AN ASSESSMENT OF LIFT SYSTEM PERFORMANCE IN SELECTED HIGH RISE BUILDINGS IN ABUJA CITY

BY

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS DEGREE IN BUILDING SERVICES

DEPARTMENT OF BUILDING,
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ZARIA, NIGERIA

AUGUST, 2021

DECLARATION

I declare that the work in this dissertation entitled AN ASSESSMENT OF LIFT SYSTEM PERFORMANCE IN SELECTED HIGH RISE BUILDINGS IN ABUJA CITY has been completed by me in the Department of Building. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

Emmanuel Chongcicimmi IBRAHIM,

__________________________________ ______________ ___________

Name of Student Signature Date

CERTIFICATION

This dissertation entitled AN ASSESSMENT OF LIFT SYSTEM PERFORMANCE IN SELECTED HIGH RISE BUILDINGS IN ABUJA CITY by IBRAHIM, Emmanuel Chongcicimmi meets the regulations governing the award of the degree of M.Sc. BUILDING SERVICES of the Ahmadu Bello University, and is approved for its' contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to the Lord God almighty and to my beloved parent Rev. and Mrs. Ibrahim Ezekiel may the Lord be gracious to them even as they live to testify the goodness of God in the land of the living. Amen

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ABSTRACT

The performance of lift systems in high rise buildings is essential for the efficiency of vertical transportation system. However, high rise buildings are often confronted with problems associated with lift system performance such as long waiting time, vibration, door operation, lighting and noise level in lift car during ride. This study assessed the performance of lift system in selected high rise building in Abuja city with the view to enhancing the efficiency of vertical transport system in buildings. The study measures performance parameters such as the Average Waiting Time (AWT), Transit Time (TRT), Time to Destination (TTD), lift car interior sound level, lift car illumination, door operation timing and sound, levelling accuracy and ride quality of lift systems. The study adopted field survey research design, encompassing measurements and a structured checklist for the collection of relevant data on 14 selected high rise buildings and 41 lift systems in the Central Business District (CBD) of Abuja city. Six tools were used to measure the performance parameters of the lift systems within the selected buildings. The performance parameters were evaluated against the standard performance requirements for an ideal lift system. Results from analysis showed that 85.7% of the selected buildings have lift systems with AWT above minimum standard requirement, 64.3% with unsatisfactory interior sound level and 71.4% with poor ride quality. Conversely, 71.4% of these buildings have lift systems with optimum illuminance and 100% with satisfactory lift door operation. Results from the inferential statistics showed significant differences ($p<0.05$) in the mean value of AWT, TRT, TTD, lift car interior sound level, and lift acceleration. Based on the findings, the selected buildings were considered to have lift systems performing below expected standard. Nonetheless, the study provided data for lift performance parameters for optimizing the service delivery of lift systems within high rise buildings in Nigeria.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACC-Acceleration;
AC -Alternative Current
ACVVVF - (AC Variable Voltage Variable Frequency)
AWT-Average Waiting Time;
ASME- American Society of Mechanical Engineers
AS/NZS- Australia Standard and New Zealand Standard
ANOVA -Analysis of variance
BCO -British Council for Offices
BS- British Standard
CIBSE -Chattered Institute Building Services Engineers
CBD- Central Business District
DC -Direct Current
DOT-Door Opening Time
DCT-Door Closing Time
DOS-Door Opening Sound
DCS-Door Closing Sound
FCDA- Federal Capital Development Authority
HTD-Height of Distance
ISO -The Industrial Organization for Standardization
ILL-Illuminance
ISL- Interior Sound Level
LTA-Lift Age
LEV-Levelling
MR-Machine Room
MRL Machine Room Less
NEII-National elevator Industry Inc
NST-Number of Stops
NFL- Number of Floors
PHC -Passenger Handling Capacity
RSD-Rated Speed
SPSS-Statistical Product and Service Solution
TRT-Transit Time
TTD-Time to Destination
UNSW -University of New South Walse
ST- Satisfactory
UST- Unsatisfactory
VEL-Velocity

LIST OF SYMBOLS

< ....Less than

≤..Less than or Equal to

±..Plus or Minus

% ....Percent

m/s..Meter per Second

m/s2 ....Meter per Second Square

dBA..Decibel

Lux ....Luminous Intensity

Fmp..Feet per Minute

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

The need for modernization due to the current development in technology and the rapid population growth in cities have given rise to high demand for high rise building construction and the use of lift systems to enhance the overall performance of the buildings. The use of staircase in high rise buildings to support the movement of people and goods between floor levels has become challenging resulting to discomfort and accident of occupants within the buildings. Therefore, this has led to the installation of lift systems in high rise buildings to enhance comfort and safety of the movement of people and goods from one floor to another (Adekomaya, Akinyemi, & Samuel, 2015). In addition, Challinger (2008) affirmed that most occupants depend on lifts to reach their destinations (terminal floor) in high rise buildings. Aliyu, Hussaini, Abubakar, Baba and Mu'awuya (2015) described high rise buildings in the case of the Nigerian context as a building with minimum of four floors as a matter of fact.

The developments of cities always come with the need to build high rise buildings and the critical role of vertical transportation systems (Wood, 2014). Moreover, each day, more than 7 billion lifts journeys are taken in high rise buildings all over the world (Wood, 2014; Neyfakh, 2015). Most of the Architecture of the 20th and 21st century would be impossible without the critical role of lift systems as office towers, hotels and high-rise apartments would hardly stand in their present form (Aliyu et al, 2015).

Consequently, the performance of lifts systems improves the quality of vertical transportation of people in high rise buildings which is responsible for reshaping modern cities by concentrating large masses of people and activities in smaller areas, creating lively communities (Bernard, 2014). The quality of a vertical transportation system is also an important factor in a tenant's choice of space in competing buildings (Stanley, 2019). Therefore, overall performance of high rise buildings both for single or multiple occupations requires adequate performance of lift systems necessary to support the buildings, business activities and its inhabitants (Pearson & Wittels, 2008).

However, the performance of lift systems basically depends on the average waiting time, average transit time and average destination time as one of the key performance indicators (Chattered Institute Building Services Engineers (CIBSE), 2010). Under up peak (incoming traffic) conditions at a constant arrival rate of 15% for duration of 15 minutes, the average waiting time, average transit time and average time to destination of office buildings should not exceed the industry de facto standard of 30s, 60s and 90s respectively (Caporale, 2004). During up-peak, passengers arrive randomly at an entrance floor (lobby), and randomly choose one of the higher floors as their destination (Al-sharif, 2016). In a commercial building context, a trip of more than a 90-second is annoying, and a 120 second trip is the limit of tolerance. Acceleration and deceleration times beyond 1.2 m/s^2 and $1.2 m/s^2$ respectively results to physical discomfort (Stanley, 2019).

More so, performance parameters such as in-car sound level, light, vibration, levelling accuracy, door operation sound and timing are considered when assessing the overall performance of lift system in buildings for modernization and optimization of service delivery (Australia Standard and New Zealand Standard (AS/NZS), 2012). For optimum lift performance, the lift's car should ensure optimum interior noise levels to be less than 48–52 dB (A) for superior ride comfort and noise levels above 60 dB (A) usually result to poor performance of the lift system (Elevator Planning for High-Rise Building, 2015). Therefore, assessing performance of lift system is especially important when considering modernization of any country (CIBSE, 2010). Currently, in Nigeria, high-rise buildings are normally serviced by lift systems, as the vertical transport equipment to provide comfort, safety and convenience to building users. Hence, this study is aiming at assessing the performance of lift systems of selected high rise building in Abuja city with the view to enhancing the efficiency of vertical transport system in high rise buildings.

1.2 Statement of Research Problem

Nowadays, high-rise buildings are normally serviced by lift systems as the vertical transport equipment (Nagatani, 2003). The performance of lift systems has always been critical to the successful operation of buildings and has become critical in the case of high rise buildings (Al-Sharif, 2016). According to CIBSE (2010) ideal performance of the lift systems should serve maximum number of people with minimum waiting time at the worst peak times so as to adequately disperse the population very fast. A waiting time of less than 20 seconds is excellent for optimum performance for high rise building.

However, high-rise building users frequently complain about long waiting times for the lift systems, which is one of the key performance indicators of the system (Linderman, 2008). Similarly, at peak hours, residents often have issues regarding the waiting times of being excessively long. Due to this, some tenants in the case of residential high rise buildings threaten to break their leases and move out of the buildings (Alhasan, 2014).

When considering the overall performance of lift system, parameters such as the light, sound, levelling accuracy, vibration in lift car and door operation timing are measured to evaluate the overall performance of an installed lift system during ride (ANS/NZS, 2012). According to CIBSE (2014) the interior of lift cars should ensure optimum interior noise levels to less than 48–52 dB (A) for superior ride comfort and noise levels above 60 dB (A) usually result to poor performance of the lift system. However, Aliyu *et al*, (2015) observed that more than 20% of the lifts studied in Nigeria were found to be vibrating too much with rising interior noise making about 25% of the passengers uncomfortable especially the age class that could not use the stairs in getting to the upper floors easily. The age of lift systems in high rise buildings also affect the performance of the system (Innovative Lift Consulting, 2019). In most of the high rise buildings, lifts doors are faced with door opening and closing operational problem which result to poor performance of the systems (Innovative Carry Consulting, 2019).

Aliyu *et al* (2015) recommended the need for the periodic assessment of the overall performance of the lift system by professionals to ensure optimum performance of lifts in high-rise buildings in Nigeria. Reviewed of previous studies (Linderman, 2008; Alhassan, 2014; Aliyu et al, 2015; Al-sharif, 2016) on lift systems in buildings vindicated alarming rate of poor performance of the systems that hindered efficiency of vertical transport system and the comfort of the users in the high-rise building. However, these studies did not cover onsite measurement assessment of lift performance parameters such as light, vibration and leveling accuracy which constitute the overall performance of lift system at the occupancy period of the buildings. Thus, the need for this study to assess the performance of lift systems in Nigeria with the view to enhancing the efficiency of the vertical transport system in high rise building.

1.3. Justification of the Study

The need to assess performance of the system will create more opportunity for improving the efficiency of the systems in high rise building in Nigeria by ensuring the comfort, safety and convenience of the building users. However, the study provides performance data which could be used for optimization of lift service delivery at peak period passenger demand in high rise building (Otis 2015). More so, since this study will be addressing a building construction sector, the study will be of great benefit to a number of groups of people such as lift Contractors, lifts installers and maintenance manager, building services engineers, property managers, tenants and client, rank amongst the top beneficiaries of this study. The study will be disseminated through international/ National journals or conferences as well as deposited in the departmental or institution's library as reference materials.

1.4 Aim and Objectives

1.4.1 Aim of the study

The study aimed at assessing the performance of lift systems of selected high rise buildings in Abuja city with the view to enhancing the efficiency of vertical transport system in buildings.

1.4.2 Objectives of the study

The objectives are to:

i. Identify the types of lift systems installed in the selected high rise buildings in Central Business District, Abuja.
ii. Measure the performance parameters of lift systems in the high rise building.
iii. Evaluate the ride quality of the lift systems in high rise building.
iv. Evaluate the performance of the lift systems against the standard requirements

1.5 Scope and Delimitation of the Study

1.5.1 Scope

This study covers selected high rise buildings within Central Business District (CBD), Abuja metropolis, specifically those that have functional installed lift systems. It includes high rise with minimum of four (4) floors and under current use for commercial and administrative functions. Also, not under construction or any form of maintenance. Only lift systems accessed within the selected high rise buildings were studied with the use of Digital Stopwatch, Measuring tape, WT85 digital sound level meter, Digital light/lux meter HS1010 and AS63D vibration Meter to measure the performance of lift systems.

1.5.2 Delimitation

The research findings were limited to samples collected during up peak period of lift ride (i.e incoming traffic; morning rushing hour). This was because the period is characterized by high lift passenger demand usually with long waiting time. Also, the performance metric record only covers that of commercial and administrative high rise buildings. This is because the study area is predominantly engage with commercial and administrative activities.

CHAPTER TWO

2.0 LITERARTURE REVIEW

2.1. Lift System Defined

A lift system is vertical transport equipment that efficiently moves people or goods between floors (levels) of a building, vessel or other structure (CIBSE, 2010). Nowadays high-rise buildings are becoming the latest trend, and this has made the use of lift system a major necessity for moving passengers and goods vertically within the buildings (British Standards Institution, BS 5655-6, 2002).

According to Rao (2017) the controllers of different types of lift systems perform using ACVVVF (AC Variable Voltage Variable Frequency) control for adequate functioning of the systems thereby improving energy saving of about 50%. In VVVF control, voltage is varied in accordance with frequency in order to control the motor torque and speed therefore optimizing energy efficiency. However, lift system can be defined as a vertical transportation machine powered by the aid of electricity to move people and goods from one terminal floor to another.

2.2. Types of Lift System

The two main types of Lifts are hydraulic and traction. Nowadays, the hydraulic and traction lifts systems are the most commonly used in high rise buildings (Andrew & Kaczmarczyk, 2011). Selection of the best-suited type of lift considers initial cost of the lift plus the building structure needed to install the lift, maintenance costs over the life of the building and running costs (Jappsen, 2002). The traction lifts systems are the most popular form of lifts designs used widely across the world and the widely commercially available lift technology (Bass, 2014). Based on the previous study there are two basic types of lift system which includes; traction and hydraulic lift.

2.2.1 Traction Lift System

The traction lift system is said to consist of the lift car and a counterweight held together by steel ropes looped around the sheave. The sheave is a pulley with grooves around its circumference usually driven by the Alternative Current (AC) or Direct Current (DC) motor and sheave grips the hoist ropes so that the ropes moves during rotation. Hence, the gripping is as the result of traction (Bhatia, 2012).

2.2.1.1 Roping Arrangements of Traction Lift

Bass (2014) stated that a roping system is used to attach the motor/gear reducer , the lift car and the counterweight as described in Figure 2.1. Bass (2014) also outlined the two most commonly used types of roping system as follows;

i. One to One roping (1:1) also called traction drum arrangement

ii. Two to One roping (2:1) also called lifting drum arrangement

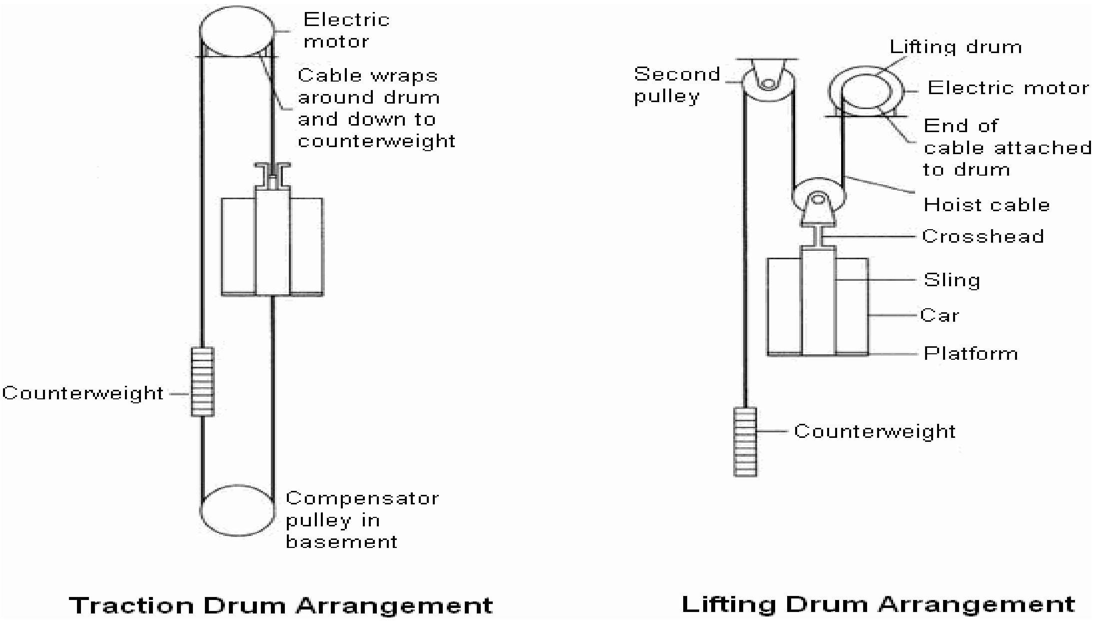

Figure 2.1Traction Roping System Arrangement

Source: Bhatia (2012)

2.2.1.1.1 One to One roping (1:1) or Traction Drum Arrangement

In a One to One roping (1:1) arrangement, the hoist ropes runs from the lift car hitch over the machine sheaves to the counterweight hitch. The lift car and the counterweight each run in their own sets of guide rails. A second governor cable runs from the car up to a governor pulley, then down to a tension pulley at the bottom of the lift shaft, and up to the car again. This cable rotates the governor pulley at a speed directly proportional to the speed of the car. In the event of excessive car speed, the governor uses another cable to activate the emergency brake jaws which grip the guide rails and slow the car to a stop (American Society of Mechanical Engineers (ASME) A17.1, 2019).

