AN EVALUATION OF RIDE QUALITY IN LIFT SYSTEMS OF SELECTED PUBLIC HIGH-RISE BUILDINGS IN ABUJA, NIGERIA

Emmanuel Chongcicimmi Ibrahim, Andrew Mhya Stanley, Buhari Mohammed Manzuma*, Olugbenga Ayeni and Ibrahim Isah
Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria, NIGERIA
*Corresponding author: bmmanzuma@abu.edu.ng

Abstract
Ride quality of lifts enhances the comfort of lift users in high rise buildings. This work investigated the ride quality of lifts in selected high-rise buildings within the Central Business District (CBD) of Abuja, Nigeria. The study adopted field survey method. Instruments like the WT85 Digital Sound Level Meter and Smart Sensor Vibration Meter alongside a checklist were used for data collection on lift cabin interior sound level and vibration during acceleration. Results show that 64.3% of the buildings have unsatisfactory interior lift sound levels and 71.4% with poor ride quality. Inferential statistical analysis showed significant differences ($p<0.05$) in the mean values of lift car interior sound levels and lift acceleration values. The assessed lift systems were considered to have unsatisfactory ride quality as majority of them produced sounds beyond established standards for optimum sound level and vibration in lift cars (≤55dBA and $1m/s^2$). For high-rise buildings considering modernization of lift systems or installation of new ones, ride quality is a factor to consider for optimum service delivery and users' ride comfort. However, the findings from the study could be of benefit to lift consultants and manufacturers when planning for lift design and installation in high rise buildings

Keywords: Lift, Noise, Ride quality, Sound, Vibration

Article history:
Submitted: 28/05/2021; Revised: 29/09/2021; Accepted: 25/10/2021; Online: 02/02/2022

1.0 Introduction

The rise in the development of new buildings with integrated lift systems to meet the demands for vertical transportation of people and goods in such buildings around the globe has made the performance of lift systems a matter of consideration (Aliyu, Hussaini, Abubakar, Baba and Mu'awuya, 2015). A lift is a hoisting or lowering mechanism, designed and equipped with a car to carry passengers or freight between two or more landings (University of New South Wales, 2019). According to Chartered Institute of Building Services Engineers, CIBSE, (2010), lift systems can be classified as either electric traction type or hydraulic type. Traction lifts have car and counterweight attached to opposite ends of hoist ropes with the ropes passing over a driving machine that raises and lowers the lift car and the lift running on load-bearing rails in the lift shaft (Müller, 2014). Traction lifts are most often used in mid-rise and high-rise buildings with five or more floors (Bhatia, 2012). Hydraulic lifts, on the other hand, are raised by forcing pressurized oil through a valve into a steel cylinder located above ground level or underground (Bhatia, 2012).

For most users of high-rise buildings, the use of lift systems has become an indispensable requirement for facilitating vertical transportation in these buildings (Li, Andy & Eddie, 2004). The performance of these lift systems has received increasing attention with lift users expecting the best of quality lift service and ride comfort during lift operation (Al-Sharif, 2017). According to Li, Kong and Suen (2004) and Monge and Gómez (2014), lift ride quality or lift ride comfort in high-rise buildings in terms of lateral and vertical vibrations, acceleration and deceleration, and jerk has become one of the important criteria for judging a lift's performance. However, 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 (Wit, 2017). According to CIBSE (2010) the subject of lift ride quality would likely become a basic requirement in modern specification or installation of new lift systems to optimize their service delivery.

Aliyu *et. al* (2015) pointed out that more than 20% of the lifts studied in Nigeria were found to be vibrating beyond expected levels with rising interior noise making about 25% of passengers uncomfortable especially the age class that could not use stairs in getting to upper floor levels. Noise produced during lift operation is also a salient factor for consideration when evaluating ride quality of lift systems (Monge & Gómez, 2014). Although lift doors are expected to be operated at their highest speed, it still needs to commensurate with safety, smoothness and noise requirement (Adekomaya & Samuel, 2016). According to CIBSE (2014), the interior of lift cars should have noise levels less than 48–52 dB(A) for superior ride comfort as noise levels above 60 dB(A) usually result to poor performance of lift systems.

