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Enhanced Indoor Environmental Quality and the Link to Individual Productivity and Organisational Performance: A Scoping Review

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Abstract

This paper provides a scoping literature review of research methods that seek to measure individual productivity and organisational performance in office buildings containing enhanced green building features and initiatives that focus on Indoor Environmental Quality (IEQ).

The paper follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework and includes thirty-nine academic papers for the period 2000 to 2020. Different research instruments are discussed, including post-occupancy evaluations (POE), longitudinal surveys, and interviews. Furthermore, a narrative focuses on specific measures, including location, amenities, comfort, engagement, individual productivity, and organisational performance. This provides insight into common research approaches and highlights where lesser used research approaches could be applied in the field of green building features and initiatives (GBFIs), including the assessment of individual productivity and organisational performance. Key findings highlight that individual productivity was measured via self-assessment in previous research. At the same time, there has been no research that has successfully measured organisational performance within the context of GBFIs. Gaps have been identified in the literature concerning the relationship between knowledge-based building occupants and measuring/monetising the implementation of GBFIs. Implications of this research indicate that there are common approaches that highlight both strengths and, more importantly, weaknesses concerning linking GBFIs to individual productivity and organisational performance. Addressing weaknesses that predominantly encompass measuring organisational performance creates the opportunity for future research in this field.

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Keywords:
green building features and initiatives (GBFIs), indoor environmental quality (IEQ), post-occupancy evaluation (POE), individual productivity, organisational performance

1. Introduction

Office workers comprising lawyers, bankers, management consultants and financial services specialists tend to be in A-grade or prime grade buildings containing GBFIs (Alker *et al.*, 2014). The success of the businesses that occupy prime office space is underpinned by individual productivity and organisational performance. Productivity in offices has shown to be difficult to accurately measure, where researchers have attempted a variety of methods (Nurick and Thatcher, 2021). Organisations assess individual productivity through either self-assessed or peer interviews or surveys. Organisational performance is comparatively easier to measure. This can be done by comparing reporting periods and/or comparing competing companies that offer similar products.

For a building to be certified green, it must contain some form of GBFI. The key GBFIs that this paper is centred around are indoor environmental quality (IEQ), which focuses on air quality, temperature, lighting, office layout, ventilation, and noise levels. The main thrust of this paper is to review the literature that examines the link between GBFIs, in the form of enhanced IEQ in green buildings and individual productivity and organisational performance. The relationship between GBFIs and individual productivity and organisational performance requires further scrutiny as green building advocates (councils and building owners) often maintain that green buildings, specifically the GBFIs linked to IEQ, yield enhanced productivity and performance (Alker *et al.*, 2014). According to the literature reviewed, this is not an entirely accurate statement, as there are findings that suggest that certain enhanced IEQ features can hinder individual productivity (Thatcher and Milner, 2012). This paper examines the research methods used to measure individual productivity and organisational performance in office buildings that contain green building features and initiatives (GBFIs). For the purposes of this paper, the definition of individual productivity is underpinned by pay, motivation, supervision and individual capability. These attributes contribute to organisational performance, which can be defined as the organisation's overall financial performance (Nurick and Thatcher, 2021). In order to review research approaches, this paper will assess the literature that collects empirical data in office contexts. The justification for a scoping literature review is to provide a concise approach to organise previous research so that commonalities and gaps become easily identifiable to generate a set of hypotheses (Tricco *et al.*, 2016).

The emergence of the green building movement appeared relatively recently in Africa, as there are only two established green building councils (South Africa and Kenya) on the continent. The Green Building Council of South Africa and the Kenya Green Building Society were established in 2007 and 2017, respectively, while green building councils in North America, Europe and Australia were formed in the late 1990s and early 2000s. Many green building advocates within Africa have claimed, with only anecdotal evidence, that green buildings result in improved productivity. Therefore, research linking enhanced IEQ to individual productivity and organisational performance plays a pivotal role in justifying the implementation of GBFIs within the African office market. Past research on the performance of green buildings has used a variety of approaches, with post-occupancy evaluations (POEs) arguably being a popular technique where quantitative and qualitative data are gathered. POE is one of the preferred methods for determining building user satisfaction levels about specific building elements of GBFIs. This is because POEs are viewed as diagnostic tools to assist in isolating specific building-related problems so that they can be addressed timeously without further compounding building user problems (Prieser, 1995).

According to Tagliaro and Ciaramella (2016), POEs are considered beneficial mechanisms for collating data to support the refinement of the real and perceived productivity of the building occupants. There have been very few longitudinal studies with a central focus on establishing a coherent link between GBFIs and employee/organisational outputs.

There are three main types of POEs:

1. Building user survey (BUS) is a standardised instrument that assesses building occupant's perceptions of their work environment
2. POEs that focus on building operations such as water, electricity, and waste
3. POEs that focus on the financial performance of the building, which is linked to a variety of line items that contribute to a building's income and expenses.

The main gap identified is that although past research is focused on the link between individual productivity and IEQ in the form of GBFIs, there is little research (and thus evidence) to link organisational performance to enhanced IEQ as the result of the implementation of GBFIs in the workplace. The theoretical model, Figure 1, developed by Nurick and Thatcher (2021), will be used based on the consolidation of earlier models and is thus the most up-to-date. Figure 1 shows the possible linkages between GBFIs, which lead to individual productivity and organisational performance. Suppose an organisation is satisfied with its rented space and performs well financially due to improved individual productivity (increased Return on Investment). In that case, there is a low chance of them seeking new rental premises upon lease expiration. If an office building experiences lower vacancies, this reduces the building's risk profile, which will reflect lower capitalisation and discount rates, thus enhancing the building value (Nurick *et al.*, 2015). Figure 1 provides a framework that underpins identifying the key methods used and assessment measures in the scoping literature review.