2.2.1.1.2 Two to One roping (2:1) or Lifting Drum arrangement

This is referred to as arrangement of hoist ropes in which one end of each hoist rope passes from a dead-end hitch in the overhead, under a car sheave, up over the drive sheave, down around a counterweight shave and up to another dead-end hitch in the overhead. The car speed is one-half the rope speed (ASME, 2019).

2.2.1.2 Counterweight

During rotation of traction drive, power is transferred from the traction drive to the lift car and counterweight. The counterweight is normally sized equal to the weight of the car plus approximately half its maximum rated capacity (ASME, 2019).

2.2.2 Hydraulic Lift System

Hydraulic lift systems raise a car using a hydraulic ram, a fluid-driven piston mounted inside a cylinder. All the weight of the lift cab is supported on the piston (Noordermeer, 2010).

Bhatia (2012) outlined three parts of the hydraulic system

- A tank (the fluid reservoir)
- A pump, powered by an electric motor
- A valve between the cylinder and the reservoir

Thumm (2004) asserted that hydraulic lift system is incredibly simple and highly effective, but it does have some drawbacks as follows;

- High energy consumption
- Lift motor has to be large enough to raise the rated load plus the dead weight of the car cage due to the absence of counterweight
- Hydraulic lifts are used in buildings up to 5 floors (14 meters rise) and have rated speeds of 0.25 m/s (50 fpm) to 0.75 m/s (150 fpm). Figure 2.2 illustrates a hydraulic lift system. The hydraulic type of lift system was not identified as installed lift systems in the selected buildings and this could be due it drawbacks outlined above by Thumm (2004).

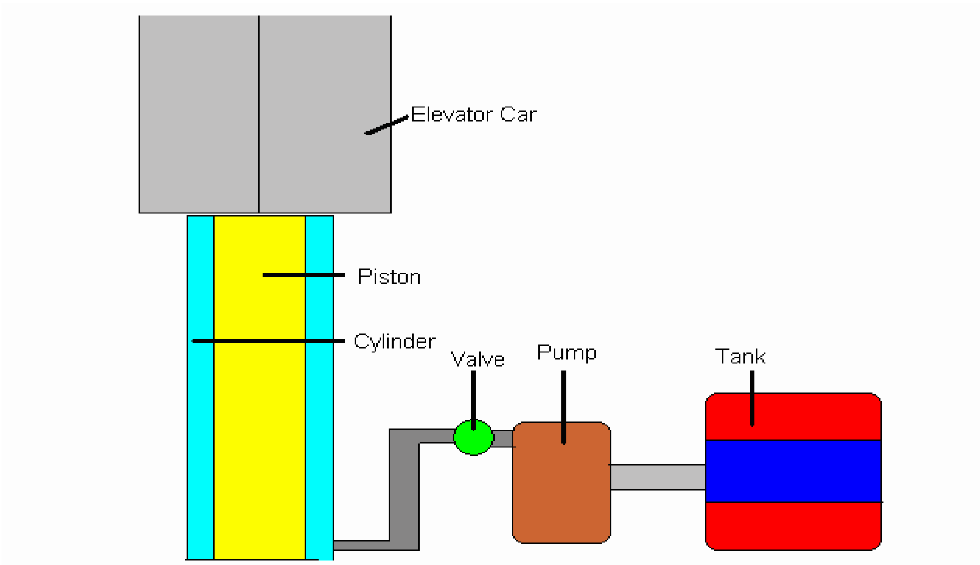

Figure 2.2 Hydraulic lift

Source: Bhatia (2012)

2.3 Comparison of lift System Type (Hydraulic and Traction)

According to Lonwic (2004) lift system shall be within the following ranges and chosen to suit the specific building requirements as part of the lift traffic analysis:

- Hydraulic passenger elevators – 15 meter rise up to 5 storeys;
- Geared traction passenger elevators – 30 meter rise up to 10 storeys;
- Gearless traction passenger elevators – above 10 storeys.

2.4 Main Components of lift System

According to Esteban, Iturrospe and Salgado (2013) lift consists of complex structural, mechanical and electrical components. The typical arrangements and components for electric traction lift system are illustrated in the Figure 2.3

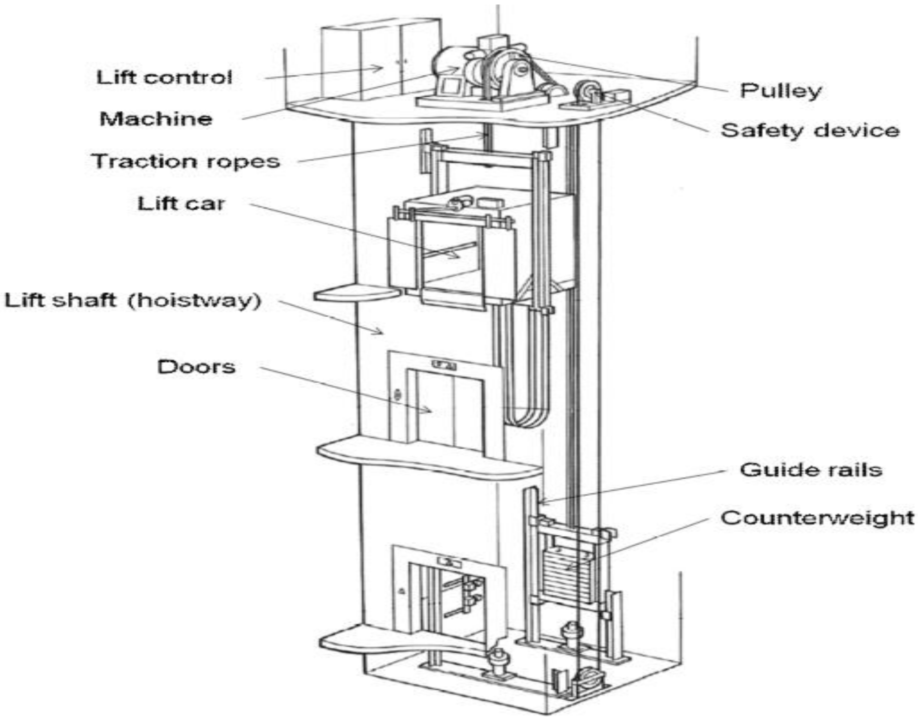

Figure 2.3 Principal components of a typical passenger electric lift

Source: CIBSE Guide D (2002)

2.5 Hoist Mechanisms of Lift System

According to Strakosch and Caporale (2010) system lift's function is to convert the electrical power, which runs the motor, into mechanical power. Lonkwic (2004) outlined two types of hoisting mechanisms namely Geared and Gearless types. However, geared and gearless lift systems were identified as types of lift systems based on hoisting mechanism.

2.5.1 Geared Lift System Type

Bhatia (2012) asserted that in a geared machine, the motor turns a gear train that rotates the sheave. Geared traction machines are used for medium-speed applications and have effective speeds from 0.5 m/s to 2.0 m/s. The slower speeds are for freight operation, while the higher speeds are typically used for passenger service in mid-rise buildings of ten stories or less. The gear lift system is characterized by the present of gear system incorporated in the hoist motor.

2.5.2 Gearless Lift System Type

Ibrahim, Oladeji, Onyebuchi, Michael and Ogonna (2014) asserted that in gearless lifts the motor powers the sheave directly and brake is mounted between the motor and drive sheave to hold the lift stationary at a floor.

Gearless traction lifts are specified for high-speed applications having effective speeds varying from 2.5 m/s to 10.0 m/s. These are generally used on taller structures with more than 10 stories. In terms of energy performance, gearless drive has no gear transmission loss thus have a transmission efficiency of 100% (Bass, 2014).

However, the gearless traction machines use low torque electric motors (generally DC motors) driven by motor generator (MG) drive or silicon-controlled rectifiers (SCR). Modern gearless traction machines use variable-voltage; variable frequency (VVVF) drives systems (Jappsen, 2002). The gearless lift is identified by the absence gear system incorporated in the hoist engine.

2.6 Machine Location of Lift System

2.6.1. Machine Room Lift system

All lifts, whether traction or hydraulic, require a machine room to store large electric motors (or hydraulic pumps) and a controller cabinet (American Society of Mechanical engineers (ASME), 2019). Therefore, lift with a room to store large electric motors and controllers cabinet are referred to machine room lift system and the machine room is located above the lift well (or below, for hydraulic lifts) (Kaczmarczyk, 2008). For this study, twenty five (25) out of forty one (41) lift systems studied within the selected buildings are machine room lift systems which formed the majority of the lift systems studied. The machine room lift is suitable for most of the buildings with pent house in the last floor.

2.6.1 Machine Room-less lift system

These are a type of lifts that do not have a machine room located on the top of the hoistway. Instead, the hoisting machine is located on the top side wall of the hoistway or on the bottom of the hoisway (Müller, 2014). However, the most significant development in the recent history of lift has been the introduction of Machine Room Less (MRL) lift system and most MRL solutions are based on gearless technology (Bass, 2014). However, the machine room less lift is a current technology trending in most high-rise building especially in Nigeria.

2.7 Dynamic Operation Electric Lift Systems

The theoretical displacement between two floors consists of four regions, as it is illustrated in figure 2.4. The bold curve represents the distance of a car cabin, the dotted line is the speed, the dot dashed line is the acceleration and the dashed curve is the jerk. The first region starts in (1) which is the initial landing floor. Then, from (1) to (2) is the acceleration region where speed is increasing. After that, from (2) to (3) is the constant speed area where acceleration and jerk are zero. Next, from (3) to (4) is the landing region until stopping and finally, (4) is the last landing floor (Esteban *et al*, 2013). However, the lift is a closed-loop system and this theoretical displacement is adapted by the control system to ensure an accurate landing position in each travel. During the travel, the lift car and counterweight are continuously varying their positions (Esteban *et al*, 2013).

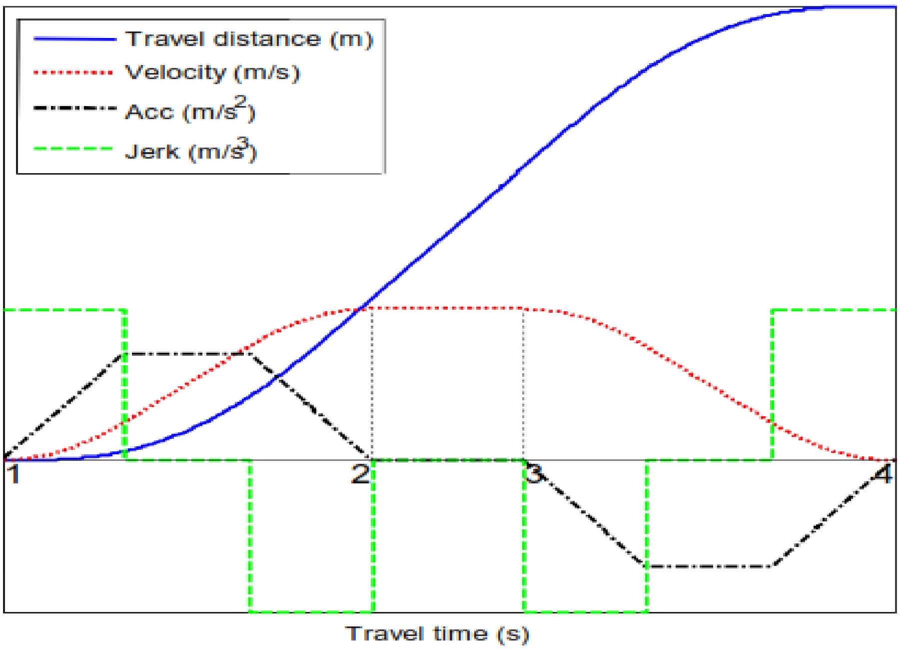

Figure 2.4 Typical speed governor signal profile of a lift system
Source: Esteban *et al.* (2013).

2.8 Lift System Handling Capacity

The lift capacity is derived from up-peak traffic analysis during design. However, the nominal capacity of the lift system and the rated maximum passenger capacity are usually prescribed from the manufacturer's catalogues (British Council for Offices (BCO), (2009). Table 2.1 provides standard nominal capacities and passenger relationship at Peak passengers per trip (normal peak = 80% of rated capacity) from the manufacturer's catalogues.

Table 2.1: Standard Nominal Passenger Lift Service Capacities

Nominal Capacity	Rated Max Passenger Capacity	Passengers Per Trip (Normal Peak)*
1140 kg (2500 lbs)	17	13
1360 kg (3000 lbs)	20	16
1600 kg (3500 lbs)	23	19
1800 kg (4000 lbs)	27	21
2250 kg (5000 lbs)	33	27
2730 kg (6000 lbs)	40	32
3180 kg (7000 lbs)	47	37
3640 kg (8000 lbs)	53	43

Source: (British Council for Offices (BCO), (2009).

According to British Council for Offices (BCO, 2009) and CIBSE Guide D Guidelines (2014), the minimum passenger handling capacity for an office is given in Table 2.2 and 2.3 below;

Table 2.2: Minimum Passenger Handling Capacity (PHC) for an office building

Facility	Percent of population to be carried in 5 minutes (10%)
Center city	12-14
Investment	11.5-13
Single-purpose	14-16

Source: CIBSE (2010)

Table 2.3: Minimum Passenger Handling Capacity (PHC) for a residential building

Facility	Percent of population to be carried in 5 minutes
Prestige	5-7
Others	6-8
Dormitories	10-11
Hotels-first quality	12-15
Hotels-second quality	10-12

Source: CIBSE (2010)

The handling Capacity = $HC = \frac{300P}{I}$ HC= handling capacity P= car capacity (NEII, 2017).

2.9 Zoning of Lift System to Enhance Performance

Zoning of life system refers to process of subdividing of the floors of the premises into clusters of stops to be served by different lift cars. This creates the need for people traveling to floors within that zone to use the same lifts, thereby reducing the probable number of stops made by the lifts. This in turn reduces the overall time lifts are accelerating and decelerating (Müller, 2014).

However, for office buildings, a single lift group can generally serve all floors in buildings up to 15 to 20 floors depending on the building population (CIBSE, 2010).

