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THE IMPACT OF PHYSICAL CHARACTERISTICS ON THERMAL PERFORMANCE OF PUBLIC PRIMARY SCHOOL CLASSROOMS IN LAGOS METROPOLIS

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Abstract

Given the literature on thermal performance in public schools, the impact of the form/ shape of a building on classrooms' thermal performance cannot be overemphasized. Since buildings are responsible for almost half of the energy consumed yearly around the world, research targeted at energy savings and thermal comfort are important towards reducing the carbon footprints of buildings on the environment, thereby mitigating climate change effects. The aim of this study is to investigate the impact of the form(shapes) of primary school building envelopes on the thermal performance of primary school classrooms in Lagos. A sample of 160 classrooms was randomly selected from the various educational districts in each local government within Lagos Metropolis. Also, subjective and objective measurements were carried out according to class II field experiment method and in consonance with the stipulated standards. Pupils showed greater adaptation for heat beyond temperatures recommended by ASHRAE, which is 24^{0}C. This can be ascribed to adaptations in the tropics. Of the 11 material types and the bungalow structure, the classrooms with Aluminium roof/ block wall/ metal windows/ cement screed floors had the highest occurrence. Also, the I-shaped form had the highest occurrence of the four typologies found, and the Revit-BIM modelling revealed that the 'U' shaped layout was found to be the least in energy loading, hence was most preferable for the tropics. These results have significant implications for stakeholders and the government in the making of climate-sensitive decisions for the construction of new school buildings.

Keywords: Building envelope, Lagos, Primary schools, Revit-BIM, Thermal performance

INTRODUCTION

Countries of the world are overwhelmed with the effects of technology advancement and the pressure of man's activities on the environment. In several countries of the world, especially in advanced communities, occupants spend most of their times indoors; hence the indoor environment becomes key determinant of the health, wellbeing and efficiency and productivity of its occupants, Harputlugil, T. (2021). Globally, more attention has been placed on providing buildings with less energy and greater thermal comfort than has been done previously. With the advent of climate change and global warming, the need to be frugal with scarce resources and use cleaner sources of energy is more paramount. Energy efficiency has become crucial as a result of the increase in demand for building services and thermal comfort in buildings (Zhang et al, 2017); a third of the energy used globally is consumed by buildings (Jastaneyah et al, 2023; Mirrahimi, 2016, Wagner, 2011). Thus, buildings that are well suited to their climes should possess appropriate features making them fit for the users, the environment, and the task they perform.

In Nigeria, the epileptic supply of power from the grid has necessitated the constant use of alternative power supply- the generator or inverter system, in most homes. Yet, a sustainable approach to development remains a 'buzz word' in construction and remains cosmetic in its approach in the provision of buildings. Such are the prevailing issues evident in the nation Nigeria. The need for climate sensitive approaches and environmentally responsible construction cannot be overemphasized.

Several studies have investigated the relationship between poor academic performance and school environment. The issues investigated include problems with student-teacher ratio, school location, school population, classroom ventilation, poor lighting in classrooms, and inconsistent temperatures in the classroom with student health problems, student behaviour, and student achievement. (Lau et al 2019; Crandell & Smaldino, 2000; Lyons, 2001). Children are more susceptible to heat stresses; however, cultural factors and acclimatization can help minimize this (UNICEF, 2023, Aynsley et al,1996). Heat stresses have an impact on learning capacity. At high temperatures, children are less able to concentrate and can exhibit irritable or aggressive behaviours. Adults (including teachers) can be similarly affected. School buildings are meant to be designed to ensure that human comfort conditions are easily and efficiently maintained through the variety of passive and active means available. Since children, spend most of their time indoors in school buildings, the indoor environment is therefore of primary importance.

In Nigeria, the academic performance of pupils in schools has been in decline (Odia & Omofonmwan, 2007). Deliberations have been made that poor performance of pupils in Nigeria is due to poor teacher motivation, differential access to facilities, poor funding, school climate etc, (Nwakasi and cummins ,2018; Fakunle, 2018; Adenuga et al, 2011). With the provision of new classroom blocks in many of these public schools, much is left to be desired. The focus is on public schools because they serve a greater percentage of the populace, they have standardized systems, curriculum and structure which will enable easy comparison.

The aim of this paper is to assess the physical characteristics of classroom building envelopes and the thermal performance of public classrooms in Lagos. The objectives are, to examine the physical characteristics of building envelopes of primary school classrooms in Lagos metropolis, and to assess the thermal performances of the primary school classrooms.

LITERATURE REVIEW

Building envelopes of classrooms

The classroom is the most significant space that houses the major functions of the school building. Classrooms need to be constructed with much consideration for ventilation, illumination, acoustics and thermal comfort which are all important factors for classroom usage. The building envelope characteristics can be examined in the following areas: Form and material specification, Design, Orientation and External factors. For the scope of this work, materials and the form of the buildings are in focus. The various elements of the building envelope can be combined to create suitable forms with distinct material specifications. The choice of materials should therefore be dependent on the function of the building envelope. Certain concepts can only be achieved with the right choice of materials, as a result of the inherent properties of that material (air to air transmittance (U- value), solar gain factor, time lag, admittance, thermal conductivity). Concrete has high thermal mass but low structural strength except precast with steel, steel has durability and strength for longer spans, and wood and brick as low thermal conductivity.

The form of Building Envelopes

A building's envelope offers basic services such as; structural support, climate control and aesthetics. The term 'envelope' consists of the shape, form, the constituent elements and material specification, and fenestrations. Building envelopes can affect thermal performance and consequently, energy usage in the following ways;

Shape or form: the form of the envelope primarily influences how the envelope will influence the internal microclimate. For instance, if the space is closed up, or an open plan, with or without a courtyard space, deep or narrow, etc. The 'form' determines how much lighting or cooling the building will require; hence, this impacts on the thermal performance of the space. The form and shape, as well as orientation determine how much solar radiation penetrates into the building envelope. The basic classroom forms or layouts that exist in Nigeria are; the linear, double loaded layouts, L and U-shaped layouts (see Figure 1, Figure 2, Figure 3, and Figure 4). The various forms of classroom layouts and their orientation can have significant effects on the thermal performance of the buildings' envelopes.

Typical plans of classroom layouts

The I or linear shaped form of classroom block exists with the classrooms laid side by side each other in one single block arrangement. See the Fig 1 below.

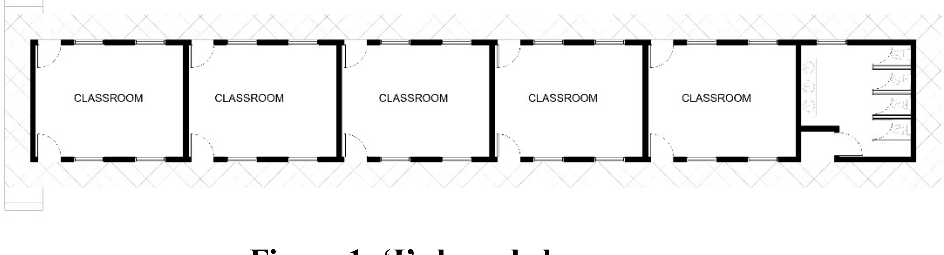

Figure 1: 'I' shaped classrooms

The next form is the u-shaped classroom block form which exists where classrooms are arranged almost entirely around a courtyard, leaving one end open. See the figure 2 below.

