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Review Article

Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature

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Abstract

Indoor environmental quality (IEQ) and its effect on occupant well-being and comfort is an important area of study. This paper presents a state of the art study through extensive review of the literature, by establishing links between IEQs and occupant well-being and comfort. A range of issues such as sick building syndrome, indoor air quality thermal comfort, visual comfort and acoustic comfort are considered in this paper. The complexity of the relationship between occupant comfort and well-being parameters with IEQ are further exacerbated due to relationships that these parameters have with each other as well. Based on the review of literature in these areas it is established that design of buildings needs to consider occupant well-being parameters right at the beginning. Some good practices in all these different areas have also been highlighted and documented in this paper. The knowledge established as part of this paper would be helpful for researchers, designer, engineers and facilities maintenance engineers. This paper will also be of great benefit to researchers who endeavour to undertake research in this area and could act as a good starting point for them.

Keywords: Occupant well-being; Indoor environment quality; Occupant comfort; Offices; Green buildings

Contents

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1. Introduction

Human beings have endeavoured to create indoor environments in which they can feel comfortable. Human health is foremost when it comes to assessing the overall comfort of the environment. If for any reason the built environment is leading to sickness or negative impact on occupant health then it is a matter of concern and could point to some design or technical flaw in the building system. As ASHRAE guidelines stated (ASHRAE, 2010), since people spend about 80–90% of their time indoors and studies have indicated that a range of comfort and health related effects are linked to characteristics of the building, there has been a growth in interest in both academic and practitioner literature on occupant health and building design. There are studies to suggest that a few symptoms of discomfort from indoor environment lead to significant reduction in work performance of occupants (EPA, 2000). New building regulations/legislations and green building guidelines have highlighted the past idea of sustainability that often ignored psychological, cultural and sociological dimensions (ASHRAE, 2004). Research has clearly established that problems with indoor environmental quality (IEQ) (thermal, acoustic, visual and air quality) of a building has a direct effect on the comfort, health and productivity of the occupants (De Giuli et al., 2012). Performance of occupants in office buildings has also been a big area of focus for researchers and practitioners (Bluyssen et al., 1995).

Research indicates that the relationship between IEQ and wellbeing is complicated. A range of indoor factors such as thermal, visual, acoustic, and chemical can impact the wellbeing of the occupants (Apte et al., 2000; Jantunen et al., 1998; WHO, 2002). These relationships could often be very complex and can have both short-term and long-term impacts on individuals (Babisch, 2008; Fisk et al., 2007; Lewtas, 2007). Issues such as sick building syndrome (SBS), building related illness, and pollutants have an impact on the overall productivity of the occupants. Studies have linked, mental health and illnesses that are not easily noticeable in the short term but could be major problems in the long term (e.g. cardiovascular diseases, asthma-related issues and obesity) to IEQ (Houtman et al., 2008; Jaakkola et al., 2013). This paper presents a state of the art analysis of research in the area of health and wellbeing of occupants and their relationship to IEQs. The focus of the review of literature is commercial and office buildings. The paper further discusses the major issues and thoughts emerging from research in this area to help researchers of the future, align their thought process, and help them establish a robust foundation for research in this area. The focus of this discussion is to establish a link between these IEQ parameters, health and well-being of occupants and implementation of green practices in building design. The methodology used to review the literature is presented in the next section and is followed by the review of state of the art literature in the area. The paper concludes with a discussion section that discusses major conclusions and the way forward.

2. Methodology

The purpose of this literature review was to document the state of the art literature and analyse the key threads of thought regarding health and well-being of occupants of office buildings. The eventual objective is to establish the state of the art in order to identify the way forward. For this study quite an extensive range of literature was reviewed. The literature included refereed journals, refereed conference proceedings, some reports available on the internet, and books. The study was conducted in a four stage cycle of identify, collect, classify and analyse.