High rise buildings with more than 20 floors (up to about 35 floors), are best served by two different lift groups; one serving the low rise and the other the higher floors. Such a zoning arrangement would cut down on the number of stops per lift, thus reducing round trip times, Transit time, time to destination and waiting time and also increasing the handling capacity of each group (ThyssenKrupp, 2014).

2.10 Lift System Door Operational Performance

All power operated doors shall be equipped with an automatic reopen device for passenger protection to meet up to door operational performance requirement (Peters, 2012).

2.10.1 Lift Door Configuration and Operation

Bhatia (2012) outlined the most common configuration of lift door operation two panels that meet in the middle and slide open laterally;

- Single-speed bi-parting doors are typically used in the larger capacity ranges. The operating speed is generally faster than side-acting doors.
- Two-speed bi-parting doors have the fastest action and are used where a wide opening is required; these types are commonly used for large passenger lifts and service lifts.

2.11 Speed of Lift System

Lift speed is determined by travel distance and standard of service and therefore, the speed should be selected such that it will provide short round time and 25 to 30 second interval, along with least number of lift systems to handle the peak loads (Strakosch & Caporale, 2010). The taller buildings above 20 floors may have high-speed lifts that do not stop at the first 10 floors. Car speed is chosen so that the driving motor can be run at full speed for much of the running time to maximize the efficiency of power consumption (Barney & Al-Sharif, 2016).

Peters (2008) stated that the overall speed of operation is determined by the acceleration time, braking time; maximum car speed; speed of door opening; degree of advanced door opening; floor- leveling accuracy required; switch timing and variation of car performance with car load.

The general rules of thumb, for the recommended lift speeds for various travel distances are shown in Table 2.4.

Table 2.4 The General Rules of Thumb, for the Recommended Lift Speeds

Number of Floors	**Car Rated speed (m/s)**
4	0.75
9	2
15	3
Over 15	5-7

Source: (CIBSE 2010)

The table above applies principally to commercial buildings; speeds in residential and institutional buildings may be subject to local design regulations.

2.12 High Rise Buildings in Nigeria

According to Aliyu *et al*. (2015) high rise buildings in Nigerian context are buildings with minimum of four (4) floors. Hence this definition is adopted as a working definition for this study.

However, Challinger (2008) affirmed that a multistory structure in which most occupants depend on lifts to reach their destinations is referred to as ‘high-rise buildings. Therefore, with respect to height a high-rise building can be defined as buildings reaching 75 feet (23meters) to 100 feet (30meters) tall or seven to ten stories.

2.13 The Vertical Transportation Problem in High Rise Building

Lift systems are designed based on the peak of the demand. The demand for the lift service is a daily cycle and for office buildings, it usually peaks at the start of working day (for example, 08:00) when workers arrive for work (Stanhope, 2004).

William and Hofmann (2006) identified lift system performance as one of the problem associated with vertical transportation problem in high rise buildings. According to Barney and Al-Sharif (2016) the vertical transportation problem is a multiple-constraint-multiple-objective problem that aims to produce a solution that is:

i. Functional.
ii. Safe.
iii. Reliable.
iv. Cost effective.
v. Meets the passenger performance requirements (waiting time and travelling time).
vi. Uses the smallest possible core space of the building.
vii. Energy efficient.

Therefore, in order to solve the problem, it is necessary to identify demand and supply. Demand is represented by the arrival of passengers for service. Supply is represented by the number of lifts, their rated speed and rated capacity to meet up performance requirements (Wit, 2017).

2.14 Assessing the Performance of a Lift System in an Existing High Rise Building

The onsite survey for measuring lift system performance of an existing building is more complicated and difficult task to do (Elevator World, 2015). It does not only assess the demand, it also measures the lift system performance under such passenger demand, waiting time, light, sound level and vibration in lift car (Caporal, 2004). Such a survey could be carried out for example following the commissioning of a new lift system in order to understand the reason for the poor performance of a lift system (Barney, 2004).

Al-Sharif (2016) outlined the following various types of data that can be gathered within this type of survey are:

i. **Actual round trip time:** The elapsed time between the arrival of a lift at the main entrance and the next arrival of the same lift at the main entrance is the actual round trip time for that lift. It is well accepted that this is a random variable and the average value is calculated by finding the mean value of these round trips during the period of the survey. Under periods of no passenger activity, the elevator might stand still, and this is referred to as *idle time* and must be removed from the value of the round trip for comparison purposes with the calculated value of the round trip time.

ii. **Actual interval:** The elapsed time between the arrival of one elevator in the group at the main entrance and the next elevator in the group is the actual measured interval. By measuring all such values and taking their average value, the average interval can be calculated. This value can be compared with the calculated value, which is representative of the quality of service.

iii. **System response time:** The system response time is the elapsed time between the registration of the landing call and the arrival of an elevator in response to the call. This can be easily recorded by an observer located in the lobby.

However, for the purpose of this study, only the average waiting time, transit time, time to destination cabin were measured during survey in the study area.

2.15 Extracting the Lift Kinematic Parameters (Distance, Velo1city, Acceleration and Jerk):

These parameters allow a simulation to be carried out of an existing installation in high rise Buildings (Al-Sharif, 2014). According to Peters (2012) the aim of conducting performance measurement is to optimized performance than to assess passenger comfort.

Measuring the kinematic parameters can easily be carried out using an accelerometer sensor placed on the floor of the car and connected to a signal conditioning and processing device (Al-Sharif & Al-Adem 2004). The vertical axis of the accelerometer provides the acceleration in the vertical direction. Integrating this measurement once will produce the velocity, twice will provide the vertical displacement. The acceleration signal can also be differentiated in order to obtain the value of jerk (Peters, 2012). For the purpose of this study, distance, acceleration and velocity were extracted as kinematic parameters for the lift performance assessment.

2.16 Traffic Assessment in High Rise building

Al-Sharif (2016) described that passenger journeys that start at an exit/entrance floor and terminate at an occupant floor are classified as incoming traffic, passenger journeys that start at an occupant floor and terminate at an exit/entrance floor are classified as out-going traffic, passenger journeys that start and terminate at occupant floors are classified as inter-floor traffic and Passenger journeys that start and terminate at entrance/exit floors are illogical/irrational journeys and are thus effectively disallowed and will not be considered any further. The four types of traffic as described by Al-Sharif (2014) are further presented in the 2 by 2 array shown in Table 2.5 and in Figure 2.5

Table: 2.5: By 2 Array of Traffic Pattern of Vertical Transport System in High Rise Building

		Occupant floor	**Exit/ Entrance floor**
Start/Origin of the passenger journey	Occupant Floor	Inter floor Traffic	Outgoing Traffic
	Exit/Entrance floor	Incoming Traffic	Irrational/logical

Source: Al-Sharif (2014).

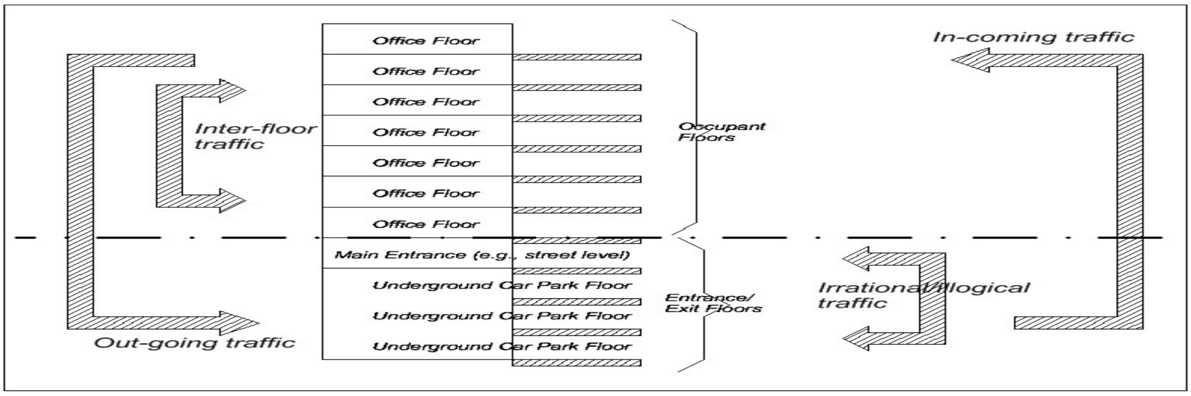

Figure 2.5 The three types of traffic in a building

Source: Al-Sharif (2016).

2.17 Ideal Performance of Lift System in High Rise Building

Stanley (2019) clearly outlined the following as ideal performance requirements for lift systems in high rise buildings:

i. Minimum waiting time
ii. Comfortable acceleration (ride quality)
iii. Accurate leveling
iv. Quick/quiet door operation
v. Comfortable lift in car lighting

The above ideal performance requirements were considered as working requirements for this study. In addition to the ideal performance outlined by Stanley (2019), the (Australia Standard and New Zealand Standard (AS/NZS), 2010) recommended six (6) performance parameters with the acceptance criteria as standard for lift system performance assessment as shown in the Table 2.6 without unduly affecting the ride quality. Therefore, this study considered these performance parameters during survey.

Table 2.6: Recommended Performance Acceptance criteria

S/N	Performance parameters	Acceptance criteria
1	Maximum acceleration	1.0 m/s^2
2	Jerk rate	1.5 m/s^3
3	floor leveling accuracy	+/ 6mm
4	In car noise levels	55db (A)
5	Door operation noise	60 db(A)
6	lift Car Lighting	100lux min

Source: (Australia Standard and New Zealand Standard (AS/NZS), 2012)

2.18 Lift Performance Metrics Standards

The standard performance metrics when using the up peak calculation method are handling capacity and interval. Performance metrics for the simulation method are handling capacity and average waiting time (NEII, 2017). More recently, with the advent of destination dispatch systems, additional metrics such as, average time to destination, average number of intermediate stops, and percentage of long waits, also apply as key performance indicators (Peters, 2008).

According to the National Elevator Industry Inc. (NEII, 2017) the key performance indicators standards for lift performance depends on performance metrics with acceptance criteria as shown in Table 2.7. The acceptance criteria are used to evaluate onsite performance measurements of lift system during the 5-minute peak traffic period.

Table 2.7: Minimum Performance Metrics

Building Type	**Interval Time(sec)**	**Average Waiting Time (Sec)**	**Time to Destination (Sec)**
Central business district multi-tenant office building	≤ 30 up peak and ≤ 40 lunch	≤ 22 up peak and ≤ 30 lunch	80 to 100
Central business district single tenant office building	≤ 30 up peak ≤ 40 lunch	≤ 22 up peak and ≤ 30 lunch	80 to 100
Suburban office building	≤ 30 up peak	≤ 25 up peak	100 to 120
Self-parking garage	≤ 45	≤ 40	100 to 120
Hotel	≤ 40	≤ 40	100 to 120
Residential	≤ 60	≤ 45	100 to 120

Source: (NEII, 2017)

The above table specifies the acceptable values for the standard parameters.

2.18.1 Lift System Waiting Time

In the case of the simulation method the relevant metrics are the handling capacity and the average waiting time. According to British Council for Offices (BCO, 2009) and CIBSE Guide D Guidelines (2010), for all building classification and lift type the average waiting time for conventional and destination control lift system should be 30s or less and 25s or less respectively for a satisfactory performance level of lift. Table 2.8 present the acceptance criteria of the average waiting time of various building type.

Table 2.8: Recommended Waiting Time for Residential Building

Average Waiting Time (Sec)	
Building type	**Acceptance criteria**
Prestige apartments	30-42
Middle-income apartments	36-48
Low income apartments	48-72
Dormitories	36-48
Hotels-first quality	18-30
Hotels- second quality	30-42

Source: BCO (2009) and CIBSE (2010).

2.18.2 Lift Transit Time

According CIBSE (2010) the transit time between terminal floors is evaluated using Table 2.9 below;

Table 2.9: Total Time Transit between Terminal Floors in Different Building Types

Transit Time (Sec)	
Building type	**Acceptance criteria**
Large offices and hotels	17-20
Small Offices and hotels	20
Hospital, nursing/residential homes	24
Residential /commercial buildings	20-30
Factories and warehouses, shops	24-40

Source: CIBSE (2010)

2.18.3 Floor Levelling Accuracy

Floor leveling accuracy for high rise building should be 6 mm +/- (maximum in either direction) (UNSW (University of New South Walse) Lifts Design Standards, 2015). For this study measuring tape was used to determine the levelling accuracy between the landing door and lift door at terminal floor.

2.18.4 Noise

UNSW (2015) established that the ambient inside the lift car should not exceed the noise exposure limit of greater than 55dBA. And door operation or other lift noise no greater than 60dBA. A sound level meter was used in measuring door and lift car sound level.

2.19 Ride Quality of Lift Systems

It is generally adopted that vibration, jerk and noise level are the quantities that need to be measured if lift ride quality is to be quantified in any meaningful way (Abraham, 1984).

Lift ride quality in terms of lateral and vertical vibration, acceleration and deceleration and jerk has become important criteria for judging a lift's performance. Noise produced during lift operation is also a salient factor for consideration (Monge & Gómez 2014). Doors are expected to be operated at their highest speed yet still need to commensurate with safety, smoothness and noise requirement. The issue of lift ride quality would likely become a basic requirement in the specifications for new and modern lift system and a symbol of quality lift service (Li, Suen & Wu, 2004).

2.20 Lift Faults and Ride Quality

Faults usually influence in the dynamic behavior causing an underperformance on the lift (Esteban, Iturrospe & Salgado 2013). Table 2.10 and Figure 2.6 present the common faults in lift systems and the causes that influence passengers comfort in the lift car.

Table 2.10: Common Faults in Lift Systems from Literature Reviews

S/N	Lift component	Fault
1	Traction machine	Rotor misalignment Bearing faults
2	Pulley/Sheave	Eccentricity
3	Suspension System	Stiffness lose
4	Guiding system	Misalignment

Source: Esteban, Iturrospe and Salgado (2013).

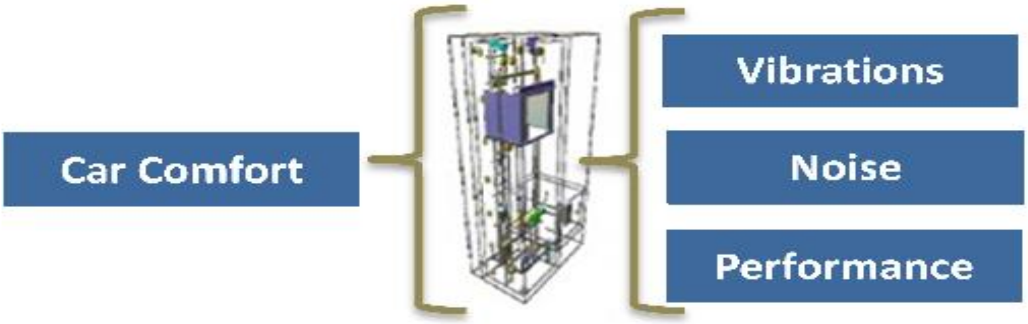

Figure 2.6 Causes that influence comfort in the lift car
Source: Monge and Gómez (2014)

According to Monge & Gómez (2014) the main ride quality problems that may appear inside a lift car are:

- High Noise Level (Leq) inside the car is due to high noise of machine, high noise of guide shoes (friction) and high airborne noise transmissibility.
- High noise level at frequency peaks inside the car as the result of resonances of lift components (car panel, car frame, machine frame…) and/or high structural vibration transmissibility from frame to car.
- High vibration levels in the car floor as the result of high mechanical vibration (unbalanced rotating mass, bearing faults, electromagnetic phenomena), and bad performance (wrong control, car floor resonance, high structural vibration transmissibility).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Research Design

The study adopts a field survey approach to achieve its objectives. A well-structured checklist was also developed for this study; this gives the guide as to which performance parameters are to be considered for measurement during the research field work. The field measurements data were obtained from the selected samples in numerical values by using appropriate scientific equipment and were used for computation and analysis.

