A REVIEW ON APPROACHES AND TOOLS USED IN ASSESSING INDOOR ENVIRONMENTAL QUALITY

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Abstract
The quality of an indoor space is very paramount as the well-being of occupants largely depends on it. Various standards have been developed to achieve quality indoor spaces. However knowledge of these standards does not guarantee quality indoor spaces. This review evaluates existing means of assessing indoor environmental quality (IEQ) and proposes the appropriate for optimum results. 41 articles from highly ranked journals were conveniently sampled between the years 2007 to 2017. Review shows that even though more publications were done in 2012, indoor air quality had more publications done within the sampled years. Both subjective and objective assessments are used for IEQ assessments. Objective assessments are preferred over subjective assessments due to some limitations with subjective assessments. Subjective assessments should be better with validation from measured data. Various tools were identified for measured data collection but it is important to choice and instrument which is well calibrated and the data range it's within the range of data to be taken. Software such as Ecotect, Design Builder, IES VE, Contam, Radiance, Energy Plus, Day Sim and TAS were identified as software for simulation purposes. However, since one software cannot be used to simulate all four variables (thermal, light, sound and air quality) of IEQ, a combination of Ecotect and Contam was proposed. The review concludes with the recommendation that both objective and subjective assessments should be used but always should be backed with validation

Keywords: assessment, environmental meters**,** indoor environmental quality, simulation, software

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INTRODUCTION

Indoor environmental quality (IEQ) simply means the quality of an indoor space with regards to occupant's health and well-being (NIOSH, 2017). The concept of indoor environmental quality for human health and well-being thus has a very broad scope and there are many variables linked to it. However, all these variables can be grouped into 4 major groups namely: Thermal comfort; Indoor air comfort; Visual comfort and Acoustic comfort (Alfano et al. 2010; Franchimon et al. 2009; REHVA 2010). Due to the importance of human health and well-being, a lot of IEQ standards and performance codes have been developed. Some of these standards and codes are by organisations such as the International Standard Organisation (ISO), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Chartered Institute of Building Service Engineers (CIBSE) and Federation of European Heating and Air Conditioning Associations (REHVA). These codes and standards have been developed to suit each of the 4 major groups of IEQ.

The term comfort runs through all the 4 major groups of IEQ and has been found to be complex to define due to its applicability to varying disciplines (Simmons, 2015). To Crawley (2001), comfort is associated to spirituality and morality. Brager and De Dear (2003), as cited in Simmons (2015), refer to comfort with attributes such as leisure, ease, convenience and privacy. Comfort on the other hand refers to physical environmental comfort through the human senses (Inkarojrit, 2005; Elzeyadi, 2002). A classical explanation of comfort in relation to the physical environment is by Fanger (1970) which states that "the state of mind in which a person expresses satisfaction with the thermal environment".

Thermal Comfort

Thermal comfort is achieved when an individual expresses satisfaction both physically and physiologically under a set of environmental conditions (Pino et al., 2012; Szokolay, 2004; ASHRAE, 2004). Environmental conditions include air velocity, relative humidity and temperature whereas physical conditions are linked to clothing and activities done by a person. The physiological processes of humans allow them to regulate their internal body temperature no matter the external thermal conditions (Koranteng, 2010). This is because the body produces energy to replace whatever energy is lost for thermal equilibrium. If this equilibrium is not achieved, the health of a person is compromised and can even lead to death (Almeida et al., 2015). Hypothalamus in the brain serves as a thermostat to regulate and exchanges heat through conduction, convection and radiation. Thermal equilibrium (S) can be achieved through Equation (1), when heat losses and gains = 0 or null.