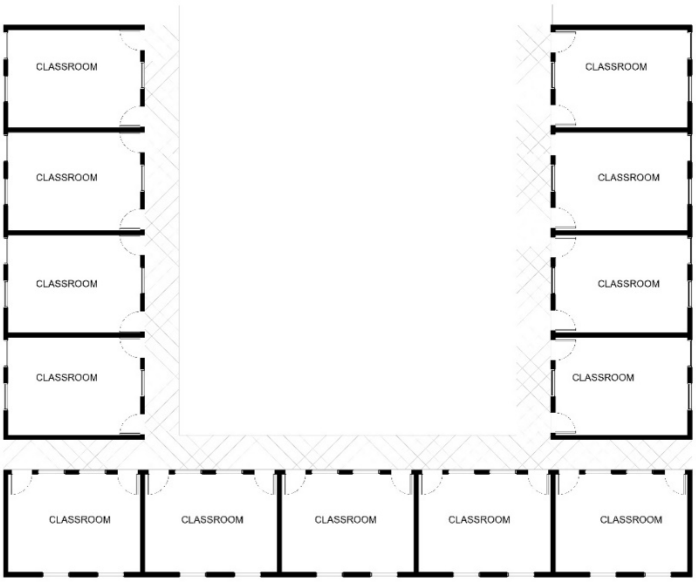

Figure 2: 'U' shaped classroom

The square shaped form or double loaded layout has classrooms arrayed on both sides of a corridor. See the figure 3 below.

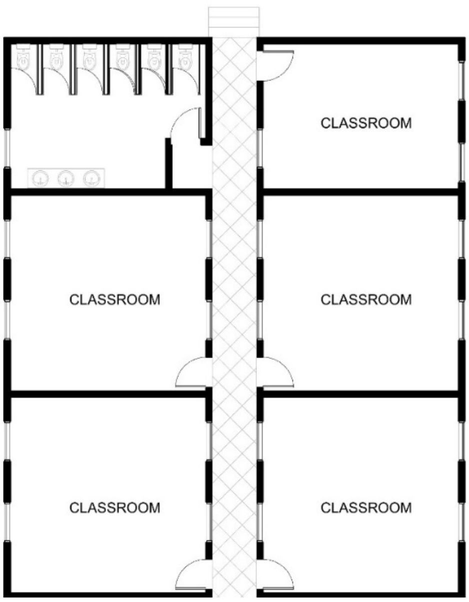

Figure 3: Square shaped / Double loaded classroom

The 'L' shaped layout has classrooms arrayed adjacent to each other along one side of the corridor. See the fig 4 below.

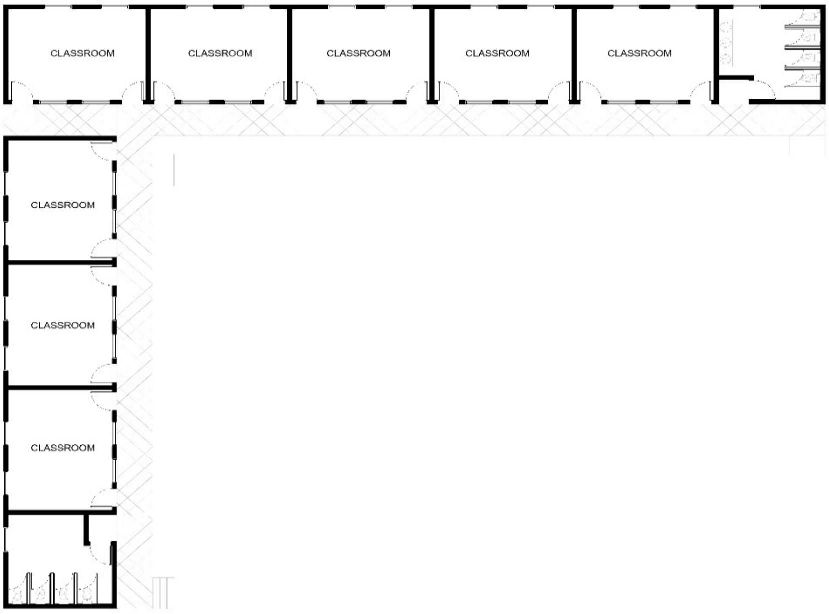

Figure 4: 'L' shaped classroom

Research on the effect of U-shaped walls on energy consumption of a building in Morroco by Srhayri et al (2022) found a reduction in the total heating and cooling consumption 0.3 -14% depending on the orientation and the depth of the rooms. Similar research on school buildings in Haiti (Hallquist,2011) with humid climate, produced the following findings; the square shaped layout was the least energy efficient, but most stable; the rectangle form was more energy efficient, but less stable than the square; while the L shape was more energy efficient compared to the square as well, but also least stable. Zhang et al's (2017) research on thermal performance of school buildings reported also that the H shape was the best design when considering both thermal performance and subjective preferences as it achieved a maximum of 13.6% in energy savings and 3.8% in thermal comfort improvement with various design options. Furthermore, it had a high rank in the students' preferences, and the courtyard type was advantageous due to its potential for energy saving and thermal comfort improvement.

Researchers have stated that for warm-humid countries, the appropriate design to use is elongated buildings with orientation towards the North and South, with the shorter side in the East or West axis, having blank walls. The direction of spaces towards the prevailing wind is also preferable (Alwetaishi et al, 2020; Koenigsberger et al, 1976; Givoni, 1976; Komolafe, 1998; Adebamowo, 2007).

Impact of roof and wall finishes and material selection

Wall material selection and specification: the thickness of the walls, whether cladded, or raised above the ground level, type of finishing, placement and number of openings, etc, has far reaching effects on the interior climate as each material has various (U-value) conductivities and thermal properties. Mansouri et al (2017) opined that wall cladding or coatings can affect significantly the level of thermal comfort experienced within a building; increasing the reflectivity of wall cladding reduces the length of hours of discomfort within the building. Thermal mass walls also possess the ability to withstand by warming up slowly before releasing heat into the interior of the space. They are therefore useful for passive heating or cooling, as the case may be.

Roof design and specification: Guichard et al (2017) stated that the roof is the part of the building directly exposed to sunlight and therefore termed as ‘a thermal buffer’ and so its insulation is therefore important. In addition, being the part of the building most exposed to solar radiation in daytime, it is considered as the weakest part of the whole building in terms of thermal performance. The type of roof used can determine how much cooling building will require. It is in direct contact with sunlight and therefore can conduct heat directly into the building. Roofing structure could include insulation and ceilings that retard or reflect heat outwards. This reduces cooling loads and need for air-conditioning or mechanical ventilation.

