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EMPIRICAL DETERMINATION OF AIR CONDITIOING INSTALLATION AND MAINTENANCE CHALLENGES IN LAGOS STATE, NIGERIA

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Abstract
Comfort of office building lies on its aeration as stuffy and hot office becomes uncomfortable for the users. In the bid to make office comfortable to end users, air conditioning (AC) set is installed to ameliorate it. However, when this AC is not well installed, it defeats the intended purpose. Therefore, this research discusses the problems involved in the installation of AC within Lagos State, Nigeria. The research entailed the administration of structured questionnaire and its analysis to ascertain its reliability and integrity using Cronbach's Alpha test. After which, multiple linear regression analysis was carried out on the retrieved data from respondents to determine the independent variables that are contributing to AC installation problems. The research findings yielded a regression model in which positioning of AC during installation is found to have a p-value of 0.02797 which makes it statistically significant as the p value is less than 0.05. Also, 55 percent of the study area showed that compressor is the most probable faulty part of the AC unit. The study therefore, proffer recommendations on how to minimize or avoid the observed problems associated with AC installation.

Keywords: *Air conditioning, Installation challenges, Maintenance, Comfort, Installation regression*

Introduction

Over the past six decades, Nigeria has undergone substantial growth in terms of both infrastructure and commerce. As a result, numerous central business districts (CBDs), including those in Lagos, have experienced a surge in commercial projects. The demolition of old residential structures has made way for the construction of large multi-story buildings, often with little consideration for the existing architectural landscape (Famuyiwa, 2019). Unfortunately, these redevelopment endeavours have introduced numerous challenges, with one of the most significant being the achievement of optimal thermal comfort within these new constructions. These challenges have been further complicated by the escalating temperatures caused by climate change and a strong preference for the incorporation of glass elements (Koranteng et al., 2012).

While air conditioning is employed to some extent for industrial applications in Nigeria, its primary use is to regulate the indoor environments of residential and commercial spaces such as offices, hotels, cinemas, halls, and supermarkets. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) defines air conditioning as the "process of treating air to simultaneously control its temperature, humidity, cleanliness, and distribution in order to fulfill the comfort requirements of those occupying the conditioned space, or for the effective execution of certain industrial or scientific processes within that space" (ASHRAE, 2011). In tropical countries like Nigeria, cooling through air conditioning has become an essential facet of modern development. Delivering air at specific temperatures and relative humidity levels is imperative for both room and office spaces. Given that weather condition is a challenging environment in tropical regions like Nigeria, particularly in Lagos, the level of challenge fluctuates with the season and geographical location.

Lawal (2000) defined maintenance as any activity designed to keep equipment or other asset in good working conditions. Monks stressed that very often; maintenance is associated with servicing equipment, replacing worn-out parts and doing emergency repairs. Maintenance measures have been given different names or classifications such as; predictive, routine, corrective, emergency, remedial, planned and unplanned maintenance. Craftsmen trained in air condition and refrigeration are required to carry out maintenance activities in related components and devices designed for cooling and ventilation. Maintenance in air conditioner system by craftsmen involves employing good operational inspection; fault models analysis skill; practical, and safety skills.

Numerous research endeavours have been conducted to address challenges related to air conditioning installation and maintenance. Obanor and Egware (2013) examined the rising prevalence of split air conditioning systems in commercial buildings in Nigeria, surpassing the utilization of room air conditioners and central air conditioning systems. The authors also explored the implementation of acoustic sensors, feature extraction, and unsupervised learning to preemptively address maintenance needs in centralized HVAC systems, proposing an approach that doesn't require altering existing infrastructure. Korolija (2011) described the formulation of regression models capable of accurately predicting annual energy demands for heating, cooling, and auxiliary requirements for diverse HVAC systems in office buildings. Layeni et al. (2019) conducted a comparative analysis of Variable Refrigerant Flow (VRF) and mini-split Air Conditioning Systems, highlighting VRF's superior technical performance while acknowledging mini-split's economic advantages. Thomas et al. (2010) introduced a comprehensive Post Occupancy Evaluation (POE) study for Indian office buildings, aiming to develop a sustainable thermal comfort standard in varied climatic zones. Xiao et al. (2014) proposed a practical algorithm, the multi-variable ESC, for optimizing evaporator and condenser fan speeds, achieving promising results without the complexities of model-based optimization. Haw et al. (2009) underscored the potential of small absorption chillers, particularly for solar-assisted air conditioning in small office buildings, yielding electricity savings and reduced environmental impact. Afonso (2006) provided an overview of cooling systems, with an emphasis on both conventional and advanced technologies, including solar cooling.

