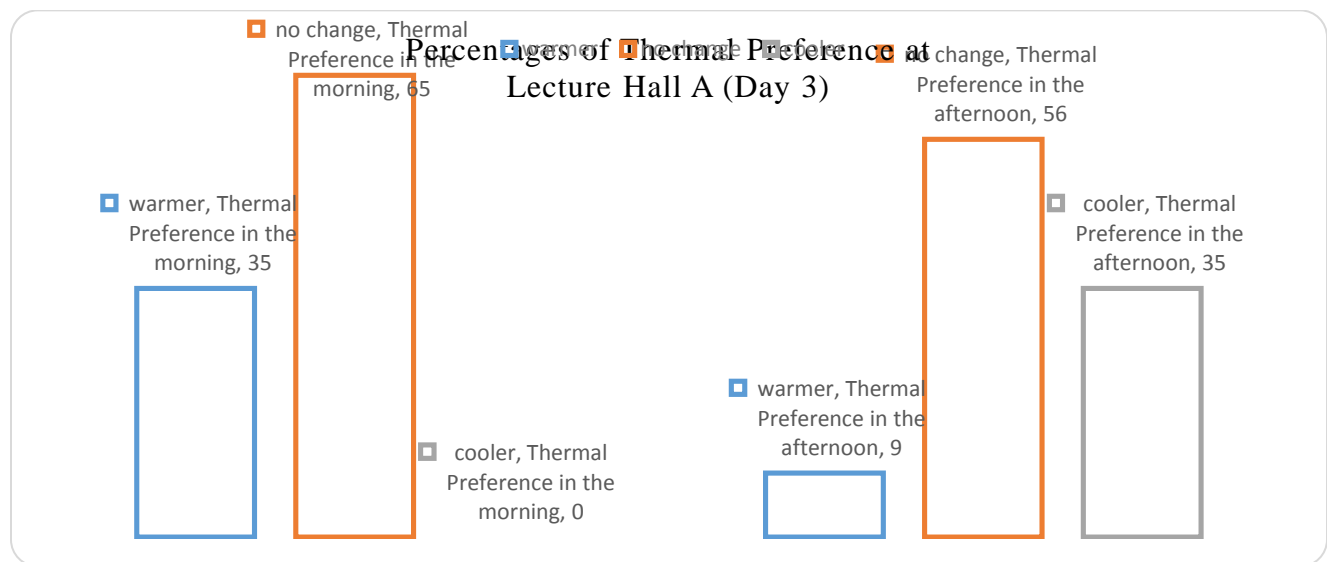


Figure 4.23: Subjective Responses to thermal preferences (sMm and sMa) at the Lecture Hall.

Source: Researcher's Field Studies, 2019

Figure 4.23 presents the respondent's preference to indoor temperature (Day 3): In the morning, 65% of respondents preferred the thermal condition at 29°C temperature; whereas in the afternoon, 56% of respondents preferred the

thermal condition at 33.3°C. This means that the majority of respondents could be thermally alright up to the temperature of 33.3°C in this building.