To achieve the desired study objectives, the following research procedures was developed and followed during the research field work:

i. Select samples through permission
ii. Locate measurement position in study area
iii. Read and record measurements as observed from the study area
iv. Organise data collected to carry out statistical analysis
v. Presentation of the result (findings) obtain from analysis for interpretation and discussion

3.2 The Study Area

The study was carried out in Abuja metropolis, which is located in the centre of Nigeria, lying between latitudes 8° 25’ 00” – 9° 20’ 00” north of the equator and longitudes 6° 45’ 00” – 7° 39’ 00” east of Greenwich Meridian with an altitude of 840 meters above sea level and a total area of 8, 000km^2. Abuja is an administrative capital of Nigeria and the fourth most populous city in Nigeria, coming after Lagos, Kano and Ibadan. It is regarded as the fastest growing city in Africa with an estimated population of 1,406,239 as at 2006. However, between 2000 and 2010, the population grew by almost 140%, with more recent estimates showing the population now exceeds 2.4 million. The City has a population growing rate of

30% per annum and density of 700/Km^2 ((National Population Commission (NPC), 2006). The City is characterized by a tropical climate, an average annual temperature of 25.7^o C and annual rainfall of 1389mm. The City has a Central Business District (CBD) dominated by large corporation offices and the three Arms Zone, encompassing the presidential Villa, Supreme Court, and National Assembly. The CBD is located at the centre of Abuja phase 1 with Garki on the South, Maitama on the North, Wuse on the west and Asokoro on the east (Central Business District Abuja, 2020). The Central Area is dominated by high rise building for different purpose such as commercial, residential, etc. as approved by the Federal Capital Development Authority (FCDA) and this serves as the basis for selecting Abuja as a study area suitable for this research work.

3.3 Population, Sample Size and Sampling Techniques

3.3.1 Population and Sample Size

The population of this study was based on the high rise buildings with specific focus on buildings with minimum of 4 floors in the Central Business District of Abuja Metropolis. To arrive at the population size for this study, a preliminary field survey was carried out to access completed high rise buildings with functional installed lift systems within Central Business District of Abuja city. This was due of the lack of reliable data of definite population size of high rise buildings with functional lift systems within the study area. From the preliminary survey, fourteen (14) accessible high rise buildings with seventy (70) functional installed lift systems were identified and used as the population frame for the study.

Therefore, the sample size for the study was selected from the population frame by purposive sampling. The identified fourteen (14) high rise buildings met the selection criteria. Whereas, from the seventy (70) lift systems within the selected buildings only forty one (41) lifts systems met the selection criteria for the sample size. Thus, selected for the study. The selected lift systems for the study within the buildings were of different brand and maintained by different lift companies.

3.3.2 Sampling Technique

Purposive sampling technique which is a type of non-probabilistic sampling techniques was adopted for this study. According to Creswell (2012) purposive sampling or judgmental sampling is a qualitative procedure in which researchers intentionally select individuals and sites to learn or understand the central phenomenon. The researcher goes to respondents or areas that can provide the best data or information to achieve the objectives of the study. The major requirement for sample selection was based on the description of high rise building by Aliyu *et al* (2015) which includes buildings with minimum of 4 floors. The following formed the selection criteria to get the sample size.

i. Building should have a minimum of four (4) floors to be considered as high rise.
ii. The building should be accessible within CBD Abuja city
iii. Building must have a functional lifts installed
iv. Lift system should be accessible during up peak period within the selected buildings
v. Lift system should be accessible within the building

Table 3.1: Selected High rise building in CBD, Abuja Metropolis

S/N	Building Name	No of floors	Approximate Height (m)	Number of functional lifts	Number of lifts Selected for study
1	LA	15	54	19	4
2	LB	12	49	15	4
3	LC	12	49	3	3
4	LD	10	39	2	2
5	LE	10	39	3	3
6	LF	8	33	3	3
7	LG	7	23	2	2
8	LH	5	24	3	3
9	LI	5	24	4	3
10	LJ	5	23	3	3
11	LK	5	23	4	3
12	LL	5	23	2	2
13	LM	4	20	3	3
14	LN	4	20	4	3
	Total			**70**	**41**

Source: Field Survey (2020)

For the purpose of anonymity, the selected high rise buildings under study were represented by label LA, LB, LC, LD, LE, LF, LG, LH, LI, LJ, LK, LL, LM and LN as shown in Table 3.1 above.

3.4 Data Collection

This can be described as a research activity which is concern with the systematic process for gathering relevant data or information with reference to the variables and research design. The collected data were primary data. The data collected include the following performance metrics such as waiting time, transit time, time to destination, door opening and closing time, acceleration, velocity and interior sound pressure level of lift car and light intensity in lift cars of the lift systems.

Physical survey was conducted to collect data that relevant to the physical aspect of selected samples which includes; building type, building height, number of floors, lift types, lift brands, lift age, machine location, rated speed and lift category.

3.4.1 Data Collection Instruments

The data for this study was collected through checklist and measurement carried out in the selected high rise building with functional installed lift systems. For the purpose of this study the following instruments were used for data collection;

i. Checklist
ii. Measurement

3.4.1.1 Check list

A well-structured checklist was used to obtain relevant information specific to lift system and the buildings. The checklist instruments used for the high rise building and lift systems are included in Appendix I for more details.

3.4.1.2 Measurement

Measurement of lift system performance parameters was carried using the following tools which include,

i. Digital stopwatch
ii. Measuring tape
iii. WST85 digital sound level meter
iv. Digital light/lux meter
v. AS63D vibration meter

3.4.1.2.1 Digital Stopwatch

The stopwatch is a handheld timepiece designed to measure the amount of time that elapses between its activation and deactivation in minute and seconds to an accuracy of ±0.1s. The digital stop watch was used in the lift performance measurement to measure the lift performance parameters such as the travel time, waiting time, round trip door opening and closing time.

3.4.1.2.2 Measuring Tape

A measuring tape is a flexible ruler used to measure size or distance and object or area surface. It consists of a ribbon of cloth, plastic, fibre glass, or metal strip with linear-measurement markings. It is a common measuring tool. It has both metric and imperial measurement markings which represent measurements in centimeters, millimeters, meters, inches and feet. The measuring tape as shown in Plate I was used for measuring the leveling accuracy of lift at landing between the lift floor and the landing floor.

Plate I: Measuring Tape

3.4.1.2.3 WT85 Digital Sound Level Meter

This is an easy to use and handy Mini Sound Level Meter designed for sound quality control that measures sound level from 30dBA up ~ 130dBA. The WT85 digital sound level meter (Plate II) is applicable for measurement of noise engineering, quality control, health prevention and various environmental noises, including noise measurement in such various places as factories, offices, transporting routes, families, stereo equipment and other places. It has auto range, wide measuring and frequency range (31.5Hz ~ 8 KHz), max/min hold, Frequency Weighting A and Wide dynamic range. The Industrial Organization for Standardization (ISO 5130:2007 and ISO 18738) standards is widely used as the reference for this type of measurement and the WT85 sound level meter has been specifically designed to meet the requirements of this standard. This was used to establish the in car lift sound pressure level and evaluate the ride comfort of passenger.

Plate II: WT85 Digital Sound Level Meter

3.4.1.2.4 Digital Light Meter HS1010

The Digital Light Meter HS1010 (Plate III) is used for measuring the intensity of light in an area. Digital Light Meter HS1010 measures parameters such as Lux (lm/m^2) and foot candle (lm/ft) with the Measuring ranges: 0.01-200000 LUX. It has the sampling rate of 2.5 times/sec with and an accuracy of ± 5% rdg+10dgts (less than 10000); ± 10%rdg+10dgts (greater than 10000) under nominal temperature of 25 °C, ±1 Digit. The instrument complies with the ISO/CIE 19476:2014 illuminance and luminance meters. It was used to measure the illumination of light inside lift cars.

Plate III: Digital Light Meter HS1010

3.4.1.2.5 Smart Sensor AS63D Vibration Meter

The AS63D vibration meter (Plate IV) is a portable vibration meter designed with built-in accelerometer for easy measurement of vibrations in machines. For acceleration, two measurement ranges (10 Hz to 1 kHz or 1 kHz to 15 kHz) can be selected. The instrument has the measurement range acceleration: 0.1 to 1999.9 m/s2, velocity: 0.1 to 199.9 mm/s, Displacement: 0.001 to 1.999mm. AS63D vibration meter is design to comply with Deutsches Institut für Normung (DIN)/ISO 10816/20816 standard having the measuring of accuracy 80Hz with acceleration of ±5% ±2 digits. The vibration meter adopts piezoelectric accelerometer transducer to transfer the vibration signals and display it in 3 units; velocity, acceleration and displacement, the acceleration value which is a performance metric can be used to evaluate the ride quality of lift system. This was used to measure the acceleration for evaluating the ride comfort.

Plate IV: Smart Sensor AS63D Vibration Meter

3.4.2 Data collection procedure

Data was collected by systematic adherence to the experimental procedure described below.

3.4.2.1 Visual Inspection

A walkthrough survey of selected high rise building was undertaken to collect data specific to each building type, location and the physical information about the lift systems. Data collected was grouped into two sections: Section A included relevant building information (building type, number floor, building height, inter floor height) and Section B included relevant information about the lift system such as lift brand, lift type, lift capacity, lift rated door opening type, number of stops, lift derive system and lift machine location. The checklist and the Record forms used during the field work are included in Appendix I for more details.

3.4.2.2 Measurement

Data was collected by strictly observing the experimental measurement procedures described to achieve the specific objectives of the study.

The objectives of the measurement are to:

i. Monitor and measure the waiting time, travelling time, time to destination and door opening/closing time of the lift during up peak period.
ii. Measure the indoor noise level of lift car.
iii. Measure luminous intensity and sound pressure level produced inside the lift car
iv. Measure vibration in lift car and levelling accuracy of lift landing

The steps clearly stated below were followed in sampling location to systematically collect data for this study;

Step 1: Sampling Locations: location of installed lift, lift lobby and car indoor space in high rise served the sampling location for the study.

Step 2: Sampling Session: the time for sampling was scheduled base on the worse case traffic session of the building also referred to as up peak period by Al-Sharif (2017) usually a period of 7:30am -2:00pm for both Commercial and Administrative office buildings within the sampling location. The sampling session varies across the buildings.

Step 3: Calibration of the Equipment: The WT85 Sound level meter, AS63D Vibration Meter, stopwatch and Digital Light Meter HS1010 were calibrated according to the manufacturer's instructions.

Step 4: Positioning of the Equipment: The WT85 sound level meter, Stopwatch and Digital Light Meter HS1010 were held by hand as described in manufacturer manual inside the lift car to a normal human standing sight level of about 1.5m (Kopecký, Krejčovský & Švarc ,

2014) above the car floor level in different sampling points. Whereas, the AS63D Vibration Meter was placed was held placing the vibration detector (probe) against the lift car floor as described by the manufacturer manual.

Step 5: Handling of the Equipment:

i. The digital stop watch was handled by hand and raised to a human standing sight level of about 1.5m above the car floor level inside car for the period of ride to monitor and measure the travel time and waiting time. Data were collected and recorded 3 times in the record sheet for each lift system at all sampling points.

ii. The sound level meter' microphone was handled by hand and raised to a height of 1.5m at the human sight level (Kopecký, Krejčovský & Švarc , 2014) during lift ride. The sound meter was used during upward and downward ride of lift. Data were collected ad recorded 3 times in the record sheet to deduce the average value for each lift system at all sampling points.

iii. AS63D Vibration Meter was held while keeping the MEAS button depressed, and holding the vibration detector (probe) against the lift car floor. This measurement was conducted for the three (3) units values; acceleration, velocity and displacement. Data were collected ad recorded three (3) times in the record sheet at all sampling points. The acceleration was used to evaluate the ride quality.

iv. Digital Light Meter HS1010 was held by hand to a height of about 1.5m at human sight level above the floor level at various points of lift car indoor space during ride. Data were collected ad recorded three (3) times in the record sheet. This was used to measure the lift car illuminance in lux. The results were displayed on the screen of the instrument.

Steps 6: Documentation of Results: The resulting values were all collected as data and documented on a sampling checklist and record form (see attached).

The Precision Requirements: AS63D vibration meter instrument was calibrated according to manufacturer manual and the certificate of calibration was issued to approve measurement. Digital Light Meter HS1010 and sound level meter are recalibrated automatically after successful measurement when switch OF and ON. This was adhered to ensure accuracy of results.

3.5 Data Analysis

Descriptive statistics and inferential statistics were used to compare means and significant levels of the lift system performance parameters. The obtained means were merged into one SPSS file for analysis.

3.5.1 Descriptive Statistics

Descriptive statistics was used to summarize the frequency distribution and the percentage of various lift system information collected by checklist within the study area. From the descriptive statistics, simpler interpretation of the data was obtained and the data was presented in a more meaningful way.

3.5.2 Inferential Statistics

The one-way analysis of variance (ANOVA), a parametric test, was used to determine whether there is significant differences between the means of two or more independent groups of variables (selected high rise buildings and the lift Performant parameters). The Duncan multiple comparison post hoc test was performed on significant ANOVA findings to identify significant pairwise differences between performance parameters of lift systems in the selected high rise buildings.

The independent Sample t-Test which is a parametric test was use to compare the means of two independent group (selected high rise building types and machine location of lift systems) to determine whether there is a significant difference between the mean of the associated independent variables.

A correlation matrix table showing correlation coefficients between variables was used to summarise lift system performance metric data and to check the extend of relationship (negative and positive) that exist between the variables across the buildings and also as an input to more advanced analysis. A Probability value (p-value) of ($p<0.05$) was used for all analyses.

CHAPTER FOUR

4.0 DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.1 Data Presentation and Analysis

This section of the study captured the presentation and interpretation of data obtained from the field survey, analysis of the data and discussion of findings as they relate to the specific objectives of the study. Relevant data retrieved from the checklist and real onsite experimental measurements on lift system performance and ride quality across the selected buildings was analyzed and presented in tabular format and charts. For the purpose of discussion and evaluation of analyzed result, all lift performance parameters across the buildings that meet up the prescribed criteria are to be considered as satisfactory (ST) whereas, all measured parameters that fail to meet the prescribed criteria as shown in Table 4.2 are to be considered as unsatisfactory (UST).

4.2 Lift System Characteristics

For the purpose of this study, a checklist was used to characterize forty one (41) lift systems installed in the selected high rise buildings. The checklist included lift system information such as lift type, lift brand, lift category, rated speed and lift machine location. Table 4.1 shows the lift system characteristics at various locations. From Table 4.1, 41 (100%) of the lift type are electric traction lift indicating that all the lifts studied are traction. Based on category Table 4.1 shows that 27 (65.9%) of the lift system are standard lift, 11(26.8%) of the systems are Panoramic lift while 3 (7.35%) of the lift system are cargo lift system. This indicates that majority of the lift across the selected high rise buildings are considered to be standard lift. It also base on machine room location, 25 (61.0%) are Machine Room (MR) and 16 (39.0%) are Machine Room Less (MRL) therefore indicating that majority of the lift system operate from a machine room as presented in Table 4.1.

From Table 4.1, 17 (41.5%) of the lifts are preprogramed with the rated speed of 1.0m/s, 20 (48.8%) are rated 1.5m/s and 4 (9.8%) are rated 2.5m/s indicating that majority of the lift system in the buildings are programmed with the rated speed of 1.5m/s (48.8%) and 1.0m/s (41.5%).