$$S = M \pm W \pm R \pm C \pm K - E \pm Res \quad (1)$$

Details on Equation (1) is shown in Figure 1

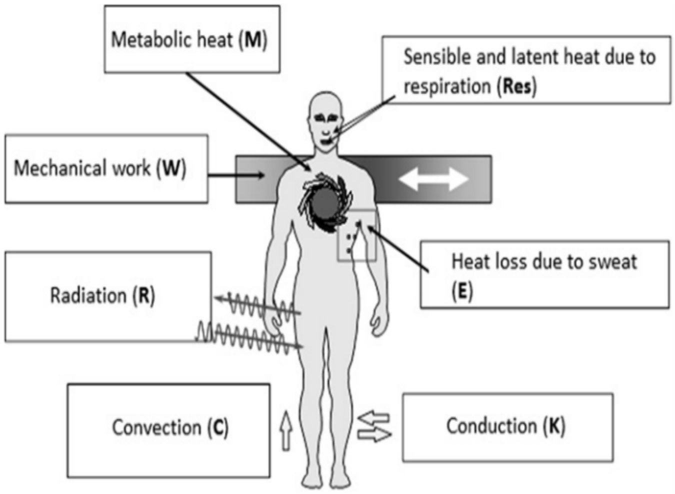

Figure 1: Thermal equilibrium through the human body (adopted from Silva, 2006)

These heat exchanges also depend on six factors to achieve thermal comfort. These factors are air temperature, T_a [ºC]; mean radiant temperature, T_{mr} [ºC], air velocity, v_{ar} [m/s]; water vapour pressure, P_a [Pa]; metabolic rate, M [met]; and clothing insulation, ICL [clo] (Fanger, 1970). The environmental factors such as air temperature, mean radiant temperature, air velocity and water vapour pressure can be measured with instruments. The individual factors such as metabolic rate and clothing insulation which cannot be measured have extensively been studied and documented in Olesen (1982), ISO (2005), ASHRAE (2009) and ASHRAE (2010). Thermal comfort can be assessed based on two distinct approaches: heat - balance approach and adaptive model approach.

Heat-balance approach

This approach uses a steady state situation and the heat balance equation to run experiments in different climatic regions for comfort. Fanger (1970) was the first to propose the heat - balance approach and this has been adopted by various studies. Fanger's studies used equations to determine the mean vote quantification of the environment of certain groups of people. This mean vote is termed Percentage Mean Vote (PMV) and has been adopted in ISO 7730 (ISO 2005) and ASHRAE 55 (ASHRAE 2010) standards. Fanger again established the relationship between the mean vote and the percentage of people feeling hot or cold (uncomfortable). This percentage of discomfort is termed Predicted Percentage Dissatisfied (PPD). The relationship between PPD and PMV is shown in Equation (2).

$$PPD = 100 - 95 \times e^{(-0.03353 \times PMV4 - 0.2179 \times PMV2)} \quad (2)$$

Equation (2) shows that it is difficult to achieve thermal neutrality with PPD. There will still be some 5% of occupants who will be uncomfortable. Due to this, ASHRAE and ISO have developed thermal sensation scales which represent the mean thermal sensation of a group of people within a given space. Table 1 is adapted from both ISO and ASHRAE.

Table 1: Thermal sensation scale

-3	-2	-1	0	+1	+2	+3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
Uncomfortable		**Comfortable**			**Uncomfortable**	

This approach has been widely accepted and can be found in various standards such as CIBSE Guide A (CIBSE, 2006); ISO 7730 (ISO 2005, 1994); ASHRAE 55 (ASHRAE 2004, 1992) to estimate thermal comfort levels in buildings (Simons, 2015). However, there have been a lot of debates on inconsistencies with the use of the PMV model (de Dear and Brager, 2002, 2001, 1998; Nicol and Humphreys, 2002; Morgan et al., 2002; Cena and de Dear, 2001; Humphreys, 1994). Other authors such as Beizaee et al (2012), Oseland (1996) and de Dear et al (1991) also argue that the

PMV model works better with air-conditioning rather than naturally ventilated buildings. The adaptive approach is thus proposed to compliment the heat-balance approach (Brager and de Dear, 1998).