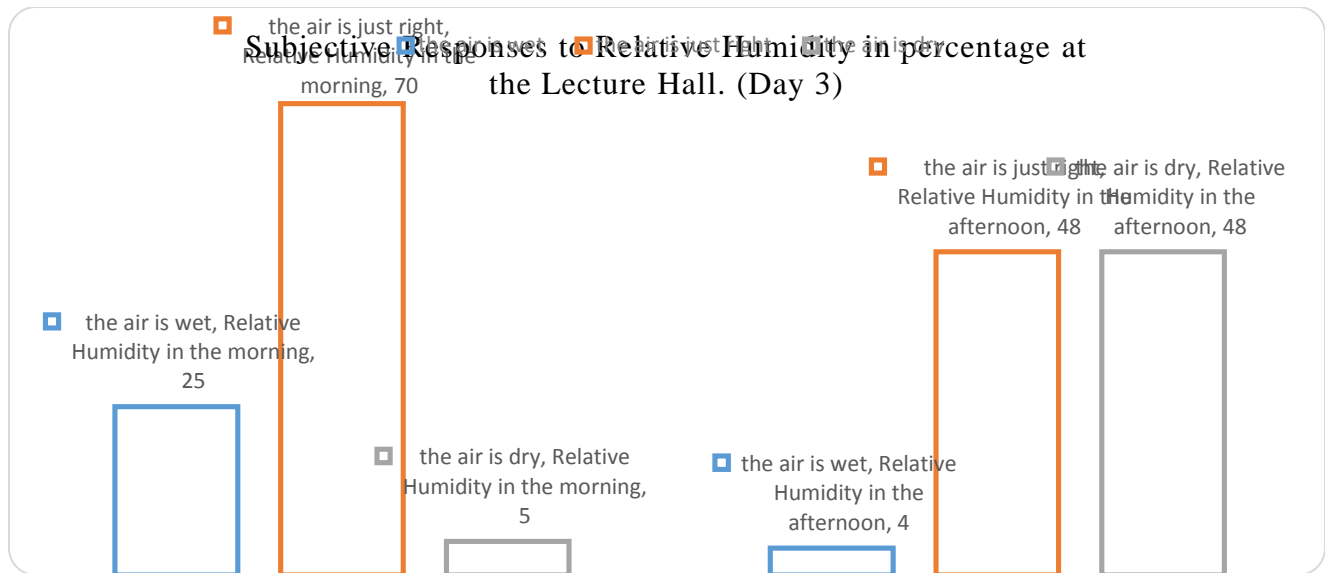


Figure 4.24: Subjective Responses to air relative humidity at the Lecture Hall A.

Source: Researcher's Field Studies, 2019

Figure 4.24 presents the respondent's votes to indoor relative humidity (RH) in Day 3 as follows: In the morning, 70% of respondents were comfortable at the RH value of 40% as measured; whereas in the afternoon, 48% of

respondents were comfortable at the RH value of 32% as measured also 48% of the respondents preferred **higher** RH value than the 32% as measured. This means that the majority of the respondents were not co.

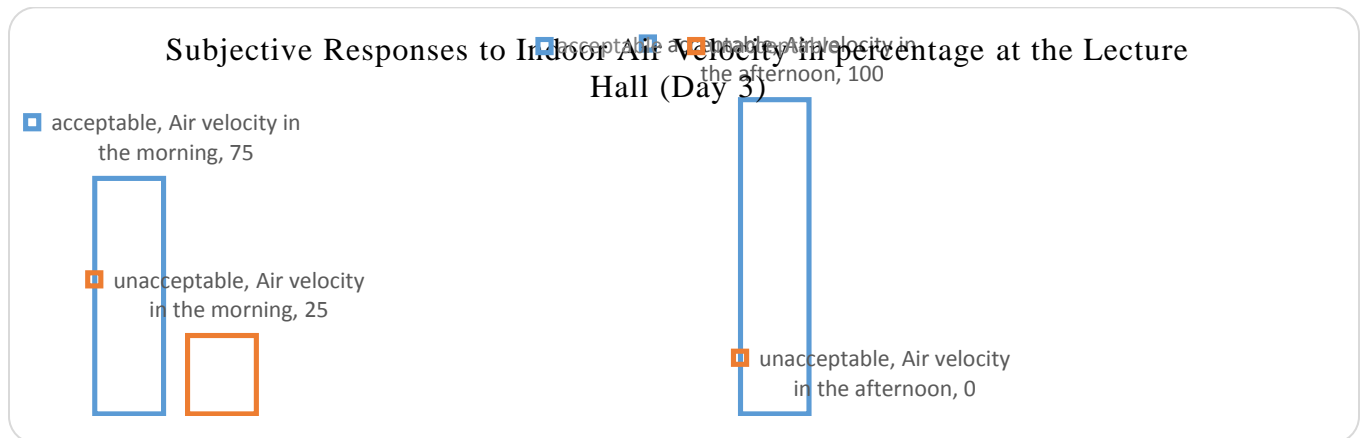


Figure 4.25: Subjective Responses on indoor air velocity at the Lecture Hall.

Source: Researcher's Field Studies, 2019

Figure 4.25 presented the respondents' acceptability or unacceptability to indoor air velocity in Day 3: 75% of respondents were comfortable with the air velocity value of 0.47m/s as physically measured in the morning; whereas 100% of respondents were comfortable

with the air velocity value of 0.4m/s as physically measured in the afternoon. This means that the majority of the respondents were comfortable with the values of air velocity ranging from $\pm 0.4\text{m/s}$ to $\pm 0.47\text{m/s}$ as measured in this building.