Fenestrations: the size, type, location and number of openings (either windows or doors) impacts on the thermal performance of a building directly. According to research by Zhang et al (2017), generally a WWR of 20–40% has the best performance in both energy demand and thermal comfort. A higher WWR is however required by deeper plan buildings to reduce the demand on lighting and to aid the loss of internal heat and discomfort. These parameters need to be considered as a compromise when deep plan rooms are unavoidable.

An assessment of a building’s physical characteristics includes any, or all, of the following: The building description; length breadth and height, surface area to volume ratio**,** window /wall ratio**,** density of classroom; building materials such as vibrated block wall, bricks, dry wall; plaster board, PVC foam (insulation) infill boards, floor type and floor finishes; material properties; conductivity (k)**,** resistivity (R), absorptivity, ‘U’ value, density**.** Others are building orientation**,** building location, landscaping, type of roofing, type of fenestration and materials.

Status of classrooms in Lagos

Lagos has total number of 1050 primary schools, (Lagos State Statistics,2013). They are grouped into 6 educational districts; namely; Oshodi, Sabo, Maryland, Agboju-Lagos, Victoria Island, and Agege, with their respective zonal heads and offices. A comprehensive survey by the Federal Government in partnership with United Nations International Pupils’ Emergency Fund (UNICEF) and the United Nations Educational, Scientific & Cultural Organization (UNESCO) in 1997 established that the quality of education offered at the primary school level was low, (ESFM report,2013).

In 2010, the population size was 986 primary schools. In 2011, the statistics had risen to 1001 primary schools with over 400,000 pupils and over 13,000 teachers. The ratio of pupils to classrooms was 13 pupils to 1 teacher (Lagos state statistics, 2012). Lagos state statistics (2013) shows population of public primary schools as 1050, which indicates an increase of 49 schools since 2011.

Thermal Performance of Classrooms

The fulfilment of several criteria has been deemed necessary for the attainment of thermal comfort in buildings. Also, it has been noted that orientation has a significant effect on thermal comfort in buildings. Pathirana, et al (2019) propounded that building form and orientation are vital in the sustainable performance of buildings, as achieving thermal comfort without the use of air conditioning is becoming difficult due to poor building designs, and global warming may make the issue worse. Similarly, other researchers proposed that for the tropics, orientation of buildings should be South, so as to take advantage of prevailing winds, (Vanhoutteghem 2015, Lauber, 2005; Szokolay, 2004; Wagner, 2011, Koeniggsberger et al, 1973).

Furthermore, reporting research in the hot dry climate of Dahnah, Lybia, for Elaiab (2014) the findings showed that insulation is key in hot climates (63% of heat gain and 60^0C of indoor temperature could be reduced) if suitable material selection was adopted; this would aid in thermally deflecting external heat. AL Sanea (2002) agreed with this by stating that roof insulation for example, 5cm thick polystyrene, when placed alongside the inner surface of the roof falls will greatly reduce heat load for up to one third (1/3) of its value, when compared with a non-insulated roof of the same material. Previous research carried out on fenestrations and reported in Adebamowo and Godwin (2012), about the analysis of the Bookshop house in Lagos Island, showed that considerable savings were made through the use of solar shading devices incorporated into the facade of the building. This cut down the penetration of heat into the internal spaces, thereby cutting down the cooling loads significantly.

Following a study of classroom envelopes in Cyprus, Katafygiotou and Serghides (2014) reported the analysis of the building envelope materials, characteristics, and thermal conductivities of the classrooms. The discussions showed that the choice of materials in Cyprus classrooms was based only on availability. Considerations for climate, comfort and enhancement of learning were lacking. Hence the constituent materials created an indoor thermal atmosphere that had considerable negative influence on the thermal performance of the classrooms. The results concluded that components with high 'U' value will transmit large amounts of heat indoors, except laid with insulation, or a void included, through which air is passed to dissipate the conducted heat. Also, Elaiab (2014) reported that in research in Dahnah Lybia, it was established that window glazing is a main factor in passive solar design. Windows are responsible for over 25-35% of total heat gain in buildings - the window material, orientation and window to wall area ratio (WWR).

METHODOLOGY

The survey was carried out between April and July 2016 in the 6 educational districts of Lagos, namely; Agege, Maryland, Ikoyi, Sabo, Agboju, and Oshodi. A sample of one hundred and sixty schools was selected from the six educational districts in Lagos state. The characteristics of the classroom blocks of the sampled public primary schools were recorded. Sketches and diagrams of the block plans and location of the measured classrooms were taken through the use of questionnaires by the trained examiners. The PMV (Predicted Mean Vote) votes from each of the surveyed classrooms were also taken via the structured questionnaire. Instruments such as the digital compass, cameras and sketch pads for physical documentation of the characteristics of the classrooms was used. See Figure 5. Measuring thermometers LM 8000, portable hygrometer, TM-82N Dual Input Type K and J Digital thermometer, air temperature and air velocity meters were used during the survey supported by online measuring apps for a wider coverage of the sampling

Figure 5: Portable handheld LM 8000 hygrometers and thermometers
Source: Field work 2017.

The class 2 field experiment method (which combines both the field survey analysis with the responses of the respondents) was used, and protocols according to ASHRAE standard 55 and ISO 7730 were observed. The research design was a mixed method of survey and quasi experiment. Data was gathered through objective and subjective measurements, and physical observation. Also used were data from weather reports and climatic stations, as well as population data from National Bureau of statistics (2012). The research population was 1050 schools. A sample of 200 schools was drawn from the 6 educational districts (from each LGA in the educational zones listed in the Abstract of Local Govt. statistics 2012). Schools were then stratified according to their form and characteristics.

Table 1: The 6 educational districts, LGAs, and the sampling technique

Educational Districts	LGA	SCHOOLS	PERCENTAGE	RATIO
DISTRICT 1	Alimosho, Agege, Ifako Ijaye	149	14%	30
DISTRICT 2	Ikorodu, Somolu, Kosofe	47	15%	30
DISTRICT 3	Epe. Ibeju Lekki, Eti-Osa, Victoria Island	182	18%	45
DISTRICT 4	Surulere, Lagos Mainland, Apapa	144	14%	30
DISTRICT 5	Badagry, Ojo, Amuwo Odofin, Ajeromi/Ifelodun	211	20%	45
DISTRICT 6	Ikeja, Mushin, Oshodi Isolo	158	15%	20

The sample frame is the six educational districts in Lagos namely: Education District 1-Agege, Education District II- Ikeja, Education District III- Ikoyi, Education District IV- Yaba, Education District V- Agboju, Education District VI- Oshodi. A sample frame was extracted from each zone in ratios according to the size of each district. A spread was ensured across each zone so as to capture the characteristics of the entire district a much as possible as shown in Table 1. 200 schools were sampled while after collation, 40 private schools in the samples were removed.

Primary data of objective measurement were taken via the use of measuring instruments. The variables measured were; Air temperature (^{o}c), Relative humidity levels (%), Air velocity (m/s), Mean radiant temperature (^{0}c). The subjects of study were mainly pupils of the ages 4-11years who are in, Nursery 1 to Primary 6.

