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Developing Air Conditioning Control And Monitoring For Energy Efficiency: Application In A Research Institute

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ABSTRACT
Energy efficiency in cooling systems is a viable way to minimize energy costs and maybe cut down on energy waste for the greater good of the environment, safety, and economic viability which can be achieve through building automation system (BAS). The term "building automation system" refers to a system that is installed in buildings and is in charge of managing the building services that include air conditioning, lighting, shading, heating, ventilation, air conditioning, alarm security systems, and many more. Inspection and load survey of air conditioners in some selected offices was carryout to ascertain energy consumes. To optimize the thermal condition of the occupants, modelling and simulation was carryout base on ASHRAE 55 standard. A total of 109 ACs units with installed power rated of capacity of 200,64KW. The result of the load survey shows that thermal comfort account for more than 56% of the energy consumed in the Nigerian Building and Road Research Institute (NBRRI) Administrative headquarters. The result for energy consumption and cost analysis after simulation for 200hours which is 25 working days in a month is 28,646.40kilowatt hour at the rate of N 65 per kilowatt hour was ₦1,862,016.00 for 2units of 2horse power under optimum condition. Air conditions were serviced, repositions and retrofitted and was resulted to more 25% energy saving at the same time conformed with ASHRAE 55 standard thermal comfort requirement.

Keywords: air condition, energy efficiency, building automation, retrofitting, cost saving

I. INTRODUCTION

Building automation system (BAS) consists of a system installed in buildings that controls and monitors building services responsible for heating, cooling, ventilation, air conditioning, lighting, shading, life safety, alarm security systems, and many more (Brambley, et al 2005). BAS aims at automating tasks in technologically-enabled environments, coordinating a number of electrical and mechanical devices interconnected in a distributed manner by means of underlying control networks. These systems may be deployed in industrial infrastructures such as factories, in enterprise buildings and malls, or even in the domestic domain. Building automation has been receiving greater attention due to its potential for reducing energy consumption and facilitating building operation, monitoring and maintenance, while improving occupants' satisfaction. These systems achieve such potential by employing a wide range of sensors (e.g., for sensing temperature, CO2 concentration, zone airflow, daylight levels, occupancy levels), which provide information that enables decision-making regarding how the building equipment will be controlled, aiming at reducing expenses while maintaining occupant comfort (Brambley, et al 2005).

Public/commercial buildings represent 18% of US primary energy consumption with carbon dioxide emissions at 36% of all US electricity use (EIA 2015; EIA 2017). Although the average total energy use per square foot has declined approximately by 10% over the past decade, total electricity consumption in commercial buildings has been steadily climbing (EIA 2016). Electricity now accounts for 61% of all energy consumed in commercial buildings, while natural gas accounts for 32%. The breakdown in end-use electrical consumption is as follows: heating, ventilation, and air conditioning (HVAC) at 33%, miscellaneous loads at 32%, lighting at 17%, refrigeration and cooking 18% (EIA 2016). Commercial buildings can save energy by using advanced sensors and automated controls in HVAC, plug loads, lighting, and window shading technologies, as well as advanced building automation and data analytics. Buildings that have advanced controls and sensors along with automation, communication, and analytic capabilities are known as smart buildings. In a fully-fledged smart building, the building systems are interconnected using information communications technologies (ICT) to communicate and share information about their operations. Smart building technologies can provide facilities operators with the tools to anticipate and proactively respond to maintenance, comfort, and energy performance issues, resulting in better equipment maintenance, higher occupant satisfaction, and reduced energy consumption and costs.

Problem Statement

In the tropic region, there is high demand for cooling system thereby improving thermal comfort for occupant in building. However, the associated cost leads to high running cost for cooling system. Energy efficiency for cooling systems offers a sustainable solution to potentially reduce energy wastage as well as minimising energy cost for the overall benefit of the environment, security and economic sustainability.

Research Justification/Significance of the Study

Nonetheless, in moving forward, it is of significance to note that the market potential in Nigeria for cooling technology is of high prospect. As such, automating and retrofitting will drastically reduce the cost of cooling office buildings. Also, the build-up on the existing energy audit developed by the Institute to produce energy efficiency measures on energy consumption, space cooling with particular interest in office building is beneficial to Nigeria and forms a case study for other public buildings.

Aim and Objective of the Study

The aim of this study is to automate and maximize energy efficiency in the Nigerian Building and Road Research Institute (NBRRI) Administrative Headquarters Abuja, in order to minimise running/maintenance cost through the following objectives to:

i. Conduct site/load survey to establish building and operational characteristics.
ii. Collection data of energy usage for re-evaluation and redesigning of the Air Conditioning system of some selected office space.
iii. Analyse data through simulation of the define space of interest in the building to identify opportunities of reducing energy use and cost.
iv. Perform analysis of the result obtain from simulation for potential modification.
v. Implementation of potential modification measures such as retrofitting and redirection of ACs flows where necessary.
vi. Install energy monitoring device in the building to determine energy consumption of the ACs after retrofitting.
vii. Installation of PIR, temp and motion switches to eliminate waist of energy and reduce the number of hours work in a day while maintaining occupant comfort.
viii. Technical and cost Performance evaluation of building automation solution.