Reviewed literature indicated a substantial body of work addressing air conditioning design and installation issues that requires reworking. This study focuses on identifying challenges; that requires extra thoughts and extra efforts such as environmental, organizational, socioeconomic, biophysical and behavioural challenges (Lundgren-Kownacki et al., 2017); encountered during the installation and maintenance of air conditioning units in public and commercial buildings in Lagos State, Nigeria.

Materials and Method

Study Area

The area under study in this paper is Lagos State in the South-Western part of Nigeria, on the coast of the Bight of Benin. It is on Latitude 6.5227o North and Longitude 3.6218o East with elevation of 41 m. It falls under the tropical climate region, hot all year round, with rainy season between April and October and dry season between November and March. Lagos State has a population of 9,013,534 as recorded in the population census conducted in the year 2006 (NPC, 2006).

Methods

The methods adopted on which the work is based are as contained in the work flow chart shown in Figure 1.

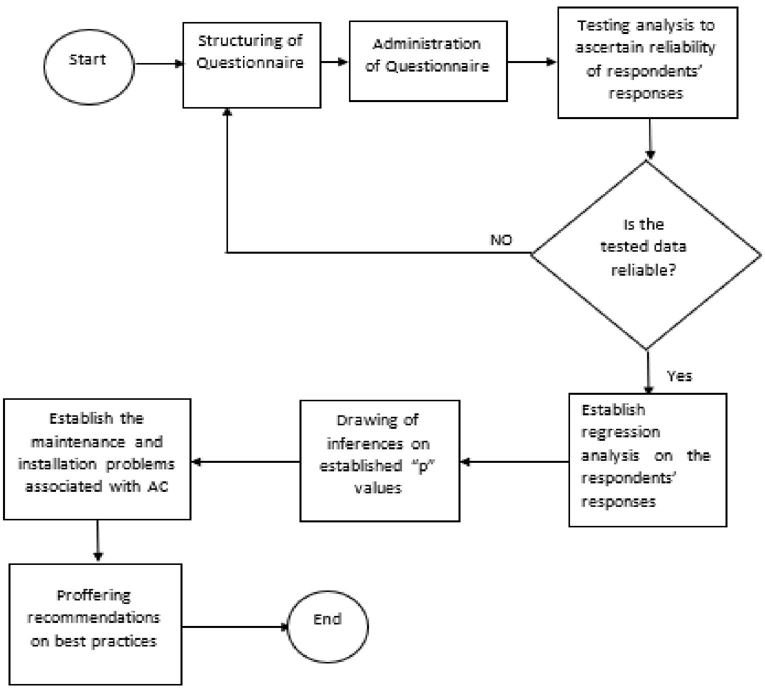

Figure 1: Work Flow Chart of the Method used for the study

Structuring and Determination of Questionnaire Reliability

Eight hundred (800) sets of questionnaires were administered, and five hundred and fifty-five (555) were returned. The collected questionnaires underwent analysis to ensure the reliability of the gathered data. This was accomplished through the application of Cronbach's alpha reliability test, a method used to evaluate the consistency of questionnaires. This test involves comparing the extent of common variance or covariance among the individual items within a tool against the overall variance. The idea is that if the instrument is reliable, there should be a great deal of covariance among the items relative to the variance. The sample of the retrieved data from the completed questionnaires is as shown in Table 1, while the coded extract of the analyzed sample data is shown in Table 2.

The coded extract was based on the use of Likert scale where the non-numeric responses from respondents were transformed into numeric based on scales of 5, 4, 3 and 2 as deemed fit to the questions raised. The analysis as computed using Excel Microsoft package is shown in Table 3.