According to National Elevator Industry Incorporation, NEII, (2017), the performance of a lift system is usually evaluated on the basis of the time it takes to perform the function of vertical transportation. This includes the time required to close the doors, start the car, move to another floor, stop the car, open the doors etc. To accomplish these actions, some levels of noise and vibration would be generated. However, the noise and vibration are often perceived as the lift ride quality by the passengers (Esteban, Iturrospe & Salgado, 2013). ISO 18738 (2012) observed that lift performance is synonymous to lift ride quality.

Therefore, the critical aspect of lift ride quality is how to define, measure, evaluate and interpret what it entails (Strakosch & Caporale, 2010). For this study, acceleration, door operation sound and lift car sound were used to evaluate the lift ride qualities in some selected high-rise buildings in Nigeria.

2.0 Methodology

2.1 Research Design

The study adopted a field survey approach to achieve its objectives. A well-structured checklist was developed and used to serve as a guide as to which performance parameters are to be considered for measurement during the research field work.

2.2 Study Area

The study was carried out in Abuja metropolis, Nigeria. The city has a Central Business District (CBD) dominated by large corporate offices and the three Arms Zone, encompassing the presidential Villa, Supreme Court, and the National Assembly. The Central Area is known for its dominance with commercial, residential, and public high-rise buildings for serving different purposes as approved by the Federal Capital Development Authority (FCDA). This serves as the basis for selecting Abuja as a study area suitable for this research work.

2.3 Population, Sample Size and Sampling Technique

The population of the study was based on the high-rise buildings with specific focus on buildings with a minimum of 4 floors in the CBD of Abuja Metropolis. To arrive at the population size for this study, a field survey was carried out to access completed high-rise buildings with functional installed lift systems within the study area. The sample size for the study was obtained from preliminary survey conducted to identify accessible high-rise buildings with functional lifts systems. This was due of the lack of reliable data of definite population size of buildings with functional lift systems within the study area. From the preliminary survey, 14 accessible high-rise buildings with functional installed lift systems were identified and used as the population frame for the study. Therefore, the study sample was selected from the population frame through purposive sampling. From the selected high-rise buildings, 70 lift systems were identified and 41 lifts systems met the sampling criteria and were used for the study. The selected lift systems for the study were of different brands and maintained by different lift companies. The selected 41 high-rise buildings met these selection criteria:

i. Buildings with a minimum of four (4) floors;
ii. The buildings are accessible within CBD of Abuja;
iii. Buildings with functional lift systems;
iv. Lift system(s) is/are accessible during up peak period within the selected buildings;

2.4 Data Collection Instrument, Procedure and Analysis

Physical survey was conducted to collect data 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. In addition, data for this study was collected through measurements carried out in the selected high-rise buildings with functional installed lift systems. For the purpose of this study, the following instruments were used for data collection;

i. WT85 digital sound level meter
ii. AS63D vibration Meter
iii. Checklist

The WT85 Digital Sound Level Meter (Figure 1a) is an easy to use and handy device designed for sound quality control measuring sound level from 30dBA up to ~130dBA. This device was used to establish the in-car lift sound pressure level which in turn was used to evaluate the ride quality of the lift systems. The AS63D vibration meter (Figure1b) is a portable device designed with built-in accelerometer for easy measurement of vibrations. The instrument has the measurement range of 0.1

to 1999.9 m/s^2 and 0.1 to 199.9 mm/s for acceleration and velocity respectively. The vibration meter adopts piezoelectric accelerometer transducer to transfer vibration signals into 3 units; velocity, acceleration and displacement. The acceleration value which is a performance metric was then used to evaluate the ride comfort of the lift systems.

To collect data, the location of the lobby of the installed lift system was first identified. The time for sampling was scheduled based on the worst-case traffic session of the building (up peak period) usually a period of 7:30am-2:00pm for both Commercial and Administrative buildings within the sampling location. The WT85 Sound level meter and AS63D Vibration meter were then calibrated according to the manufacturers' instructions. The WT85 sound level meter was handheld inside the lift car as described in the manufacturer's manual to a normal human standing sight level of about 1.5m (Kopecký, Krejčovský & Švarc, 2014) above the car floor level at different sampling points during lift ride.