Temperature and humidity readings (indoor and outdoor) were taken at intervals of 1 hour (for 6-hourly readings) from the centre of the classrooms and at the seating and standing height of the pupils. The orientation of the classroom and the external context of the building were also noted. Clothing levels (a standard uniform) was 0.5clo corresponding with light summer clothing, according to ASHRAE clothing standards. Structured questionnaires recording the details of the buildings' characteristics (elements) were filled out. Discussions and training sessions were conducted prior to the survey, with trained assistants, and also with primary school teachers to determine if the language used and questions asked would be easily understood by the pupils. The thermal comfort questionnaire for the pupils was adapted according to the Humphrey's model (2007) for children.

FINDINGS

The characteristics of the public-school classroom blocks in Lagos state are presented thus: the results shown in Table 2, Table 3, and Figure 6 show the outputs from the field survey.

Table 2: Occurrence of the classroom typologies

Classroom Layout	Linear Layout	Double Loaded	L-shaped Layout	U-shaped Layout
Frequency of samples	120	10	22	8

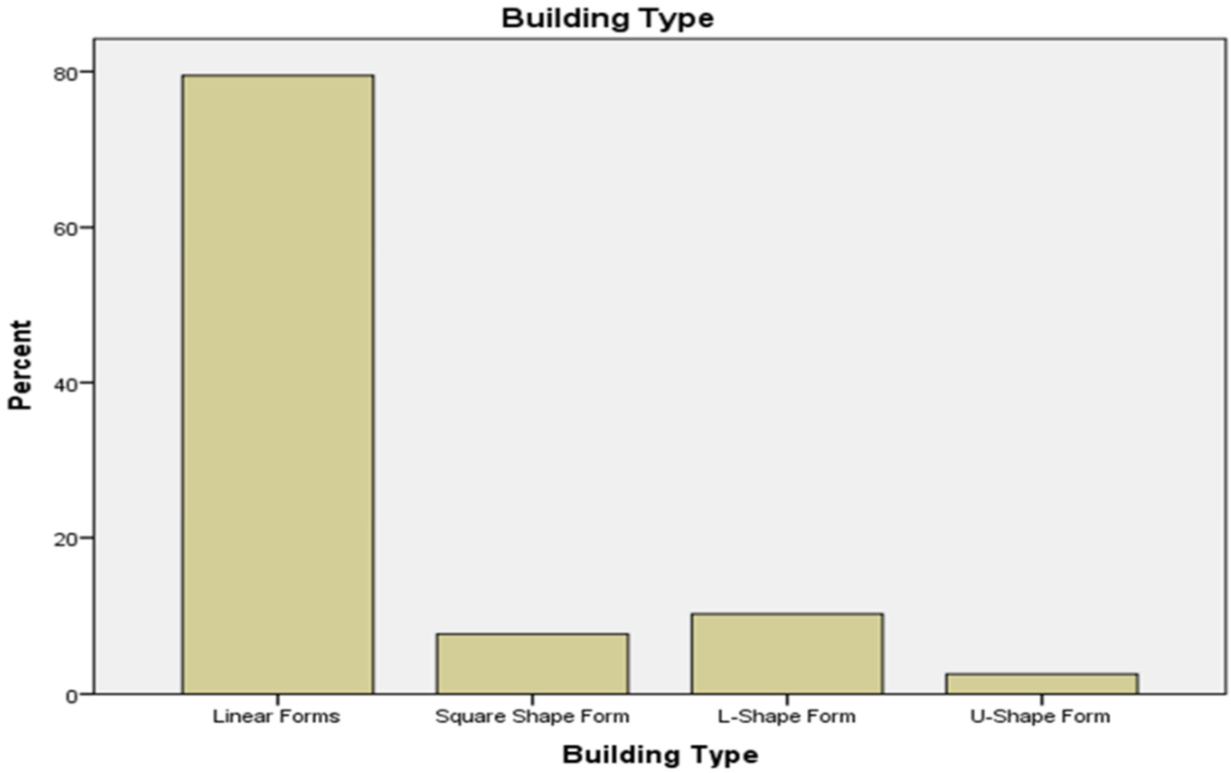

Figure 6: Bar Chat Representing Classroom Typologies in the Field Survey

Table 3: Frequency of Occurrences of Classroom Layout Types

Building Types	Percent	Valid Percent	Cumulative Percent
Linear Form	79.5	79.5	79.5
Square shape Form	7.7	7.7	87.2
L-shape Form	10.3	10.3	97.4
U-shape Form	2.6	2.6	100.0

From the samples taken, the highest classroom typology in occurrence was the linear form, followed by the L-shaped form, the square shaped and finally the U-shaped form of classroom. A Revit-BIM simulation of each classroom form was carried out to determine the energy loading within each block of classroom form. The classroom forms were simulated as a composite form. See the Appendix for the simulation report.

Physical Characteristics of Classroom Envelopes

Table 3 shows type of structures of primary school buildings in Lagos ranging from bungalow to two-story buildings. The highest structure is the two-story building. The most popular building type in primary schools in Lagos was the bungalow with 69.2% while both the first floor and the second-floor types accounted for 15.4% each.

Table 4: The height (levels of floors) of the classroom blocks

GROUPS	Percent	Valid Percent	Cumulative Percent
Bungalow	69.2	69.2	69.2
First Floor	15.4	15.4	84.6
Second Floor	15.4	15.4	100.0
Total	100.0	100.0	

Material of Classrooms and Frequency of Distribution

The different types of classroom material specifications are 12 in number, in A- K in Table 5.

Table 5: 12 variants A- K with similar characteristics

	ROOF	WALL	WINDOW	FLOOR
A	Asbestos	Block wall	Metal	Cement Screed
B	Aluminum	Block wall	Wooden	Tiles
C	Aluminum	Block wall	Metal	Cement Screed
D	Concrete	Block wall	Metal	Cement Screed
E	Aluminum	Block wall	Glass	Cement Screed
F	Aluminum	Wood partition	Glass	Cement Screed
G	Asbestos	Block wall	Concrete fins	Cement Screed
H	Aluminum	Block wall	Wood	Cement Screed
I	Aluminum	Block wall	Metal	Terrazzo
J	Aluminum	Block wall	Glass	Terrazzo
K	Aluminum	Block wall	Glass	Tiles

Table 5 shows occurrence of material specification of the schools, while Table 6 shows the frequency distribution of each material variant in the diagram. Aluminium roof/ block wall/ metal windows/ cement screed floors have the highest occurrence at thirty percent (30.8%), followed by aluminium roof/ block wall/ wooden windows/ cement screed floors at twenty percent (20.5%). At fifteen percent (12%) was aluminium/ block wall/ metal windows/ terrazzo floor, and all the others typologies at 5% and below. This is shown in Table 6.

