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Indoor Environmental Quality (IEQ) for residential buildings: Literature Review

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Abstract: Users' perception of Indoor Environmental Quality (IEQ) is critical for sustainable residential development. IEQ factors that affect evaluation of quality life for occupants in residential buildings are thermal comfort, air quality, light quality and indoor acoustics. This study critically reviewed literature on IEQ for residential buildings with the view to establish an improved IEQ concept on sustainable development. The objectives of this study were to identify the IEQ factors and examine findings on users' perception for residential buildings. Materials and methods obtained from Google Scholar adopted a critical literature review of sixty-two selected published journals between 1970-2023.The findings revealed that thermal comfort, indoor air quality, light and acoustic relate to physical characteristics for residential buildings. However, IEQ for residential buildings are influenced by building orientation, gender and age. Each space within the same residential building has different IEQ. Therefore, the proposed IEQ evaluation models will help architects, other building team professionals and the policy makers to identify the problems. This study underscores the need for new perspective on users' perception of IEQ for mud residential buildings as the key element required for sustainable development.
Keywords: Indoor Environmental Quality, Perception Users, Residential Buildings.

Introduction

Indoor Environmental Quality [IEQ] for sustainable buildings are standards that improve global and local environment (Abbaszadeh et al., 2016; Baeza & Rajagopalan, 2020; Djamila and Chu Chi Ming, 2015; Geng et al., 2019; Mewomo et al., 2023). IEQ building performance improves indoor comfort, cost effectiveness and adaptability which are achievable throughout a building's lifecycle. Occupants' productivity, quality of life and health are greatly affected by indoor environmental quality in buildings (IEQ). A comprehensive analysis of IEQ in buildings always consider factors like thermal conditions, air quality, lighting, and acoustic. Each element has its unique widely used evaluation theories and international standard (Quesada-Molina & Astudillo-Cordero, 2023). These evaluation theories include measurement protocols and analysis methods. The most common methods are subjective survey and objective field measurements (Quesada-Molina & Astudillo-Cordero, 2023). However, the subjective method is highly determined by occupants. Most critical reviews on IEQ are centred on industrial and institutional buildings. Although, there is limited research on IEQ critical review for residential buildings. Critical review on IEQ for residential buildings has become an important sustainable development concern in this era of climate change and global warming. The purpose of this study is to determine a critical literature review on IEQ for residential buildings, with a view to establish an improved IEQ for sustainable residential development. The objectives of this study were to identify the IEQ factors in residential buildings and examine findings on users' perception for residential buildings.

Materials and Methods

The study sourced from Google Scholar and adopted a critical literature review of sixty-two (62) selected published journals, books and conference proceedings from 1970-2023. The selection was based on the research aim and objectives. The result was analysed through content and thematic analysis.

Review Studies

1. IEQ Factors in Residential Buildings

The factors that affect IEQ in buildings are thermal comfort, air quality within the building, lighting, and acoustics.

a) Thermal Comfort

Thermal comfort is defined as the state of mind, which expresses satisfaction with the thermal environment (Nicol & Raof, 2017). Similarly, Human and Safety Executives [HSE] also suggested that an environment achieved reasonable comfort when at least 80% of its occupants are thermally comfortable (Mewomo et al., 2023). ANSI/ASHRAE 55-2010 defines comfort as the rate where most occupants are more comfortable. The idea of what is comfortable has certainly changed from one time, place, and season to another (Chappells & Shove, 2005; Daghigh & Sopian, 2009; Enescu, 2017). Large variation exists on indoor thermal comfort, which differs with climate, times of year and culture. These responses and actions depend on lifestyles, beliefs, and gender. This ensures human race survival in almost all the wide variety of conditions found across the planet. The interaction between the occupants, the buildings, and its surrounding areas directly influences satisfaction levels because of thermal comfort within a building (Nagashima et al., 2018). Thermal comfort variables include indoor air temperature, relative humidity, airflow rate and radiant heat transfer between human body and the surrounding (Al horr et al. 2016; Daghigh & Sopian, 2009). Building materials and envelop keep wanted heat inside or unwanted heat from outside. Thermal comfort models are in two main categories: the objective and subjective approaches (Djongyang et al., 2010; Larsen et al., 2020). The objective approach as presented by Fanger (1970) indicated the famous Predicted Mean Vote [PMV] and Predicted Percentage Dissatisfaction [PPD] Model, which is the classical heat-balance approach, while the subjective approach presents adaptive thermal comfort as shown in Table 1 below on differences between Objective and Subjective Models.