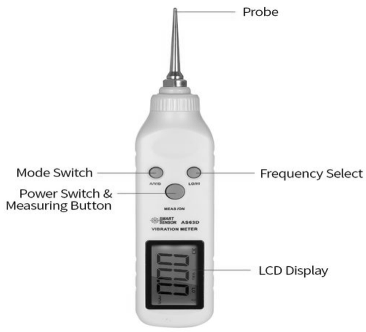

Figure 1a: WT85 Digital Sound Level Meter Figure1b: Smart Sensor AS63D Vibration Meter

The sound meter was used during upward and downward ride of lift. Data was collected and recorded 3 times in the record sheet to deduce the average value for each lift system at all sampling points. The AS63D Vibration Meter on the other hand, was held placing the vibration detector (probe) against the lift car floor as described by the manufacturer's manual. Using the vibration meter, measurements were taken for three-unit values; acceleration, velocity and displacement. Data was collected and recorded 3 times in the record sheet at all sampling points. The acceleration was then used to evaluate the ride quality. The resulting values were all collected as data and documented on a sampling checklist and record form. Due to the lack of prescriptive requirements on the ride quality performance and widely acceptable standard for lift performance, data from various standard guidelines and regulatory bodies (CIBSE, AS/NZS, NEII) were sourced out from literature and used as standard for evaluating the lift ride quality of the selected lift system (Table 1). Descriptive statistics was used to summarize the frequency distribution and the percentages 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. In addition, one-way analysis of variance (ANOVA), a parametric test, was used to determine whether there are significant differences between the means of two or more independent groups of variables (selected high-rise buildings and the lift performance 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.

Table 1: Harmonized Standards for Lift Ride Quality

S/N	Parameters	Acceptance Criteria	Source
1	Door operation sound (Leq dBA)	≤60dBA	CIBSE, AS/NZS, NEII
2	Equivalent Lift car sound (Leq dBA)	≤55dBA	CIBSE, AS/NZS, NEII,
3	Maximum Acceleration	1m/s^2	CIBSE, AS/NZS, NEII
4	Maximum Velocity	1m/s	CIBSE, AS/NZS, NEII

***Source*: CIBSE (2010); AS/NZS (2012); NEII (2017).**

3.0 Results and Discussion

3.1 Characteristics of the Lift Systems

From Table 2 and Figure 2, all the lift systems studied are traction lift drive system with 29 (70.7%) of the lift systems with age between 5 and 8 years. None of the lifts has reached the industry standard life of 20 years (Brooks, 2021) and are therefore expected to continue to perform optimally with good maintenance. This is corroborated by Liu and Wu (2018) in their assertion that routine maintenance will not only guarantee quality rides but also improve the longevity of lift systems. Majority (23 out of 41) of the lift system are rated at 1m/s, 15 are rated at 1.5 m/s and only 3 of the lifts can accelerate to a speed of 2.5 m/s.

Table 2: Lift System Characteristics

Characteristics	Variables	Frequency (No)	Percentage (%)
Drive System	Traction lift system	41	100.0
Age	a) 1-4 years	3	7.3
	b) 5-8 years	29	70.7
	c) 9-11years	7	17.1
	d) 12-15 years	2	4.9

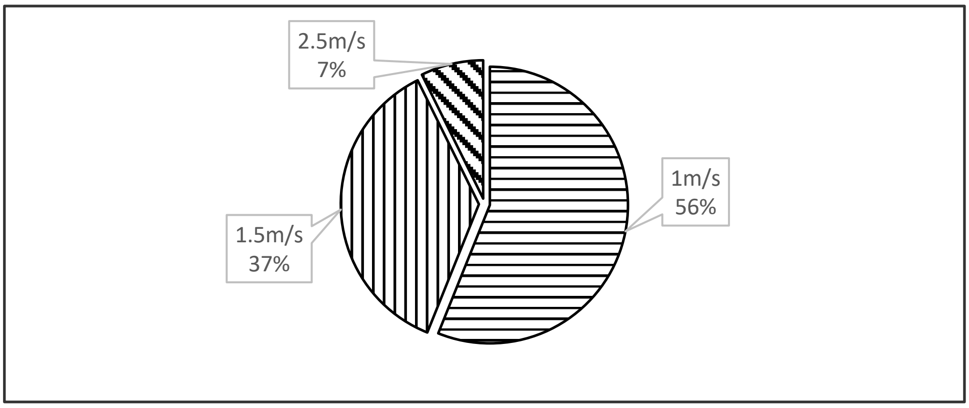

Figure 2: Lift rated speed

3.2 Lift System Ride Quality Assessment

Lift performance parameters are usually considered when evaluating ride quality of lift systems. 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. Noise produced during lift operation is also a prominent factor for consideration. Table 3 presents ride quality parameters as observed and their various level of acceptance with harmonized standards. For the purpose of anonymity, the selected high-rise buildings under study were represented by labels PA, PB, PC, PD, PE, PF, PG, PH, PI, PJ, PK, PL, PM and PN.