Adaptive model approach

This approach is more dynamic and it deals with an individual physically and psychologically interacting with the surrounding environment for comfort. Brager and de Dear (1998) are of the view that, the individual has a responsibility of creating his own thermal environment through behaviours and habits. The heat-balance approach ignored these behaviours and habits and this led to over reliance on air-conditioning for comfort (Kempton et al, 1992). In the 1970s where energy crises started, there was the need to move away from the reliance on air-conditioning which uses more energy.

The adaptive approach simply deals with individuals adjusting to their environment for comfort. This adaptation comes in three different forms: Behavioural, Physiological and Psychological (de Dear et al., 1997). Various equations have been developed to calculate thermal comfort using the adaptive approach and the most prominent is Equation (3) (ASHRAE, 2004; ASHRAE, 2010).

$$T_C = 17.8 + 0.31T_O \qquad (3)$$

Where:

T_C is the comfort temperature,

T_O is outdoor air temperature.

The adaptive model is present in ASHRAE 55 (ASHRAE 2010) and can be used for thermal comfort assessment. However, it must be noted that this model works with metabolic rates of 1.0 to 1.3 met (sedentary) (Almeida et al., 2015). Softwares such as the ASHRAE Thermal Comfort Tool have thus been developed with these models for thermal comfort assessments (Fountain and Huizenga 1996).

Indoor Air Quality (IAQ)

Oil crises during the 1970s brought about energy conservation and therefore air tightness became dominant for less heat losses. However air tightness led to less natural ventilation and these increased air pollutants in spaces (Almeida et al., 2015). Pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (CH_2O), volatile organic compounds (VOCs), particulate matter (PM) are some examples. Exposure to these pollutants beyond an acceptable limit brings discomfort. Continuous exposure to high levels of these pollutants causes diseases related to sick building syndrome, cancer and respiratory problems (Abdul-Wahab et al., 2015; Berglund, 1992) Countries across the world have developed their acceptable pollutant limit to manage IAQ but data from the World Health Organisation (WHO) surpass all. Table 2 presents some indoor pollutant concentration limits by WHO and other agencies.

Table 2: Indoor pollutants concentration limits

Pollutant	Limit	Source
Carbon dioxide (CO_2)	1000 ppm	(ANSI/ASHRAE, 2004)
Carbon monoxide (CO)	8.6 ppm	(WHO, 2000; ANSI/ASHRAE, 2004)
Volatile organic compounds (VOCs)	600 µg/m3	(HKSAR, 2003a; FiSIAQ, 2001; HKEPD, 1999)
Formaldehyde (CH_2O)	100 µg/m3	(WHO, 2000; ANSI/ASHRAE, 2004)
Particulate matter (PM_{10})	50 µg/m3	(Bluyssen, 2010; Salthammer, 2011)
Particulate matter ($PM_{2.5}$)	25 µg/m3	(Bluyssen, 2010; Salthammer, 2011)

The list in Table 2 presents the concentration limits of the key indoor pollutants. VOCs comprises of a host of other pollutants that are harmful to man if exposed above the acceptable limits. To Almeida et al. (2015), CO_2 is a very important pollutant when analysing IAQ. This is because its major source is from human respiration and thus its levels are quite high with high occupancies. CO_2 can also be found on almost every standard relating to IAQ.

Visual Comfort (Indoor Lighting Quality)

Lighting within indoor spaces is very important for the delivery of any task. Currently, up to 80% of data is visually handled. This prompts that the decision on the choice of light has a more critical effect on handling of data sufficiently. In a working environment, illumination is an essential part of ergonomic rules. Apart from the fact that light influences an individual's well-being, it has likewise a positive effect on ones delivery at work. Light also has a very significant part in managing Non-Image

Forming (NIF) functions such as circadian rhythms, alertness, well-being and mood. Lighting within the work environment depends on ergonomic standards and needs to meet well-being necessities.