II. METHODOLOGY

- Inspection of some offices of interest was carryout in the institute administrative headquarter to ascertain the operational working capabilities of some air conditioning system, during which performances issues was observed in the fourth floor at the general offices of admin and personnel and the account and finance departments.
- Modelling and simulation of selected spaces was carryout and the result of which was carefully studies and analysed for implementation.
- Energy monitor equipment (Smappee Infinity) was installed and the readings taken for further analysis and implementation.
- Retrofits some of the office ACs and monitoring the effects of the outcome.

Scope/Limitation of the Study

The study is limited to implementing the recommendation of the energy audit on cooling load conducted in NBRRI while developing building automation system for the NBRRI Administrative Headquarters Abuja by redesigning/retrofitting the cooling load (Air Conditioning System).

III. LITERATURE REVIEW

S/N	Author	Year	Topic	Finding
1	Abu, A.S.P.,	2021	Energy consumption analysis and potential energy savings of a Public Building in Nigeria.	It is recommended to consider ESOs as part of the Institutes' initiative to reduce energy consumption and operational costs. Also, educate staff on awareness of wasteful energy practices and to install sub-metering systems at each floor that will provide detailed analysis of energy consumption of various systems.
2	Dunn P.,	2015	Measurement and Data Analysis for Engineering and Science.	Building operators can use these static pressure readings to control the HVAC systems to operate at a particular duct static pressure, and can even use the measurement to identify HVAC system faults
3	Wang, W. S.,	2013	Advanced Rooftop Control (ARC) Retrofit: Field-Test Results.	The study found approximately 50% electricity savings for RTUs with a three-year payback, even in regions with low electricity prices (Wang et al. 2013).
4	Gabriel I. F.,	2021	Evolution of Smart Buildings	System reliability is an important issue also. Developing a decentralized network or a local area network (LAN) is the key will solve the system reliability issues and simplify IB networks. Distributed intelligence is a major optimal solution to ensure connection through complex IB and BA systems.
5	Tolga T.,	2012	"How to defeat the massive plug-load monster"	Describe plug loads are a major provider to building energy consumption, especially in offices. In commercial buildings, plug loads are one of the fastest-growing end uses in terms of energy consumption and typically account for 30-35 percent of the total electricity used

HVAC controls accordingly, thereby avoiding wasted HVAC usage.

IV. MATERIALS AND METHOD

METHODOLOGY

- Inspection of some offices of interest was carryout in the institute administrative headquarter to ascertain the operational working capabilities of some air conditioning system, during which performances issues was observed in the fourth floor at the general offices of admin and personnel and the account and finance departments.
- Modelling and simulation of selected spaces was carryout and the result of which was carefully studies and analysed for implementation.
- Energy monitor equipment (Smappee Infinity) was installed and the readings taken for further analysis and implementation.
- Retrofits some of the office ACs and monitoring the effects of the outcome.

1.1 Materials required

The materials needed for this project is listed as follows:

- 3phase Energy Monitor
- PIR/Sensor/motion switches
- Conductors (wires 4mm)

- Galvanized pipes
- Conduits pipes
- Insulating tapes
- Duct tapes
- Workshop jackets (Overall)
- Bags of cement
- Paints
- Software for simulation
- Stand-alone internet
- Temperature and Humidity Sensor
- AC Flow meter
- AC Leak sensor
- Sharp and Plaster sand

1.2 Method

This project is focus on retrofitting the ACs, this imply changing the direction of low (repositioning) of the split units, PIR switches for the ACs was installed where necessary, we consider which AC to be load or peak load to allow for installation of motion sensor or any other switch that will meet up the requirement. To actualize these, a simulation software was required to identify where the ACs will be reposition and how many AC is required for each space to meet with the standard. To sustain the outcome of the project we developed a maintenance schedule sheet with date and signature in each office.

Since this study has a research dimension, monitoring energy consumption and Energy Saving Opportunities reported in Vesma, (2011) will be used as a reference to improve data collection where necessary and Operation and Maintenance (O&M) activities. Based on the available resource, the energy team will define the area to be audited and time frame in order to achieve the desired objective of the study.

Firstly, the building complex has no historical data for comparison and the total electricity consumption is measured by only one meter installed at the energy outflow terminal from the incoming 500kVA transformer. The meter was installed in November, 2018 and the building was occupied in January, 2019. To address this issue, the energy audit team installed Smappee Infinity energy management system to aid in identifying, measure and evaluate the load contributors to the total building energy consumption.

Then the Cooling Load Calculation Method will be use. In this study the CLTD/SCL/CLF method will be considered to calculate the required cooling loads. No alterations to the original method, including the values of all coefficients.

Electricity consumption by air-conditioning, from site survey, the largest rated component is air-conditioning. Therefore, electricity sub-metering system installed by the audit team provided the contribution of the air conditioning load to the overall electrical usage of the building complex. The air-conditioning system consists of multiple split air conditioning systems independently controlled by occupants in offices, construction laboratories, conference/seminar rooms, library and so on. There are a total of 109 units with total installed rated power capacity of 200.64kW. The monthly electricity consumption profile of air condition over the entire audit period shows the average monthly proportion of electricity consumption of air conditioning equipment is 52.19% which may vary from dry season to wet season. Again, we are considering to changing the direction of flow.