From the results shown in Table 3, the lift systems of buildings PB, PH, PI and PM were observed to have satisfactory acceleration with mean values within the benchmark of acceptance criteria (1m/s^2). Whereas, the lift systems in PA, PC, PD, PE, PF, PG, PJ, PK, PL and PN were observed to have unsatisfactory acceleration indicating high vibration of lift systems during ride. Vibration above the accepted criteria indicates high vibration which may result in discomfort of passenger during ride operation (Monge & Gómez, 2014).

Table 3: Ride Quality Evaluation of Selected High-Rise Buildings

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
PA	51.60 ± 1.04^{ab}	ST	1.09 ± 0.06^{ab}	UST	1.30 ± 0.12^{bc}	UST
PB	48.45 ± 1.59^{a}	ST	0.87 ± 0.05^{a}	ST	0.90 ± 0.03^{a}	ST
PC	51.95 ± 0.49^{ab}	ST	1.08 ± 0.13^{ab}	UST	1.40 ± 0.06^{bcd}	UST
PD	58.20 ± 1.38^{bcd}	UST	1.75 ± 0.03^{c}	UST	1.65 ± 0.14^{cde}	UST
PE	52.90 ± 4.44^{ab}	ST	1.69 ± 0.47^{c}	UST	1.39 ± 0.24^{bcd}	UST
PF	62.30 ± 1.67^{cd}	UST	1.09 ± 0.12^{ab}	UST	1.75 ± 0.03^{de}	UST
PG	56.25 ± 0.03^{bc}	UST	1.65 ± 0.87^{c}	UST	1.45 ± 0.14^{bcd}	UST
PH	63.70 ± 3.75^{d}	UST	0.91 ± 0.03^{a}	ST	1.55 ± 0.03^{bcde}	UST
PI	58.00 ± 0.40^{bcd}	UST	0.94 ± 0.14^{a}	ST	1.25 ± 0.02^{b}	UST
PJ	60.45 ± 3.20^{cd}	UST	1.50 ± 0.12^{bc}	UST	1.65 ± 0.03^{cde}	UST
PK	52.65 ± 1.76^{ab}	ST	1.75 ± 0.09^{c}	UST	1.60 ± 0.06^{bcde}	UST
PL	55.65 ± 0.95^{bc}	ST	1.28 ± 0.18^{abc}	UST	1.55 ± 0.20^{bcde}	UST
PM	58.20 ± 1.09^{bcd}	UST	0.97 ± 0.08^{a}	ST	1.25 ± 0.09^{b}	UST
PN	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 ($p < 0.05$).

Therefore, majority of the buildings are said to have a problem of passenger discomfort during rides. This usually occurs as lift system ages coupled with poor maintenance culture. This is evident as majority of the lift systems are within the age range of 5-8years (Table 2). Other factors that may be responsible may include inadequacies in design and installation. Similarly, the interior sound produced during ride by the lift systems across PA, PB, PC, PE, PK and PL were considered to be satisfactory as shown in Table 3. Whereas, the lift systems in PD, PF, PG, PH, PI, PJ, PM and PN were considered to have unsatisfactory sound level resulting in noise in the lift car of most buildings. The rising interior noise in lift systems usually results in passengers' discomfort especially the aged class that cannot use the stairs in getting to upper floors easily. 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.

3.3 Lift System Door Operation

An ideal lift system ride quality must ensure quick and quiet door operation. Table 4 shows the results of lift systems door operation assessment. The data was analyzed using one-way ANOVA followed by Duncan multiple comparison post hoc test.

Irrespective of the door opening and closing orientation (side or center opening), the sound produced during opening and closing of lift doors affects ride quality. However, for optimum ride quality the sound level must not exceed maximum value for ride quality bench mark as shown in Table 4. As observed, the lift systems door operation sound is satisfactory for 99% of the buildings. Thus, indicating quiet operation of lift system door with less impact on the overall ride quality of lift systems as suggested by NEII (2017).