Table 1: Example of the retrieved data from administered questionnaire

ID. No	Gender	Age	Qualification	Profession	Year of Usage	Working Experience	Type of Organisation	Type of System Adj.	Usage Habit	Operating Hours	Frequency of Service
1	Male	50 >	Diploma	Others	1 – 5	1 – 5	Other	Single AC	Hot Cond	2 – 4	Quarterly
2	Male	20 - 29	Diploma	Management	6 – 10	1 – 5	Other	Central AC	When in Room	>8	Monthly
3	Male	30 –39	Degree	Management	11 – 15	1 – 5	Bank	Single AC	Hot Cond	2 – 4	Monthly
4	Female	50 >	Post Grad.	Engineer	11 – 15	>16	Other	Single AC	Hot Cond	2 – 4	Monthly
5	Female	40 - 49	Post Grad	Engineer	11 – 15	>16	Shop	Single AC / Fan	Hot Cond	5 – 8	Quarterly
6	Female	30 –39	Diploma	Others	6 – 10	6 – 10	Shop	Single AC / Fan	Hot Cond	2 – 4	Rarely
7	Male	50 >	Degree	Engineer	> 16	>16	Shop	Central AC	Warm Cond	5 – 8	Monthly
8	Female	40 - 49	Post Grad	Management	11 – 15	6 – 10	Other	Single AC / Fan	Hot Cond	>8	Quarterly
9	Male	20 - 29	Degree	Management	1 – 5	1 - 5	Bank	Central AC	Hot Cond	2 – 4	Monthly
10	Female	30 - 39	Degree	Engineer	6 -19	6 - 10	Other	Single AC	Hot Cond	5 - 8	Quarterly

Table 2: Example of the retrieved coded data from administered questionnaire

ID. No	Gender	Age	Qualification	Profession	Year of Usage	Working Experience	Type of Organisation	Type of System Adj.	Usage Habit	Operating Hours	Frequency of Service
1	1	4	1	3	1	1	3	3	2	2	5
2	1	1	1	2	2	1	3	4	3	4	4
3	1	2	1	2	3	1	2	3	2	2	4
4	2	4	1	1	3	4	3	3	2	2	4
5	2	3	1	1	3	4	1	4	2	3	5
6	2	2	1	3	2	2	1	4	2	2	2
7	1	4	1	1	4	4	1	4	5	3	4
8	2	3	1	2	3	2	3	5	2	4	5
9	1	1	1	2	1	1	2	4	2	2	4
10	2	2	1	1	2	2	3	3	2	3	5

Table 3: Example of the Cronbach's Alpha analysis output from administered questionnaire

ID. No	Gender	Age	Qualification	Profession	Year of Usage	Working Experience	Type of Organisation	Type of System Adj.	Usage Habit	Operating Hours	Frequency of Service
1	1	4	1	3	1	1	3	3	2	2	5
2	1	1	1	2	2	1	3	4	3	4	4
3	1	2	1	2	3	1	2	3	2	2	4
4	1	3	1	3	3	3	2	3	2	3	5
5	2	2	1	3	1	1	1	5	5	3	5
6	2	2	1	3	4	1	3	3	4	2	5
7	2	3	1	3	3	3	3	5	4	2	5
8	1	4	1	1	3	4	1	5	2	2	4
9	1	2	1	2	2	1	1	1	3	2	5
10	1	4	1	2	4	4	1	5	2	3	4
		1.0391	0.0687	0. 520539	0.981145	2.142761	1.35556	1.2034	1.32189	1.025589	0.847138

Table 4: Interpretation of Cronbach's alpha values

Alpha value	Interpretation
$\alpha = 0$	There is no consistency
$\alpha = 1$	There is complete consistency
$0.80 \leq \alpha \leq 0.95$	Very good reliability between various items of a multiple item scale
$0.70 \leq \alpha \leq 0.8$	There is good reliability between the various items of a multiple scale
$0.60 \leq \alpha \leq 0.70$	There is fair reliability between the various items of a multiple scale
$\alpha < 0.60$	There is poor reliability

Cronbach's alpha is calculated using Equation (1)

$$\alpha = \frac{K}{K-1}\left(\frac{S_y^2 - \sum S_i^2}{S_y^2}\right) \quad (1)$$

***where:* α is** Cronbach's Alpha; **K is** the number of items in the scale; and **S$_i$**, **S$_y$** are the sum of the item scores for each item and the sum of the total scores for all items respectively.

The Cronbach's alpha reliability decision is guided by the values of alpha got from the expression of equation (1). The alpha interpretation is as shown in Table 4.