Table 1: Objective and Subjective Models

Objective Model (PMV-PPD).	Subjective (Adaptive Model)
Consistent ventilation.	Changing ventilation.
Air condition buildings.	Naturally ventilated buildings.
Objective based.	Subjective based.
Quantitative based data.	Qualitative based data.
Human as passive role	Human as active role
Narrow Temperature tolerance.	Wider Temperature tolerance.

Source: Fanger (1970)

Thermal comfort parameters concept is measured by indoor ambient temperature and relative humidity as presented in Figure 1 below (Thermal Comfort Zone on Psychometric Chart). This determines its absence in the comfort zone, and how it is regarded as unsatisfactory and needs improvement. Nasir et al. (2011) posited that thermal comfort is measured in a variety of methods. These include seven-point ASHRAE scale, Bedford scale and scale of Humphrey and Nicole, which uses subjective evaluation. The Malaysian normal thermal comfort indicates temperature (dry bulb temperature) ranges from 25.5^{o}c to 28.5^{o}c and 45% to 80% for Relative Humidity [RH]. It also reveals a 20 square feet per person as the indoor ventilation maximum thermal comfort level. ANSI/ASHRAE standard 55-2010 for temperature is between 22.5^{o}c and 26^{o}c, while 40% to 60% for RH. ANSI/ASHRAE standard 62.1-2010 of carbon dioxide is 1000pm.

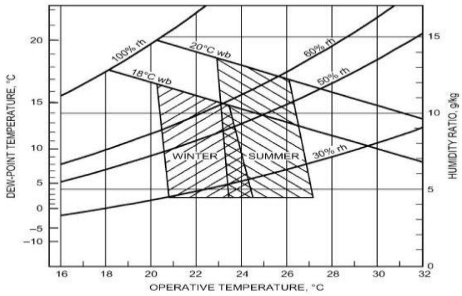

Figure 1: Thermal Comfort Zone on Psychometric Chart.
Source: Lei (2014).

Nicol and Roaf (2017) studied “Rethinking Thermal Comfort” and the authors posited that everyday 90% of Japanese subjects are comfortable with temperature between 18^{o}C to 28^{o}C. At extremes, the comfortable indoor temperature is as low as 10^{o}C and as high as 35^{o}C or more. Similarly, Cole et al. (2008) buttressed that the ability to change climate or activities level enables the individual comfort in different temperature. The authors concluded that PMV within the range of -1, 0 or 1 and 5, 4, or 3 on the ASHRAE and Bedford scale respectively as indicated in Table 2 below are regarded as the comfortable environment. PMV developed in climate chamber revealed that psychological or social dimension has no impact on comfort.

Table 2: ASHRAE and Bedford Scale

ASHRAE Descriptor	Numerical	Bedford Descriptor	Numerical
Hot	3	Much too warm	7
Warm	2	Too warm	6
Slightly warm	1	Comfortably warm	5
Neutral	0	Comfortable neither warm nor cool	4
Slightly cool	-1	Comfortably cool	3
Cool	-2	Too cool	2
Cold	-3	Much too cool	1

Source: Nicol and Roaf (2017)