Table 4: Lift System Door Operation Assessment

Buildings	DOS (dBA) (Mean ± S.E)	BM (dBA) ≤60	DCS (dBA) (Mean ± S.E)	BM (dBA) ≤60
PA	39.40 ± 0.64[a]	ST	41.55 ± 0.14[ab]	ST
PB	41.96 ± 2.10[ab]	ST	40.25 ± 4.53[ab]	ST
PC	48.05 ± 4.92[bcd]	ST	47.55 ± 3.43[bc]	ST
PD	48.10 ± 0.46[bcd]	ST	47.80 ± 2.25[bc]	ST
PE	50.70 ± 1.67[d]	ST	40.40 ± 1.04[ab]	ST
PF	48.95 ± 1.53[bcd]	ST	40.35 ± 4.01[ab]	ST
PG	42.25 ± 0.26[abc]	ST	38.60 ± 1.73[a]	ST
PH	46.00 ± 0.40[abcd]	ST	41.80 ± 0.29[abc]	ST
PI	52.70 ± 2.31[d]	ST	47.66 ± 2.29[bc]	ST
PJ	50.00 ± 4.21[bcd]	ST	47.05 ± 3.03[abc]	ST
PK	49.50 ± 4.16[bcd]	ST	47.25 ± 2.34[bc]	ST
PL	50.25 ± 1.70[cd]	ST	46.35 ± 2.97[abc]	ST
PM	45.80 ± 0.87[abcd]	ST	45.10 ± 0.12[abc]	ST
PN	50.20 ± 1.50[bcd]	ST	50.20 ± 2.02[c]	ST
F	**2.578**		**2.181**	
p-Value	**0.017**		**0.041**	

DOS-Door Opening Sound; DCS-Door Closing Sound BM- Benchmark: ST-Satisfactory; UST-Unsatisfactory.
Values in the same column with different superscripts ([a, b] and [c]) are significantly different within the groups ($p < 0.05$).

3.4 Lift Ride Quality across Lift Categories

The result presented in Table 5 shows the lift ride quality across lift system categories in terms of Indoor Sound Level (ISL), Acceleration (ACC), Door Opening Sound (DOS), and Door Closing Sound (DCS).

Table 5: Lift Ride Quality across Lift Categories

Parameters	Standard (Mean ± S.E)	Panoramic (Mean ± S.E)	Cargo (Mean ± S.E)	F	P-value
ISL. (dBA)	56.24 ± 1.03	53.07 ± 0.76	58.29 ± 1.89	1.688	0.198
ACC. (m/s^2)	1.44 ± 0.06	1.57 ± 0.09	1.49 ± 0.07	0.608	0.551
DOS (dBA)	46.59 ± 0.85	50.99 ± 2.64	47.78 ± 2.07	1.956	0.155
DCS (dBA)	43.10 ± 0.94[a]	49.12 ± 1.98[b]	45.85 ± 1.19[ab]	4.290	0.021

— Satisfactory sound level — Unsatisfactory Sound Level; ISL – Indoor Sound Level; ACC-Acceleration; 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 ($p < 0.05$).

As observed in Table 5, the lift category across the selected buildings were considered to have acceleration values above the acceptance criteria for good ride quality. Hence, all lift categories across buildings experienced vibration. This is due to high vibration and sound level as revealed by NEII (2017). Moreover, standard and cargo lift categories make more sound than panoramic lift systems. Other parameters like the DOS and DCS are all satisfactory across the lift categories. This measured up to the standard for noise requirement in lift cabins as asserted by Adekomaya and Samuel (2016).

4.0 Conclusion

Lift systems in building PA (51.60dBA), PB (48.43dBA), PC (51.95dBA), PE (52.90dBA) and PK (52.65dBA) constituting 35.71% of the studied samples have acceptable sound levels. However, 64.29% of the buildings have lift systems with high sound levels resulting in noisy rides. However, the sound often made from door operation was considered to be satisfactory. The ride quality of the lift systems in 71.42% of the buildings is considered to be poor since the acceleration (vibration) is above the acceptance criteria ($1m/s^2$). Buildings with cargo lift systems were observed to make more interior noise than other lift systems, therefore considered to have the poorest ride quality. The main conclusion of this study is that maintenance might be an issue with most of the lifts installed in the studied buildings as none of the them has been in service for more than the recommended industry standard age of 20 years. The problem is more common in cargo lifts as they are not mostly used for conveyance of humans.