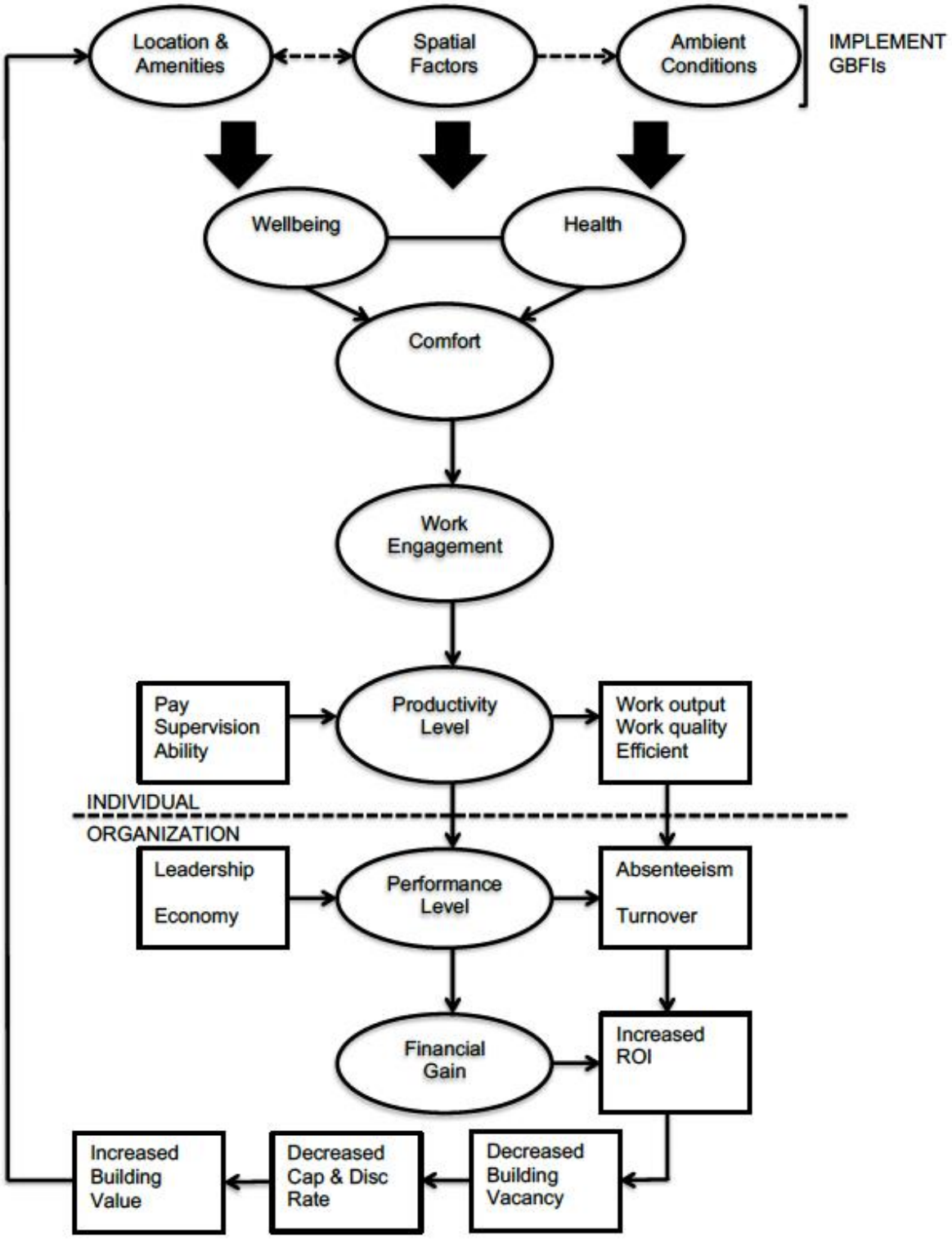

Figure 1: Linkages of GBFIs to productivity and performance (Nurick and Thatcher, 2021: 29)

2. Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher *et al.*, 2009) framework was applied, involving the four steps of identification, screening, eligibility, and inclusion. A scoping review was utilised as it provides a mapping process (Levac *et al.*, 2010; Peters *et al.*, 2015) used to identify relevant areas for further enquiry in an area where there is only emerging evidence to provide clarification for key concepts and gaps (Tricco *et al.*, 2016). On the other hand, a systematic review offers a more detailed approach

that focuses on a specific research question in a relatively mature area. At the same time, a meta-analysis only refers to the statistical analysis encompassed within a systematic review. The application of the PRISMA framework allows for a transparent, logical approach that exhibits how articles were classified as included. A traditional literature review seldom provides this logical approach for the reader.

The process of identifying articles was relatively broad. The keywords of green building features and initiatives, post-occupancy evaluation, office productivity, organisational performance and indoor environmental quality were entered in Scopus and Google Scholar from 2000 to 2020. The keywords were selected as they covered a relatively broad spectrum that could be encapsulated within the scoping literature review. Additionally, some of the keywords corresponding to the theoretical framework are exhibited in Figure 1. It should be noted that a limitation of this scoping literature review is the exclusion of articles that only focus on a single GBFI, as there is potentially an exhaustive list of individual building components/features, which do not directly, or at best, very loosely link to IEQ. The reason for the twenty years is that the keywords are prominent in research areas in developed markets in the twenty-first century's first decade. This is due to the establishment of green building councils in North America, Europe, the United Kingdom and Australia in the late 1990s and early 2000s.

The search criteria were refined by intentionally focusing on peer-reviewed academic articles that specifically focused on methods for determining the impact of GBFIs on office workers. These academic papers included a variety of methods for assessing the impact of enhanced IEQ on office building occupants. Some papers applied slight variations of previous methods, while others attempted to apply new approaches to measuring individual productivity and organisational performance changes. In contrast, green building councils became more prominent in Africa and Asia circa 2010.

Over a hundred and twenty thousand journal articles were found using Google Scholar and Scopus, which contained at least one of the keywords. Two hundred twenty-five articles that contained more than one of the keywords were identified, with one hundred and eighty articles excluded at this point since they only focused on the building, not the occupants. Forty-five academic articles were screened as they contained more than two of the keywords and examined building occupants. Four articles were removed because they were literature reviews. The remaining 41 articles were considered eligible and focused on building components and/or people within simulated or natural settings. However, two articles were excluded because they only focused on IEQ and not people. This resulted in two groups of included articles (n = 39) of people within offices (experiments, n = 11, non-experiments, n = 28). Figure 2 provides a flow diagram of the PRISMA process used in the scoping literature review.