The first step was the identification of the main keywords. Since the main focus of the study was to analyse the impact of the indoor environment quality on health and well-being of the office occupants, the keywords used for the search were: *occupant well-being, indoor environment quality, occupant comfort, well-being and green buildings*. Science direct and Google scholar engines were used to search the literature. After collecting the articles the bibliographies of the collected articles were scrutinised to identify any relevant articles that were missed in the first search results. The third step of classification was based on three criteria:

(a) Year of publication: The literature presented in this paper was published between 1970 and 2015. This gave us the opportunity to see if the thought process has evolved over time with the introduction of new technology. However, still the major focus of the review is 2000 onwards in order to analyse the current state of the art knowledge. Fig. 1 below documents the frequency of articles from different decades since 1970 s.

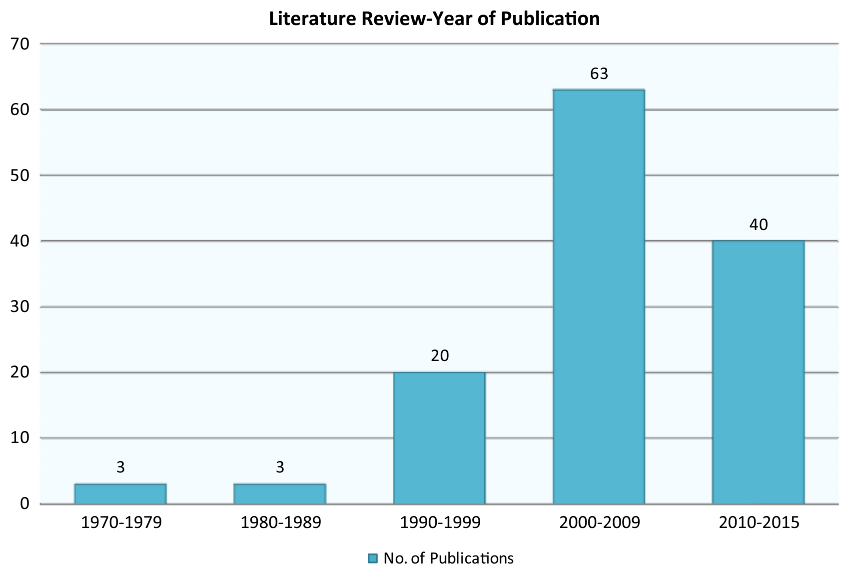

Figure 1. Frequency of year of publication used in the study.

Table 1
Journals that are used for this state of the art study.

Journals	5 yr. impact factor (2014)	Journal citation
New England Journal of Medicine, Massachusetts Medical Society	54.390	268,652
Archives of Internal Medicine, JAMA Network	13.098	38,021
Journal of Allergy and Clinical Immunology, Elsevier	10.715	38,706
International Journal of Epidemiology, Oxford Journals	8.615	16,999
Environmental Health Perspectives, US Dept of Health and Human Services	8.440	34,489
Renewable and Sustainable Energy Reviews, Elsevier	7.445	21,901
Environment International, Elsevier	6.657	12,067
Applied Energy, Elsevier	6.330	23,996
American Journal of Public Health, Apha publications	5.101	29,771
Journal of Environmental Psychology, Elsevier	4.607	4285
Clinical & Experimental Allergy, Wiley Online Library	4.501	10,303
Science of the Total Environment, Elsevier	4.414	39,706
Indoor Air, Wiley Online Library	4.351	2937
Atmospheric Environment, Elsevier	3.780	41,715
Building and Environment, Elsevier	3.598	10,723
Journal of Exposure Analysis and Environmental Epidemiology, Nature	3.147	2876
Environment and Behavior, Sage	3.005	3472
Energy and Buildings, Elsevier	2.884	13,417
American Speech-Language-Hearing Association	2.795	6186
International Journal of Sports Medicine, Thieme	2.453	6238
Automation in Construction, Elsevier	2.414	2637
Building Research & Information, Taylor & Francis	2.156	1175
Applied Ergonomics, Elsevier	2.143	3269
The Annals of Occupational Hygiene, Oxford Journals	2.035	2636
The Journal of the Acoustical Society of America, AIP Scitation	1.736	37,633
Journal of the Air & Waste Management Association, Taylor & Francis	1.560	4248
Hortscience, American Society for Horticultural Science	1.471	5001
International Journal of Industrial Ergonomics, Elsevier	1.366	2169
Real Estate Economics, The American Real Estate and Urban Economics Association	1.329	744
Journal of the Illuminating Engineering Society, Taylor & Francis	0.958	147
American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE	0.304	547

(b) Reputation of Journal: It was important to ensure that good quality and more reputable journals are used for this study. In addition, we wanted to ensure that more reputable publishers of journals are used. Therefore, we tried to limit our analysis to journals that met these two criteria. The list of journals and their publishers are listed in Table 1 below.