V. RESULT AND DISCUSSION

5.1 Simulation Result

ASHRAE 55 defines thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment", although ASHRAE 55 is predominately adopted in the United States, nonetheless it is well known around the world as the standard for designing, commissioning, and testing indoor spaces and systems. This standard is often written in parallel with other well-known international standards such as ISO 7730.

This simulation report measures thermal comfort using ASHRAE 55 standard's chart or method as shown in Figure 1 below:

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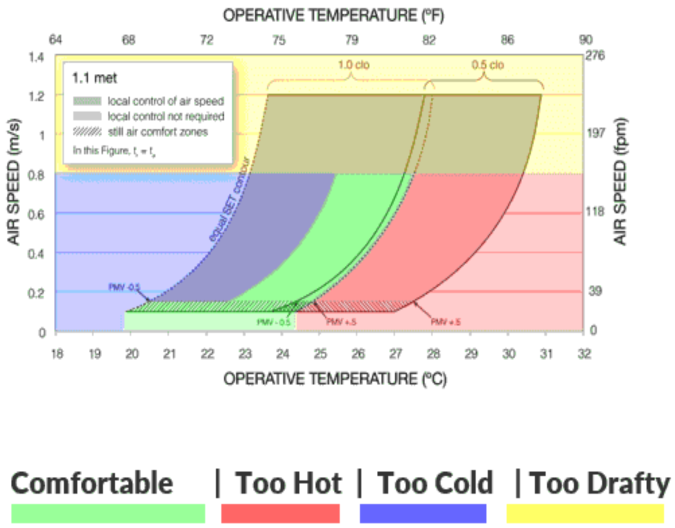

Fig. 1: Thermal Comfort Method/Chart

ASHRAE 55 Standards (Jenkins, 2020)

The ASHRAE standard 55 was first published in 1966. The standard is updated every 3 to 7 years. These updates are conditioned on current research, practical experience, and recommendations from designers, manufacturers, and end users. The most notable, as well as most recent iterations of the standard are the 2004, 2010, and 2017 editions.

ASHRAE Standard 55 – 2004

The 2004 ASHRAE update introduced a few critical changes that lessened the criteria gap between it and its ISO standard counterparts. This included the adoption of the computer model method, the introduction of the adaptive method (or model that relates indoor design temperature ranges to outdoor meteorological parameters) based on research that supports natural ventilation designs, and the recognition of elevated airspeed preference for general occupant thermal comfort.

ASHRAE Standard 55 – 2010

The 2010 update reintroduced standard effect temperature (SET) as the method of evaluating and determining the cooling effect of elevated airspeeds and indoor air movement as a whole, made large revisions to clearly specify mandatory minimum requirements in both design analysis and documentation to comply with the standard, and added a general satisfaction survey and post-occupancy evaluation (POE) as a method of pre-emptively as well as retroactively evaluating thermal comfort for occupants in a space.

ASHRAE Standard 55 – 2017

The newest 2017 ASHRAE 55 standard update includes a new element that can take into consideration the change in occupants' thermal comfort from direct solar radiation, in addition to the existing scope, requirements, conditions, and parameters we will discuss below.

ASHRAE 55 Thermal Comfort Terminologies (Jenkins, 2020)

ASHRAE 55's terminologies are categorised by Environmental Factors/Inputs, and Predictive Results/Outputs. Both input and output categories have their subdivisions. These categories and their subdivisions are discussed next.

Environmental Factors/Inputs

Airspeed/Velocity:

The rate of air movement at a given point in time regardless of the direction.

Clo:

The unit used to represent the thermal insulation from clothing, where 1clo = winter clothing and 0.5 clo = summer clothing. There is a difference between clothing insulation (Icl), which includes even parts of the occupants' body uncovered by clothing, and garment insulation (Iclu), which only refers to heat transfer obtained from skin to clothing contact.

Metabolic Rate (M):

The rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in

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terms of unit area of the total body surface. In this standard, the metabolic rate is expressed in met units. This unit is accounted for as the personal activity of occupants, where 1 met is a person at rest.

Fig. 2: Chart explaining different metabolic rates for activity types (Sandip, 2018)

Relative Humidity (RH):

The ratio of the partial pressure (or density) of the water vapour in the air to the saturation pressure (or density) of water vapour at the same temperature and the same total pressure.

Mean Radiant Temperature (tr):

The uniform surface temperature of an enclosure where an occupant would exchange the same amount of heat as in the actual non-uniform space, calculated from the weighted temperature average of each surface divided by the total area of the space.

Predictive Results/Outputs

Predicted Mean Vote (PMV):

An index that predicts the mean value of votes of a group of occupants on a seven-point thermal sensation scale that is based on the balance of heat within the human body. This balance, much like thermal neutrality, is obtained when an occupant's internal heat production is the same as its heat loss. As humans, our thermoregulatory system modifies our temperature by sweat secretions to keep us thermally balanced and to avoid local discomfort. Different methods can be used to assess this for different combinations of metabolic rate, insulation, temperature, airspeed, mean radiant temperature, and relative humidity, and our computation method will be addressed in the latter part of this article.