Nicol et al., (2012) as cited in Nicol and Roaf (2017) also posited that the different acceptable temperature depends on modified conditions such as the change in clothing or activity level, which enable the individuals' comfort accessible opportunities. Humphreys et al. (2016) observed that free-running buildings use no mechanical option; but the building form and materials decide the occupants' comfort life which is based on the relationship between indoor and outdoor temperature. Comfort is a multidimensional system. However, despite its valued ability that deals with variable conditions, the field study approach findings have concentrated continuously on comfort temperature for a group of occupants or their environment. It takes little account of thermal environment aspect other than temperature as criticized. There have been attempts to link the two approaches: the 'rational' typified by indices such as PMV, and the 'empirical' typified by the adaptive approach. The index approach (ASHRAE PMV) defines comfortable environments in climate chambers as the role of thermal comfort. The approach suggests building conditions observed in the experiment for occupants' comfort range. The empirical typified adaptive approach uses survey with four physical variables. These variables are clothing insulation, metabolic rate, culture, and climatic season. Rami and Oselend, (1996) as cited in Nicol and Roaf (2017) observed that the way an individual experience, interpret and interact with the world is closely associated with differences in age and effect of gender as shown in Figure 2 below on adaptive comfort.

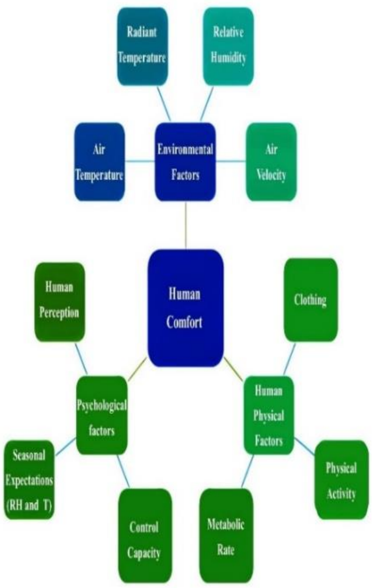

Figure 2: Adaptive Comfort
Source: (Rami& Oselend,1996) as cited in Nicol and Roaf (2017)

The PMV uses two types of approaches: skin temperature and heat evaporation. The environmental dissatisfaction assessment is achieved through the occupants' activity level in thermal comfort survey. The heat exchange balance between the occupants and environment is a function of the activity level. Thermal comfort variables are conduction, evaporation and radiation. Conduction is the heat balance between occupants and the environment. ANSI/ASHRAE standard 55-2010 averred that evaporation is the condition of the mind which expresses satisfaction with thermal environment. It is evaluated by subjective evaluation. Although radiation plays a significant role for achieved thermal comfort, it also requires air temperature, air movement and controlled relative humidity to do so as seen in Figure 3 below on human thermal comfort in transitional space. The thermal environment and personal factors affect the heat transfer within its environment. The condition of the mind directly influences the psychological factors. Nicol and Roaf (2017) explored the relationship between indoor and outdoor temperatures for free-running dwellings from reports and surveys data sets on "Rethinking Thermal Comfort" in different parts of the world.

At the time of the survey, the dwellings that are heated or cooled show a greater indoor temperature range than outdoor temperature compared to naturally ventilated (free running) dwellings at any given period. This suggests that occupants use the powerful adaptive opportunity of mechanical heating or cooling system to fit the temperature for varied comfort needs. In a world of rapid cultural and architectural changes, the challenge for provision of comfort exacerbates the pressures. The indoor environments are more delightful when the cost and need for energy use is reduced to cope with extreme weather and power outages.

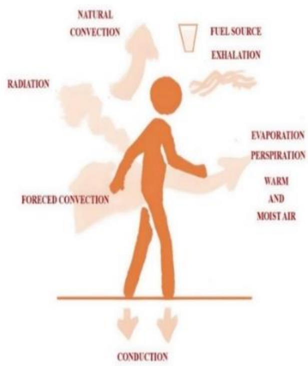

Figure 3: Human Thermal Comfort in Transition Space
Source: Pawar (2018)