Commission Internationale de l'Eclairage (CIE) has published various standards, technical reports and recommendations on indoor lighting quality such as CIE 49-1981: Guide on the Emergency Lighting of Building Interiors; CIE 52-1982: Calculations for Interior Lighting: Applied Method; CIE 55-1983: Discomfort Glare in the Interior Working Environment, CIE 60-1984: Vision and the Visual Display Unit Work Station, CIE 117-1995: Discomfort Glare in Interior Lighting, CIE 123-1997: Low vision - Lighting Needs for the Partially Sighted and CIE 184:2009: Indoor Daylight Illuminants. CIE has also jointly published ISO-CIE standard ISO 8995-1 (CIE, 2001/ISO 2002) which is on indoor work places. Table 3 shows the various lighting levels required within specific tasks in office spaces.

Table 3: Required lighting levels in office spaces

Office task	Required luminance level (lux)
Filing, copying, circulation, etc.	300
Writing, typing, reading, data processing	500
Technical drawing	750
CAD workstation	500
Conference and meeting rooms	500
Reception desk	300
Archives	200

Source: CIE, 2001/ISO 2002

Other factors that come into play for visual comfort are limiting unified glare rating (UGR_L) and the minimum colour rendering index (R_a). For office spaces, UGR_L should be averagely 20 and R_a approximately 80. However, if the required lighting levels are achieved, UGR_L and R_a are good.

Acoustic Comfort (Indoor Sound Quality)

When a building is able to protect its occupants from noise or provide an acoustic environment appropriate for the intended purpose of the building then acoustic comfort is achieved (Al horr et al., 2016). Exposure to noise at certain levels can be very harmful to the human being. Guarnaccia et al. (2013) outlines various effects of noise on humans both auditory and non-auditory. It is therefore very important to have acceptable levels of sound in indoor spaces for acoustic comfort.

The National Institute of Occupational Safety and Health (NIOSH) have developed the maximum allowable daily noise dose. The maximum allowable daily noise dose is measured against the number of hours a person is safe at that level. Table 6 shows the various allowable limits and their times.

Table 4: Average Sound Exposure Levels needed to reach the maximum allowable daily dose of 100%

Time to reach 100% noise dose	Exposure level per NIOSH REL
8 hours	85 dB(A)
4 hours	88 dB(A)
2 hours	91 dB(A)
60 minutes	94 dB(A)
30 minutes	97 dB(A)
15 minutes	100 dB(A)

NIOSH further explains that when one stays beyond the time limit to reach 100% dose within a given exposure level, then harm is inflicted on that individual. However, indoor sound discomfort starts at lower decibels. In office spaces, there are different recommended maximum allowable decibels for comfort. Table 5 details out some standards on offices and their respective allowable decibels for indoor comfort.

Table 5: Office spaces and their indoor sound comfort levels

Occupancy type	***Maximum allowable sound level per standard***		
	BS8233	AS2107	ASHRAE
Private office	40 dB	50 dB	35 dB
Meeting room	40 dB	40 dB	35 dB
Open plan office	45 dB	50 dB	40 dB

(Source: Field, 2010)

Depending on the country or geographic location of the assessor, one of the above standards can be used to determine indoor sound comfort levels. BS8233 is a British standard, AS2107 is an Australian standard and ASHRAE is an American standard. Knowledge of the various standards with regards to sound IEQ is very good as it helps to reduce prejudice. However, knowledge of the groupings and their respective codes or standards does not guarantee proper assessment of IEQ. The approaches and tools used in assessment contribute greatly to outputs. This study therefore seeks to review literature on various approaches and tools used in assessing IEQ for better comfort.

METHODOLOGY

The study is a review and thus adopts mostly qualitative approaches with some quantitative frequencies to establish the principally used tools or methods.