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

Table 1: Seven-point thermal sensation scale (Beizaee and Firth et al)

Predicted Percentage of Dissatisfied (PPD):

An index that establishes a quantitative prediction of the percentage of thermally dissatisfied occupants (i.e., too warm or too cold). The PPD is calculated from the PMV, as it can be found from the distribution of individual thermal sensation votes compiled collectively.

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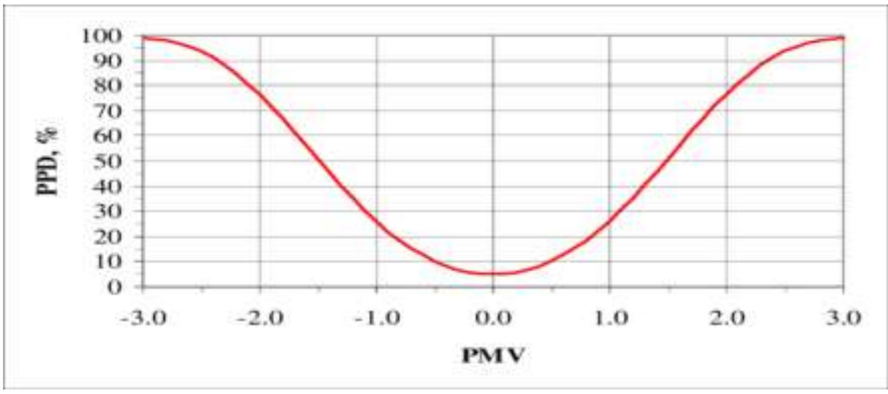

Fig. 3: PPD as a function of PMV (Markov, 2002)

Simulation Parameters

Enumerated below are simulation parameters that were adopted while designing and running the simulation. The simulation was designed and executed on Blender 2.93 in order to produce realistic results. Since the likelihood of turbulence occurring within the office space is minimal, thus 0.0 was selected as the likely value. While a wind velocity of 0.1 was selected to ensure vortexes and turbulences are not automatically created during simulation. A metabolic rate (MET) of 1.1 was chosen to reflect the expected state of busy staffs.

Parameter	Value
Wind Velocity	0.1
Wind Turbulence	0.0
MET (Metabolic Rate)	1.1
Simulation Duration	2,500 milliseconds (ms)

Table: 2: Simulation Parameters

Wind Velocity Report

Simulation result captured in Figure 5 reveals AC1 and AC2 produces clear airflow and smooth large-scale convection current. This smoothness is equally observable when wind currents from both ACs mildly collide. Nonetheless, wind velocity from AC1 will likely influence staffs located in partitions P1 and P3 to consider wind velocity as draft. However, staff metabolism rate (Figure 4) and clothes will play a key role in determining the validity of such complains. Thus a staff who is busy typing will find ambience temperature more comfortable compared to a staff that is idling, chatting or reading during office hours.

Fig. 4: Staff metabolism

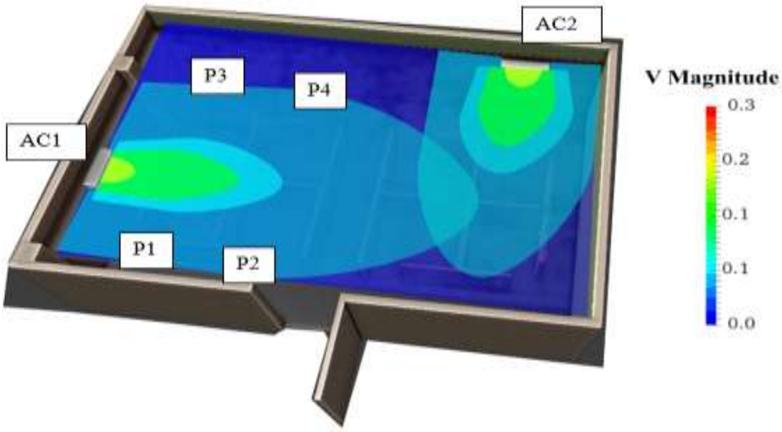

Fig. 5: Wind velocity simulation result

Temperature Field Report
Figure 6 represents simulation results showing the temperature field after 2500ms. A brief summary of the results is enumerated below:

i. The entire office is adequately covered by both ACs and achieves ASHRAE 55's **Slightly Cool** score (light green).
ii. Spaces around the light green boundary recorded ASHRAE 55's **Cool** score – this is due to their proximity to both ACs. This area covers the entire partitioned area.
iii. ASHRAE 55's score of **Slightly Cold** is assigned to the area within **Cool** boundary.
iv. While **Cold** score is assigned to the immediate vicinity of the ACs.
v. A final score of **Too Cold** is assigned to the area around both AC outlets.