From Table 4.1, 3 (7.3%) of the lifts are within the age range of 1-4yrs, 29 (70.7%), within the age range of 5-8yrs, 7 (17.1%) within the age range of 9-11yrs and 2 (4.9%) of the lift system are within the age range of 12-15yrs. Majority of the lifts studied across the buildings are within the age range of 5-8 from the time of installation.

Table 4.1: Lift System Characteristics

S/n	Characteristics	Variables	Frequency (No)	Percentage (%)
1	Drive System	Traction lift system	41	100.0
2	Category	a) Standard lift system	27	65.9
		b) Panoramic lift system	11	26.8
		c) Cargo lift system	3	7.3
	Machine Location	a) Machine room lift	25	61.0
		b) Machine room less lift	16	39.0
3	Rated Speed	a) 1.0m/s	17	41.5
		b) 1.5 m/s	20	48.8
		c) 2.5m/s	4	9.8
4	Age	a) 1-4yrs	3	7.3
		b) 5-8 yrs	29	70.7
		c) 9-11yrs	7	17.1
		d) 12-15yrs	2	4.9
		e) 1-4yrs	3	7.3

Source: Filed Survey (2020)

4.2.1 Lift System Brand in the Selected High Rise Buildings

For the purpose of this study, a checklist was used during survey to identify the various brand of lift systems selected for study across the buildings. Figure 4.1 shows that the highest number of lifts brands are BrB (9) followed by BrA (7), BrE (6), BrF (6), BrG (3), BrD(3), BrC (3), BrH (2) and BrI (2).

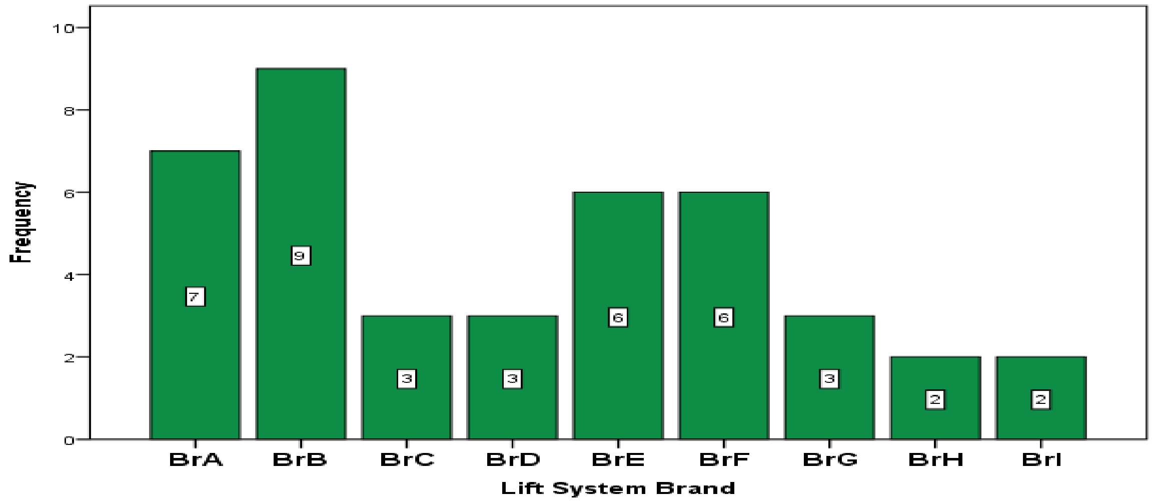

Figure 4.1: Lift System Brands
Source: Field Survey (2020)

4.2.2 Lift System Consultant/Maintenance Company

Lift systems across the buildings are maintained by different consultant/maintenance companies. Figure 4.2 shows that MA, MB and MG company maintain one (1) building each out of the selected buildings, while MD, MC, ME and MF Lift Company maintain the lift systems in two (2) out of the selected buildings and MD company maintain the lift systems in five (5) of the selected high rise buildings. Hence indicating that majority of the lifts in the buildings are maintained by MD lift consultant/maintenance comspany.

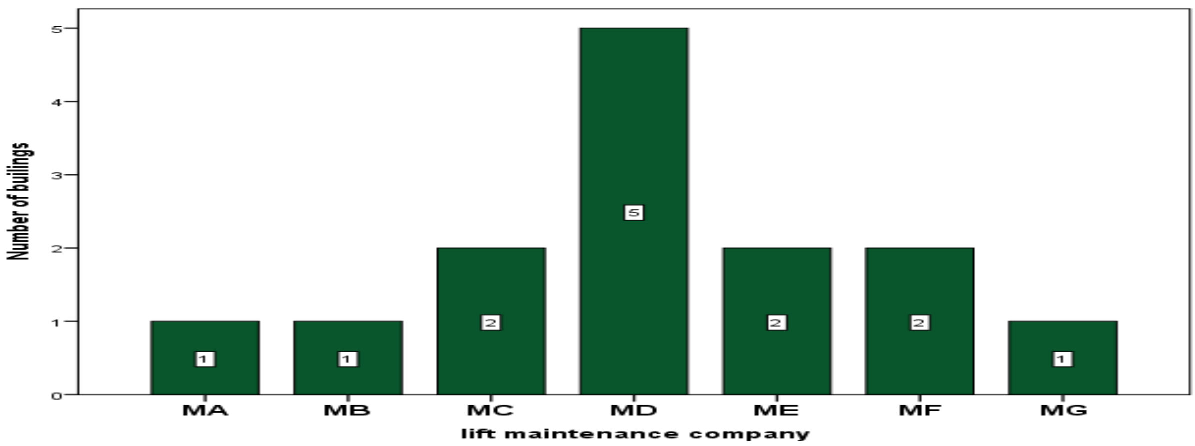

Figure 4.2: Lift Maintenance Company
Source: Field Survey (2020)

4.3 Prototype standard for lift performance metric Assessment

Data from various standard guidelines where sourced out through extensive literature review from various regulatory bodies. The harmonized performance standard data provides guideline for evaluating the parameters of lift system performance. Table 4.2 shows the harmonized standard for lift performance metrics during up peak period onsite measurement.

Table 4.2 Harmonized Standards for Lift Performance Metric for and Up Peak Period Measurement

S/N	Parameters	Acceptance Criteria	Source
1	Average waiting time (s)	≤ 35	CIBSE, AS/NZS, NEII
2	Transit time (s)	≤ 60	CIBSE, AS/NZS, NEII
3	Time to destination (s)	≤100	CIBSE, AS/NZS, NEII
4	Door opening time (s)	≤3.5	CIBSE, AS/NZS, NEII,
5	Door closing time (s)	≤4.0	CIBSE, AS/NZS, NEII
6	Door operation sound ((Leq dBA)	≤60	CIBSE, AS/NZS, NEII
7	Illuminance of lift car (Lux)	≥100	CIBSE, AS/NZS, NEII
8	Door opening sound (Leq dBA)	≤60	CIBSE, AS/NZS, NEII
9	Levelling accuracy (mm)	±6	CIBSE, AS/NZS, NEII,
10	Equivalent Lift car sound (LeqdBA)	≤55	CIBSE, AS/NZS, NEII,
11	Maximum Acceleration	$1m/s^2$	CIBSE, AS/NZS, NEII
12	Maximum Velocity	1m/s	CIBSE, AS/NZS, NEII

Source: **Field Survey (2020)**

From the above Table 4.2 the acceptance value for lift in-car sound (LeqdBA) and Maximum Acceleration were used to evaluate the ride quality of lift systems.

Due to lack of prescriptive requirements on ride quality performance and widely acceptable standard for lift performance, reference to CIBSE (Chartered Institute of Building Services Engineers) vertical transport System in Building, NEII (National Elevator Industry Inc.) Building Transportation Standards and Guidelines, Australia Standard and New Zealand Standard (AS/NZS) and industry *de facto* standard of 30:60:90 (waiting; transit; time to destination respectively) has been made to articulate a harmonized standard (Table 4.1) to be used as a benchmark to compare and evaluate the lift system performance parameters for the purpose of this study.

4.4 Evaluation of Lift System Performance in Selected High Rise Buildings

Table 4.3 showed the result of the statistical test for the performance parameters of different lift systems in high rise buildings within Central Business District, Abuja city. P-values along the column is showing significant difference of the Average Waiting Time (AWT), Transit Time (TRT), and Time to Destination (TTD) and Levelling Accuracy (LEV) between the various lift systems in the buildings. For the Average waiting time of the lift systems, a significant difference was observed ($P < 0.05$) across the buildings. A significant decrease ($P < 0.05$) in the average waiting time was observed in lift systems across building LA and LB when compared with building LF - LN. Likewise a significant increase in the average waiting time was seen in the lift systems of building LK, LI and LH compared to LA-LE, while there is no significant difference ($P>0.05$) between LF to LK. For the Transit Time (TRT) and Time to Destination (TTD) in all the various lift systems, a significant decrease ($P < 0.05$) was observed in the lift systems of high rise building LA, LB and LJ, when compared with the lift systems in LC, LD, LG and LF.

Likewise the Leveling and Illuminance showed a significant difference ($P < 0.05$) among the lifts across buildings. A significant increase ($P < 0.05$) was observed in both the Leveling and

Illuminance as seen in lift system of LN compared with the rest of the other lifts in the buildings.

Table 4.3: ANOVA of Lift System Performance Parameters

Buildings	***AWT (Sec) (Mean ± S.E)***	***TRT (Sec) (Mean ± S.E)***	***TTD. (Sec) (Mean ± S.E)***	***LEV (±mm) (Mean ± S.E)***	**ILL (lux) (Mean ± S.E)**
LA	31.50 ± 0.87[a]	26.00 ± 1.15[a]	57.50 ± 2.02[a]	7.50 ± 4.33[ab]	73.00 ±14.43[ab]
LB	30.00 ± 0.58[a]	27.50 ± 0.87[abc]	57.50 ± 0.29[a]	0.33 ± 0.33[a]	124.50 ± 22.23[abc]
LC	51.50 ± 3.17[bcd]	30.50 ± 0.29[cde]	82.00 ± 2.89[bcd]	4.00 ± 0.58[ab]	165.00 ± 66.39[abc]
LD	41.50 ± 2.59[abc]	30.00 ± 1.16[bcde]	71.50 ± 1.44[ab]	4.00 ± 1.16[ab]	117.50 ± 14.72[abc]
LE	41.00 ± 5.19[ab]	27.00 ± 1.15[ab]	68.00 ± 6.35[ab]	1.00 ± 0.58[a]	152.00 ± 3.46[abc]
LF	47.50 ± 5.49[bcd]	30.00 ± 1.16[bcde]	77.50 ± 4.33[bcd]	0.33 ± 0.13[a]	130.50 ± 0.87[abc]
LG	51.50 ± 3.17[bcd]	28.50 ± 0.87[abcd]	80.00 ± 4.04[bcd]	6.00 ± 2.31[ab]	132.00 ± 11.55[abc]
LH	55.50 ± 3.75[cd]	27.00 ± 1.16[ab]	82.50 ± 4.91[bcd]	6.50 ± 3.75[ab]	75.00 ± 2.89[ab]
LI	60.00 ± 8.66[d]	28.50 ± 1.44[abcd]	88.50 ± 10.10[cd]	4.50 ± 2.59[ab]	95.00 ± 14.43[abc]
LJ	47.00 ± 3.46[bcd]	25.50 ± 0.86[a]	72.50 ± 4.33[b]	1.50 ± 0.86[a]	183.50 ± 59.76[bc]
LK	58.00 ± 1.15[d]	32.00 ± 1.73[e]	90.00 ± 0.58[d]	1.57 ± 0.92[a]	162.00 ± 53.12[abc]
LL	43.50 ± 5.48[abc]	28.00 ± 0.58[abc]	71.50 ± 4.91[ab]	2.50 ± 0.29[a]	189.00 ± 58.89[c]
LM	51.50 ± 5.48[bcd]	31.50 ± 0.29[de]	83.00 ± 5.77[bcd]	10.00 ± 3.46[bc]	67.50 ± 1.44[a]
LN	47.00 ± 1.15[bcd]	27.00 ± 0.58[ab]	74.00 ± 0.58[bc]	15.00 ± 2.89[b]	188.50 ± 9.82[c]
F	**4.459**	**3.848**	**4.772**	**3.498**	**1.654**
p-Value	**0.000**	**0.001**	**0.000**	**0.003**	**0.029**

AWT-Average Waiting Time: **≤ 35sec**; TRT-Transit Time: **≤60sec**; TTD-Time to Destination: **≤100sec**; LEV-Levelling: **±6mm**; ILL-Illuminance: **≥100 lux.** Data analyzed using one way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same columns with different superscripts a, b and c are significantly different within the groups ($p < 0.05$).

4.3.1 Average Waiting Time (AWT)

From the above Table 4.3 the result showed onsite measurement mean value of average waiting time for the lift systems of the selected buildings in Central Business District of Abuja city during up peak period. The AWT of passenger for most of the lift systems across the buildings are above the accepted standard performance requirements when compared with the bench mark as presented in Table 4.3. However, LA and LB with mean average waiting time of 31.5sec and 30.0sec respectively are considered to be the buildings with satisfactory passenger waiting time. Hence, indicating long waiting time of passengers for lift systems in building LC-LN. According to NII (2017) the average waiting should be considered as a key performance indicator for examining lift system performance in high rise building. Moreover, excellent performance level of lift system in high rise building should also fall within the industry *de facto* standard of 30:60:90 (waiting; transit; time to destination respectively) (Al-Sharif, 2016). Measuring the performance of a lift system in an existing high rise buildings especially using onsite real measurement of the average waiting time is more complicated using stop watch measuring (Al-Sharif, 2016). However, the analyzed data for average waiting time of this study were measured using stopwatch measurement. From Table 4.3, TRT and TTD of the lift systems across the buildings are within the performance acceptance criteria value stated as bench mark. Hence, indicating satisfactory travel speed within all the buildings.

4.3.2 Levelling Accuracy of lift system

For optimum performance of lift system, the levelling accuracy must not exceed ±6mm stated as Bench Mark (BM) in Table 4.3. However, the leveling accuracy of lift systems in building LA, LH, LM and LN were observed to have leveling values above the bench mark, indicating poor levelling between cabin floor and the landing floor during lift stop. Conversely, the levelling values of lift systems in building LB, LC, LD, LE, LF, LG, LI, LJ, LK and LL are considered to be within the acceptance criteria of ±6mm stated as bench mark. Hence, indicating satisfactory levelling during stops in majority of the buildings.

4.3.3 Lift System Illuminance

For optimum lighting performance of lift car indoor environment, 100 lux is considered to be the minimum standard requirement stated as bench mark in Table 4.3. From Table 4.3, the luminous intensity of car indoor environment of the lift system in building LB, LC, LD, LE, LF, LG, LJ, LK, LL and LN meet up the acceptance criteria for good lighting performance in lift car. Whereas, the lift systems in the building LA, LH, LI and LM are considered to have illuminance value above the bench mark. Hence, suggesting a poor lighting performance of lift system in some of the buildings (LA, LH, LI and LM).

4.4 Lift System Door Operation

An ideal lift system performance must ensure quick and quite door operation (Stanley, 2019). However this depends on door opening and closing time and door opening and closing sound measurements as shown in Table 4.4.

Table 4.4 shows the result of the statistical analysis of the different measurement of lift system door operation in buildings.