Data collection

For this study was realised through the use of the keywords or sentences such as IEQ assessment tools, instruments for measuring IEQ, simulation software for IEQ, indoor air measurements, lighting quality in indoor spaces, simulating thermal comfort, software for indoor air quality, simulating indoor lighting quality, indoor sound quality assessment, software for simulating sound in buildings, portable environmental measuring devices, CO_2 monitors, lux meters and sound meters. The main search engine used was Google search and Google scholar.

Even though keywords or phrases above were used to search for data, the actual data areas needed for the study is:

1. Processes used in IEQ assessments
2. Tools or equipment's that are used for IEQ data acquisition
3. The various simulation softwares for IEQ assessments
4. The means by which IEQ assessment is validated

Sampling

Convenient sampling was used to sample out articles from the search results in either Google scholar or Google search. Google scholar and search was used due to the fact that database is easily accessible. A total of 50 articles or research papers were sampled within the last decade (2007 – 2017) with the scope of needed data. Preferences were also given to articles or research papers published in high impact journals and also with high citations.

RESULTS AND DISCUSSIONS

Based on the sampling techniques adopted, 41 out of the 50 articles were settled on and discussed. Table 6 presents the various publishers and journals with their respective impact factors used for this review.

Table 6: Publishers and journals literature was taken from

Publisher	Journal	Global Impact Factor (SJR)	Total citations	No. of articles used
Acoustical Society of America	Journal of the Acoustical Society of America	0.75	4492	1
Elsevier	Energy	2.00	18256	2
Elsevier	Energy Procedia	0.47	9116	2
Elsevier	International Journal of Sustainable Built Environment	0.22	41	3
Elsevier	Building and Environment	2.01	4747	9
Elsevier	Energy and Buildings	2.09	10215	5
Emerald	Facilities	0.42	148	1
Emerald	Engineering Computations	0.42	148	1
Hindawi	Advances in Meteorology	0.46	588	1
Hindawi	The Scientific World Journal	0.34	6181	1
IJECS	International Journal of Engineering and Computer Science	0.56	-	1
National Institute of Standards and Technology	Journal of Research of the National Institute of Standards and Technology	0.37	69	2
Sage	Journal of Building Physics	0.72	90	1
Sage	Indoor and Built Environment	0.55	309	3
Sage	Building Service Engineering and Technology	0.40	98	1
Science Publications	American Journal of Environmental Sciences	0.24	122	1
Scientific Research	Journal of Building Construction and Planning Research	0.82	142	1
Taylor and Francis	Journal of Illuminating Engineering Society	0.66	73	1
Taylor and Francis	Science and Technology for the Built Environment	0.58	297	1
Taylor and Francis	Architectural Science Review	1.02	99	1
John Wiley and Sons Inc.	Environmental Progress and Sustainable Energy	0.53	1010	1

Wiley – Liss Inc.	Environmental Quality Management	0.19	27	1

From Table 6, it is realised that the publisher Elsevier had the highest number of articles published in different journals with a total of 21. The journal with the highest number of articles is Building and Environment of Elsevier with 9. However, on impact factor, the Energy and Buildings journal of Elsevier had 2.09 as the highest. The highest number of citations recorded by all journals in Table 6 is 18,256 and this is by the Journal of Energy, also of Elsevier.