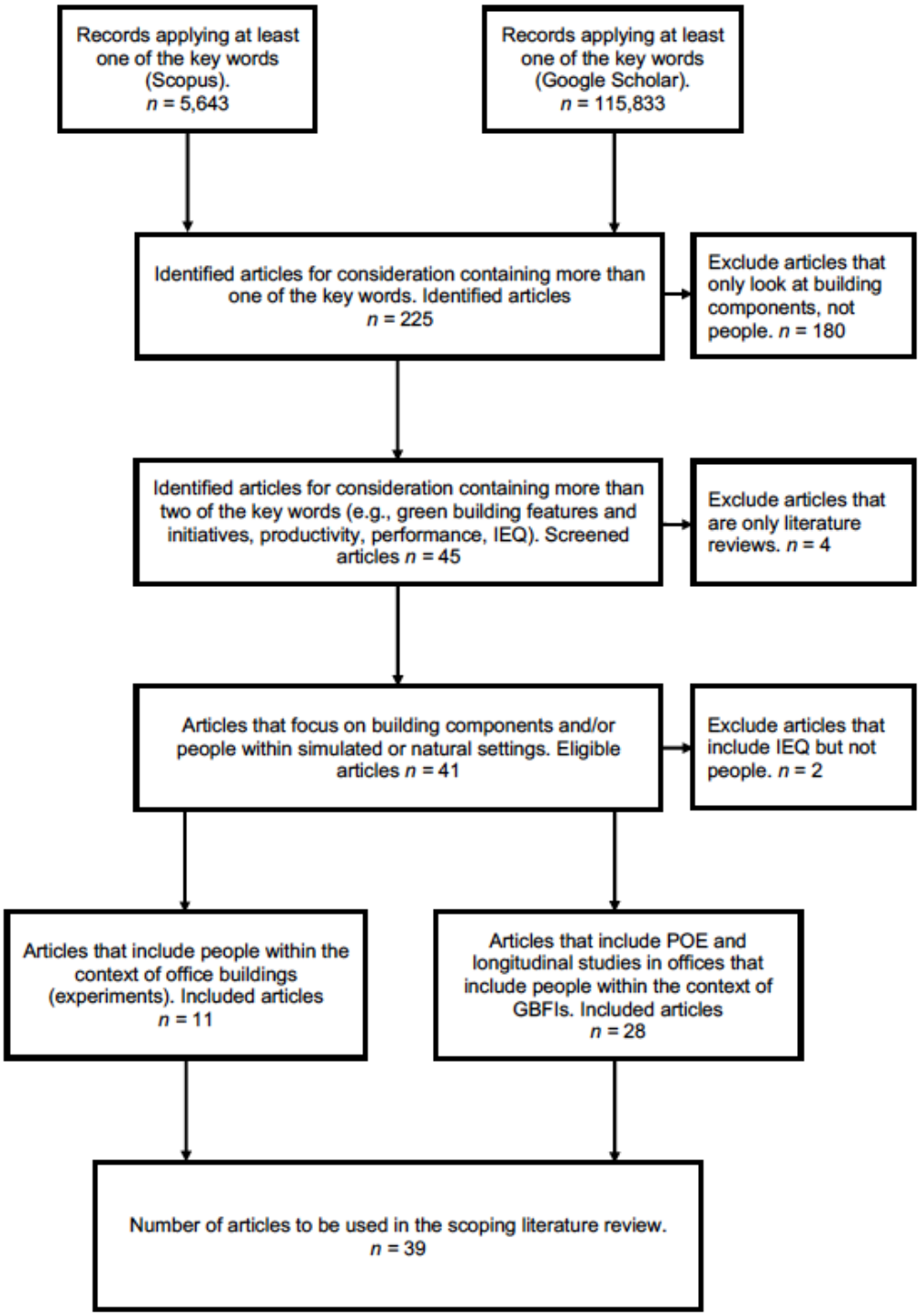

Figure 2: PRISMA Flow Diagram adapted from Sadick and Kamardeen (2020)

2.1 Selection of Studies for Review

The 39 journal articles comprising this scoping literature review used a variety of research designs. The overall breakdown of the research design for the sample included 26 (67%) articles that use some form of survey only (i.e., conventional survey, POE or BUS), 8 (21%) articles use both surveys and simulated experiments, 3 (8%) articles only use simulated experiments, and 2 (5%) articles applied interviews as a form of data collection. The sample size used by the selected articles ranged from a few hundred to several thousand. There was a variety in the measures that were chosen for analysis. As per Table 1, the data collection techniques were either cross-sectional (19 articles, 49%) or longitudinal (20 articles, 51%). However, there were some commonalities across the majority of the selected studies. This

included studies focused on IEQ of buildings containing GBFIs and how this impacted the user experience, including satisfaction levels. Methods of analyses exposed a group of standard approaches, including ANOVA (13 articles, 33%), descriptive statistics (20 articles, 51%), multivariate analysis (2 articles, 5%), non-parametric statistics (2 articles, 5%) and Spearman's rank-order correlation (2 articles, 5%). Many of the findings highlighted thermal comfort, temperature, ventilation, indoor air quality (IAQ), personal control of one's environment, building aesthetics, acoustics (both general and internal partitioning) and office configuration (open plan vs shared offices vs individual cellular offices) as the common GBFIs in the selected studies. The details of each journal article are given in Table 2. The order of the articles is chronological, starting in the year 2000.

Method of Analysis	**Number**	**Percentage (%)**
ANOVA	13	33%
Descriptive Statistics	20	51%
Multivariate Analysis	2	5%
Non-Parametric Statistics	2	5%
Spearman's Rank-Order Correlation	2	5%
TOTAL	**39**	**100%**
Duration of Data Collection	**Number**	**Percentage**
Cross-sectional	19	49%
Longitudinal	20	51%
TOTAL	**39**	**100%**

Table 1: Method of Analysis and Duration of Data Collection (n = 39)

Further geographical analysis of the included articles indicated that the research was conducted across 17 countries. Most countries (14) are located in the northern hemisphere, while the remaining countries (3) are in the southern hemisphere. Most of the studies were conducted in one country; however, two of the studies researched buildings located in two countries, resulting in forty-one separate country-specific occurrences. Figure 3 shows the geographical spread of all seventeen countries.

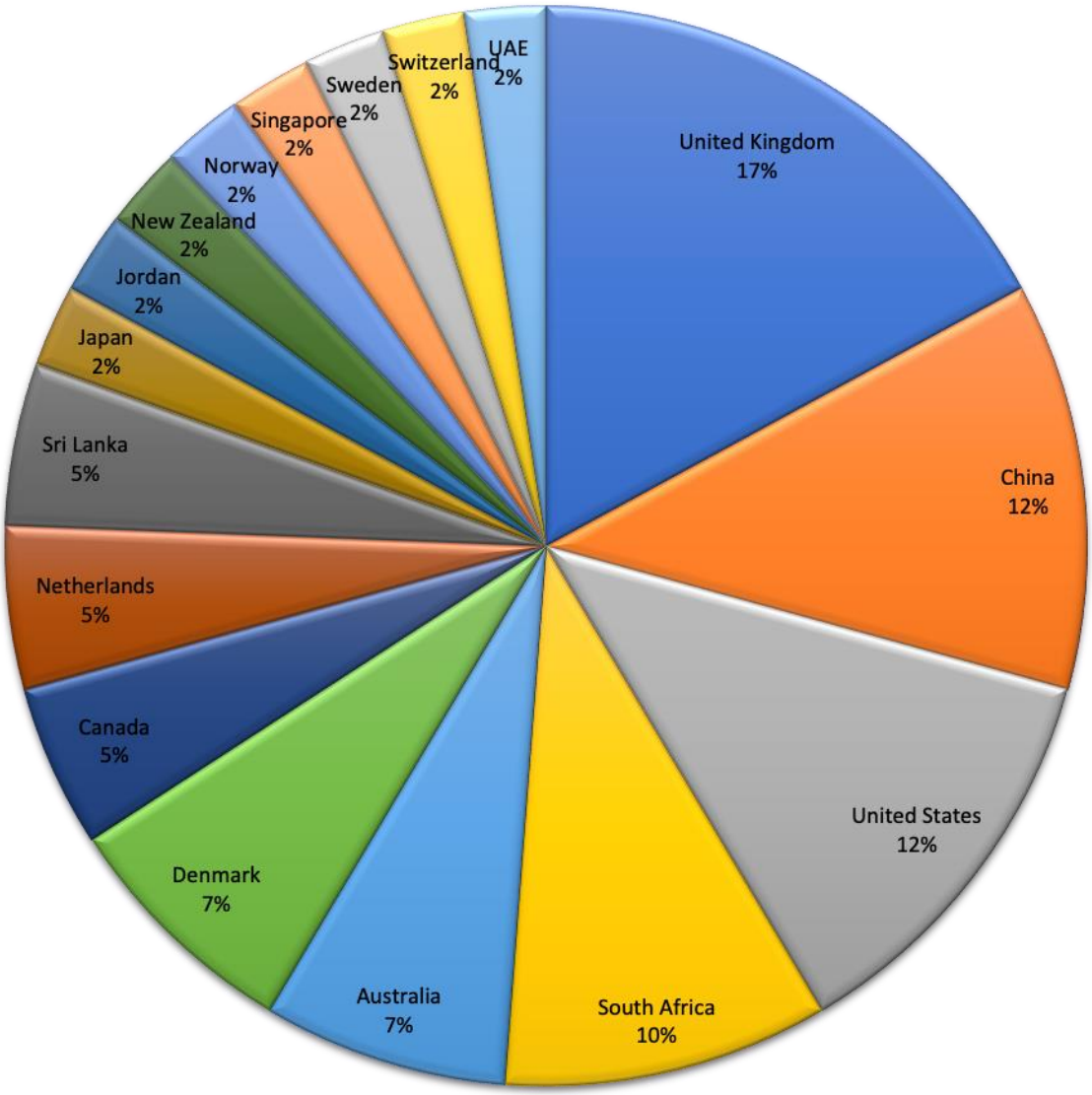

Figure 3: Geographical spread of research

2.2 Results

The results in Table 2 below are derived from research conducted in different geographical locations (North America, Europe, Asia and Africa). Table 2 provides a breakdown for each of the 39 papers in terms of research design, subject and setting, method of analysis, duration of data collection, and results. This indicates that similar findings should be considered robust and somewhat conclusive, as each of these locations experiences different climatic conditions, which contribute to office building occupant comfort levels.