Vargas et al. (2017) expounded on the role of lobbies and short-term thermal transitions as cited in Nicole and Roaf (2017), the findings suggest that fieldwork has identified the patterns in thermal perception. The authors observed that the occupants' thermal perception possibly is altered in positive direction on judicious use of lobby spaces. In the long-term, the effect of air-conditioning on thermal history is reversed and the temporal thermal comfort theory is supported through thermal sensations which reward the program that occupants enjoy in non-uniform environments (de Dear, 2011). The evaporative cooling effect measurement through mist fan oscillation studied by Farnham et al., (2017) as cited in Nicol and Roaf (2017) illustrate the use of field surveys as ways of examinations for transient conditions. The development of comfort theory, therefore, lies in three directions. The first direction underlies the left-hand side mechanisms of the involuntary responses from physiological system that occupants' interaction with the outside thermal environment… This is seen in Figure 4 below on thermal regulatory system (Nicol & Roaf, 2017).

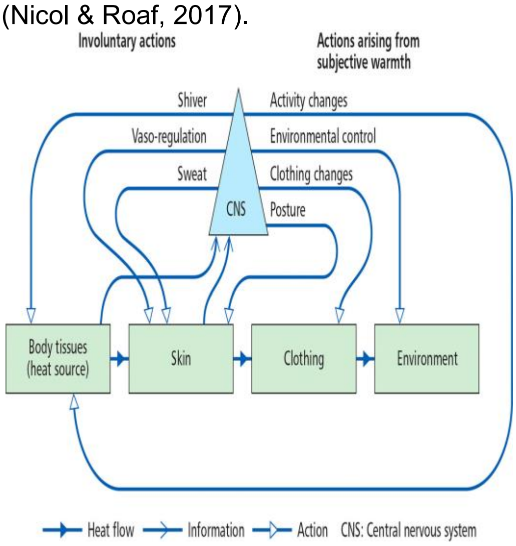

Figure 4: Thermal Regulatory System
Source: Nicol and Humphrey's (1973) adopted from Nicol and Roaf (2017).

Emergence research by Pallubinsky et al. (2017) as cited in Nicol and Roaf (2017), suggested that a mild thermal discomfort is good for occupants' health. The second direction of the comfort theory is on building the occupant's engagement, either conscious or semi-conscious actions, to handle and modify the thermal comfort environment. The third direction is the building designs and constructions which has addressed the first two challenges that need attention. There are additional important concerns that involve engagement for the research community. These challenges involve improved accessibility and utility of thermal comfort research results to designers, regulators, decision-makers, and inhabitants. The research results used for comfortable building designs by architects and engineers is another challenge. Good building designs for the future or decades ahead are determined by the cost and quality of comfort provided in the buildings.

b) Indoor Air Quality [IAQ]

Air quality is defined as the adequate ventilation air provided in a building (Quesada-Molina & Astudillo-Cordero, 2023). United States Environmental Protection Agency [US EPA] (2012) and World Building Design Guide [WBDG] (2017) reported that IAQ is the acceptable air in which there are no contaminants or any harmful concentrations that satisfy a substantial majority of people. Kukadia and Upton (2019) reiterated that good IAQ comprises factors such as adequate indoor air ventilation distribution and control for airborne contaminants. The amount of air contaminants presents in each space give rise to IAQ problems for non-industrial buildings. The three related factors for indoor air quality evaluation research are Carbon dioxide [CO_2], Volatile-Organic Compound [VOC] and Ultrafine Particulate Matter [UFPM] concentrations in buildings. UFPs are particulate matter of Nano scale size (Less than 100 nanometres in diameter), which are very important contaminants that require standard IAQ control. The major indoor UFPs sources occur naturally from smoke cooking and fruits (the situation is peculiar to most rural communities), or manufactured from printers, fax machine and photocopier emissions. Excessive indoor UFPs is a threat to human health (Health Effects Institute [HEI], 2013). Regulations do not exist for this ambient air pollution particles size. The concentration for ultrafine particles should be less than 20% indoor compared to outdoor air. The basic rule is only applied to selected criteria with respect to absorbing particles of filter performance evaluation in mechanical ventilation system (David, 1993). Organic compounds, emitted as gases from certain solids and liquids that have high vapour pressure at ordinary room temperature are known as VOC. US EPA (2012), reports that VOC sources vary from paints, building materials and office equipment such as copiers and printers. Many VOCs concentrations are consistently up to ten times higher at indoors than outdoors. VOC concentrates in spaces should be less than 300ppb for acceptable IAQ (Piasecki, 2019).