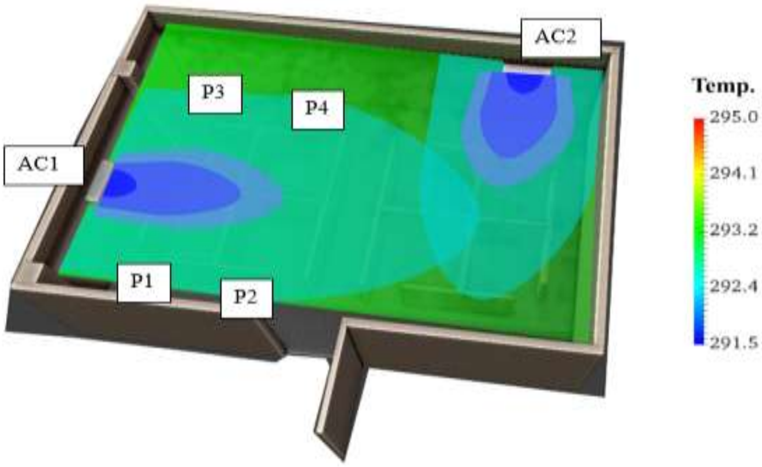

Fig. 6: Temperature field simulation result

Effective Draft Temperature (EDT) Report
The EDT result captured in Figure 7 reveals a large percentage of the enclosed office space has a comfortable ambience temperature. However, as started earlier, staffs in P1 and P3 may complain of drafty conditions if their rate of metabolism drops below 1.1 MET.

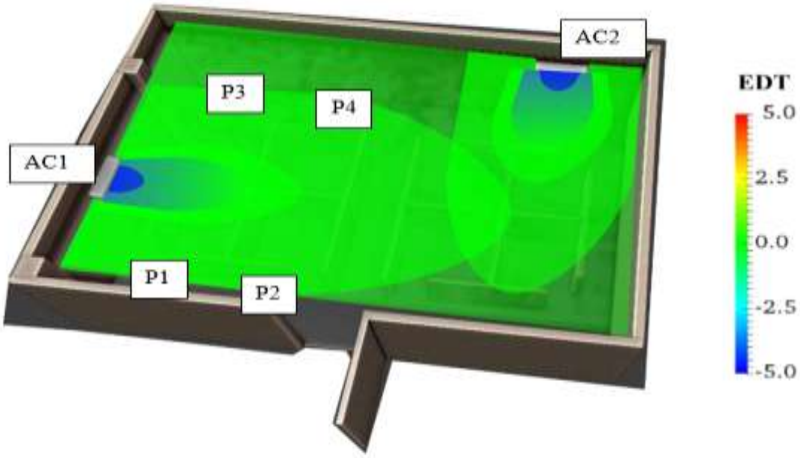

Fig. 7: Temperature field simulation result

Conclusion

The simulation assumes zero cool leakages within the enclosure and that the ACs are working at optimum performance. Moreover, staffs are expected to meet a minimum of 1.1 MET during office hours in order to properly measure AC draftiness.

5.2 Equipment/Instrument used for the studies

i. Purchases of measuring instruments/equipment necessary for the load survey were done and already taking of readings has begun. Below are pictures of the instruments/equipment

Fig. 8: Energy Monitoring Device

Fig. 9: An Anemometer for Measuring Air flow of ACs

Fig. 10: Digital Temperature and Humidity meter

- Also modelling and simulation of some selected office spaces was carryout and the result of which justified the need for reposition some air conditioners retrofits, for overall economic benefit of the institute and government.
- Equipment such as anemometer for measuring ac flow velocities, temperature and humidity sensors, moisture and humidity sensors were obtained to measure the thermal comfort of the selected spaces
- Some ACs positions were change from adjacent to opposite direction and all ACs were services for optimal performance.
- Smappee infinity energy monitoring and measuring device was installed to ascertain the actual load incurred by ACs within a given space.


Figure 11: Team Members Taking Thermal Comfort Reading Using Anemometer, Humidity, Moisture and Temperature Sensors.

Table 1: Result obtained from the selected area of study on the 25th January 2022.

Time (Hr)	Temperature (℃)	Humidity (%)	Wind Speed (m/s)
09:00	25.1	29.4	0.949
10:00	23.4	33.3	0.843
11:00	22.9	36.7	1.230
12:00	22.1	24.4	0.367
13:00	25.5	33.7	0.704
14:00	23.7	30.6	0.722
15:00	23.1	35.2	1.235
16:00	23.4	37.7	1.312

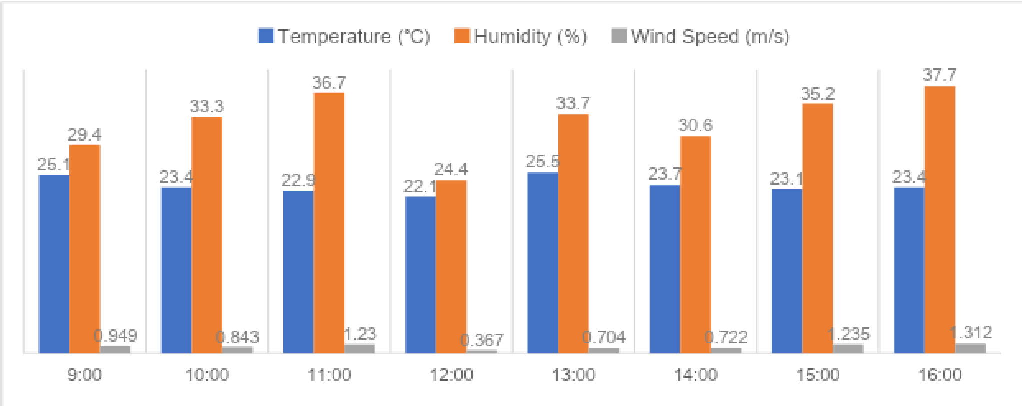

Figure 12: Performance Evaluation AC1

Table 2: Result obtained from the selected area of study on the 26th January 2022.