Eleven articles were conducted in simulated laboratory conditions that included people but not specifically within the organisational context of GBFIs. These experiments indicated that improving the office environment could result in improved productivity (Clements-Croome and Baizhan, 2000). These results can be extrapolated in more detail, such as removing air pollution positively impacting health and work productivity (Wargocki *et al.*, 2002; Wyon, 2004) and high temperatures and humidity adversely affecting concentration levels (Fang *et al.*, 2004).

It was established by Vischer (2007) that comfort comprised three elements: physical, psychological and functional, where all three elements contribute to individual productivity.

This was confirmed by Wiik (2011), who found that physical and psychosocial environments significantly impacted productivity in an office building. Additionally, it was also found that behavioural components had a more significant influence on productivity than physical components in an office environment (Haynes, 2008).

Loftness *et al.* (2009) found that POEs benefit building occupants to assess building control, health, and productivity. In terms of office design, results indicated higher productivity levels with individual and shared offices compared to open-plan offices (De Been and Beijer, 2014). Haynes *et al.* (2017) partially agreed but noted that the configuration of open-plan offices was the main contributing factor that influenced productivity levels. However, Byrd and Rasheed (2016) stated that methods measuring perceived productivity were not sufficiently conclusive to substantiate the link between productivity and enhanced IEQ.

Leaman and Bordass (2007) conducted research that focused on comfort in terms of IEQ and their impact on health and productivity, with a specific focus on satisfaction. Results from the 28 articles contained POE, interviews and longitudinal surveys. All of these included people within the context of GBFIs. The findings indicated that generally, occupants of green buildings were satisfied with IEQ compared to conventional buildings; however, not all occupants were satisfied with enhanced IEQ, specifically the influence of comfort and control in buildings containing GBFIs.

According to Schwede *et al.* (2008), the physical attributes of an office environment that most influenced productivity were the acoustic and visual environments. The impact of green buildings on organisations and individuals researched by Kato *et al.* (2009) found that organisations tried to link GBFIs to productivity, employee retention and corporate environmental awareness. However, employees cited enhanced company image and environmental awareness as the factors that influenced their perceptions regarding GBFIs.
Research by Singh *et al.* (2010) supported the notion that green buildings with enhanced IEQ resulted in superior health and perceived productivity of office building occupants. Gou, Lau and Chen (2012) found that subjective satisfaction with IEQ improved health and productivity. However, objective building measurements indicated that green buildings were uncomfortably cold in winter, thus highlighting a possible design flaw.

Gou, Lau and Zhang (2012) found that occupants of green buildings were more satisfied with the IEQ when compared to a conventional buildings. The green building occupants perceived that they were healthier and more productive (Niewenhuis *et al.*, 2014). This was contrary to research by Gou *et al.* (2013), who found mixed results for occupant satisfaction for green buildings. Gou and Siu-Yu Lau (2013) found that green building occupants were generally satisfied with the thermal environment. Still, contrasting indoor temperatures concerning the season was a source of discomfort. Therefore, green building design is needed to ensure satisfactory ventilation to meet occupant comfort requirements, as there is a relationship between perceived thermal satisfaction and measured individual productivity (Tanabe *et al.*, 2015).

It was established that many variables affect work productivity, especially for occupants located in open-plan office spaces (Guerin et al., 2012). Gou *et al.* (2014) stated that it was difficult to measure the impact of IEQ on office building occupants, where the main priorities were perceived health and productivity when comparing green and conventional buildings. Research conducted by Thatcher and Milner (2012) indicated contrary results, which highlighted that occupants of green buildings did not show improvements in psychological and physical wellbeing or perceived productivity. Research produced by Agha-Hossien *et al.* (2013) showed that enhanced IEQ resulted in an increase in productivity that was based on individual self-assessment. Further research by Feige *et al.* (2013) stated a relationship between

the actual building and comfort levels. However, the link between comfort levels and work productivity was not fully confirmed.

Hedge and Dorsey (2013) and Thatcher and Milner (2014a) reported that IEQ factors alone did not result in occupant satisfaction. Both sets of authors continued by stating that ergonomics (i.e., physical workplace design) need to be considered in combination with IEQ (specifically thermal comfort and ventilation) to impact occupant satisfaction, health, and productivity positively. Research by Thatcher and Milner (2014) stated that although green buildings may positively impact occupant wellbeing, there was insufficient evidence to conclusively prove that green buildings result in improved health and productivity. Additional research is required to link individual productivity to organisational performance, specifically about financial gain. Activity-based work (ABW) environments/collaboration spaces require IEQ that focuses on air quality and building aesthetics, resulting in enhanced productivity, health, and building satisfaction (Candido *et al.*, 2016). This was supported by Thatcher and Milner (2016), who stated that enhanced IEQ resulted in an increase in perceived productivity and physical wellbeing. A different set of results were published by MacNaughton *et al.* (2016) in that green buildings must give the impression to building occupants of a high performing building to influence the perceptions and impact of IEQ on occupants. Mallawaarachchi *et al.* (2016), Mulville *et al.* (2016), Chadburn *et al.* (2017) and Mallawaarachchi *et al.* (2017) all, to a greater or lesser degree, highlighted individual system control as a factor that influenced IEQ satisfaction.

Green buildings generally resulted in higher job satisfaction and superior individual productivity assessments when compared to conventional buildings; however, some conventional buildings outperformed some green buildings in these metrics (Newsham *et al.*, 2017). Elnaklah *et al.* (2020) compared green and conventional buildings in terms of various IEQ factors and found that comfort was superior in green buildings, however individual productivity was slightly higher in conventional buildings, and there was no significant difference in absenteeism and presenteeism in either building type. It was established by Lee *et al.* (2020) that regardless of a green refurbishment or a new green building, the results were the same in IEQ user satisfaction and experienced health symptoms.

2.3 Measures and Variables

Table 3 below unpacks the key measures, and previous researchers used them. The last measure, organisational performance, has not been analysed in any of the chosen journal articles cited in Table 2.

2.4 Critique

Although the office environment seems to have been researched extensively in terms of the ambient environment and its impact on individual productivity, there are still areas that are either continuously re-examined or neglected altogether. The majority of journal articles used for this scoping literature review focused on the impact of IEQ on individuals in terms of their perceived productivity, thermal comfort, health and wellbeing. The applied overarching methods were POE, longitudinal studies, cross-sectional studies, and interviews.

The trends that appeared regarding measures included: user satisfaction with IEQ features such as temperature, thermal comfort, humidity, air quality, ventilation, noise, lighting, office configuration, and individual control of the ambient environment. Other non-building measures that appeared were: physical and mental wellbeing (Singh *et al.*, 2010), perception of working conditions (Thatcher and Milner, 2012), job satisfaction, absenteeism, presenteeism and perceived productivity (Thatcher and Milner, 2014b).