Roulet and Foradini (2002) in a study observed that two concepts are useful based on CO_2 concentration for IAQ evaluation. Firstly, is the amount of CO_2 emitted by occupants, which depends on their body size and activity level. Secondly, the tracer gas used, where the CO_2 concentration indoors is higher than outdoors. The CO_2 concentrates generated depend on the indoor fresh air exchange observed. The direct analysis determined its adequacy. ANSI / ASHRAE standard 62.1-2010 in a study stated that the occupancy used space, mass balance generated, CO_2 and dilation fresh air supply is 1000ppm approximately. The CO_2 concentration decay is used for Air Change Rate calculation. Equation 1 below shows the calculation for air change rate.

Air Change Rate= $|1n(Cn)| = \left|1n\left(\frac{C(t)-Co}{CO-Co}\right)\right|$ --------1

Where:

Co = the initial concentration at the beginning of the decay period.

C(t) = the final concentration at the end of decay period.

CO = the outdoor concentration.

In the same vein, Gigdem and Arzuhan's (2011) studied human exposure to air pollutants. The findings indicate that air within the building is more seriously polluted than outdoor air. Air pollutants in most cases are 25 and 100 times occasionally higher at indoor than outdoor (Jones & Molina, 2017). Therefore, environmental pollutants are regulated currently based on potential cancer cause or other health effects. This potential is determined through risk health assessment process. However, the risk assessment process is not useful for established energy or conserve ventilation requirements on buildings since there are no numerical correlation rates and specific risk levels. Gigdem and Arzuhan (2011) argued that the sustainable design goal in response to users' requirements, reduces human impact on the environment both at the local and global levels. Sustainable IAQ enhances the occupants' health, comfort, and productivity. This is achieved through sustainable design criteria such as good functional space, finishes and furnishings, building equipment, occupants' activities and building maintenance (Steinemann et al., 2017). ANSI/ ASHRAE Standard 62.1-2013 are self-imposed regulations institute on ventilation, responsible for setting industrial standard. However, ANSI / ASHRAE Standard 62.1-2010 on ventilation concluded that IAQ related problems are ventilation and air condition, which include temperature and humidity impact controls. ASHRAE standard 55-2010 has described acceptable temperature and humidity parameters for typical buildings.

c) Lighting Quality

The daily rhythm of natural light sets the biological clock, while its seasonal rhythm influences the occupants' mood. The presence of lighting is necessary for several occupants' health sustenance (Wahl et al., 2019). Lighting is measured in lux or foot-candles (1FC=10.76 Lux). Visual comfort standards recommended maintains the minimum and average desk activities at 30FC and 50FC illumination respectively. Janssens and Wayendt, (2007) opined that natural and supplemented lightening combination recommend 70FC illumination to avoid over exposure and glare. Wong (2017) also reiterated that building openings control daylight, glazing types and the configuration of reflecting surfaces. The occupant's visual stimulation connects the outdoor environment that changed the dynamics over day. Electrical lighting systems in a building complement the natural light. Visual quality is a function of many variables. These include light spectrum, luminance or intensity that impinge on a surface, the amount of glare, visual contact with outdoor environment and natural lighting available. Optimal lighting provides a comfortable and healthy visual environment that supports occupants' activities (Preoser et al., 1991). Glare from light uniformity is the most important factor for illumination intensity in any given space (Dilaura et al., 2011).

d) Indoor Acoustics

Indoor acoustic measurement depends on the major factors which are optimisation and central monitor. The main factors considered are as follows:

i. Background Noise Level ([BNL] Un-weighted, A-weighted octave-band and total equivalent Noise Criterion [NC]).
ii. Reverberation Time [RT], that deals with Noise Isolation [NI] between rooms. It is measured in octane-band.
iii. Speech Intelligibility [SII], it is the ability for talkers to listen.