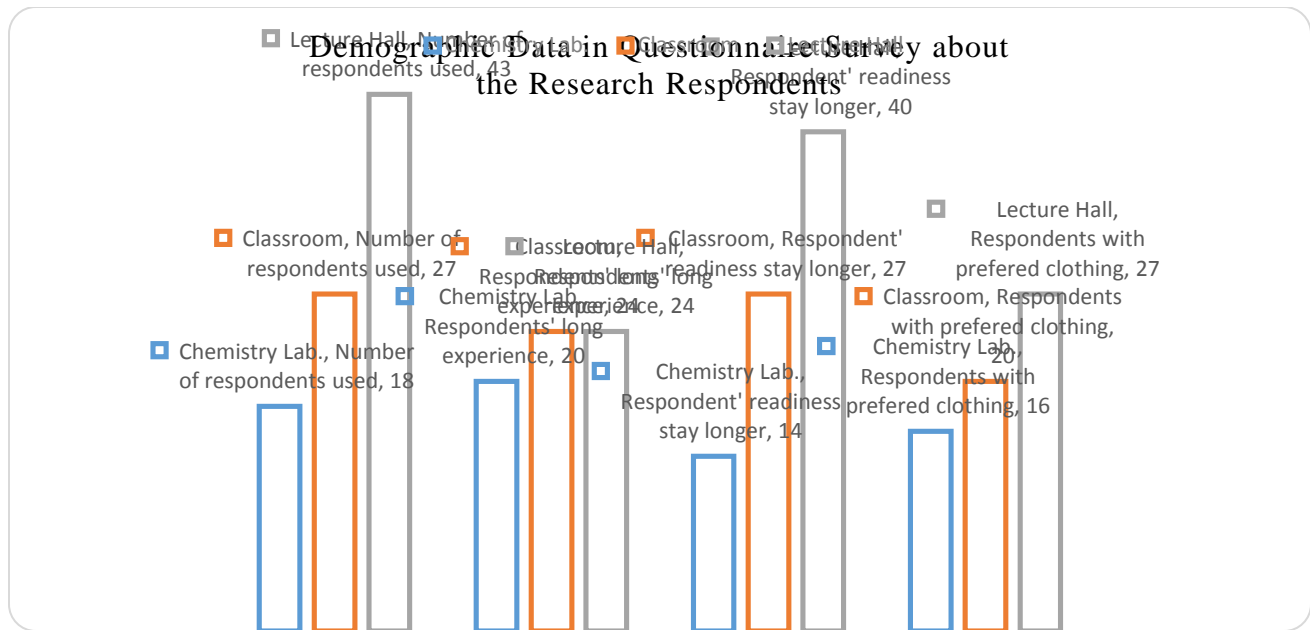


Figure 4.26: Respondents' basic data as used in the Questionnaire Survey.

Source: Researcher's Field Studies, 2019

Fig 4.26 presents the information that was kept to help researcher in the discussions.

4.4 Summary of Results

4.4.1 Field study results

1. Based on the above presentations about the bioclimatic responses and the indoor thermal conditions in the study area, bioclimatic

responses of the three field study buildings were recorded and converted into percentages of the three scales (AAPn%), (IAPn%) and (NAPn%).

Table 4.2 Bioclimatic Responses Assessed on the three Field Studies buildings.

S/No.	Laboratory Building Complex (Day 10)	Classroom Building Complex (Day 2)	Lecture-Hall Building Complex (Day 3)
Percentages of Adequately Applied Principles (AAP%)	18%	27%	41%
Percentages of Inadequately Applied Principles (IAP%)	45%	32%	27%
Percentages of None Applied Principles (NAP%)	36%	41%	32%

Source: Researcher's Analysis, 2019

It now follows from Table 4.2 above that the **Adequately Applied** (AAP) principles of bioclimatic design were applied as variously as possible in the design of the three buildings:

- i. **41%** in the design of Lecture Hall building,
- ii. **27%** in the design of Laboratory building and then

- iii. **18%** in the design of Classroom building.

2. The synchronized measurements on these buildings showed not any value of Temperature and Relative Humidity satisfied up to 80% respondents according to the comfort votes: See below for the findings of the subjective measurements on comfort.

Table 4.3 Synchronized records of physical and subjective measurements (pM and sM), during morning and afternoon sessions on thermal variables at Field Studies and Comfort Votes of case study building occupants.