The most prevalent methods of analysis were descriptive statistics or some form of multiple regression. While all of the journal articles either focused on the building or individuals operating within the building, no studies predominantly focused on the organisation and how GBFIs may impact the organisation's financial performance. This was a result of past researchers not attempting to link the impact of enhanced IEQ at an organisational level or, in the case of Feige *et al.* (2013), not being able to conclusively link improved individual productivity to an improvement in organisational performance that was measured by financial gain to the company. This was hypothesised but not definitively proven.

A challenge that needs to be acknowledged is that productivity may also be influenced by non-GBFIs factors within an organisation, such as implementing new executive leadership, which may drastically change strategic and operational policies, such as IT and HR regulations. One of the main weaknesses of previous studies is that individual productivity is self-assessed by the individual and/or their supervisor, which seldom results in a fully quantifiable set of comparable outputs over a period of time. Quantitative data has been collected via laboratory studies, which artificially simulates the office environment. This approach has its disadvantages, as the research subjects are generally aware of the purpose of the experiment, which can result in skewed data.

Ideally, measuring individual productivity needs to occur over a relatively long period in the actual office environment, which usually occurs through longitudinal studies. The main challenge with longitudinal studies is that when an organisation moves from an old to a new green building, the buildings are not identical, distorting the data. The differences in buildings tend to occur due to physical elements that are not directly linked to GBFIs, such as new internal configurations for working and resting stations (e.g., cafeteria and toilet locations). The location of the new building will impact commuting times. Additional amenities that are close or offered in the new building may impact individual productivity to a greater or lesser degree.

One of the challenges that have become apparent as a result of conducting a scoping literature review is the inconsistency concerning the assessed variables. Many variables tend to be analysed in isolation to productivity. This is often done without considering the impact of other variables within the greater context of GBFIs and individual productivity. These variables tend to include ambient conditions, spatial conditions, location, amenities, comfort and engagement. Most studies listed in Table 1 did not have a theoretical model that provides a foundation for their chosen variables. An example of such a model is exhibited in Figure 1, which shows the relationships between the variables.

There seems to be a lack of standardised approaches to measure the variables. These approaches include POE, BUS, close-ended questionnaires, environmental monitoring systems, different types of simulated office experiments and longitudinal studies. This inconsistency concerning the approach also creates difficulty when comparing results across several studies. There is additional inconsistency within the types of surveys that have been used across the different studies. This is mainly due to the time, i.e., cross-sectional vs longitudinal. A significant challenge is the inability to compare many studies, as each study seems to, at most, examine one or two GBFIs. Therefore, it may be beneficial to switch the focus solely from GBFIs to IEQ, allowing for a more high-level comparison across studies.

Another challenge is the inability to ascertain if there are commonalities across industry sectors, as most of the included studies chose not to disclose the company type to maintain anonymity. A final problem is how building(s) are incorporated into various studies. Some studies focus on one building containing GBFIs, while others attempt to compare conventional and green buildings. When comparisons are conducted, there is an additional difficulty in defining the sufficient and accurate criteria that are able to generate data that can result in

meaningful conclusions. Therefore, measuring individual productivity within the context of organisational performance over a period of time in competing organisations may result in a data set that can assist in linking individual productivity to organisations' performance by providing quantifiable data to support the proposition that the implementation of GBFIs pertaining to IEQ in an office building increases individual productivity thus leading to an enhancement in organisational performance.

Some gaps require further research when comparing what has been done within the identified journal articles to the model linking GBFIs pertaining to IEQ to productivity and performance (Figure 1). There needs to be a specific focus on how knowledge-based building occupants can measure and/or monetise the implementation of GBFIs. This is a vital point, as capital expenditure by real estate companies is usually linked to some form of long-term return on investment (ROI). One of the variables that influence ROI is the vacancy rate, which is underpinned by the tenant's satisfaction with the space and/or the financial success of companies occupying the space to renew leases upon expiration. This will also impact valuation variables (discount and capitalisation rates), as is shown in Figure 1. Comparing companies located in buildings containing GBFIs against similar companies located in conventional buildings could provide an insight into linking GBFIs to organisational performance.

3. Discussion

The benefit of a scoping literature review within this field of research is that it has provided a systematic approach to identifying specific journal articles that encapsulate office buildings, occupants, GBFIs, enhanced IEQ, and the resulting impact of several measures and variables on occupant comfort, wellbeing, and productivity. There appear to be commonalities regarding conducting research in measuring productivity in office space where IEQ has been enhanced. Additionally, there seem to be similar trends concerning the results regarding the emerging variables that have the most vital links to productivity and the indoor environment. The main findings revolve around occupants' satisfaction or comfort with the ambient environment and control thereof, focusing on air quality and temperature. The measurement of productivity is either through the supervisor (Newsham *et al.*, 2017) or, in most cases, self-assessed (Schwede *et al.*, 2008; Kato *et al.*, 2009; Agha-Hossien *et al.*, 2013; Mallawaarachchi *et al.*, 2016; Haynes *et al.*, 2017) when conducted in an organisation.

There are a variety of research designs, where the majority were cross-sectional studies, longitudinal studies, BUS, and/or POE. Most of the results highlighted office building occupants' wellbeing, comfort, and perceived productivity as the main findings across most articles classified as eligible/included. None of the studies managed to link individual productivity to organisational performance successfully, nor has this been a core research objective for the majority of the researchers in this field of study. One study attempted to find this link as a secondary component of their research (Feige *et al.*, 2013); however, the results were inconclusive. Therefore, there remains a gap in this research field, as the impact of the implementation of GBFIs, specifically enhanced IEQ, on individual productivity and its link to organisational performance (Figure 1) has yet to be established.

4. Conclusion

There is minimal focus on how GBFIs impact specific organisations or industries. Although individual employees underpin organisations, there has yet to be research linking GBFIs to individual productivity and organisational performance within an office environment. The majority of the sample of journal papers have indicated that enhanced IEQ is positively received by office building occupants, as there is, to a greater or lesser extent, an improvement in self-assessed productivity, which physical and non-physical measures have influenced. It

should be noted that the main limitation of this scoping literature review includes the assessment of academic research conducted only within the last twenty years, which may indicate a bias towards certain types of research designs and methods of analysis.

5. Implications for Further Research

Several financial institutions offer products for long-term investment. Typically, these products are categorised as low, medium, and high-risk investment options. The asset allocation that comprises these investment categories differs depending on the asset managers and the financial institution. The next step in this research area would be to quantitatively assess the impact of GBFIs, specifically enhanced IEQ, on organisational performance by comparing the same tenant type (e.g., financial services companies) located in green buildings and cross-mapping their organisational performance against IEQ scores. Financial services companies located in green buildings with different IEQ ratings can be compared with the annualised return. A further study could be conducted to determine if there is a relationship between specific IEQ attributes (GBFIs) and annualised return (organisational performance). This would provide further insight into linking individual productivity and organisational performance to GBFIs. This analysis will hopefully provide further insight into the strategy of implementing GBFIs within an office environment.