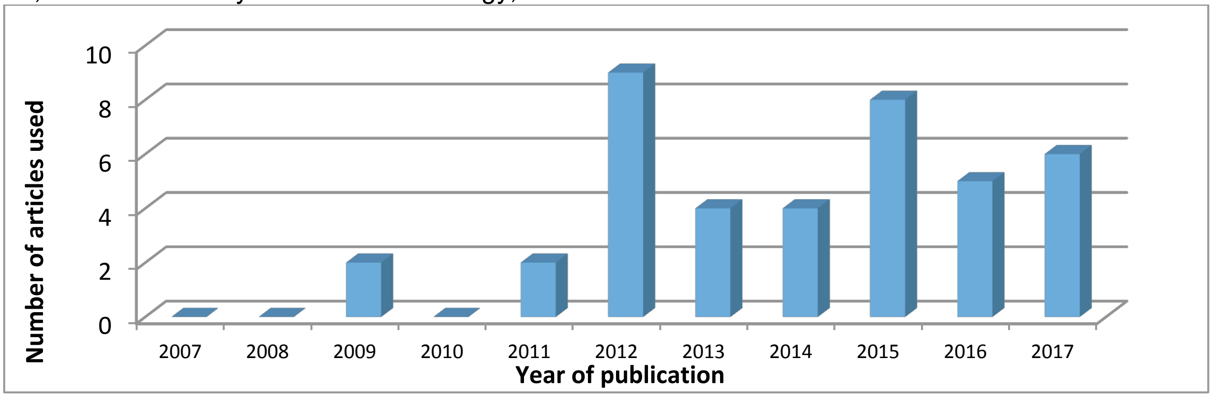

Figure 2. Number of publications per year used for review

Even though only articles from 2007 to 2017 were sampled for this review, the years of publications were analysed to know the year with more publications on IEQ. From Figure 2, it is clear that about half of publications used are within the last 2 years (2015 – 2017). However, 2012 have the highest number of publications with 9 articles. Knowledge of the various authors referenced in text as a support to Figure 2 is necessary to debunk all forms of ambiguity and thus Table 7 gives in text citations of the various authors in their corresponding years.

Table 7: Years of publications and their in text citations

Year of publication	Authors in text citation
2007	-
2008	-
2009	Ali et al,2009; Liu and Zhai, 2009
2010	-
2011	Brunsgaard et al, 2011; Reinhart and Wienold, 2011; Koranteng and Mahdavi 2011.
2012	Ng et al, 2012; Catalina and Lordache, 2012; Hwang and Kim, 2012; Kadiyala and Kumar, 2012; Chithra and Nagendra, 2012; Marino et al, 2012, Ncube and Riffat, 2012; Cao, et al, 2012; Choi et al, 2012.
2013	Díaz-Vilarino et al, 2013; Amos-Abanyie et al, 2013; Lim, 2013; Heinzerling et al, 2013.
2014	Jovanovic et al, 2014; Liang et al, 2014; Kakitsuba, 2014; Simons et al, 2014.
2015	Kapsis et al, 2015; Wang et al, 2015; Salleh et al, 2015; Dols et al, 2015; Prakash and Ravikumar, 2015; Ramalho et al, 2015; Harmati and Magyar, 2015; Lim, 2015; Simons et al, 2015.
2016	Harmathy et al, 2016; Laskari et al, 2016; Al horr et al, 2016; Parajuli et al, 2016; Shih et al, 2016.
2017	Pichatwatana et al, 2017; Kang et al, 2017; Stazi et al, 2017; Piasecki et al, 2017; Hongisto et al, 2017; Asadi et al, 2017.

There is also the need to align the various authors in this review to the four IEQ factors (thermal comfort, lighting quality, air quality and sound quality) to know the weight of articles backing each discussion. Table 8 shows authors and their respective IEQ factor they are associated with.

Table 8: Authors and their respective IEQ factors

	Thermal Comfort	Indoor Air Quality	Acoustic Comfort	Visual Comfort
Authors	Liang et al, 2014; Simmons et al, 2014; Brunsgaard et al, 2011; Catalina and Lordache, 2012; Hwang and Kim, 2012; Lim, 2013; Laskari et al, 2016; Pichatwatana et al, 2017; Prakash and Ravikumar,	Ncube and Riffat, 2012; Dols et al, 2015; Amos-Abanyie et al, 2013; Ali et al,2009; Ramalho et al, 2015; Catalina and Lordache, 2012; Chithra and Nagendra, 2012; Hwang and Kim, 2012; Ng et al, 2012; Lim, 2013; Jovanovic et al, 2014; Kadiyala and Kumar,	Catalina and Lordache, 2012; Hongisto et al, 2017; Hwang and Kim, 2012; Lim, 2013; Shih et al, 2016; Wang et al, 2015	Liang et al, 2014; Kapsis et al, 2015; Laguela et al, 2013; Catalina and Lordache, 2012; Harmathy et al, 2016; Hwang and Kim, 2012; Lim, 2013; Kapsis et al, 2015;