Variables' of thermal comfort		Laboratory Building Complex		Classroom Building Complex		Lecture-Hall Building Complex		Average Value of Comfort Votes in all cases	Values of Dis-comfort in all cases
		m	a	m	a	m	a		
Indoor Air Temp. (°C) Or (%)	pM	27.7	30	29.7	33.7	29	33.3	31°C	31°C
	sM	67	44	38	50	65	56	53%	47%
Indoor Air Relative Humidity (RH %)	pM	27.7	26	35.3	35.3	40	32	33RH%	33RH%
	sM	56	78	38	50	70	48	57%	43%
Indoor Air Velocity m/s	pM	±0.57	±0.47	±0.67	±0.6	±0.47	±0.4	0.53m/s	0.53m/s
	sM	88	99	84	79	75	100	88%	12%

Source: Researcher's Analysis, 2019

Comfort Zone is attained at range of combined temperature and humidity with up to 80% comfort votes for the majority of people using the indoor space. From Table 4.3 none of the values of respondents' comfort votes (with respect to indoor air temperature and indoor air

relative humidity) attained the percentage of 80%.

5.1 CONCLUSIONS AND RECOMMENDATIONS

Based on the records of about 40% highest use of **adequately applied principles** (AAP) in design of the three field study buildings, the indoor thermal discomfort in the area about the following variables is thus:-

Indoor air temperature measurements;

A. At the Lecture-hall building, Day 3, where the (AAP) % was 41%:

- i. 35% of indoor users were uncomfortable with the 29°C temperature measurements in the morning session, and
- ii. 44% of indoor users were also uncomfortable with the 33.3°C temperature measurements in the afternoon session.

It is now clearly indicated that the comfort votes was not up to the 80% standard in the indoor conditions of this building.

B. At the Laboratory building, Day 1, where the (AAP) % was 27%:

- iii. 33% of indoor users were uncomfortable with the 27.7°C temperature measurements in the morning session, and
- iv. 56% of indoor users were also uncomfortable with the 30°C temperature measurements in the afternoon session.

C. At the Classroom building, Day 2, where the (AAP) % was 18%:

- v. 62% of indoor users were uncomfortable with the 29.7°C temperature measurements in the morning session, and
- vi. 50% of indoor users were also uncomfortable with the 33.7°C temperature measurements in the afternoon session.

Indoor air relative humidity measurements:

D. At the Lecture-hall building, Day 3, where the (AAP) % was 41%:

- vii. 30% of indoor users were uncomfortable with the 40RH relative humidity of indoor air measurements in the morning session, and
- viii. 52% of indoor users were also uncomfortable with the 32RH relative humidity of indoor air measurements in the afternoon session.

E. At the Laboratory building, Day 1, where the (AAP) % was 27%:

- ix. 44% of indoor users were uncomfortable with the 27.7RH relative humidity of indoor air measurements in the morning session, and
- x. 22% of indoor users were also uncomfortable with the 26RH relative humidity of indoor air measurements in the afternoon session.

F. At the Classroom building, Day 2, where the (AAP) % was 18%:

- xi. 62% of indoor users were uncomfortable with the 35.3RH relative humidity of indoor air measurements in the morning session, and
- xii. 50% of indoor users were also uncomfortable with the 35.3RH relative humidity of indoor air measurements in the afternoon session.

In this research, thermal parameters (air temperature, air relative humidity and air velocity) were recorded within the indoor conditions of the three varying bioclimatic designs in the study area. The research

respondents were tolerant to some extent with the thermal discomfort nature of the study area which indicated that their comfort zone is shifted up.

Bioclimatic responses is as high as forty percent (40) % of adequately applied in designing buildings in the area. The remaining sixty percentage (60) % of the applicable principles were either **not applied** (NAP) or **inadequately applied** (IAP).

Conclusively, average values of these measured parameters within the three buildings revealed that 47% of indoor users were uncomfortable with the 31°C indoor air temperature; 43% of indoor users were uncomfortable with the 33RH% indoor air relative humidity but almost 100% of the respondents were comfortable with the indoor air speed across the buildings.

5.2 Recommendations

To design an indoor thermally comfortable and more bioclimatic responsive buildings in the area, the following recommendations would have to be considered about the use of bioclimatic principles:

- i. At least more than fifty percent (50) % of the appropriate principles of bioclimatic design for the area must have to be applied adequately in designing buildings before the indoor conditions of such buildings be comfortable for up to the required 80% of the indoor space users.
- ii. To regulate the transfer of heating into the indoor spaces in the area, all the outer and inner wall leaves along the enveloping walls of the building must be designed with massive walling materials. This design would ensure that the enveloping walls take longer time to conduct heat from the outside environment.
- iii. To protect the infiltration of dust borne air into the buildings in which important things are spoilt, all

openings along the enveloping walls must be correctly sized and positioned at the required heights.

- iv. *Special designs*: roof garden, balcony garden, impluvium, courtyard fountains, etc could help in the thermal regulation process.

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