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Appendix

Table 2: Selected sample of journal articles (included *n* = 39)

Author(s)	Research Design	Subject and Setting	Method (s) of Analysis	Duration of Data Collection	Results
Clements-Croome and Baizhan (2000)	Occupational Stress Indicator (OSI) Survey.	Focus on crowded offices/physical environments, impacting job satisfaction and productivity.	Spearman rank correlation coefficient, multiple regression, F-test.	Cross-sectional	Improving the office environment could result in improved productivity.
Wargocki *et al.* (2002)	The experiment of removing air pollution sources in two buildings, where thirty subjects participated in each building.	Comparison of perceptions of work performance in an office environment when air pollution loads are changed.	Descriptive statistics, t-test, Wilcoxon test, chi-squared.	Cross-sectional	Removal of air pollution positively impacted health and work performance in an office building.
Fang *et al.* (2004)	Experiment and simulated office work of 30 female subjects.	Impact of indoor temperature and humidity on SBS and performance.	Descriptive statistics, ANOVA, Wilcoxon rank test.	Cross-sectional	Uncomfortably high temperatures (gender-specific) and humidity levels adversely affect concentration levels.

Wyon (2004)	The experiment of up to five hours of where sources of air pollution were removed in a simulated office. The experiments took place in two offices, *n* = 26 for each office.	Investigation of indoor air quality (IAQ) on occupant behaviour and productivity.	Multivariate analysis, Wilcoxon test.	Two separate eight-week experiments.	Air quality and sufficient ventilation are positively linked to occupant behaviour and productivity in an office building.
Vischer (2007)	Survey, *n* = 520 from five office buildings.	Investigating the relationship between comfort and performance in an office environment.	Descriptive statistics	Cross-sectional	Environmental comfort comprises three elements: physical, psychological and functional comfort. Personalising space is linked to psychological comfort, which can impact performance.
Leaman and Bordass (2007)	POE from 177 buildings focused on comfort, temperature, air quality, lighting, noise, configuration, health, and perceived productivity.	Dissatisfaction with green buildings, tolerance of green buildings.	ANOVA, Pearson's correlation	Cross-sectional	Generally, occupants are more satisfied. However, some of the granular data indicates some dissatisfaction with certain GBFIs.

Haynes (2008)	Analysis of two data sets. n_1 = 996, n_2 = 422. Data sets focused on comfort, office layout, interaction and distraction.	Impact of the office environment on perceived productivity of occupants.	Descriptive statistics, Factor analysis/Cronbach's alpha.	Cross-sectional	Behavioural components have a larger impact on productivity than the physical components for office occupants.
Schwede *et al.* (2008)	Analysis of 48 surveys of over 5,000 occupant self-assessments.	Occupant satisfaction with new and old workplace designs.	Descriptive statistics of quantitative and qualitative data.	Cross-sectional over four years	Physical attributes of the workplace impact productivity, which designers do not properly address. The acoustic and visual environment are the most influential factors for building occupants.
Loftness *et al.* (2009)	National Environmental Assessment Toolkit (NEAT) - assesses the efficacy of POE.	Value add of POE for building occupants and facility managers.	Descriptive statistics, ANOVA, Pearson's correlations.	Cross-sectional	POEs offer many benefits to building occupants with regard to building control, health and productivity.

Kato *et al.* (2009)	Analysis of two data sets, where n = 128. There were two surveys; one targeted management and the other employees.	Perceptions of office buildings occupants located in green buildings.	Descriptive statistics	Cross-sectional	Green building affects an organisation and individuals differently. Organisations cited productivity, employee retention and environmental awareness. Employees cited enhanced company image and environmental awareness.
Singh *et al.* (2010)	A longitudinal study (surveys) involving case studies where building occupants moved from a conventional building to a green building. Case study 1, n = 56, case study 2, n = 207.	Investigation into the perceived effects of a green building on occupant health and productivity.	t-test	Eight months	The data supported the notion that green buildings with enhanced IEQ result in superior health and perceived productivity of office building occupants.

Wiik (2011)	Questionnaire that converts data into an indoor productivity index (IPI). The survey included twelve companies. Three companies moved premises; nine companies refurbished premises, where n = 484.	The development of a model predicts the economic benefits of refurbishing or moving premises in terms of productivity.	Analysis of Variance (ANOVA), t-test, Pearson's correlation, Cronbach's alpha.	Pre-occupancy surveys. Post-occupancy survey - six, eleven and twenty months after moving into new premises.	Both the physical and psychosocial environments significantly impact productivity in an office building.
Gou, Lau and Chen (2012)	Post-occupancy study in the form of a BUS, where n = 182.	Subjective and objective evaluation of the thermal environment of a green building.	Pearson's correlation	Data collection occurred at the end of summer and mid-winter for six days.	Subjective satisfaction with and control of IEQ resulted in improved health and productivity. Objective measurement indicated that the building was uncomfortably cold in winter, thus highlighting some design flaws of the green building.
Gou, Lau and Zhang (2012)	Post-occupancy study in the form of a BUS for two case studies, where n_1 = 57, n_2 = 42. The survey focused on IEQ attributes.	IEQ comparison of two green buildings and a conventional building.	Case study, descriptive statistics and t-test.	Data was collected in summer and winter.	The perception of the green building occupants was that they were more satisfied with the IEQ than the occupants of the conventional building. Green building occupants perceived that they were

					healthier and more productive.
Guerin *et al.* (2012)	POE, where two samples were applied - calibration sample (n = 101), validation sample (n = 102). The survey focus was on occupant satisfaction and performance.	Evaluation of building occupants works performance and satisfaction focused on IEQ criteria for green buildings.	Descriptive statistics, t-test.	Cross-sectional	Many variables affect occupants' work performance, specifically for occupants located in open-plan office space.
Thatcher and Milner (2012)	Longitudinal study comparison of two groups, where n = 240. One group moved into a green building, and the other group remained in a conventional building.	An investigation to determine if green buildings actually result in enhanced physical and psychological wellbeing.	Descriptive statistics, t-test. Seven measures were analysed.	Time 1 - before employees moved into a green building. Time 2 - six months after employees moved into a green building.	Results were contrary to the industry narrative regarding the green building. The green building group did not produce a consistent result that indicated a significant improvement in psychological and physical wellbeing and perceived productivity.

Agha-Hossien *et al.* (2013)	POE, where *n* = 162.	Employee satisfaction regarding energy performance can be used as a predictor of perceived productivity.	Self-assessment of productivity and analysis of absenteeism data.	Pre and Post OE six months apart.	Employees were satisfied with the new work environment focused on space configuration and quality. Employee self-assessed productivity increased.
Feige *et al.* (2013)	Questionnaires, structured interviews, and physical measurements inside office buildings. The research comprised 18 office buildings where *n* = 1,500 employees.	The relationship between sustainable office buildings occupant's comfort, self-assessed performance and work engagement.	Descriptive statistics, correlation analysis.	The questionnaire and measurements occurred twice over summer and winter.	There is a relationship between building and comfort levels. The link between comfort and work performance is not fully confirmed. Linking work performance and financial gain to the company still requires research.
Gou *et al.* (2013)	BUS focused on comfort and satisfaction. The sample included nine green buildings and five conventional buildings, with total occupants of *n* = 1,251.	Comparing green and conventional buildings focuses on occupant satisfaction and comfort.	Case study, descriptive statistics and t-test.	Data was collected in summer and winter.	Mixed results for occupant satisfaction and comfort for green buildings.
Hedge and Dorsey (2013)	POE where *n* = 35 for two green-certified office buildings. The research focused on ergonomic and IEQ measures.	Investigating the impact of ergonomics and IEQ factors on health, performance and satisfaction.	Chi-squared, t-test, Pearson's correlation, factor analysis, stepwise	Cross-sectional	IEQ factors alone do not result in occupant satisfaction. Ergonomics needs to be considered

			linear regression.		in combination with IEQ to impact occupant satisfaction, health, and performance positively.
Gou and Siu-Yu Lau (2013)	POE as a BUS was conducted in an office building, which comprised a survey (n = 182) and physical measurements.	POE of thermal environment in a green building.	Descriptive statistics	Data collection occurred at the end of summer and mid-winter for six days.	The majority of occupants were satisfied with the thermal environment. Contrasting indoor temperatures in relation to the season was a source of discomfort for building occupants. Green building design needs to ensure satisfactory ventilation to meet occupant comfort requirements.
De Been and Beijer (2014)	WODI Light online questionnaire across 87 case studies, spanned across different sectors, with n = 11,799.	Measuring employee satisfaction with the working environment, with a specific focus on office type.	Regression analysis	Five and half years.	Results indicate a higher level of productivity with individual and shared offices versus larger open-plan offices.