	2015; Stazi et al, 2017; Wang et al, 2015; Simons et al, 2015; Koranteng and Mahdavi, 2011	2012; Laskari et al, 2016; Parajuli et al, 2016; Prakash and Ravikumar, 2015; Liu, 2009; Stazi et al, 2017; Wang et al, 2015.		Pichatwatana et al, 2017; Wang et al, 2015; Reinhart and Wienold, 2011
TOTAL	**13**	**18**	**6**	**11**

Table 8 presents a picture of more publications on IAQ than any other IEQ factor with a total of 18. Acoustic comfort has the lowest with a total of 6 publications and thus needs more attention when looking at IEQ. It must however be noted that some authors published on all four IEQ factors and therefore the total number of publications in Table 8 will not tally with the total number of publications used for the review. The content of these publications were discussed for knowledge in IEQ assessment processes, tools and equipment used for IEQ data collection, the various simulation software used for IEQ assessment and the means by which simulated results can be validated.

IEQ assessment processes

From literature reviewed, IEQ assessment processes can be categorised into 2 methods (Subjective and Objective methods) (Heinzerling et al, 2013; Peretti and Shavion, 2011; Nicol and Wilson, 2011). The subjective methods are less expensive and an easy to use means of IEQ assessments in buildings. This is because there are no special skills or tools required but as with any qualitative data collection, the right questions should be asked. Due to its easiness to use there are a great number of survey techniques used over the years and has been detailed in Peretti and Shavion (2011). There have been several problems associated with surveys for IEQ. As documented in Nicol and Wilson (2011) surveys are always challenged with asking the right questions, finding an evocative period of survey and interpreting the results for discussion. Other technical parameters such as over lighting, glare ratios and even unseen gaseous emissions are difficult to assess through surveys (Heinzerling et al, 2013).

Due to the limitations with subjective methods, objective methods are the preferred choice. Objective methods involve either the use of instruments to collect data or simulating in appropriate software for results. For better accuracy and objectivity, simulated data is validated with measured instruments data (Amos-Abanyie et al, 2013). Objective methods are expensive, labour intensive and complex thus there should be no compromise in order to achieve good results (Heinzerling et al, 2013). With accuracy and calibration also an issue to contend, there is the need to find easy to use but accurate tools for data collection. To curb these challenges, some authors combine both the subjective and objective methods in their research. Majority of articles reviewed use the combined approach of both subjective and objective methods and thus it is appropriate to adopt this tactic when doing IEQ assessment.

Tools or equipments that are used for IEQ data acquisition

Subjective data collection uses questionnaire in the form of surveys. However, there are various tools that can be used for objective data collection. This section analysis the various tools and instruments that have been used for research over the past ten years. Table 9 outlines the various tools and their measured variables.

Table 9: IEQ instruments used for various measured variables

Measured variables	IEQ instrument	Author(s)
Sound	Noise meter TES 1353L	Shih and Hsia, 2016
Air quality	Q - Track Instrument	Ramalho et al, 2015
Carbon Monoxide (CO)	CO T82 data logger	Parajuli et al, 2016
Illuminance	TES-1335 Light Meter	Liang et al, 2014
Relative humidity, Air temperature, CO_2	Delta OHM RH-Temperature-CO2 HD37B17D Data logger	Liang et al, 2014
CO_2, CO, PM, Illuminance, Air temperature	EnviroBot	Choi et al, 2012
Air temperature	Hobo Sensor H8 data logger	Amos-Abanyie et al, 2013
Air temperature, Humidity	AOSONG GSP 958	Wang et al, 2015
Illuminance	XYI TES-1330A	Wang et al, 2015
Sound	XM 804	Wang et al, 2015
CO_2	TJHY EZY-1S	Wang et al, 2015
Air temperature	Data taker DT500	Stazi et al, 2017
Air temperature, Humidity, Sound, Illuminance	Babuc / A	Stazi et al, 2017
Air temperature, Humidity	Squirrel Grant SQ2010 data logger	Pichatwatana et al, 2017
Illuminance	Lux meter TES1 330	Pichatwatana et al, 2017
Relative humidity, Air temperature	Onset Hobo Sensors	Simons et al, 2014.