Time (Hr)	Temperature (°C)	Humidity (%)	Wind Speed (m/s)
09:00	24.8	24.7	1.083
10:00	21.5	29.7	0.527
11:00	20.9	30.4	0.938
12:00	21.4	33.2	0.549
13:00	24.5	30.8	1.678
14:00	24.0	28.6	1.573
15:00	24.1	31.7	1.342
16:00	24.8	33.2	0.782

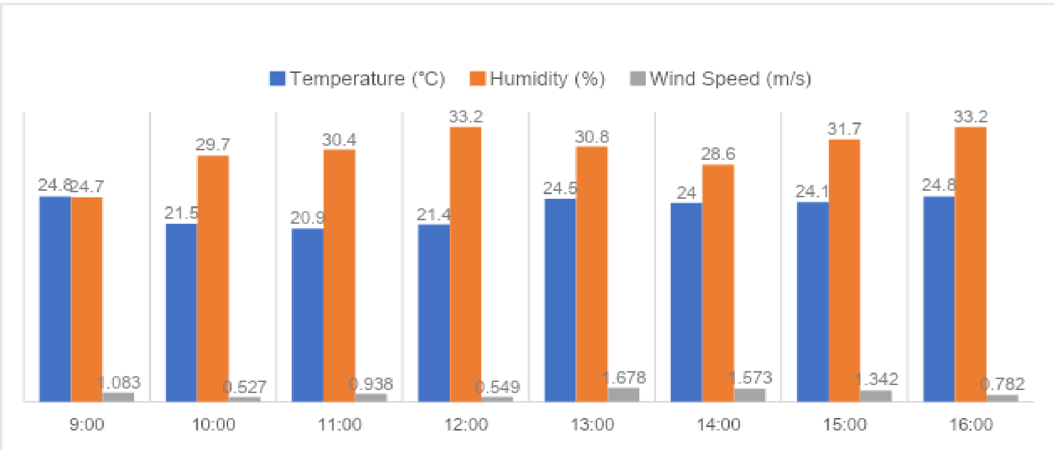

Figure 13: Performance Evaluation AC1

Table 3: Result obtained from the selected area of study on the 27th January 2022.

Time (Hr)	Temperature (°C)	Humidity (%)	Wind Speed (m/s)
09:00	26.4	29.2	0.131
10:00	25.2	32.5	0.992
11:00	25.1	30.5	2.032
12:00	24.5	28.9	2.334
13:00	24.1	30.6	0.590
14:00	24.5	29.9	1.302
15:00	24.6	29.0	1.235
16:00	24.4	31.3	1.962

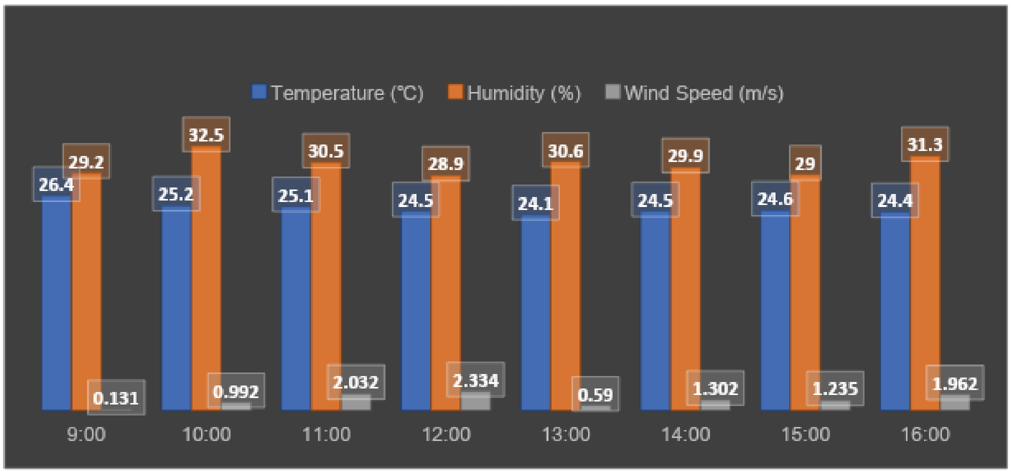

Figure 14: Performance Evaluation AC1

Table 4: Result obtained from the selected area of study on the 28th January 2022.