(c) Top ten cited papersThe analysis also highlighted the top ten cited paper as of 2015 (see Table 2).

Table 2
Top ten cited papers in this state of the art study.

Top 10 cited papers		Number cited
1.	Thermal comfort. Analysis and applications in environmental engineering (Fanger, P.O. 1970. Thermal comfort analysis and applications in environmental engineering).	5489
2.	Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution (Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287 (9), 1132–1141).	5409
3.	Fine particulate air pollution and mortality in 20 US cities, 1987–1994 (Samet, J.M., Dominici, F., Curriero, F.C., Coursac, I., Zeger, S.L. 2000. Fine particulate air pollution and mortality in 20 US cities, 1987–1994. New England Journal of Medicine, 343 (24), 1742–1749.)	2200
4.	Adaptive thermal comfort and sustainable thermal standards for buildings (Nicol, J. F., & Humphreys, M. A. 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Buildings, 34(6), 563–572.)	711
5.	Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55 (de Dear, R.J., Brager, G.S. 2002. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE standard 55. Energy and Buildings, 34 (6), 549–561.)	601
6.	Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information (Daisey, Joan M., William J. Angell, Michael G. Apte, 2003. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air 13 (1), 53–64.)	552
7.	Ozone in indoor environments: concentration and chemistry (Weschler, C.J., 2000. Ozone in indoor environments: Concentration and chemistry. Indoor Air, 10 (4), 269–288.)	462
8.	The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity (Wargocki, Pawel, et al., 2000. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity." Indoor Air 10 (4) 222–236.)	420
9.	Sick building syndrome: a study of 4373 office workers (Burge, S., Hedge, A., Wilson, S., Bass, J.H., Robertson, A. 1987. Sick building syndrome: A study of 4373 office workers. The Annals of Occupational Hygiene, 31 (4A), 493–504.)	400
10.	Air pollution combustion emissions: characterisation of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects (Lewtas, J. 2007. Air pollution combustion emissions: Characterisation of causative agents and mechanisms associated with cancer, reproductive, and cardiovascular effects. Mutation Research/Reviews in Mutation Research, 636 (1), 95–133.)	353

The final step in the process was the analysis of the papers that were downloaded. Based on the analysis of these papers they were divided into following categories by topic. The topics are: indoor air quality, sick-building syndrome and well-being, thermal comfort, acoustic comfort, visual comfort as well as green solutions and indoor comfort. Therefore, the structure of rest of this paper is divided into these sections only. Once these sections have been presented, the paper discusses major issues that can have an impact on design of buildings. With the recent upsurge in design of green buildings and use of green building guidelines globally, the discussion presented helps establish a link between the health and well-being parameters and parameters within green building guidelines.

3. Indoor air quality in office buildings

Indoor air quality (IAQ) is an important issue that has both short term and long term impacts on the health of occupants (Wargocki et al., 2002b). There are two common strategies in building design that are employed to deal with the IAQ in a building. The first one is to improve the indoor air quality by increasing the ventilation rate, which in turn reduces air pollutant (Daisey et al., 2003). The second is by reducing the source of pollution within and outside the building in order to reduce the introduction of pollutants in the indoor air. Recent studies have established that the increasing outdoor air supply rates in non-industrial environments improve the air quality and reduce the concentration of air pollutants (Wargocki et al., 1999). The rate at which outdoor air is supplied should be proportional to the pollutants within the building. The amount of pollutants inside the building will vary depending on the load and number of occupants. Therefore, the building needs to have a mechanism to accurately assess the indoor pollutants and vary the rate of introducing outdoor air accordingly. The sources of indoor pollutants are both building material, office equipment (fax, computers) and occupants (Bakó-Biró et al., 2004; Bluyssen et al., 1996). The new green building guidelines have focused on use of low polluting building material as well as effective management of IAQ through appropriate air handling systems (Wargocki et al., 2002a).