Table 6: Percentage of Occurrence of Material Typologies Surveyed

Roof-Wall-Window-Floor	Percent	Valid Percent	Cumulative Percent
Asbestos- Block- Metal- Screed	5.1	5.1	5.1
Aluminium- Block- Glass- Terrazzo	5.1	5.1	10.3
Aluminium- Block- Glass- Tiles	5.1	5.1	15.4
Aluminium- Block- Wood- Tiles	2.6	2.6	17.9
Aluminium- Block- Metal- Screed	30.8	30.8	48.7
Concrete- Block Metal- Screed	5.1	5.1	53.8
Asbestos- Block- Concrete Screed	2.6	2.6	56.4
Aluminium- Block- Glass- Screed	5.1	5.1	61.5
Aluminium-Block- Wood- Screed	20.5	20.5	82.1
Asbestos- Block- Wood- Screed	5.1	5.1	87.2
Aluminium- Block- Metal- Terrazzo	12.8	12.8	100.0
Total	100.0	100.0	

The Indicators of Thermal Performance of Classrooms

The result shown in Figure 8 reveals that 24% of the pupils rated the TSV as 'okay', 22% rated it as warm, 17% rated it hot while 9% rated it a bit warm. Also, 14% voted 'cold', 11% rated it cool and 3% rated it a bit cold. In total 48% were in the warm range and 28% in the cold range.

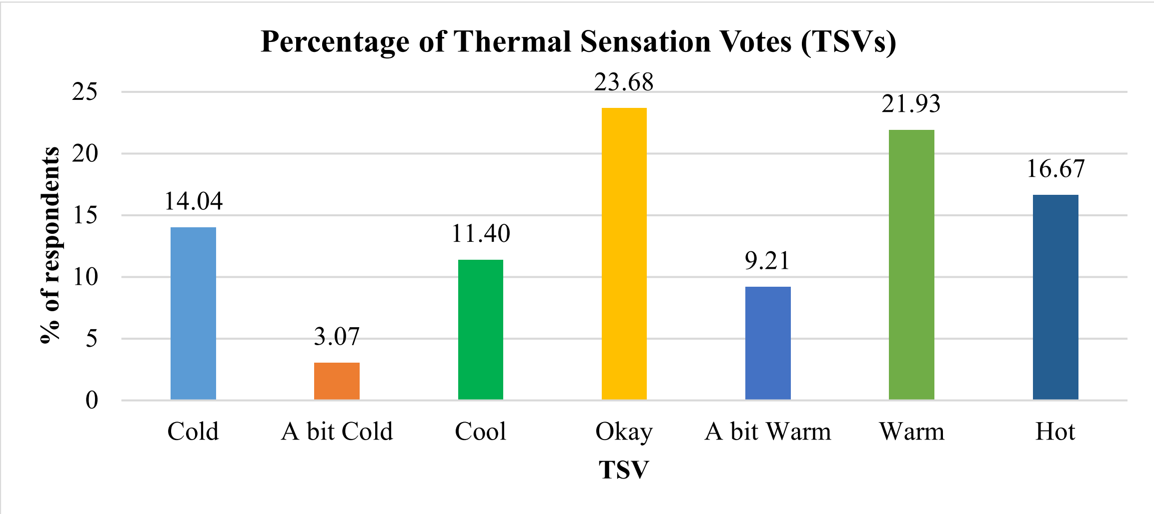

Figure 8: TSV Response Distribution Pattern

As shown in Figure 9, the TPV (Thermal Performance Vote) versus TSV (Thermal Sensation Vote) showed preference for cooler indoor condition by over 50% of the pupils. Furthermore, TPV shows 'okay' at the highest distribution at twenty seven percent (27%), followed by pupils who wished to be a little cooler at twenty three percent (23%), those just warm at eighteen percent (18%). While in the cold range, pupils who wished to be 'a little cold' at fifteen percent (15%) and those who wanted to be 'much colder' at four percent 4%.

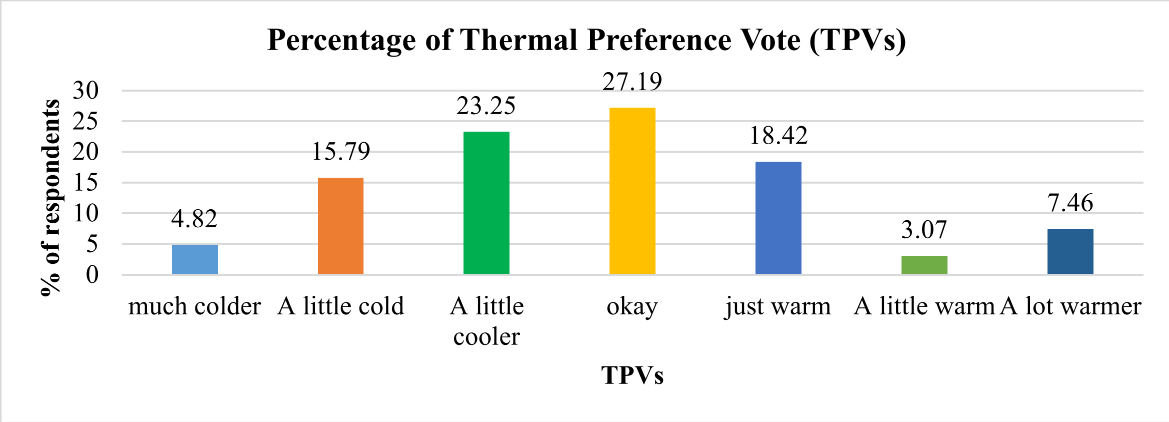

Figure 9: TPV Response Distribution Pattern

The results of analysis of data as shown in Figure 10 indicated that Fifty six percent (56%) of the pupils were happy regardless of their TSV or TPV, twenty five percent (25%) were tired while seventeen percent (17%) were sleepy. It is worthy of note that most of the activities the time of survey were sedentary, with a few of the pupils returning from break time. A greater percentage of pupils felt happier in the hot range of the thermal sensation votes than those in the cold range. This shows great adaptation for hot periods; greater percentage of pupils felt happier in the hot range of the thermal sensation votes than those in the cold range. This shows great adaptation for hot periods.

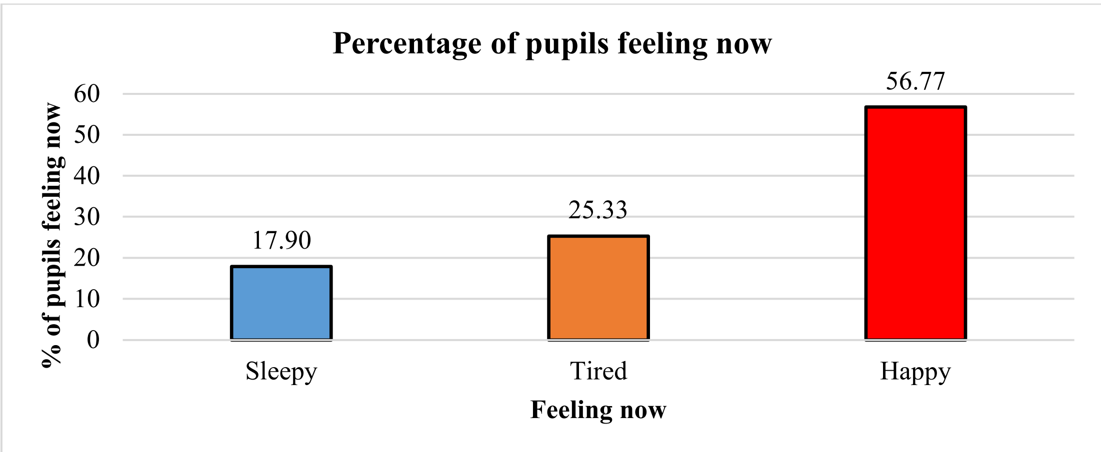

Figure 10: Percentage Vote For "Feeling Now"

As can be seen in Figure 11, apart from those that are in the normal range (okay), the feelings of 'happiness' was higher in the 'warm' to 'hot' range than in the 'cold' range. While the feelings of 'sleepiness' were running hand in hand as you move towards the cold range.