Gou *et al.* (2014)	BUS comprising 14 buildings where *n* = 1,251 occupants. The survey focused on temperature, light, noise, perceived health and perceived productivity.	Green building IEQ satisfaction which can impact office occupant comfort, health and productivity.	Analysis of Variance (ANOVA), F-test, Pearson's correlation.	Data was collected in summer and winter.	Difficult to measure the impact of IEQ on office building occupants. Perceived health and productivity are highest compared to conventional buildings for occupants located in highly rated green office buildings.
Niewenhuis *et al.* (2014)	Longitudinal study which focused on workplace satisfaction, concentration, air quality and subjective productivity. A sample of *n* = 67.	The introduction of green features in an office building. Measuring the difference in occupants in terms of wellbeing and productivity.	Analysis of Variance (ANOVA), chi-squared.	Three weeks	Green features contribute to employee welfare and organisational output in terms of productivity.
Thatcher and Milner (2014b)	Longitudinal study comparison of two groups. One group moved into a green building, and the other group remained in a conventional building, with *n* = 41.	To determine whether a green building results in a healthier, more productive office environment.	Descriptive statistics, t-test, F-test, chi-squared.	Time 1 - two months before moving to the green building. Time 2 - two weeks, six months after moving into the green building. Time 3 - three weeks, one year after moving into the green building.	Results suggest that green buildings may positively impact the well-being of occupants. The results do not conclusively prove that green buildings enhance the occupants' health and productivity.

Thatcher and Milner (2014a)	A longitudinal study (POE) involved moving from conventional buildings to three green buildings. The sample was: n_1 = 161, n_2 = 56, n_3 = 108. The survey focused on psychological and physical wellbeing, job satisfaction, propensity to continue working at the organisation, productivity, absenteeism, presenteeism.	Focus on ergonomics for green building that contributed to the design of the interior design rating tool.	Descriptive statistics, t-test.	Pre-occupancy survey - three months before moving into a green building. Post-occupancy survey - six months after moving into a green building.	Ergonomics has a role to play in green building design, with a specific focus on thermal comfort and ventilation.

Tanabe *et al.* (2015)	Survey of office workers n_1 = 105. The survey focused on health, indoor environment, fatigue, self-assessed performance, and usage of cooling items. Experiment and simulated office work, n_2 = 11 for the chamber.	Investigating changes in the thermal environment regarding the impact on individual productivity in an office building.	Descriptive statistics and correlation tests.	Phase 1 - four months, Phase 2 - two months.	There is a relationship between perceived thermal satisfaction and actual measured (Phase 2) individual productivity.
Byrd and Rasheed (2016)	Review of measuring productivity. Two surveys - the first focus on self-assessed productivity. The second survey included twenty-one factors that focused on environmental and social aspects in an office environment. Both surveys had n = 49.	Measuring productivity of green buildings within the context of IEQ.	Review of measuring productivity and a survey.	Cross-sectional	Methods of measuring perceived productivity are not conclusive to substantiate the link between productivity and enhanced IEQ.

Candido *et al.* (2016)	POE, time-lapse surveys, IEQ measurements for 65 buildings with 7,000 responses. Nine IEQ measures and four satisfaction measures:	Workplace layout and occupant satisfaction with IEQ components for activity-based working (ABW).	Analysis of Variance (ANOVA), Cohen's *d*	Cross-sectional	Building occupants were satisfied with IEQ regarding air quality, building aesthetics, perceived productivity, building satisfaction, health and collaboration space for ABW layout.
MacNaughton *et al.* (2016)	Environmental monitoring system (phase 1 and 2), survey (phase 2). Sample comprised $n = 30$ (phase 1) and $n = 24$ (phase 2).	Environmental perceptions and health before and after moving to a green building.	Univariate and multivariate analysis	Two weeks (phase 1) six days (phase 2).	Building occupants in the green building experienced enhanced IEQ. A green building must exhibit high performance and give the perception of high performance (IEQ) for it to influence building occupants.
Mallawaarachchi *et al.* (2016)	Survey and semi-structured interviews. Measures comprised self-assessment of productivity, thermal conditions, visual quality, IAQ and acoustic quality, where $n = 65$.	Examining the relationship between IEQ and enhanced productivity of green buildings occupants.	Non-parametric statistics, Spearman's correlation.	Cross-sectional	Several IEQ factors influenced individual productivity, such as air quality, acoustics and system control.

Mulville *et al.* (2016)	Survey, n = 95. Measures comprised ambient environment, air quality, temperature, humidity, noise, lighting, occupant behaviour, health, wellbeing and proximity to windows.	Examines the ambient environment on perceived comfort, health, wellbeing and productivity in an office building.	Spearman's correlation	Five weeks during the summer months.	Certain environmental factors have a greater influence on productivity, such as noise level access to systems control.
Thatcher and Milner (2016)	A longitudinal study (POE) involved moving from conventional buildings to three green buildings. Treatment group - employees moved from conventional to green buildings. Contrast group - employees remained in the conventional building. Samples comprised n_1 = 97, n_2 = 41, n_3 = 73.	Investigation into whether green office buildings enhance user experience due to improved IEQ.	Review of academic literature, descriptive statistics, t-test, F-test, chi-squared.	Pre-measures were taken three months before moving to a green building. Post-measures were taken twelve months after moving into a green building.	There was an increase in perceived productivity and improvement in physical wellbeing.
Haynes *et al.* (2017)	The survey, where n = 220. Self-assessment of productivity and an evaluation of the office environment. Focused on lighting, temperature, cleanliness, interruptions and work interaction.	Investigation into the open-plan offices focusing on if productivity benefits outweigh productivity penalties.	Descriptive statistics, Factor analysis/Cronbach's alpha.	Cross-sectional	The configuration of open-plan offices is the main contributing factor in influencing productivity levels.

Chadburn *et al.* (2017)	Close-ended questionnaire of employees in professional companies, where *n* = 213. The survey focused on seven aspects of productivity.	Drivers of individual productivity of knowledge-based workers, focusing on the physical and social environment.	Descriptive statistics	Cross-sectional	Individual productivity is dependent on the physical and social environment. The main driver of productivity is an office with good ventilation and temperature control.
Mallawaarachchi *et al.* (2017)	Survey and semi-structured interviews were used to test two hypotheses, where *n* = 65.	Examining the relationship between built environment and productivity of green buildings occupants.	Spearman's correlation	Cross-sectional	There is a statistically significant relationship between green buildings and occupant productivity regarding air quality, system control, acoustical partitioning, amount of space and open-plan office design.