Development of Regression Model on the Retrieved Data

A multiple linear regression analysis was carried out on the retrieved data from the administered questionnaires as there are several variables being hypothetically considered to affect the installation and maintenance of air conditioning (AC) system in the area under consideration. Therefore, this subsection considered the computation of the mean time to failure (MTTF) of the installed AC; and establishes the regression equation on the factors considered.

2.3.1 Computation of Mean Time to Failure (MTTF)

The MTTF is computed to assist in the formulation of the regression model as this will be the dependent variables for all other variables being considered for the research study.

By computation, MTTF is as defined in Equation (2).

$$MTTF = H_{op}/N_{ff} \quad (2)$$

where Hop is the total operating hours of equipment, and Nff is the frequency of the observed number of failures within the operating hours of the equipment respectively.

Equation 2 was used to compute the MTTF for each respondent's response by using the duration, and number of breakdown repairs encountered by respondents in the respective building as indicated in the questionnaires. The following assumptions were used in the computation:

i. the air conditioners are being used eight (8) hours in a day;
ii. offices are opened five times in a week;
iii. there are 52 weeks in a year (12 calendar months);
iv. the number of repairs serve as the number of observed frequencies of failure.

Therefore, the computed MTTF for respondents with ID 1 to ID 5 is as presented in Table 5.

Table 5: Sample cases showing computation of MTTF

Respondent ID	Duration of Usage (Months)	No of Repairs Observed	Operating Hours Computation	MTTF
1	24	1	$24 \times 8 \times 5 = 960$	$960/_1 = 960$
2	24	3	$24 \times 8 \times 5 = 960$	$960/_3 = 320$
3	24	1	$24 \times 8 \times 5 = 960$	$960/_1 = 960$
4	24	1	$24 \times 8 \times 5 = 960$	$960/_1 = 960$
5	12	2	$12 \times 8 \times 5 = 480$	$480/_1 = 480$

2.2.2 Regression Modelling of the Retrieved data

Multiple linear regression using Analysis of Variance (ANOVA) was carried out to establish if the variable factors (independent factors) such as methods of adjusting, operating conditions, usage habit, operating hours, frequency of servicing, installation personnel and positioning of installed AC, have relationship with the MTTF (dependent factor).

Results and Discussion

Regression analysis model

The regression output from the excel package analysis is as shown in Table 6.

Interpretation of the Regression Model Output

R square: 0.375745142, which is coefficient of determination gives the proportion of the variance in the response variable that can be explained by the variables. It shows that 37.57% of the variation in installation and maintenance of AC can be explained by the number of the eight variables considered.

Standard Error: 0.8626, stands as the average distance that the observed values fall from the regression line. The F: 3.4609 is the overall statistic for the regression model.

Significance F: 0.00335 is the p-value associated with the overall F statistic. It shows that the indicated explanatory variables combined have a statistically significant associated with the response variable. In the sample space being considered, the p-value is less than 0.05, indicating that the variables combined have a statistically significant association with the AC installation and maintenance.

The p-values. The individual p values assist in establishing if there is statistically significant relationship with the dependent variable (AC installation and maintenance).

With reference to Table 4.2, it should be noted that the X variable 1, X variable 2, X variable 3, X variable 4, X variable 5, X variable 6, X variable 7 and X variable 8 represent methods of adjusting, operating conditions, usage habit, operating hours, frequency of servicing, switching mode of appliances when not in office, positioning of installed AC, and installation personnel respectively.

It is evident from Table 6, that "Methods of Adjusting installed AC" is not statistically significant (p = 0.36189). The "Operating conditions" as independent variable is statistically insignificant as (p = 0.199934). Also, "usage habit" is not statistically significantly (p = 0.95107). Likewise, for "operating hours", "frequency of servicing", "switching mode of appliances when not in office", "installation personnel" are all not statistically significant as they have p values of 0.61022, 0.38942, 0.62598 and 0.08122 respectively. However, the variable "positioning of installed AC", is statistically significant as it has a p value of 0.02797.