P-values along the column with different superscripts is indicating a significant difference of the different door operation parameters such as Door Opening Time (DOT), Door Closing Time (DCT), Door opening sound (DOS); Door closing sound (DCS) including Lift Capacity (LTC). For both the door opening time and door closing time there is no significant difference ($p > 0.05$) observed in between and within the different lifts in the buildings. For the door opening sound and door closing sound a significant difference was observed ($P < 0.05$) between some of the lift systems across the buildings. A significant decrease ($P < 0.05$) was observed in Door opening time of building LA when compared with building LE, LI and LL. Likewise a significant increase in the Door closing time was seen in building LK and LN when compared with the rest of the other buildings.

Table 4.4: ANOVA of Door Operation of Lift System

Buildings	***DOT (Sec) (Mean ±S.E)***	***DCT (Sec) (Mean ± S.E)***	***DOS (dBA) (Mean ± S.E)***	**DCS (dBA) (Mean ± S.E)**
LA	2.94 ± 0.21	2.94 ± 0.23	39.40 ± 0.64^{a}	41.55 ± 0.14^{ab}
LB	2.88 ± 0.21	2.84 ± 0.21	41.96 ± 2.10^{ab}	40.25 ± 4.53^{ab}
LC	3.27 ± 0.04	3.26 ± 0.03	48.05 ± 4.92^{bcd}	47.55 ± 3.43^{bc}
LD	3.42 ± 0.30	3.69 ± 0.25	48.10 ± 0.46^{bcd}	47.80 ± 2.25^{bc}
LE	3.20 ± 0.19	3.28 ± 0.10	50.70 ± 1.67^{d}	40.40 ± 1.04^{ab}
LF	2.97 ± 1.45	2.28 ± 1.56	48.95 ± 1.53^{bcd}	40.35 ± 4.01^{ab}
LG	3.26 ± 0.03	3.27 ± 0.03	42.25 ± 0.26^{abc}	38.60 ± 1.73^{a}
LH	3.19 ± 0.36	3.19 ± 0.35	46.00 ± 0.40^{abcd}	41.80 ± 0.29^{abc}
LI	3.01 ± 0.17	3.01 ± 0.17	52.70 ± 2.31^{d}	47.66 ± 2.29^{bc}
LJ	2.87 ± 0.21	2.92 ± 0.23	50.00 ± 4.21^{bcd}	47.05 ± 3.03^{abc}
LK	3.16 ± 0.25	3.11 ± 0.24	49.50 ± 4.16^{bcd}	47.25 ± 2.34^{bc}
LL	3.06 ± 0.08	3.08 ± 0.14	50.25 ± 1.70^{cd}	46.35 ± 2.97^{abc}
LM	3.28 ± 0.03	3.14 ± 0.04	45.80 ± 0.87^{abcd}	45.10 ± 0.12^{abc}
LN	3.09 ± 0.13	3.11 ± 0.14	50.20 ± 1.50^{bcd}	50.20 ± 2.02^{c}
F	**1.280**	**1.337**	**2.578**	**2.181**
p-Value	**0.282**	**0.251**	**0.017**	**0.041**

DOT-Door Opening Time: ≤3.5Sec; DCT-Door Closing Time: ≤4.0Sec; DOS-Door Opening Sound: ≤60dBA; DCS-Door Closing Sound: ≤60dBA. Data analyzed using one way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same column with different superscripts $^{a, b}$ and ^{c} are significantly different within the groups ($p < 0.05$)

4.4.1 Door Opening and Closing Timing/Sound of lift System within the Buildings

Irrespective of the door opening and closing orientation (side or center opening), the timing of the car door during operation affect performance of lift (CIBSE, 2010). However, for optimum performance the door operational timing must meet up the standard performance stated as bench in Table 4.4. From Table 4.4, lift systems door opening and closing timing is satisfactory 99% of the buildings. Thus, indicating quick operation of lift system. The sound produced by lift system in the all the buildings is considered to be satisfactory during door operation.

4.5 Lift System Ride Quality Assessment

Lift performance parameters are usually considered when evaluating ride quality of lift system. It is generally accepted that vibration (acceleration) and sound level are quantities that need to be measured if lift ride quality is to be evaluated in any meaningful way (Abraham, 1984). Noise produced during lift operation is also a salient factor for consideration (Li, *et all,* 2004). For this study, vibration measurement is considered in terms of acceleration and velocity with respect to the vibration meter adopted for the study. Table 4.5 showed the result of the statistical analysis of the different building ride quality parameter measurement of the lift systems.

P-values along the column with different subperscript are indicating significant differences in the mean value of ride quality parameter of the lift system such as lift system sound level, acceleration and velocity. A significant difference ($p > 0.05$) was observed in all the performance metrics for various lift system ride quality. For the approximate sound level a significant increase ($p < 0.05$) was observed in between LD, LH and LF when compared with LA, LB LC and LE buildings. Likewise the Acceleration in LN, LK, LG and LE lift system was significantly increased compared with the other buildings. The Velocity in LN and LF was significantly higher than that of the rest of the buildings. In most of the other buildings, the lift system showed no significant difference between and within them.

Table 4.5: ANOVA of Ride Quality Parameters

Buildings	**Sound Level (dBA) (Mean ± S.E)**	**BM 55Dba**	**Acceleration (m/s^2) (Mean ± S.E)**	**BM $1m/s^2$**	**Velocity (m/s) (Mean ± S.E)**	**BM 1m/s**
LA	51.60 ± 1.04^{ab}	ST	1.09 ± 0.06^{ab}	UST	1.30 ± 0.12^{bc}	UST
LB	48.45 ± 1.59^{a}	ST	0.87 ± 0.05^{a}	ST	0.90 ± 0.03^{a}	ST
LC	51.95 ± 0.49^{ab}	ST	1.08 ± 0.13^{ab}	UST	1.40 ± 0.06^{bcd}	UST
LD	58.20 ± 1.38^{bcd}	UST	1.75 ± 0.03^{c}	UST	1.65 ± 0.14^{cde}	UST
LE	52.90 ± 4.44^{ab}	ST	1.69 ± 0.47^{c}	UST	1.39 ± 0.24^{bcd}	UST
LF	62.30 ± 1.67^{cd}	UST	1.09 ± 0.12^{ab}	UST	1.75 ± 0.03^{de}	UST
LG	56.25 ± 0.03^{bc}	UST	1.65 ± 0.87^{c}	UST	1.45 ± 0.14^{bcd}	UST
LH	63.70 ± 3.75^{d}	UST	0.91 ± 0.03^{a}	ST	1.55 ± 0.03^{bcde}	UST
LI	58.00 ± 0.40^{bcd}	UST	0.94 ± 0.14^{a}	ST	1.25 ± 0.02^{b}	UST
LJ	60.45 ± 3.20^{cd}	UST	1.50 ± 0.12^{bc}	UST	1.65 ± 0.03^{cde}	UST
LK	52.65 ± 1.76^{ab}	ST	1.75 ± 0.09^{c}	UST	1.60 ± 0.06^{bcde}	UST
LL	55.65 ± 0.95^{bc}	ST	1.28 ± 0.18^{abc}	UST	1.55 ± 0.20^{bcde}	UST
LM	58.20 ± 1.09^{bcd}	UST	0.97 ± 0.08^{a}	ST	1.25 ± 0.09^{b}	UST
LN	58.50 ± 2.42^{bc}	UST	1.70 ± 0.12^{c}	UST	1.83 ± 0.07^{e}	UST
F	**4.148**		**4.751**		**4.720**	
p-Value	**0.001**		**0.000**		**0.000**	

BM- Bench Mark; ST-Satisfactory; UST-Unsatisfactory; Data analyzed using one way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same column with different superscripts $^{a, b}$ and ^{c} Are significantly different within the groups ($p < 0.05$).

4.5.1 Ride Quality Evaluation in High Rise Building

From the results, the lift systems in LB, LH, LI and LM are observed to have satisfactory acceleration with mean value within the bench mark for acceptance criteria. Whereas, the lift systems in LA, LC, LD, LE, LF, LG, LJ, LK, LL and LN are observed to have unsatisfactory acceleration indicating high vibration of lift system during ride. Vibration above the accepted criteria indicates high vibration which may result to discomfort of passenger during ride (Li *et all,* 2004). Therefore, majority of the buildings are said to have a problem of passenger discomfort during lift system ride. This usually occurs as the result of lift system age and inadequacies in design and maintenance (Aliyu *et'al*, 2015). Similarly, the interior sound produced during ride by the lift systems across LA, LB, LC, LE and LK were considered to be satisfactory. Whereas, the lift systems in LD, LF, LG, LH, LI, LJ, LL, LM and LN were considered to have unsatisfactory sound level resulting to noise in lift car of most buildings. The rising interior noise in lift system usually results to passengers discomfort especially the age class that could not use the stairs in getting to the upper floors easily (Aliyu *et'al,* 2015). From Table 4.5, the study indicates poor ride quality in most of the lift system across the buildings since the lift systems produced high vibration (acceleration) and noise during ride. Interior sound of lift car is proportional to the acceleration (NEII, 2017).

4.6 Performance metrics Assessment of Lift Category

Table 4.6 showed the result of the statistical analysis of the different lift category performance parameters.

P-value along the row with different superscripts is indicating a significant difference of the different lift category such as the Standard lift, panoramic lift and Cargo lift in all the different high rise buildings. The result shows that there is no significant difference recorded ($p > 0.05$) in the values of Average waiting time, Transit time, Time to destination, Illuminance, interior sound level, Velocity, Door opening Time, Door closing time and Door opening sound . While a significant increase was observed in the Door closing sound of the panoramic lift category compared with the standard and the cargo lift category.

Table 4.6: ANOVA of Performance Metrics across Lift Categories

Parameters	***BM***	***Standard (Mean ± S.E)***	***Panoramic (Mean ± S.E)***	***Cargo (Mean ± S.E)***	***F***	**P-value**
AWT (sec)	≤35 (sec)	44.55 ± 2.067	50.42 ± 2.61	53.79 ± 2.88	2.745	0.077
TRT (m/s)	≤60 (sec)	28.12 ± 0.39	29.33 ± 0.80	29.36 ± 1.44	1.121	0.336
TTD (Sec)	≤100(sec)	72.62 ± 2.21	79.75 ± 3.04	83.14 ± 3.97	2.978	0.063
ILL (lux)	≥100 lux	123.34 ± 9.11	161.00 ± 34.53	146.00 ± 35.87	1.064	0.355
ISL. (dBA)	≤55dBA	56.24 ± 1.03	53.07 ± 0.76	58.29 ± 1.89	1.688	0.198
ACC. (m/s^2)	$1m/s^2$	1.44 ± 0.06	1.57 ± 0.09	1.49 ± 0.07	0.608	0.551
DOT (Sec)	≤3.5(sec)	3.14 ± 0.07	3.22 ± 0.04	3.04 ± 0.14	0.398	0.674
DCT (Sec)	≤4.0(sec)	3.13 ± 0.07	3.23 ± 0.05	2.98 ± 0.12	0.870	0.427
DOS (dBA)	≤60dBA	46.59 ± 0.85	50.99 ± 2.64	47.78 ± 2.07	1.956	0.155
DCS (dBA)	≤60dBA	43.10 ± 0.94^{a}	49.12 ± 1.98^{b}	45.85 ± 1.19^{ab}	4.290	0.021

BM- Bench Mark; AWT-Average Waiting Time; TRT-Transit Time; TTD-Time to Destination; ILL-Illuminance; ISL-; Interior Sound Level; ACC-Acceleration; DOT-Door Opening Time; DCT-Door Closing Time; DOS-Door Opening Sound; DCS; Door Closing Sound; Data analyzed using one way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same row with different superscripts $^{a, b}$ and ^{c} are significantly different within the groups ($p < 0.05$).

4.6.1 Waiting Time of Lift Category

The result in Table 4.6 shows that there is long average waiting time of passengers for lift system across the different lift category in the selected buildings when compared with the bench mark. Nonetheless, standard lift is considered to have the least mean value of average waiting time.

4.6.2 Illuminance of Lift system Category

The result presented in Table 4.6 indicates that all lift system category have satisfactory interior illuminance of lift car across the buildings. However, panoramic lift is considered to have higher illumination as compared with standard and cargo lift system. Panoramic lift system allows better visual comfort due to its transparent design nature. Hence, allowing the impact of both natural and artificial lighting on the lift car indoor environment.

4.6.3 Door operation of Lift Category

The result presented in Table 4.6 shows that lift system categories have optimum door operational performance across the buildings. However, cargo lift system was considered to be more efficient having the least mean value of 3.04sec and 2.98sec for door opening and closing respectively. Door operation affect lift system performance and therefore, the opening and closing time must be considered during lift traffic design to optimize service delivery of the system (Al-Sharif, 2016).

4.7 Performance Assessment of Lift Maintenance Companies

Table 4.7 showed the result of the statistical analysis of the different lift maintenance companies. Values along the column with different subperscript are indicating a significant di fference in mean values of lift performance parameters across maintenance companies. No significant difference was recorded ($p > 0.05$) in the values of Levelling, Transit time and illuminance in between and within companies. A significant decrease ($p < 0.05$) was observed in the average waiting time of MA and MB compared with the rest of the other companies, MC has a significant value in the average waiting time. Likewise a significant ($p < 0.05$) decrease was observed in MA company in the time to destination compared with the rest of the other company.

Table 4.7: ANOVA of Lift Performance across Lift Companies

Lift Company	*AWT (Sec) (Mean ± S.E)*	*TRT (Sec) (Mean ± S.E)*	*TTD (Sec) (Mean ± S.E)*	*LEV (mm) (Mean ±S.E)*	**ILL (lux) (Mean ± S.E)**
MA	31.50 ± 0.87^{a}	26.00 ± 1.15	57.50 ± 2.02^{a}	7.50 ± 4.33	73.00 ± 14.43^{a}
MB	30.00 ± 0.58^{a}	27.50 ± 0.87	57.50 ± 0.28^{b}	0.33 ± 0.33	124.50 ± 22.23^{ab}
MC	51.50 ± 2.01^{bc}	29.50 ± 0.61	81.00 ± 2.26^{bc}	5.00 ± 1.16	148.50 ± 31.03^{ab}
MD	47.00 ± 2.14^{bc}	29.20 ± 0.69	76.20 ± 2.42^{bc}	4.38 ± 1.56	150.10 ± 11.56^{ab}
ME	57.75 ± 4.33^{c}	27.75 ± 0.89	85.50 ± 5.19^{c}	5.50 ± 2.09	85.00 ± 7.96^{b}
MF	49.25 ± 3.07^{bc}	28.50 ± 1.40	77.75 ± 3.99^{bc}	5.75 ± 2.48	125.50 ± 37.25^{ab}
MG	43.50 ± 5.49^{b}	28.00 ± 0.58	71.50 ± 4.91^{b}	2.50 ± 0.23	189.00 ± 58.89^{b}
F	**6.804**	**1.096**	**5.789**	**0.639**	**1.878**
p-Value	**0.000**	**0.384**	**0.000**	**`0.698**	**0.112**

AWT-Average Waiting Time; TRT-Transit Time; TTD-Time to Destination; LEV-Levelling; data analyzed using two way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same columns with different superscripts $^{a, b}$ and ^{c} are significantly different within the groups ($p < 0.05$).

4.7.1 Performance of Lift System versus Maintenance

Table 4.7 showed the mean value of performance parameters of lift systems in buildings maintained by lift maintenance companies. The buildings maintained by MA and MB were considered to have satisfactory passengers waiting time than other buildings. The leveling accuracy of lifts maintained by MB is more adequate as compared with other buildings. The illuminance of lifts in buildings maintained by the companies is considered to be satisfactory except for the buildings maintained by MA and ME. Therefore, this inference provides a suggestive preliminary basis for the choice of lift consultancy or maintenance Company by a lift client. Lift system performance and maintenance go hand in hand. Poor maintenance is indicated by increased floor-to-floor lift ride and waiting times. According to FMLink Group (2019), there is need for property manager to carefully observe the time lift functions and compare them with the manufacturer's specifications in order to evaluate the overall system performance.