For high-rise buildings considering modernization of lift systems or the installation of new systems, lift ride quality is a factor to be given due consideration for optimum service delivery and users' ride comfort. It is also recommended that for optimum performance, the routine maintenance of the lifts should be prioritized by the managers of the surveyed buildings.

References

Adekomaya, O., & Samuel, O. D. (2016). *Assessment of Risk in Maintenance and Repairs of Elevators in Nigeria.*

Aliyu, A. A., Hussaini, A. F., Abubakar, M. Baba G. B., & Mu'awuya, M. A. (2015). Problems Associated with Elevators in High-Rise Commercial Buildings in North-Western State Capitals of Nigeria. Journal of Energy Technologies and Policy.

Al-Kodmany, K. (2015). Tall Buildings and Elevators: *A Review of Recent Technological Advances*; *5*(1), Pp. 1070-1104. Retrieved from www.mdp i.com/journal/buildings/.

Al-Sharif, L. (2016). Modern Elevator Traffic Engineering: Elevator Traffic Surveys. *An article on Selected Topics in Mechatronics: Elevator Traffic Analysis and Design*. 25(4):133-187.

ASME (American Society of Mechanical Engineers) (2017). Safety Code for Existing Elevators and Escalators.

Bhatia, A (2012). *Building Elevator Systems*. Continuing Education and Development, Inc. Greyridge Farm Court. Retrieved https://pdhonline.com/courses/m376/m376content.pdf

Brooks, D. (2021). Elevator Life Cycle. Retrieved from https://www.libertyelevator.com/blog/elevator-life-cycle/

CIBSE (2010). *CIBSE Guide D: Transportation Systems in Buildings*. The Chartered Institution of Building Services Engineers; London.

Esteban, E., Iturrospe, A. & Salgado, O. (2013). *Vibration-based condition monitoring for residential lifts*. Retrieved from https://www.research gate.net/ publication /263468252_ Vibration based condition monitoring for residential lifts/citation/download

International Organization for Standardization (ISO) (2014). Applicability of ISO standards & noise estimation tool: Requirements with guidance for use (ISO/DIS Standard No. 45001). https://www.diva-portal.org/smash/get/diva2:1082708/FULLTEXT01.pdf

ISO 18738-1 (2012). Measurement of ride quality — Part 1: Lifts (elevators). Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:18738:-1:ed-1:v1:en

Kopecký, M., Krejčovský, L., & Švarc, M. (2014). *Anthropometric Measuring Tools and Methodology for the Measurement of Anthropometric Parameters*.

Li, K. K., Andy, M.T. & Eddie, W. K. (2004). *A General Survey on Lift Ride Quality at Public Buildings of the Hong Kong Special Administrative Region.* Retrieved from The Government of the Hong Kong Special Administration Region. http://www.iaq.gov.hk/cert/doc/CertGuide-eng.pdf.(acce

Liu, H. and Wu, J. (2018). Research on Preventive Maintenance Strategy of Elevator Equipment. *Open Journal of Social Sciences*, **6**, 165-174. doi: 10.4236/jss.2018.61012.

Monge, R. and Gómez, A. (2014). Methodology to identify noise and vibrations problems for ride Retrieved from https://liftsymposium.org/download/ Lift and Escalator Symposium Proceedings 2015.pdf

Müller, J. (2014). Lift Systems in High-Rise Buildings: Handling Capacity and Energy Efficiency. Symposium on Lift and Escalator Technologies, Northamption.

NEII (National Elevator Industry, Inc) (2017). Vertical Transportation Standards. Retrieved from http://www.neii.org/neii1.cfm

Strakosch, G. and Caporale, R. (2010). *The Vertical Transportation Handbook.* Hoboken; New Jersey: John Wiley & Sons, Inc.

University of New South Wales (UNSW) (2015). Design and Construction Specifications Lift Design Standards. Retrieved from https://www.estate.unsw.edu.au/sites/ default/ files/ documents/SECTION-E.5-Lift-Design-Standards.pdf

Wit, J. (2017). Elevator Planning for High-Rise Buildings. *Deerns Consulting Engineers Publication,* The Netherlands, Amsterdam, www.deerns.com.