Table 6. ANOVA Results

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8	20.60449721	2.575562152	3.460981576	0.00335244
Residual	46	34.23186642	0.744171009		
Total	54	54.83636364			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.524860235	1.023372726	-0.512873	0.610494448	-2.58480269	1.53508222	-2.5848	1.53508222
X Variable 1	0.122802375	0.133346837	0.92092454	0.361894552	-0.14561089	0.391215637	-0.14561	0.39121564
X Variable 2	0.148491563	0.114188314	1.300409451	0.199938367	-0.08135759	0.378340719	-0.08136	0.37834072
X Variable 3	0.007060038	0.114433993	0.061695283	0.951072786	-0.22328364	0.237403719	-0.22328	0.23740372
X Variable 4	-0.047370556	0.092293346	-0.51326079	0.610225328	-0.23314742	0.138406314	-0.23315	0.13840631
X Variable 5	0.134754774	0.155089551	0.868883639	0.389421763	-0.1774243	0.446933849	-0.17742	0.44693385
X Variable 6	-0.071401087	0.145515953	-0.49067532	0.625988744	-0.36430951	0.221507335	-0.36431	0.22150733
X Variable 7	0.705156847	0.310708414	2.269513201	0.027970505	0.07973325	1.330580446	0.079733	1.33058045
X Variable 8	0.821187504	0.460622832	1.782776379	0.081222633	-0.10599817	1.748373175	-0.106	1.74837317

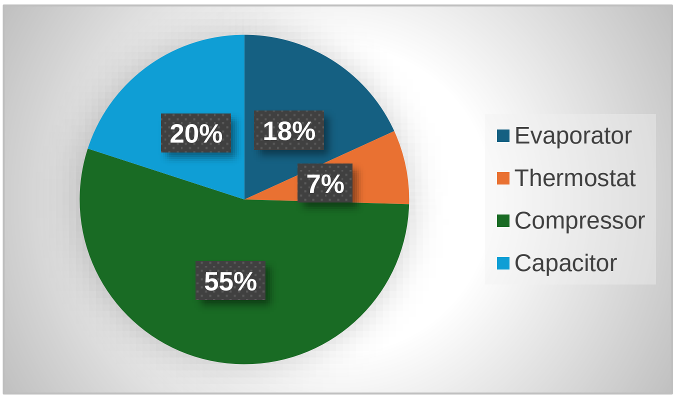

Figure 2: The pie chart analysis of respondents on AC installation problems

Coefficient: The coefficients for each explanatory variable give the average expected change in the response variable, assuming the other explanatory variable remains constant. In this study, for having a better positioning being observed for the installation of AC, there is an additional effect of 0.70515 for effective functionality and maintenance of the AC system provided all other dependable factors remain constant. This implied that the AC installed professionally and well positioned would have functionality of 0.70515 better than that of an AC not properly installed.

Also, the intercept of the coefficient is interpreted to be that the expected maintenance output for an installed AC without putting the right recommended positioning into consideration will be -0.52486. Indicating that the AC will not work optimally.

Estimated Regression Model

The estimated regression model as inferred from analysis is as expressed in Equation (3).

$$M\_ACI=0.70515X\_ACP-0.52486 \quad (3)$$

Where MACP is the maintenance operation effectiveness and XACP is the AC positioning at installation time.

Determination of the most Probable AC Parts associated with Maintenance Problems

The maintenance challenges are to know the most probable and challenging parts which are caused by factors that are not limited to dirty condenser coil, fan problems, leaking ducts and usage. However, based on the respondents' responses, the three most likely challenges being encountered in the use of the AC in office building are evaporator, electrical unit (capacitor) and any other part of the AC unit (compressor, thermostat, condenser coil, expansion valve). The frequency of responses based on the fifty-five retrieved questionnaires are as charted in a pie chart of Figure 2.

The pie chart revealed that 55% of the respondents affirmed that the compressor of the AC unit is the most challenging. This therefore corroborate the initial regression model that established positioning of AC during installation as the most statistically significant as factor to be considered in installation.

Conclusion

The study has established that methods of adjusting of AC, its operating conditions, usage habit, operating hours, switching mode of appliances when not in used contribute insignificantly to AC installation challenges and maintenance. However, the expertise of personnel for AC installation cannot be traded off for any other factors as established standards must be adhered to. The study has further affirmed that the recommended positioning off the floor must be strictly adhered to as established among all the factors considered for AC usage.

It was also established that poor maintenance culture and inadequate maintenance strategy employed by the building owners or management staff of establishments utilizing the buildings are contributing greatly to the high cost of using air-conditioning systems.

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