4.8 Door Operation Performance across Lift Companies

Table 4.8 showed the result of the statistical analysis of the different lift maintenance companies. A

value along the column with different subperscript is indicating a significant difference in values of the various maintenance companies. No significant difference was recorded ($p > 0.05$) in the values of Door Opening Time, Door closing time and Door opening sound in both between and within the various maintenance company. While a significant ($p < 0.05$) decrease was observed in MA and MB in the Door opening sound; compared to the rest of the other company.

INFERENCE: This indicates that the door operational performance across the lift system in the buildings maintained by the various lift companies are satisfactory as presented in Table 4.

Table 4.8: ANOVA of Lift Door Operation Performance of Lift Companies

Lift Company	***DOT (Sec) (Mean ± S.E)***	***DCT (Sec) (Mean ± S.E)***	***DOS (dBA) (Mean ± S.E)***	**DCS (dBA) (Mean ± S.E)**
MA	2.94 ± 0.21	2.93 ± 0.23	39.40 ± 0.63^{a}	41.55 ± 0.14
MB	2.88 ± 0.21	2.84 ± 0.21	41.96 ± 2.10^{ab}	40.25 ± 4.53
MC	3.26 ± 0.02	3.27 ± 0.02	45.15 ± 2.56^{abc}	43.08 ± 2.64
MD	3.23 ± 0.11	3.20 ± 0.10	49.49 ± 0.88^{c}	45.20 ± 1.44
ME	3.10 ± 0.19	3.10 ± 0.18	49.35 ± 1.82^{c}	44.73 ± 1.67
MF	3.08 ± 0.13	3.03 ± 0.12	47.90 ± 2.14^{bc}	46.07 ± 1.42
MG	3.07 ± 0.08	3.08 ± 0.14	50.25 ± 1.70^{c}	46.35 ± 2.97
F	**0.779**	**0.844**	**3.858**	**0.754**
P-value	**0.592**	**0.545**	**0.005**	**0.611**

DOT-Door Opening Time; DCT-Door Closing Time; DOS-Door Opening Sound; DCS; Door Closing Sound. Data analyzed using one way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same columns with different superscripts $^{a, b}$ and ^{c} are significantly different within the groups ($p < 0.05$).

4.9 Lift System Ride quality across different maintenance companies

Table 4.9 showed the result of the statistical analysis of the different lift maintenance companies. Values along the column with different subperscript are indicating a significant di fference in values of the various maintenance companies. A significant difference was recorded ($p < 0.05$) in the values of the interior sound level, acceleration and velocity between and with the various lift maintenance companies. A significant decrease ($p < 0.05$) was observed in the interior sound and acceleration of lift systems of MB and ME lift maintenance company compared with the rest of the other companies. Likewise for the velocity a significant ($p < 0.05$) decrease was observed in MB lift Maintenance Company compared the rest of the other company.

INFERENCE: Table 4.9 shows that majority of the lift system maintained by all lift companies (MA-MG) are said to have optimum interior sound lever. Conversely, most of the lifts maintained by companies are experiencing problems associated with vibration of lift car.

Table 4.9: ANOVA of Lift Ride Quality of Different Company

Lift Company	**Interior Sound (dB) (Mean ± S.E)**	**BM ≤55dBA**	**Acceleration (m/s^2) (Mean ± S.E)**	**BM $1 m/s^2$**	**Velocity (m/s) (Mean ± S.E)**	**BM 1m/s**
MA	51.60 ± 1.04^{ab}	ST	1.09 ± 0.06^{ab}	UST	1.30 ± 0.12^{b}	UST
MB	48.45 ± 1.59^{a}	ST	0.87 ± 0.05^{a}	ST	0.90 ± 0.03^{a}	ST
MC	54.10 ± 0.98^{abc}	ST	1.36 ± 0.15^{ab}	UST	1.42 ± 0.07^{bc}	UST
MD	56.31 ± 1.37^{bcd}	UST	1.59 ± 0.11^{b}	UST	1.65 ± 0.05^{c}	UST
ME	60.85 ± 2.11^{d}	UST	0.92 ± 0.06^{a}	ST	1.40 ± 0.06^{bc}	UST
MF	59.32 ± 1.59^{cd}	UST	1.23 ± 0.13^{ab}	UST	1.45 ± 0.10^{bc}	UST
MG	55.65 ± 0.95^{bcd}	ST	1.28 ± 0.18^{ab}	UST	1.55 ± 0.20^{bc}	UST
F	**4.041**		**4.197**		**5.213**	
p-Value	**0.004**		**0.003**		**0.001**	

BM- Bench Mark; ST-Satisfactory; UST-Unsatisfactory; Data analyzed using one way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same columns with different superscripts $^{a, b}$ and ^{c} are significantly different within the groups ($p < 0.05$).

4.10 Lift performance across lift brands

Table 4.10 showed the result of the statistical analysis of the different lift brands. Values along the column with different subperscript are indicating a significant differ ence in the mean value of lift parameters for lift brands. No significant difference was recorded ($p > 0.05$) in the mean values of TRT in both between and with the various lift brands. A significant decrease ($p < 0.05$) was recorded in the AWT in BrA, BrC and BrD as compared with BrE and BrG. A significant increase in the Levelling accuracy was recorded in BrI as compared with the rest of the lift brands. For illuminance a significant ($p < 0.05$) increase was observed in BrI and BrH as compared with BrE, while for time to destination the significant increase was recorded in BrG as compared with BrA and BrD.

INFERENCE: From Table 4.10, all the lift systems brands are considered to be to have satisfactory levelling accuracy and illuminance level across the buildings except for BrE and Bri respectively. However, all of the lift brands except for BrA are considered to have been experiencing long passenger waiting time since the brands have unsatisfactory AWR.

Table 4.10: ANOVA of Lift Performance across Lift Brands in Nigeria

Lift Brand	AWT (Sec) (Mean ± S.E)	TRT (Sec) (Mean ± S.E)	TTD(Sec) (Mean ± S.E)	LEV(mm) (Mean ± S.E)	ILL (lux) (Mean ± S.E)
BrA	39.50 ± 4.36^{a}	28.00 ± 1.15	67.50 ± 4.96^{a}	3.92 ± 2.51^{a}	101.75 ± 14.39^{ab}
BrB	44.33 ± 3.18^{ab}	28.83 ± 0.57	73.17 ± 4.18^{abc}	3.44 ± 1.08^{a}	140.50 ± 21.21^{ab}
BrC	41.50 ± 2.59^{a}	30.00 ± 1.15	71.50 ± 1.44^{ab}	4.00 ± 1.15^{a}	117.50 ± 14.72^{ab}
BrD	41.00 ± 5.19^{a}	27.00 ± 1.15	68.00 ± 6.35^{a}	1.00 ± 0.58^{a}	152.00 ± 3.46^{ab}
BrE	57.75 ± 4.34^{b}	27.75 ± 0.89	85.50 ± 5.19^{bc}	5.50 ± 2.09^{a}	85.00 ± 7.95^{a}
BrF	49.25 ± 3.07^{ab}	28.50 ± 1.40	77.75 ± 3.99^{abc}	5.75 ± 2.48^{a}	125.50 ± 37.25^{ab}
BrG	58.00 ± 1.16^{b}	32.00 ± 1.73	90.00 ± 0.58^{c}	1.57 ± 0.92^{a}	162.00 ± 53.12^{ab}
BrH	43.50 ± 5.48^{ab}	28.00 ± 0.58	71.50 ± 4.91^{ab}	2.50 ± 0.29^{a}	189.00 ± 58.98^{b}
BrI	47.00 ± 1.16^{ab}	27.00 ± 0.57	74.00 ± 0.57^{abc}	15.00 ± 2.88^{b}	188.50 ± 9.52^{b}
F	**2.883**	**1.423**	**2.198**	**2.722**	**2.466**
p-Value	**0.031**	**0.224**	**0.044**	**0.020**	**0.021**

AWT-Average Waiting Time; TRT-Transit Time; TTD-Time to Destination; LEV-Levelling; data analyzed using one way ANOVA followed by duncan multiple comparison post hoc test. Values along the same c olumns with different superscripts $^{a, b}$ and ^{c} are significantly different within the groups ($p < 0.05$).

4.11 Door Operation across Lift Brands

Table 4.11 showed the result of the statistical analysis of the different door operation across lift brands. Value along the column with different superscripts is indicating a significant difference in values of the lift brand of various maintenance companies. No significant difference was recorded ($p > 0.05$) in the values of Door Opening Time, Door closing time Door opening sound and Door closing time in both between and with the various maintenance companies. A significant increase ($p <0.05$) was observed in the BrC and BrD lift brand in term of the lift car passenger capacity compared with the rest of the lift brands.

INFERENCE: From Table 4.11, All lift brands across the buildings operate at optimum door opening and closing timing and an also door operation sound level with exception of Brc which has unsatisfactory door opening time. However, BrD (mean=20.00) has the highest passenger capacity.

Table 4.11: ANOVA of Door Operation across Lift Brands

Lift Brand	***LPC (Mean ± S.E)***	***DOT (Sec) (Mean ± S.E)***	***DCT (Sec) (Mean ± S.E)***	**DOS (dBA) (Mean ± S.E)**	**DCS (dBA) (Mean ± S.E)**
BrA	18.50 ± 1.40^{b}	2.96 ± 0.12	2.89 ± 0.13	44.17 ± 2.26	40.95 ± 1.81
BrB	17.83 ± 1.35^{a}	3.13 ± 0.09	3.13 ± 0.09	44.09 ± 1.84	42.13 ± 2.19
BrC	19.50 ± 0.87^{b}	3.73 ± 0.30	3.68± 0.25	48.10 ± 0.46	47.80 ± 2.25
BrD	20.00 ± 1.15^{b}	3.20 ± 0.19	3.28 ± 0.10	50.70 ± 1.67	40.40 ± 1.03
BrE	12.75 ± 1.48^{a}	3.10 ± 0.18	3.10 ± 0.18	49.35 ± 1.82	44.73 ± 1.66
BrF	12.65 ± 1.59^{a}	3.07 ± 0.13	3.03 ± 0.12	47.90 ± 2.14	46.07 ± 1.42
BrG	9.00 ± 0.57^{a}	3.16 ± 0.25	3.11 ± 0.24	49.50 ± 4.15	47.25 ± 2.33
BrH	9.83 ± 1.58^{a}	3.06 ± 0.08	3.08 ± 0.14	50.25 ± 1.70	46.35 ± 2.97
BrI	9.90 ± 1.56^{a}	3.09 ± 0.13	3.11 ± 0.14	50.20 ± 1.50	50.20 ± 2.02
F	**6.671**	**1.431**	**1.639**	**1.470**	**1.980**
P-value	**0.000**	**0.221**	**0.151**	**0.206**	**0.080**

VEL-Velocity; LPC-Lift Passenger Capacity; DOT-Door Opening Time; DCT-Door Closing Time; DOS;DoorOpening Sound; DCS;Door Closing Sound.data analyzed using one way ANOVA followed by Duncan mult iple comparison post hoc test. Values along the same columns with different superscripts $^{a, b}$ and ^{c} are significantly diff erent within the groups ($p < 0.05$).

4.12 Ride Quality of Lift Brands

Table 4.12 showed the result of the statistical analysis for the ride quality of lift brands. Values along the column with different subperscript are indicating a significant differ ence in values of the brands. A significant difference was recorded ($p < 0.05$) in the values of the interior sound level and Acceleration between and within the brands. A significant decrease ($p <0.05$) was observed in the interior sound level of BrB, BrD and BrG brand compared to BrE lift brand. Likewise for the Acceleration a significant ($p < 0.05$) decrease was observed in BrE brand compared to the BrG and BrC lift brands. For the velocity no significant difference was observed between the lift brands.

INFERENCE: 66.66% of lift brands have satisfactory interior sound level. Conversely, majority of the lift system brand across the buildings are considered to be vibrating as only 14.28% of the lift brands are considered to have unsatisfactory acceleration mean value in Table 4.12. However, Lift BrE (acceleration mean= 0.92) is said to be the lift brand with optimum lift ride quality and less vibration.

Table 4.12: ANOVA of Ride Quality of Lift Brand

Lift Brand	***Sound Level (dB) (Mean ± S.E)***	***BM*** $\leq$***55dBA***	***Acceleration (m/s²) (Mean ± S.E)***	***BM 1m/s²***	***Velocity (m/s) (Mean ± S.E)***	**BM 1m/s**
BrA	56.95 ± 2.55^{ab}	ST	1.09 ± 0.06^{a}	UST	1.52 ± 0.11	ST
BrB	52.22 ± 1.22^{a}	ST	1.19 ± 0.12^{ab}	UST	1.25 ± 0.09	ST
BrC	58.20 ± 1.38^{ab}	UST	1.75 ± 0.02^{c}	UST	1.65 ± 0.14	ST
BrD	52.90 ± 4.44^{a}	ST	1.69 ± 0.47^{bc}	UST	1.39 ± 0.23	ST
BrE	60.85 ± 2.11^{b}	UST	0.92 ± 0.06^{a}	ST	1.40 ± 0.06	ST
BrF	59.32 ± 1.59^{ab}	UST	1.23 ± 0.13^{abc}	UST	1.45 ± 0.09	ST
BrG	52.65 ± 1.76^{a}	ST	1.75 ± 0.08^{c}	UST	1.60 ± 0.05	ST
BrH	55.65 ± 0.95^{ab}	ST	1.28 ± 0.18^{abc}	UST	1.55 ± 0.20	ST
BrI	55.50 ± 2.42^{ab}	ST	1.70 ± 0.12^{bc}	UST	1.83 ± 0.06	ST
F	**2.459**		**3.890**		**1.928**	
p-Value	**0.003**		**0.003**		**0.089**	

BM- Bench Mark; ST-Satisfactory; UST-Unsatisfactory; Data analyzed using one way ANOVA followed By Duncanmultiple comparison post hoc test. Values along the same columns with different superscripts a, b and c are significantly different within the groups ($p < 0.05$).

4.13 Lift Performance between Administration and Commercial Lift System

Table 4.13 shows results of the statistical independent t-test showing the difference between lift systems in administration and commercial buildings. For all the parameters between the administration and commercial buildings, there is no significant difference ($p > 0.05$) with the exception of number of floor and lift capacity as a significant increased ($p < 0.05$) in values of the was number of floor and lift capacity.

INFERENCE: Table 4.13 shows that commercial buildings are said to be buildings with higher number height, number of stops and lifts systems with high rated speed. Majority of the lift systems in commercial buildings are older than of administrative building. However, commercial buildings have older lift with large passenger capacity compared to administrative buildings. In terms of height and number floors, commercial buildings selected are considered to have more floors than administrative buildings.