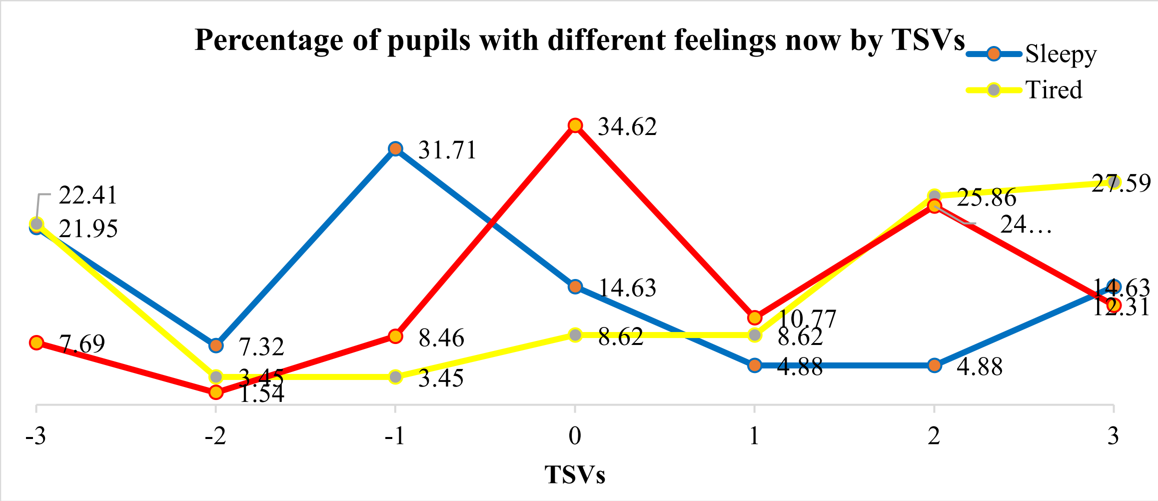

Figure 11: Inferential Statistics of TSVs

Also, as can be seen in Figure 12, there is significant positive linear relationship between the TSV and Air temperature ($p < 0.05$) in the classroom. It shows that while the air temperature of the classroom increases, the TSV of the respondents rose from the cold region to the hot region.

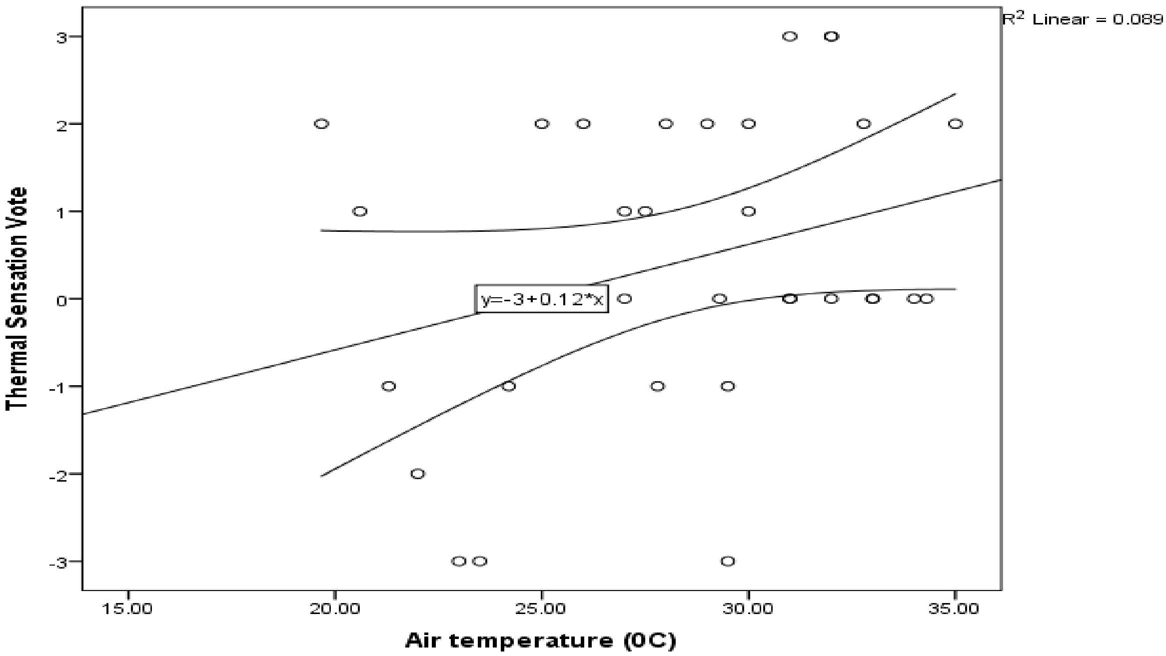

Figure 12: Relationship between TSV and Air Temperature

DISCUSSION AND CONCLUSION

This study was a survey of about 160 government schools in Metropolitan Lagos. For the physical characteristics, the results showed that material variant which had the highest occurrence was the Aluminium roof/ block wall/ metal windows/ cement screed floors variant of all the twelve types. The bungalow structure was also the highest in occurrence amongst the types- the bungalow, first floor and second floor.

A computer simulation analysis was run on Revit-BIM software package. The buildings were simulated as whole composites, as a result of varied samples in the survey. The results showed that the L and U-shaped layout have the least cooling loads - 7295W, compared with those of the other forms. This is similar to results presented by Srhayri et al (2022) which stated that there were lesser cooling loads in U-shaped buildings in all climate types. The U layout therefore offers a greater advantage for thermal efficiency. As stated by Koenigsberger et al, (1976), with proper orientation of the linear layout in the East West direction (which reduces the surface area exposed to the sun-path) the linear option could have been suitable. The use of landscaping, vegetation, reflective glass or sun shading low thermal conductivity materials to reduce cooling loads is also beneficial.

The responses of the pupils showed that there was a great adaptation to heat unlike what was prescribed by ASHRAE. At 29^0C, many respondents voted in as being comfortable. Pupil's responses were "happy" irrespective of the value of the objective measurements taken. This is in favour of the adaptive thermal comfort theory. The U-shaped plan had the lowest cooling loads of all the 4 forms of classrooms (I shaped, L shaped, Square shaped and U-shaped) owing to its self – shading nature, unlike the findings of Zhang et al's (2017), which says the best form for educational buildings is the H form. However, the H form consists of two U shaped forms inverted, hence this can be adapted to the findings of this research.