Time (Hr)	Temperature (°C)	Humidity (%)	Wind Speed (m/s)
09:00	26.2	28.1	1.085
10:00	25.0	32.4	0.908
11:00	22.3	30.5	0.946
12:00	23.9	29.2	0.827
13:00	23.9	31.5	1.734
14:00	24.7	34.5	1.157
15:00	24.2	30.3	1.530
16:00	24.4	30.	2.305

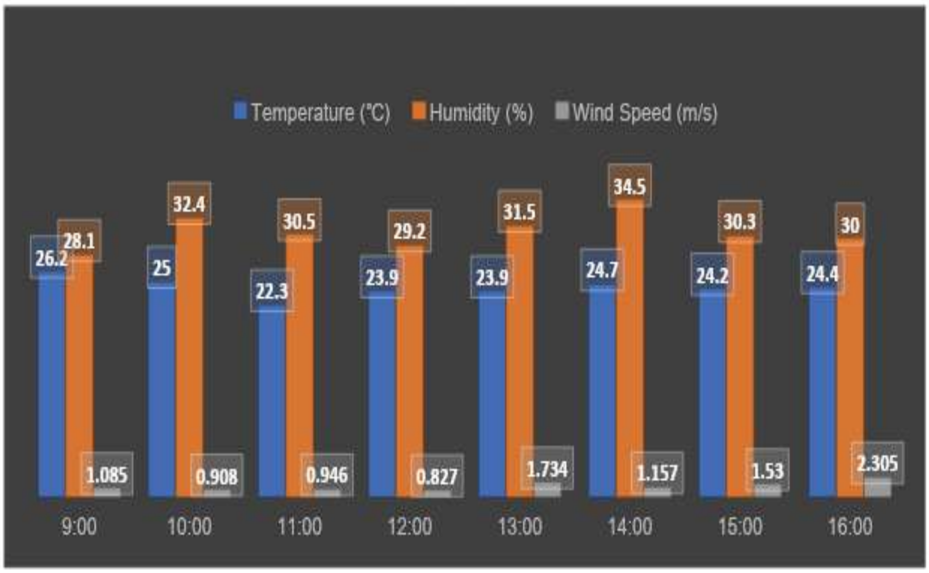

Figure 15: Performance Evaluation AC1

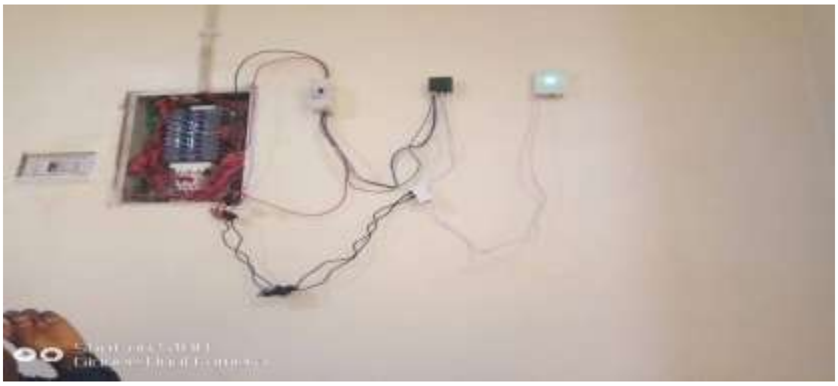

Fig. 16: Installed Energy Monitor Measuring Power Consumption of Air Conditioners

5.3: AC Power Usage Simulator/Estimator

Compute AC Power Usage and Cost

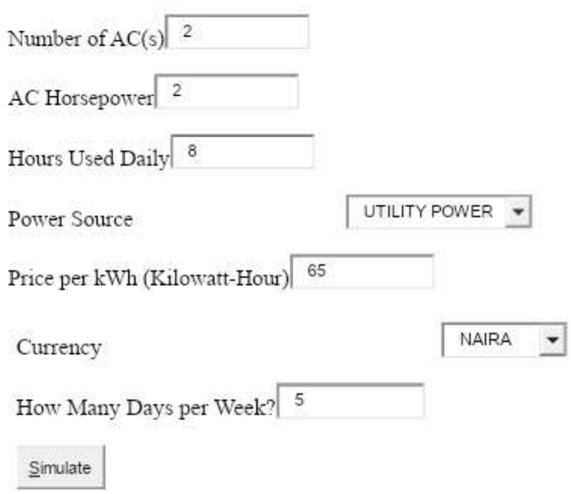

Table 5:

Time (Minutes)	Consumption (Wh)	Consumption (kWh)	Amount (65/kWh)
1	49.73	0.05	3.23 NGN
2	99.47	0.10	6.47 NGN
3	149.20	0.15	9.70 NGN
4	198.93	0.20	12.93 NGN
5	248.67	0.25	16.16 NGN
6	298.40	0.30	19.40 NGN
470	23,374.67	23.37	1,519.35 NGN
471	23,424.40	23.42	1,522.59 NGN
472	23,474.13	23.47	1,525.82 NGN
473	23,523.87	23.52	1,529.05 NGN
474	23,573.60	23.57	1,532.28 NGN
475	23,623.33	23.62	1,535.52 NGN
476	23,673.07	23.67	1,538.75 NGN
477	23,722.80	23.72	1,541.98 NGN
478	23,772.53	23.77	1,545.21 NGN
479	23,822.27	23.82	1,548.45 NGN
480	23,872.00	23.87	1,551.68 NGN

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The result of the simulation shows ACs consumption in kilowatt hour(kwh) for a period of eight working hours in a day with it corresponding amount under optimal working condition.