i. Background Noise Level [BNL]: BNL is the continuous sound pressure level at a given location. The major outdoor noise contributors are traffic, general building construction, people, and music. Apart from outdoor ambient noise, BNL inside is related to the building envelop, noise generating devices or systems, window status and furnishing detail (Quesada-Molina & Astudillo-Cordero, 2023). American National Standard [ANSI S12.2-2008], (2008) averred that those suitable conditions for different occupants' activities and BNL must be within an acceptable range especially at mid and higher frequencies. The measured level compared with A–weighted criteria was developed for specific spaces used. The octane band and total BNL is measured in dB and dBA respectively; the corresponding Noise Criteria [NC] rating is determined. The evaluated result is compared to recommended standard values for noise acceptability in the environments (ANSI S12.2-2008, 2008).

ii. Reverberation Time [RT]: This is the measured sound persistence in space after an original sound production by the multiple interactions with surface air and alternative disasters travelled absorbed sound energy. The

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acoustic absorption value is related to the surface areas, volumes, and the number of occupants in the room (Mewomo et al., 2023). Sabine (1922) established a relationship between RT of a room, its volume, and total absorption known as reverberation equation as shown in equation 2 below.

$$RT = \frac{41n10^6}{C} \quad \frac{V}{Sa} \approx 0.1611m^{-1}\frac{V}{Sa} \quad \text{--------------------2}$$

Where:

C = the room speed of sound measure in metre per second [m/s]

V = the room volume measure in metre cubic (m^3)

S = total surface area of the room measures in metre square (m^2)

a = the average absorption coefficient of the room surfaces.

Acoustic conditions are better in conventional than sustainable buildings. This is because sound absorbing materials such as acoustic ceilings, partitions and carpets are more widely used in conventional than sustainable buildings (Cascone et al., 2019; Lei, 2014). However, such materials are not considered environmentally friendly. Long (2006) proposed optimum RTs for various types of indoor spaces. Noise Isolation [NI] depends on materials choice, building construction quality and ventilation design for each space, which affect the noise Isolation performance of the walls, doors, between room and corridors.

iii. Speech Intelligibility [SII]: It measures a listener's direct word fraction or sentences understood. The speech level signal minus background noise in dB and reverberation time depends on noise ratio signal which is the degree of noise that inhibits intelligibility. The signal to noise ratio is negative when it is higher than speech level. SII value between 0.45 and 0.75 indicate acceptable speech intelligibility and less than 0.45 is considered poor (American National Standard Institute [ANSI], S3.5-1997). The recommended acceptable speech privacy indicates 0.20 as the maximum achieved SII value (Warnock, 1973). King (2022) posited that environmental noise is classified among the most important social concern. This concern pertains acoustic isolation between units in residential built environments; noise intrusion from external sources from building walls, noise generated through plumbing and High Voltage Air Conditioning [HVAC] systems. However, acoustics quality has been achieved by the appropriate noise attenuation for building walls and control of equipment. Efforts are made to isolate plumbing noise, block flanking sound paths through fixed walls and floors. Torresin et al., (2023) argued that a good acoustic environment keeps noise at levels without interference with activities of occupants in any residential building space. The author posited that noise abatement begins with avoidance of factors that generate noise, and sensitive space located away from known sources. Sound attenuation barriers and absorptive room surfaces control noise transmission within rooms and through the building structure (Torresin et al., 2023). The physical characteristics such as the background noise level, reverberation time and noise isolation determine the acoustic condition of any building. Acoustic quality affects the occupants' ability to communicate. It also affects experience as well as productivity and efficiency.