With the exception of Hobo, none of the instruments outlined in Table 9 have been repeatedly used by another author. However, these instruments suited the data collected because most of them were well calibrated and their reading ranges were within the range of data to be collected. Therefore it is necessary to choose an instrument that is well calibrated and within the data collection range for IEQ data collection.

The various simulation softwares for IEQ assessments
Simulation softwares are sometimes used either solely or with instruments measured data to assess IEQ. This review highlighted softwares such as Ecotect, Design Builder, IES VE, Contam, Radiance, Daysim, TAS and Energy Plus. These software's are thus explored for their capabilities in IEQ assessment. Table 9 presents the various software and their assessment capabilities towards the four main IEQ variables.

None of the softwares in Table 10 can play the sole role of being able to assess all the four IEQ variables. The closest software is Ecotect which can assess three out of the four IEQ variables. Ecotect thus becomes a key software to consider when doing IEQ assessment. The only software listed to deal with air quality assessment which is the gap for Ecotect is Contam. Therefore a combination of Ecotect and Contam is a good choice for IEQ assessment.

Table 10: Software and their IEQ assessment capabilities

Software	*IEQ variable*				
	Thermal Comfort	***Visual Comfort***	***Air quality***	***Sound quality***	***Authors***
Ecotect	✓	✓		✓	Harmathy et al, 2016; Harmati and Magyar, 2015; Laguela et al, 2013;
Design Builder	✓	✓			Lim, 2015
IES VE	✓	✓			Lim, 2015
Contam	✓		✓		Dols et al, 2015; Ng et al, 2012; Liu, 2009
Radiance		✓			Harmathy et al, 2016; Harmati and Magyar, 2015; Laguela et al, 2013;
Energy Plus	✓	✓			Harmathy et al, 2016; Amos-Abanyie et al, 2013;
Daysim		✓			Kapsis et al, 2015; Reinhart and Wienold, 2011
TAS	✓				Simons et al, 2015

The means by which IEQ assessment is validated
Validation simply means the act of checking or proving the validity of something. In IEQ assessments, different forms of both subjective and objective assessments can be done. For accuracy in results, one set of data or results is compared with the other for agreement. Surveyed results are compared with measured data for validation. If there is an agreement in results, then the assessment can be deemed accurate. To validate subjective assessments, statistical tools such as regression are used to establish relationship with field data (Heinzerling et al, 2013; Catalina and Lordache, 2012). The advent of software has also brought into the scope simulations for IEQ assessments. However, due to possible errors with simulations, measured data is also used to check its accuracy through the statistical analysis root mean square difference (RMSD) and the corresponding coefficient of variance of root-mean-squared error (RMSE) (Amos-Abanyie et al, 2013). Depending on the assessment path chosen, it is very important to use one of these validation means for objectivity and accuracy.

CONCLUSION
This review has established the various standards and requirements needed within an indoor space for total Indoor Environmental Quality (IEQ) based on articles reviewed. Assessing an indoor space and comparing with the required or acceptable level informs one of how quality an indoor space is. Both subjective and objective assessments can be done. But there are more challenges with

subjective assessments. Validation for subjective assessments can be used to debunk the accuracy of IEQ assessments and must be encouraged. However, due to the phenomenological nature of subjective assessments, objective assessments should be further added to conclude on findings. The study thus recommends that IEQ assessments should be done with the combination of both subjective and objective assessments.

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