One of the areas of research in literature is the use of natural ventilation. A properly designed natural ventilation system, if designed properly has the potential to provide considerable energy savings from cooling needs (Brager and Borgeson, 2010). There is research to indicate that occupants of naturally ventilated offices have fewer sick building syndrome symptoms than occupants of air-conditioned offices (Seppänen and Fisk, 2002). However, natural ventilation can also be harmful in cities where outdoor air pollution is high. Exposure to Particulate Matter (PM) and ozone has major negative impacts on occupant health (Pope et al., 2002; Samet et al., 2000; Weschler, 2006). Mechanically ventilated buildings generally have a filtering mechanism before outdoor air enters the building. However, for naturally ventilated buildings there is no such filter leading to often uncontrollable levels of PM and ozone. The concentration of ozone in indoor environment depends on parameters such as outdoor concentration, air exchange rates, indoor emissions, surface removal rates and chemical reaction (Weschler, 2000).

In order to investigate the overall indoor air quality, biological, chemical and physical monitoring is needed (Bluyssen, 2004; Clausen et al., 2001; Mølhave, 2008). A range of methodologies have been suggested in the literature to measure indoor air quality. These methodologies include experiments such as study of bio markers, study of sample of individuals in combination with environmental inventories and laboratory studies where individuals are exposed to controlled environmental conditions. What is missing from most of the current studies is the study of occupant psychological and physiological state and their impact on how human body reacts to indoor air quality (Bluyssen et al., 2011a,b). This has led to the development of occupant satisfaction questionnaires which are analysed in conjunction with indoor air quality parameters (Andersen et al., 2009). However, more research is needed to further evaluate different available approaches and standard questionnaires for occupants.

4. Sick building syndrome (SBS)

SBS is a group of health problems that are caused by the indoor environment such as an office building or a dwelling (De Dear and Brager, 2002). Closure of natural openings, use of new construction material which are not properly tested and certified, and type of furniture, office equipment (printer, personal computer) could all contribute to SBS (Assimakopoulos and Helmis, 2004, Bakó-Biró et al., 2004). Uncomfortable temperature and humidity, chemical and biological pollution, physical condition, and psychosocial status are some of the factors identified as root causes of SBS (Simonson et al., 2002, Wang et al., 2007; Wolkoff and Kjærgaard, 2007; WHO, 1983). Symptoms experienced by people with SBS include irritation of the eyes, nose, and throat, headache, cough, wheezing, cognitive disturbances, depression, light sensitivity, gastrointestinal distress and other flu like symptoms (Burge et al., 1987; Mendell and Smith, 1990; Hudnell et al., 1992). A long list of factors with complex relationships has been identified in the literature leading to SBS (Stolwijk, 1991; Teeuw et al., 1994). Research indicates that SBS symptoms are 30–200 percent more frequent in mechanically ventilated buildings (USEPA, 2007). SBS leads to an increase in self-reported illness absences and reduced productivity in offices (Wargocki et al., 2000, Brightman, 2005; Singh, 1996). There are several studies which conclude that SBS leads to a rise in hospital visits especially for female occupants of mechanically ventilated and air conditioned buildings compared to occupants of naturally ventilated buildings (Preziosi et al., 2004).

In addition to ventilation there are factors such as moulds, dust, mite, allergens, indoor aldehydes, Volatile Organic Compounds (VOC), airborne fungi, pesticides, tobacco smoke, lighting, air exchange or circulation rates, carbon monoxide, carbon dioxide which may lead to SBS symptoms (Takigawa et al., 2009). As Redd (2002) said, chronic exposure to the air in water-damaged buildings is often linked to allergic and irritation symptoms on pulmonary functions. There is also evidence to prove that asthma and hypersensitivity pneumonitis were associated with atopy and inflammation triggered by exposure to biological contaminants in indoor air (Apostolakos et al., 2001; Boulet et al., 1997; Dharmage et al., 2002). Results from office building studies in the United States have shown that fungal concentrations in floor or chair dust lead to eye irritation, asthma and upper respiratory symptoms (Chao et al., 2003). Research has also established that fungal concentrations can lead to lower job satisfaction.