2. Users Perception for Residential Buildings

Housing satisfaction is defined by Galster and Hesser (1981) as the reality of the current residential context, the perceived gap between respondents' needs and aspiration. Housing satisfaction is a major determinant of user's general wellbeing and an indicator of quality life. Lekjep (2016) and Babalola et al (2020) posit that in Nigeria, existing studies focus on the general performance of public housing to meet occupants' needs and expectations. These studies established that the physical characteristics of residential buildings have significant influence on the occupants' satisfaction with their environment. Users' satisfaction not only evaluates the level of individual residential environmental quality satisfaction and its value, but also a valid method to improve the quality of residential environment through architectural designs and policies (Lekjep, 2016). Amerigo and Aragones (1997) cited in Lekjep (2016), posit that the study of satisfaction dates to 1940. Users' perception evaluation is considered as a criterion for residential quality satisfaction. The spatial layout, physical factors and building elements are expected to meet the required standard and to satisfy the users. Users' residential satisfaction assessment has been the subject of continuous research endeavours in many disciplines, such as architectural design and urban design (Lekjep, 2016). In architectural design, the level of users' satisfaction in the spatial layout created serve as one unit of measurement in complete design assessment (Baeza & Rajagopalan, 2020). Information about users' satisfaction for evaluation is critical to alternative design option. Lekjep (2016) observed that a valid and reliable understanding of users' satisfaction is paramount to architects if the current trend towards users' centred design intensifies continuously.

Results and Discussions

1. The IEQ Factors in Residential Buildings.

Literature revealed that thermal comfort expresses the overall environmental satisfaction of the mind. It is assessed by subjective evaluation.

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Since different people prefer different environmental conditions, it is very difficult to define thermal comfort. More complex formulae developed, include factors such as surface temperatures, humidity, air velocity, activity levels and clothing in addition to air temperature. Solar radiation, wind and humidity are included in the design as dynamic inputs that define building geometry, construction systems and operational parameters (ASHRAE, 2011; Ricardo et al., 2015). The occupants' psychological state and controls' ability over surroundings also play an important role in environmental comfort. A building where windows and doors are opened not only allows for natural ventilation, but also give occupants a sense of connection to the outdoors. Bioclimatic design embeds these mechanisms and uses the outdoor climate conditions to promote human heat balance through the design elements right application (Beccali, et al., 2018).
The adaptive comfort concept addresses the need for a more flexible defined numerical parameters that affect the thermal comfort of the indoor environment. Figure 5 below Occupant Environmental Satisfaction [OES] shows the human psychology alongside physical characteristics and adaptive behaviour.

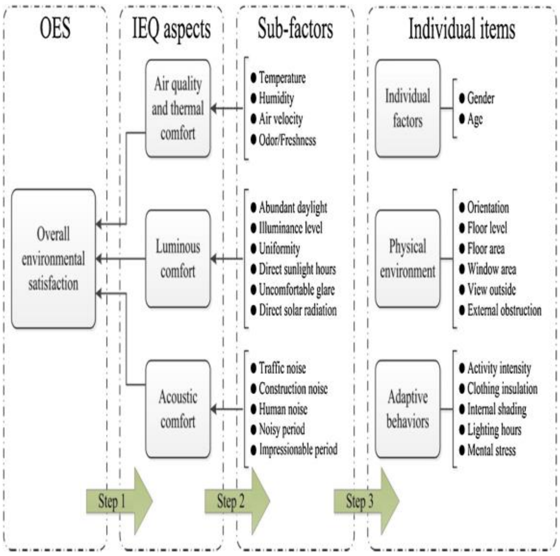

Figure 5: Occupant Environmental Satisfaction [OES]
Source: Xue et al. (2016)
Adaptive thermal comfort theory suggests the outdoors connection and control over the immediate environment, which allows human adaptation to (and even prefer) a wider range of thermal conditions that is generally considered comfortable (Rami & Oseland, 1996; Nicol & Humpherys 2002; Nicol et al., 2012). Empirical research showed that outdoor climate influences indoor comfort because humans adapt naturally to different temperatures at different times of the year. The most recent version of ASHRAE Standard 55-2010 recognises adaptive factor's role that establishes thermal comfort. This includes an Adaptive Comfort Standard [ACS] that allows a wider range of indoor temperatures for naturally ventilated buildings, which are necessarily more susceptible to outdoor conditions (Nicol & Humpherys, 2002). Figure 6 below on adaptive chart shows the monthly mean outdoor temperature which is around 26°C. This suggests that in Nigeria 90% of the occupants are comfortable with temperature up to 28°C.