This research fills the gap in literature with microclimatic data for warm humid regions of Lagos state and the relevant stakeholders will be furnished with the necessary information for the provision of future classroom facilities. This research will help strengthen vulnerable societies by increasing their resilience to climate change (heat in this instance) by empowering the educational sector with suitable infrastructure for quality education which are actions towards the fulfilment of the SDG (Sustainable Development Goals) 6.

Future research

The impact of the material variants of the classrooms on the thermal comfort of pupils can be further explored for selected classroom variants to determine the best materials that are suitable for school classrooms in the tropics. Also, the impact of orientation, external features such as landscaping, nearness to water bodies, as well as building height can be explored

Acknowledgements

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APPENDICES
Revit-BIM MODEL OF THE CLASSROOM BLOCKS

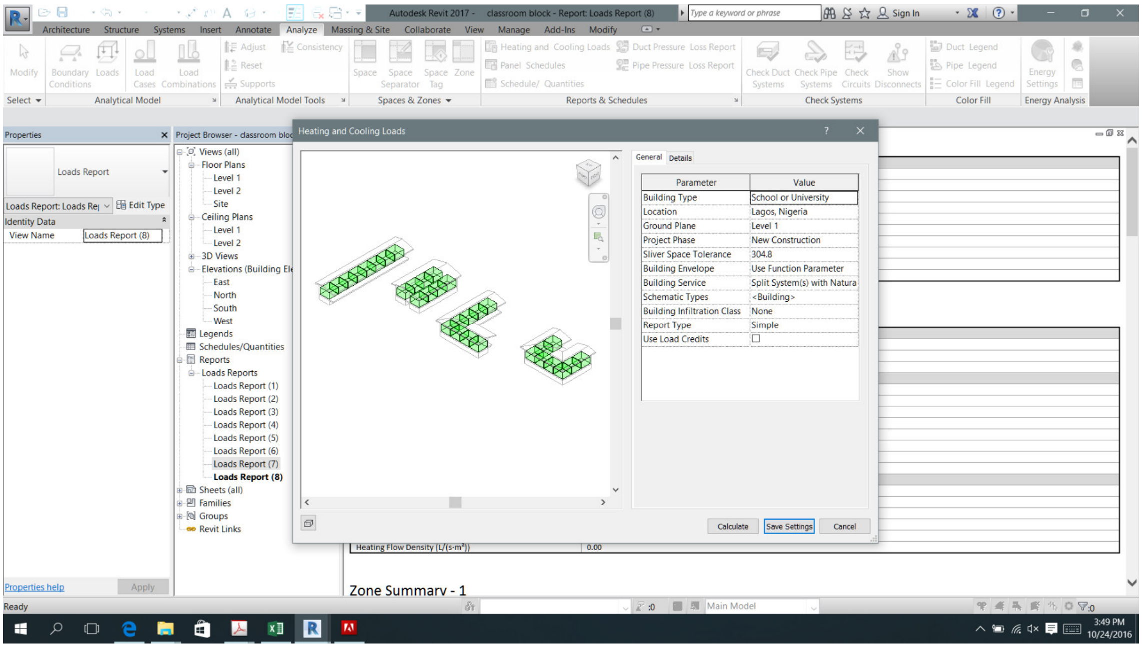

Plate 1: Classroom block load report

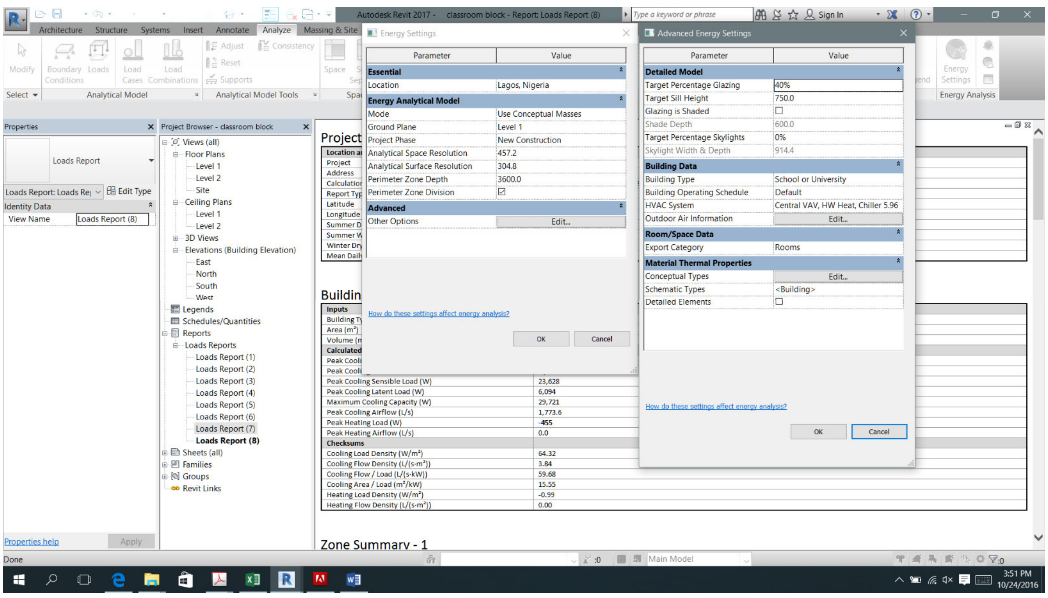

Plate 2: Loading report showing energy settings

Summary of all classroom cooling loads

Project Summary

Location and Weather	
Project	Project Name
Address	## Street City, State Zip
Calculation Time	Monday, October 24, 2016 3:48 PM
Report Type	Simple
Latitude	6.45°
Longitude	3.40°
Summer Dry Bulb	32 °C
Summer Wet Bulb	28 °C
Winter Dry Bulb	22 °C
Mean Daily Range	5 °C

Building Summary

Inputs	
Building Type	School or University
Area (m^2)	462
Volume (m^3)	1,126.74
Calculated Results	
Peak Cooling Total Load (W)	**29,721**
Peak Cooling Month and Hour	April 10:00 AM
Peak Cooling Sensible Load (W)	23,628
Peak Cooling Latent Load (W)	6,094
Maximum Cooling Capacity (W)	29,721
Peak Cooling Airflow (L/s)	1,773.6
Peak Heating Load (W)	**-455**
Peak Heating Airflow (L/s)	0.0
Checksums	
Cooling Load Density (W/m^2)	64.32
Cooling Flow Density ($L/(s{\cdot}m^2)$)	3.84
Cooling Flow / Load ($L/(s{\cdot}kW)$)	59.68
Cooling Area / Load (m^2/kW)	15.55
Heating Load Density (W/m^2)	-0.99