Newsham *et al.* (2017)	Analysis of office building occupants (*n* = 14,569) in green and conventional buildings. Occupant productivity measures: great place to work, external value, management, happy to be here, manager assessed performance, HVAC complaints.	Analysis of green and conventional buildings. The main focus is organisational performance across the data set.	Building level - non-parametric Wilcoxon signed-rank test. Employee level - multivariate analysis of variance with covariates (MANCOVA).	Cross-sectional	Note: not all green buildings outperformed all conventional buildings. Generally, green buildings scored higher regarding job satisfaction and value to clients. Green buildings also tended to yield higher job performance assessments conducted by managers.
Elnaklah *et al.* (2020)	POE of five green buildings and eight conventional buildings, *n* = 502 building occupants. The focus of the study was measurement of air temperature, humidity, CO_2 concentration, individual productivity measured by absenteeism and presenteeism.	Investigation into the comparison of IEQ quality of green buildings versus conventional buildings.	Descriptive statistics, t-test, Cohen's d	A longitudinal study collected data over three campaigns over approximately 18 months.	Thermal comfort in green buildings is superior to conventional buildings. Individual productivity was slightly higher in the conventional buildings, with no significant difference between absenteeism and presenteeism.
Lee *et al.* (2020)	POE of occupants (*n* = 367) in office buildings (*n* = 14). Main measures comprised: windows view from desk, temperature, humidity, lighting level, daylight, air quality and indoor environment.	Investigation into satisfaction and health symptoms experienced by users of green refurbished office buildings compared to new certified green buildings.	Multivariate analysis, pairwise analysis	Cross-sectional across the sample of buildings that took approximately two years.	Both categories of the building had superior IEQ compared to conventional buildings. Refurbished conventional buildings to green-certified buildings exhibited similar satisfaction and health symptoms relating to IEQ to that of a new certified green building.

Table 3: Measure and corresponding application by other researchers

Measure	Application by previous researchers
Ambient conditions (IEQ/IAQ)	Multiple approaches to measuring IEQ/IAQ. Hedge *et al.* (1996) focused on temperature, lighting, glare, ventilation, internal drafts, insufficient air movement, dryness, humidity, ambient noise distraction, unpleasant air odour, stale air, dusty air and electrostatic shock in a questionnaire to assess perceptions of the IEQ in a sick building syndrome (SBS) study. This questionnaire was used by Thatcher and Milner (2012, 2014b, 2016). Another popular application for measuring IEQ/IAQ is the BUS (Gou *et al.*, 2013; 2014), which focuses on comfort, including assessing perceptions of temperature, light, noise, and air quality.
Spatial conditions	The scale developed by Thatcher and Chunilal (2015) compared workspace type and quality was conducted when an organisation moved from a conventional building to a green-certified building. This scale consists of 13 items that showed good discriminant validity and internal consistency reliability (Thatcher & Chunilal, 2015). The ergonomics theory underpins the items, including frequency of use, functionality, personal space, privacy and collaborative space (McCormick, 1970; Orborne, 1982). Candido *et al.* (2016) conducted a study that somewhat focused on spatial comfort and individual space containing seven items based on the BOSSA Time-Lapse IEQ questionnaire. Mallawaarachchi *et al.* (2017) partially looked at spatial quality. The focus was on personal control workstations, distractions, privacy, office instrumentality, space arrangement, office orientation and space flexibility, based on similar items that were identified by Heerwagen (2000).
Location and amenities	Currently, no validated scale exists to assess satisfaction with location and amenities. Therefore, a scale will be developed and pilot-tested that assesses the critical amenities as identified by Alker *et al.* (2014). A draft version of possible questions was included as an Appendix to the Alker *et al.* (2014) report, but this has not been empirically tested. The questions that focused on location pertained to the office's proximity to different transport routes, nodes and commute times. The questions that focus on amenities include showers, storage facilities for bicycles and clothes, quality of food at the office, and proximity of external amenities such as shops.
Comfort	A POE was deemed an appropriate tool for assessing comfort by Bordass and Leaman (2005) as it provided a feedback mechanism. Therefore the following researchers listed in T-table 1 applied a POE and/or a BUS: Leaman and Bordass (2007); Gou, Lau and Chen (2012); Gou and Siu-Yu Lau (2013); Gou *et al.* (2013); Thatcher and Milner (2014a); Elnaklah *et al.* (2020). Another method of measuring comfort was to conduct simulated experiments that intentionally changed the indoor environment (Wargocki

	et al., 2002; Fang *et al.*, 2004). Feige *et al.* (2013) assessed comfort by applying questionnaires, structured interviews and conducting physical measurements within an office. Mulville *et al.* (2016) and Chadburn *et al.* (2017) used questionnaires that included comfort as a measure. According to Vischer (2007) and Laughton and Thatcher (2018), discomfort is categorised as physical or psychological. Psychological comfort was assessed through Laughton and Thatcher's (2018) self-developed 6 item scale. The scale showed good internal consistency reliability in a previous study. Physical comfort was measured using the SBS questionnaire from Hedge *et al.* (1996). There were 15 items on this scale, and it was assessed using a 4-point scale ranging from never (4), 1-3 times per month (3), 1-3 times per week (2), and every day (1). Good internal consistency reliabilities have been reported on subsequent administrations of this scale.
Engagement	Feige *et al.* (2013) attempted to measure work engagement using descriptive statistics and multiple regression by trying to identify a correlation between engagement, environmental features, IEQ, SBS, work performance and organisational citizenship behaviour. This was based on the mental state of employees, which is underpinned by vigour, dedication and absorption (Demerouti and Bakker, 2008). The scale created by Schaufeli *et al.* (2006) focused on vigour (high energy levels and mental resilience), dedication (high involvement levels and enthusiasm) and absorption (high concentration levels). Utrecht Work Engagement Scale (short version), nine items (3 each for vigour, dedication, and absorption) measured on a 7-point Likert-type scale from "never" to "always". These scales were based on a previous study by Schaufeli *et al.* (2002) using the Maslach-Burnout Inventory-General Survey (MBI-GS), where engagement and burnout were analysed.
Individual productivity	Absenteeism and presenteeism are viewed as potential indicators of productivity (Roelofsen, 2002; Danielsson and Bodin, 2008; Thatcher and Milner, 2012; Agha-Hossien *et al.*, 2013; Thatcher and Milner, 2014b; 2014a; Elnaklah *et al.*, 2020). Self-assessed productivity is another approach to determining productivity levels, where respondents were asked to rate their perceived productivity on a scale from 0-to 100% within the context of their full capacity (KPIs) (Thatcher and Milner, 2012). Another more structured measure of productivity is by conducting psychometric tests, which use different reasoning tests containing quantitative and qualitative assessments (Byrd and Rasheed, 2016). The BUS also requires self-rating of productivity, which used a scale ranging from decrease (-20%) to increase (+20%) (Gou *et al.*, 2013). Another version of the BUS measured perceived productivity using a 7-point Likert scale ranging from "less productive" to "more productive" (Gou *et al.*, 2014).
Organisational performance	No previous researchers were able to establish a link between GBFIs to both individual productivity and organisational performance. Therefore, there are no commonly used items to assess this measure within a knowledge-based office environment.