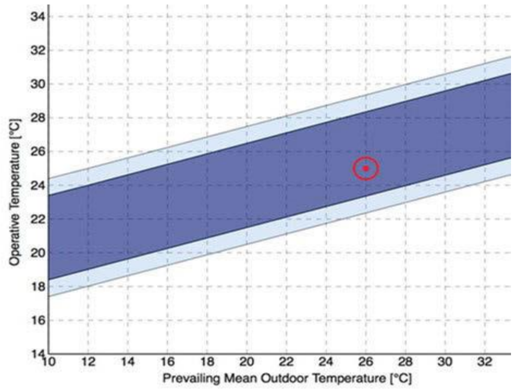

Figure 6: Adaptive Comfort Chart
Source: ASHERAE 55 (2010)
Most occupants are aware of the harmful effect of outdoor air pollution on health. However, not many are aware that IAQ also has significant harmful effect on users' health. The major cause of poor IAQ is ventilation. The IAQ problems are alleviated through design and modification implementations. Visual quality is made up of efficiency and comfort. The occupants' abilities that involve vision is determined by the perform task measured. Visual performance supports good lightning quality, which improves occupants' interpersonal communication and well-being. Acoustic quality in buildings is an important aspect of occupants' comfort. Positive acoustic quality achieved in a room depends on spatial configurations and building materials designed for appropriate resonance patterns, while private conservation in overly quiet rooms is masked by noise. Indoor acoustic conditions are the most difficult aspect to control for IEQ optimization. This result influences the building integrity directly as well as occupants' health, safety, and comfort in an acoustic environment.

2. Users' Perception for Residential Buildings

Scholars examine the concept of users' perception variously. Humphrey et al. (2016) and Piasecki (2019) argued that the most common ways that research measure residential perception of IEQ is with one to seven (1 - 7) or one to five (1 - 5) points scale respectively. Usually '1' represents the lowest score and '5' or '7' represent the highest scores.

Questions are structured as 'open ended' or 'close ended'. For example, a resident's level of satisfaction with different spatial layout in various orientations is: 1-very dissatisfied, 2-dissatisfied, 3-fairly satisfied, 4-satisfied and 5-very satisfied. Beamish (1993) developed and tested two instruments intended to measure the liveability of single-family houses. The first instrument is known as the 'House plan Evaluation Checklist' (HPEC) and the second instrument is the 'Housing Satisfaction Scale' (HSS). The professionals used the HPEC for the house plan liveability evaluation which has 0-4-point rating scale. '0' represents does not have, '1'- poor, '2'- fair, '3'-good and '4'-excellent. The user's satisfaction evaluation used HSS rating scale with specific features of their house. Common statistical test that are used to measure housing satisfaction, ranges from simple mean score calculation to more complicated multiple regression analysis. Other statistical analysis includes the use of one or more of these methods, chi-square, ANOVA, Path analysis and correlation.

Conclusion and Recommendation

IEQ is characterised by dynamic timely policy and decision-making. It is inclusive, effectual for community engagement and collaboration, integrative as well as positive evidence-based reasoning for sustainable development. ASHRAE, BEDFORD and HUMPHERYS models are the basic institutional component scales for thermal comfort. The level of effectiveness is measured by the performance of each component of IEQ to achieve comfort, good health, and productivity. In general, however, very few studies have specifically examined the performance of residential buildings constructed with mud brick that meet the users' needs and expectations in the Nigerian context. As a result, little is known on the different dimensions users' respond to their evaluation of IEQ perception for mud residential buildings in Nigeria. There is need for further research on users' perception of IEQ for mud residential buildings especially now that the issue of climate change and global warming is a threat to human comfort. This will bridge the gap in literature. This will also extend the understanding of the key elements that could be manipulated to improve on users' perception of IEQ for mud residential buildings in Nigeria.

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