Table 4.13: Independent Sample T-Test of Lift System Performance Parameters for Administration and Commercial Building

Parameter	**ADMIN (Mean± S.E)**	**COMM (Mean ± S.E)**	**p- Value**
HTD	27.00 ± 2.72	28.13 ± 1.92	0.730
NST	8.83 ± 0.92	9.25 ± 0.66	0.707
RSD	1.17 ± 0.06	1.37 ± 0.10	0.108
LTA	6.33 ± 0.41	7.88 ± 0.74	0.107
LFC	13.06 ± 1.10	16.40 ± 0.95	0.027
NFL	5.83 ± 0.29	7.75 ± 0.69	0.029
AWT	47.92 ± 2.49	46.19 ± 2.19	0.606
TRT	28.58 ± 0.62	28.44 ± 0.49	0.852
TTD	76.50 ± 2.79	74.63 ± 2.42	0.615
LEV	4.07 ± 1.09	5.04 ± 1.13	0.551
ILL	126.92 ± 15.34	136.69 ± 12.97	0.628
ISL	57.03 ± 1.28	55.45 ± 1.04	0.342
ACC	1.29 ± 0.08	1.31 ± 0.09	0.913
VEL.	1.53 ± 0.05	1.42 ± 0.06	0.189

HTD-Height of Distance; NST-Number of Stops; RSD-Rated Speed; LTA-Lift Age; LFC-Lift capacity; NFL-Number of floors ; AWT-Average Waiting Time; TRT-Transit Time; TTD-Time to Destination; LEV-Levelling; ILL-Illuminance; LTA-Lift Age; ADT-;Interior Sound level ACC-Acceleration; VEL-Velocity; LTC-Lift Capacity; ADMIN-Administration; COM-Commercial. Data analyzed using independent sample T-test. Values are significantly different within the groups ($p < 0.05$).

4.14 Lift Performance across Machine Location

Table 4.14 shows results of the statistical independent t-test showing the machine room lift and machine room less. There is significant increase of values ($p < 0.05$) in AWT, TRT and TTD in machine room less (MRL) lift than machine room (MR) lift systems, and for the rest of the remaining performance parameters showed no significant difference ($p < 0.05$) across the building type and the machine location.

INFERENCE: Table 4.14 shows that the machine room lifts are installed in buildings with higher distance (HTD), NST (Number of Stops) compare to the machine room less lifts. Lift system in buildings with machine room are preprogrammed with higher rated speed (RSD). The buildings with machine room have lifts with satisfactory door operation as compared with building having machine room less lifts as shown in Table 4.14. The interior sound level, levelling accuracy, door operation of the lift system in both MR and MRL are satisfactory.

Table 4.14: Independent Sample T-Test of Lift System Performance Parameters for Lift Machine Location

Parameters	MR	MRL	p- Value
	(Mean ± S.E)	(Mean ± S.E)	
HTD	30.00 ± 2.57	25.05 ± 1.63	0.133
NST	9.86 ± 0.88	8.20 ± 0.56	0.118
RSD	1.46 ± 0.10	1.10 ± 0.05	0.004
AWT	43.23 ± 2.18	51.00 ± 2.14	0.015
TRT	27.52 ± 0.49	29.58 ± 0.49	0.005
TTD	70.75 ± 0.49	80.58 ± 2.25	0.005
LEV	5.30 ± 1.30	3.89 ± 0.86	0.382
ILL	121.09 ± 12.52	145.05 ± 15.17	0.227
ISL	56.17 ± 1.37	56.09 ± 0.82	0.960
ACC	1.27 ± 0.09	1.34 ± 0.08	0.609
DOT	3.09 ± 0.08	3.18 ± 0.07	0.466
DCT	3.09 ± 0.07	3.14 ± 0.08	0.612
DOS	46.24 ± 1.05	48.71 ± 1.15	0.119
DCS	43.66 ± 0.98	45.26 ± 1.29	0.323

HTD-Height of Distance; NST-Number of Stops; NFL- Number of Floors; RSD-Rated Speed; AWT-Average Waiting Time; TRT-Transit Time; TTD-Time to Destination; LEV-Levelling; ILL-Illuminance; ISL-;Interior Sound Level ACC-Acceleration; VEL-Velocity; DOT-Door Opening Time; DCT-Door Closing Time; DOS-Door Opening Sound; DCS-Door Closing Sound; MR-Machine Room Lift and MRL Machine Room Less Lift. Data analyzed using Independent sample-test. Values are Significantly Different within the groups ($p < 0.05$).

4.15 Correlation Matrix of Lift System Performance Data

Table 4.15 showed a correlation analysis of all lift performance data collected for performance evaluation to observe the nature of relationship that exist between the performance data. A positive correlation coefficient means the value of one variable increases as the value of the other variable increases as well or as one decreases the other decreases. A negative correlation coefficient indicates that as one variable increases, the other decreases or as one variable decreases, the other increases. A correlation with double asterisks (**) signify very significant while those with single asterisk (*) signify significant ($p < 0.05$).

INFERENCE: The correlation matrix of the Table 4.15 below shows the relationships that exist between the various parameters such as height of distance, number of stops, number of floors, rated speed, average waiting time, transit time, time to destination, levelling, Illuminance, lift age, Acceleration, velocity, lift capacity, door opening time, door closing time, door opening sound, door closing sound. Table 4.15 indicates that there is a very significant positive correlation between the following parameters;

i. Number of Stops (NST) and Height Distance of the buildings (HTD)
ii. Number of floors (NFL) and NST and HTD
iii. Rated Speed (RDS) of lift system and NFL, NST and HTD
iv. Average Waiting Time (AWT) and RDS
v. Transit Time (TRT) and AWT

Additionally, there is a very significant negative correlation that exists between the following parameters;

i. Average Waiting Time and NST, NFL and HTD
ii. Time to Distance (TTD) and HTD and NFL
iii. Velocity (VEL) and HTD, NST and RDS

Table 4.15: Correlation Matrix between Lift System Performance Parameters

	HTD	NST	NFL	RSD	AWT	TRT	TTD	LEV	ILL	LTA	ACC	VEL	LTC	DOT	DCT	DOS	DCS
HTD	-																
NST	0.99**	-															
NFL	0.61**	0.63**	-														
RSD	0.57**	0.59**	0.57**	-													
AWT	-0.56**	-0.59**	-0.33*	0.61**	-												
TRT	-0.17	-0.16	0.10	-0.251	0.38*	-											
TTD	-0.54**	-0.56**	-0.28	-0.63**	0.98**	0.56**	-										
LEV	-0.15	-0.15	-0.41**	-0.37*	0.16	-0.12	0.12	-									
ILL	-0.22	-0.19	0.08	-0.04	-0.15	-0.16	-0.17	-0.12	-								
LTA	0.17	0.19	0.38*	0.12	-0.13	0.19	-0.08	0.15	0.05	-							
ACC	-0.25	-0.20	-0.03	-0.15	0.001	-0.02	-0.003	0.06	0.23	0.13	-						
VEL	-0.43**	-0.41**	-0.29	-0.40**	0.35*	0.06	0.33*	0.10	0.16	0.29	0.31*	-					
LTC	0.76**	0.76**	0.72**	0.62**	-0.59**	-0.09	-0.55**	-0.41**	-0.05	0.26	-0.08	-0.34*	-				
DOT	-0.03	-0.02	0.15	-0.19	0.23	0.38*	0.28	-0.06	-0.15	0.28	0.26	0.18	-0.01	-			
DCT	-0.01	-0.01	0.16	-0.19	0.24	0.29	0.28	-0.10	-0.13	0.23	0.28	0.22	0.01	0.98**	-		
DOS	-0.44**	-0.45**	-0.11	-0.28	0.39**	0.13	0.38*	-0.13	0.44**	-0.02	0.02	0.30	-0.14	0.21	0.25	-	
DCS	-0.28	-0.28	-0.20	-0.30	0.29	0.15	0.29	0.21	0.37*	0.18	0.02	0.22	-0.20	0.22	0.22	0.71**	-

HTD-Height of Distance; NST-Number of Stops; NFL-Number of Floors; RSD-Rated Speed; AWT-Average Waiting Time; TRT-Transit Time; TTD-Time to Destination; LEV-Levelling; ILL-Illuminance; LTA-Lift Age; ACC-Acceleration; VEL-Velocity; LTC-Lift Capacity; DOT-Door Opening Time; DCT-Door Closing Time; DOS-Door Opening Sound; DCS-Door Closing Sound. Source: Author's Analysis (2020), Pearson Correlation with (*) indicating significant and (**) very significant.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

From the research, the major findings are as follows:

i. Traction lift system is the most commonly installed type of lift system used in selected high rise building within Central Business District, Abuja metropolis.

ii. The buildings have 90% of traction lifts installed at an average preprogrammed rated speed of 1.0m/s

iii. From the selected buildings, 65.9% of the lifts installed are standard lift and 39.0% of the lifts are having machine room located within the buildings.

iv. The average waiting time of passengers in 85.71% of the selected buildings are considered to be above the acceptance criteria in Table 4.2.

v. The levelling accuracy of lifts in 28.57% of the buildings exceeded the acceptance criteria. Whereas, 71.43% of the buildings have lift systems with optimum levelling accuracy.

vi. Illuminance level of lift systems in 71.43% of the buildings are above the acceptance criteria.

vii. Lift system in Building LA (51.60dBA), LB (48.43dBA), LC (51.95dBA), LE (52.90dBA) and LK (52.65dBA) constituting 35.71% have optimum in car sound level.

viii. The ride quality of lift systems in 71.42% of the buildings are considered to be poor since the acceleration (vibration) is above the acceptance criteria.

ix. Buildings with cargo lift system are considered to make more interior noise than others lift systems.

x. Panoramic lift system in the selected high rise building have high illuminance level than other lift categories (i.e Standard and Cargo lift)

xi. Standard lift system provide minimum passenger waiting time than the other categories (i.e. Cargo and panoramic lift system)

xii. Operation of door lift system within the selected buildings is quick and quite operation.

xiii. There is a correlation (both negative and positive relationship) between some lift performance parameters and the selected building information

5.2 Conclusion

Most significantly, the study concludes that the selected high rise buildings were considered to have assessed lift systems performing below expected performance standard as 85.7% of selected high rise buildings experienced long passenger waiting time, 64.0% with lift systems having unsatisfactory interior sound and 71.4% with lift systems having poor ride quality.

5.3 Recommendations

This study provided lift system performance experimental data of what occurs in fourteen selected high rise building. It is recommended that:

i. The performance data collected for this research can be used for optimization of lift systems service delivery within CBD.

ii. Future research should consider other methods for assessing lift system performance such as simulation method.

iii. Future research on lift system performance should be conducted for lift installed in other building type such as residential, academic building, hospital etc.

iv. Future research should consider examining the impact of lift age on overall performance of lift system in high rise buildings.

5.4 Contributions to Knowledge

The contributions to knowledge of this research work are:

i. The research established that 90% of the lift systems are rated with the average speed of 1.0m/s in the selected high rise buildings.

ii. The research established that 85.7% of the selected buildings are said to have experienced long waiting time (AWT>35sec) in Central Business District, Abuja.

iii. The research established that there is unsatisfactory sound performance of lift systems (≤55dbA) in 64.3% of high rise buildings in Abuja city.

i. The research established that 71.4% of the selected buildings are having lift with poor right quality as the vibration value exceed the acceptance criterion for a satisfactory ride quality (Acceleration>1m/s^2).

ii. The research provides available performance parameters data such as the AWT, Sound level, light level and acceleration in lift car for optimization of lift systems service delivery in CBD, Abuja City.

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APPENDIX 1

CHECK LIST

CHECKLIST FOR THE ASSESSMENT OF LIFT SYSTEM PERFORMANCE IN HIGH RISE BUILDINGS

Section A: Building Information

S/n	General Building information	Description
1	Building Type (office, Hotel, Hospital, commercial etc.)	
2	Building Location	
3	Approximate Building population	
4	Floor to floor distance	
5	Age of building	
6	Number of entrances	
7	Number floors	
9	Basement: Parking	

Source: field survey (2020)

Section B: General information of Lifts

S/n	General Lifts information	Description
1	Lift type	
2	Lift age	
3	Lift brand (model)	
4	Lift rated Capacity (Number of persons)	
5	Lift rated speed	
6	Lift control type (conventional or destination control)	
7	Number of lift in the building	
8	Door dimension	
9	Door size	
10	Lighting type	
11	Lift power source	

Source: field survey (2020)

RECORD SHEET: General Survey of lift system and building information

S/N	Bldg Type	Location of Building	Bldg Name	Bldg Label/ No of floors	Lift Type	Lift age /no of stops	Lift Brand	Lift Consultant	Number of lift installed	Number of functional lift	Lift category (standard lift, Cargo lift, Panoramic lift)
1											
2											
3											
4											
5											
6											
7											
8											
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10											
11											
12											
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17											
18											
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21											
22											

Source: field survey (2020

RECORD SHEET

s/n	Building type	Location	Lift type	Lift brand	No of lift	Functionality	
						No of functional lift	No of non-functional lift
1							
2							
3							
4							
5							
6							
7							
8							
9							
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35							
36							
37							

Source: field survey (2020

Lift Door Time and Sound Level Measurement

S/N	Building Type	Lift Door Type	Lift Door Dimension	Door timing (sec)								Sound Level							
				Door opening (sec)				Door closing (sec)				Door Opening (db)				Door Closing (db)			
1				**1st**	**2nd**	**3rd**	**AVG**	**1st**	**2nd**	**3rd**	**AVG**	**1st**	**2nd**	**3rd**	**AVG**	**1st**	**2nd**	**4rd**	**AVG**
2																			
3																			
4																			
5																			
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27																			
28																			

Source: field survey (2020)

Vibration frequency measurement of lift system

S/N	Building Type	Lift Type	Machine Room location	Lift Category	KINEMATIC PARAMETERS											
					Acceleration (m/s^2)				Velocity (m/s)				Displacement (m)			
					1st	2nd	3rd	AVG	1st	2nd	3rd	AVG	1st	2nd	3rd	AVG
1																
2																
3																
4																
5																
6																
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8																
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27																

Source: field survey (2020)

Illuminance measurement in lux, levelling accuracy, waiting and Transit time

S/N	Building Type	Car Size/Capacity		Illuminance of Lift (lux)				Levelling Accuracy (±mm)				Waiting Time (sec)				Transit Time (sec)			
		Inside Car Dimension (mm)	Car Capacity (kg)	Lift Indoor Lighting															
				1st	2nd	3rd	AVG	1st	2nd	3rd	AVG	1st	2nd	3rd	AVG	1st	2nd	3rd	AVG
1																			
2																			
3																			
4																			
5																			
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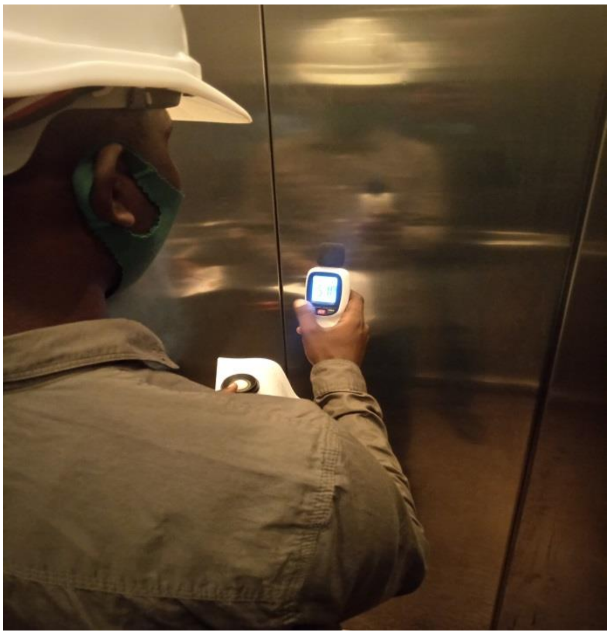
Source: field survey (2020)

APENDIX 2:

Pictures of Researcher and Measurement Sampling Location

Levelling Acuracy measuremen

Vibration measurement on lift floor



Door sound measurement of lift car

Indoor sound measurement of lift system

Lift control sytem board box

iluminance measuremnt of lift indoor inviroment

Vibration measurement in panoramic lift car floor

Vibration measurement in standard lift car floor