Table 6 showing monthly total

Hours	Consumption (Wh)	Consumption (kWh)	Amount (65/kWh)
200	28,646,400.00	28,646.40	1,862,016.00 NGN

The result is for energy consumption and cost analysis for only 200hours which is 25 working days in a month in kilowatt hour at the rate of N 65 per kilowatt hour

5.4: Repositioning of ACs

Some ACs were reposition for optimum performance as suggested by the simulation report in fig. 5, 6 & 7 and the impact of which was validated as shown in the fig. below

Fig.17: Showing the new position of the two ACs from the red box to the current position

Figure 18: Showing the new position of the second AC from the red box to the current position

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5.5 Energy Monitoring Result

The result of the daily energy consumption of any structure is a function of many factors. The chat in fig. 14 shows variation in the consumption pattern of the two ACs under investigation and this can be attributed to power supply, working condition, individual efficiency of the ACs amongst other things.

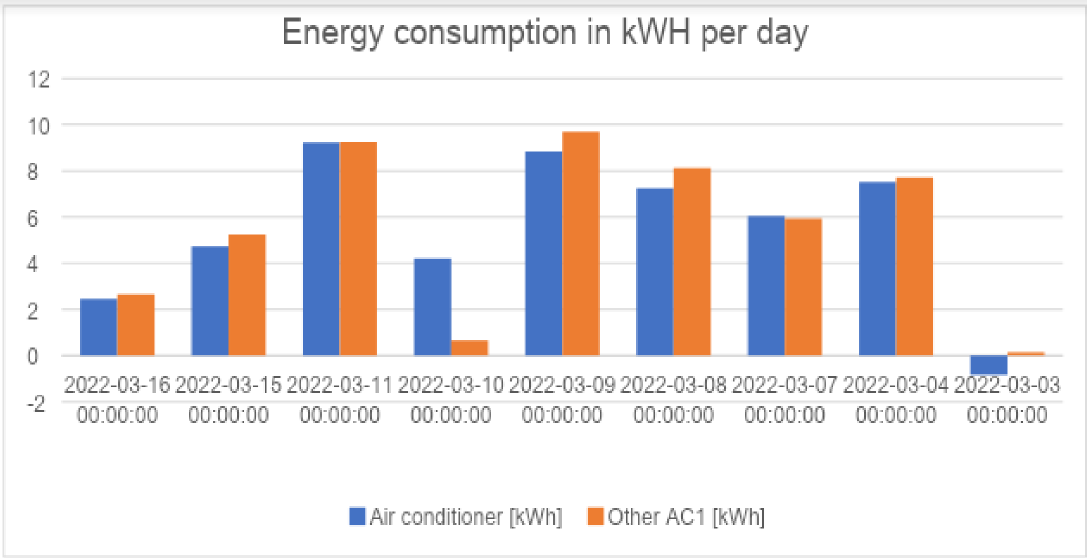

Figure 19: Shows the daily consumption of the two ACs in kilowatt hour

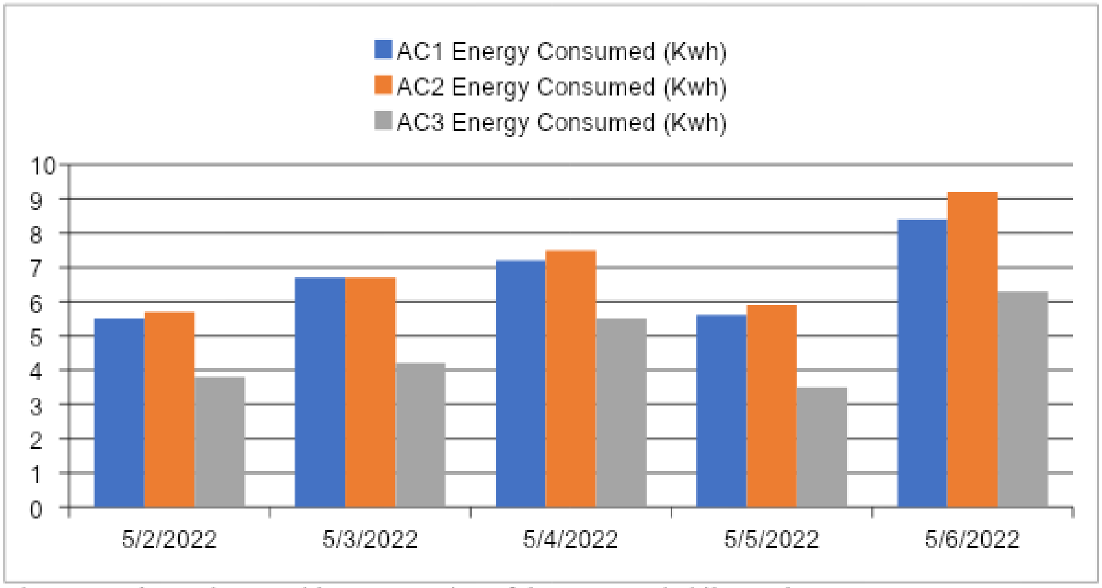

Figure 20: Shows the Monthly consumption of the two ACs in kilowatt hour

VI. CONCLUSION

from report of the simulation and data obtained shows great potential of energy and cost saving through automation by regular servicing, repositioning and retrofitting some ACs as well as introduction of sensors and smart switches.

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