I-shaped Classroom

Zone Summary - 1

Inputs	
Area (m²)	116
Volume (m³)	281.68
Cooling Setpoint	23 °C
Heating Setpoint	21 °C
Supply Air Temperature	12 °C
Air Volume Calculation Type	Split System(s) with Natural Ventilation
Relative Humidity	46.00% (Calculated)
Psychrometric Message	None
Calculated Results	
Peak Cooling Load (W)	**7,487**
Peak Cooling Month and Hour	April 10:00 AM
Peak Cooling Sensible Load (W)	5,963
Peak Cooling Latent Load (W)	1,523
Peak Cooling Airflow (L/s)	447.5
Peak Heating Load (W)	**-111**
Peak Heating Airflow (L/s)	0.0
Checksums	
Cooling Load Density (W/m²)	64.81
Cooling Flow Density (L/(s·m²))	3.87
Cooling Flow / Load (L/(s·kW))	59.78
Cooling Area / Load (m²/kW)	15.43
Heating Load Density (W/m²)	-0.96
Heating Flow Density (L/(s·m²))	0.00

1 Spaces

Space Name	Area (m²)	Volume (m³)	Peak Cooling Load (W)	Cooling Airflow (L/s)	Peak Heating Load (W)	Heating Airflow (L/s)
3 Space	14	35.21	980	60.0	-18	0.0
5 Space	14	35.21	895	54.8	-12	0.0
6 Space	14	35.21	895	54.8	-12	0.0
7 Space	14	35.21	895	54.8	-12	0.0
8 Space	14	35.21	895	54.8	-12	0.0
9 Space	14	35.21	895	54.8	-12	0.0
10 Space	14	35.21	895	54.8	-12	0.0
11 Space	14	35.21	963	58.9	-18	0.0

Square shaped Classroom

Zone Summary - 2

Inputs	
Area (m^2)	116
Volume (m^3)	281.68
Cooling Setpoint	23 °C
Heating Setpoint	21 °C
Supply Air Temperature	12 °C
Air Volume Calculation Type	Split System(s) with Natural Ventilation
Relative Humidity	46.00% (Calculated)
Psychrometric Message	None
Calculated Results	
Peak Cooling Load (W)	**7,645**
Peak Cooling Month and Hour	April 10:00 AM
Peak Cooling Sensible Load (W)	6,121
Peak Cooling Latent Load (W)	1,523
Peak Cooling Airflow (L/s)	459.4
Peak Heating Load (W)	**-123**
Peak Heating Airflow (L/s)	0.0
Checksums	
Cooling Load Density (W/m^2)	66.18
Cooling Flow Density ($L/(s{\cdot}m^2)$)	3.98
Cooling Flow / Load ($L/(s{\cdot}kW)$)	60.09
Cooling Area / Load (m^2/kW)	15.11
Heating Load Density (W/m^2)	-1.06
Heating Flow Density ($L/(s{\cdot}m^2)$)	0.00

2 Spaces

Space Name	Area (m^2)	Volume (m^3)	Peak Cooling Load (W)	Cooling Airflow (L/s)	Peak Heating Load (W)	Heating Airflow (L/s)
12 Space	14	35.21	980	60.3	-18	0.0
13 Space	14	35.21	895	55.1	-12	0.0
14 Space	14	35.21	895	55.1	-12	0.0
15 Space	14	35.21	963	59.2	-18	0.0
16 Space	14	35.21	980	60.3	-18	0.0
17 Space	14	35.21	895	55.1	-12	0.0
18 Space	14	35.21	895	55.1	-12	0.0
19 Space	14	35.21	963	59.2	-18	0.0

L- Shaped Classroom

Zone Summary - 3

Inputs	
Area (m^2)	116
Volume (m^3)	281.68
Cooling Setpoint	23 °C
Heating Setpoint	21 °C
Supply Air Temperature	12 °C
Air Volume Calculation Type	Split System(s) with Natural Ventilation
Relative Humidity	46.00% (Calculated)
Psychrometric Message	None
Calculated Results	
Peak Cooling Load (W)	**7,295**
Peak Cooling Month and Hour	April 10:00 AM
Peak Cooling Sensible Load (W)	5,772
Peak Cooling Latent Load (W)	1,523
Peak Cooling Airflow (L/s)	433.1
Peak Heating Load (W)	**-111**
Peak Heating Airflow (L/s)	0.0
Checksums	
Cooling Load Density (W/m^2)	63.15
Cooling Flow Density (L/(s·m^2))	3.75
Cooling Flow / Load (L/(s·kW))	59.37
Cooling Area / Load (m^2/kW)	15.84
Heating Load Density (W/m^2)	-0.96
Heating Flow Density (L/(s·m^2))	0.00

3 Spaces

Space Name	Area (m^2)	Volume (m^3)	Peak Cooling Load (W)	Cooling Airflow (L/s)	Peak Heating Load (W)	Heating Airflow (L/s)
20 Space	14	35.21	980	59.6	-18	0.0
21 Space	14	35.21	895	54.4	-12	0.0
22 Space	14	35.21	895	54.4	-12	0.0
23 Space	14	35.21	895	54.4	-12	0.0
24 Space	14	35.21	861	52.4	-12	0.0
25 Space	14	35.21	833	50.6	-12	0.0
26 Space	14	35.21	833	50.6	-12	0.0
27 Space	14	35.21	934	56.8	-18	0.0

U-Shaped Classroom

Zone Summary - 4

Inputs	
Area (m^2)	116
Volume (m^3)	281.68
Cooling Setpoint	23 °C
Heating Setpoint	21 °C
Supply Air Temperature	12 °C
Air Volume Calculation Type	Split System(s) with Natural Ventilation
Relative Humidity	46.00% (Calculated)
Psychrometric Message	None
Calculated Results	
Peak Cooling Load (W)	**7,295**
Peak Cooling Month and Hour	April 10:00 AM
Peak Cooling Sensible Load (W)	5,772
Peak Cooling Latent Load (W)	1,523
Peak Cooling Airflow (L/s)	433.1
Peak Heating Load (W)	**-111**
Peak Heating Airflow (L/s)	0.0
Checksums	
Cooling Load Density (W/m^2)	63.15
Cooling Flow Density ($L/(s{\cdot}m^2)$)	3.75
Cooling Flow / Load ($L/(s{\cdot}kW)$)	59.37
Cooling Area / Load (m^2/kW)	15.84
Heating Load Density (W/m^2)	-0.96
Heating Flow Density ($L/(s{\cdot}m^2)$)	0.00

4 Spaces

Space Name	Area (m^2)	Volume (m^3)	Peak Cooling Load (W)	Cooling Airflow (L/s)	Peak Heating Load (W)	Heating Airflow (L/s)
28 Space	14	35.21	980	59.6	-18	0.0
29 Space	14	35.21	895	54.4	-12	0.0
30 Space	14	35.21	861	52.4	-12	0.0
31 Space	14	35.21	833	50.6	-12	0.0
32 Space	14	35.21	833	50.6	-12	0.0
33 Space	14	35.21	849	51.6	-12	0.0
34 Space	14	35.21	895	54.4	-12	0.0
35 Space	14	35.21	980	59.6	-18	0.0