Based on the research on SBS it is important that buildings be designed that reduce the exposure to indoor chemicals, there should be a continuous monitoring of indoor air, as well as monitoring and control of all the water pipes and wet areas to avoid water leakage. Monitoring of water pipes will lead to reduction in dampness which is the root cause of lots of mould and mite related problems (Redd, 2002). Selection of appropriate, third party certified building materials is also crucial to ensure good indoor environmental quality [IEQ] and reduction in SBS (Takigawa et al., 2009).

5. Thermal comfort

Thermal comfort is probably the most important and easily defined parameter of IEQ. For occupants to produce to their full capability, their work space needs to be thermally comfortable. However, thermal comfort is based on thermal adaptation of individual occupant which is correlated to factors such as geographic location and climate, time of year, gender, race, and age (Quang et al., 2014).

Human body tries to maintain a temperature of around 37 °C. The temperature is maintained through heat exchange between human body and the environment through convection, radiation, and evaporation (Standard ASHRAE 55, 2010). Thermal comfort has a direct impact on energy consumption of any building as any sense of discomfort of occupants leads to tweaking of controls to non-optimal levels (Catalina and Iordache, 2012; Corgnati et al., 2009). Thermal comfort is influenced by six factors; four of which that could be classified as environmental parameters include air temperature, mean radiant temperature, air relative humidity, and air velocity. The other two are classified as personal factors and include human metabolic rates and insulation through clothing (Katafygiotou and Serghides, 2014). All these factors need to be considered at the design phase of the building itself (Steemers et al., 1992). Gender, age, and climatic conditions all have an impact on the thermal comfort perceived by the occupant (Nicol and Humphreys, 2002; Smolander, 2002). The location and typology of the building along with outdoor climate and season also influence thermal comfort of occupants (Frontczak and Wargocki, 2011).

According to Standard, ASHRAE 55 (2010) and Standard, ISO 7730 (1994), thermal comfort is defined as "*the state of mind that expresses satisfaction with the thermal environment in which it is located*". These standards are used as benchmarks by designers of buildings worldwide. The concept of passive design in buildings has evolved over the last 15 years however, achieving passive standards in cold climate of Northern Europe is different from achieving it in Middle East where mechanical cooling is necessary to achieve optimal level of cooling and occupant comfort (Nicol and Pagliano, 2007). Whereas, in tropical climate buildings are naturally ventilated and end up consuming significantly less energy, which gives occupants the feeling that they are closer to nature (Fisher, 2000). Thermal comfort is also found to be well-maintained using less energy consuming measures such as local air conditioning and task – ambient conditioning (Zhang et al., 2010). The perception of comfort differs from one to the other climate and is also influenced by the culture (Lovins, 1992). The eventual thermal adaptation of an occupant in an environment and their perception of comfort are defined by three factors: behavioural adjustment, physiological adaptation, and psychological habituation or expectation as described by Nikolopoulou and Steemers (2003). There have been several past researches that have looked at defining the principle of temperature variation in built environment (Humphreys, 1978) or ideal temperature limits in the built environment (Fanger, 1970). There are quite established methods for measuring thermal comfort. Metrics such as Predicated Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) people are quite common and used extensively by designers globally (Al Horr, 2013; Papadopoulos et al., 2008). The PMV model is extensively used in buildings with HVAC systems in cold temperatures and warm climate for both summer and winter. However, it can also be applied in non-air-conditioned buildings in warm climates using an expectancy factor (Fanger and Toftum, 2002). The physical adaptation of the environment and design of buildings for thermal comfort needs to be considered at design stage itself as alteration of structure post construction is inefficient and expensive (Indraganti et al., 2014; Jazizadeh et al., 2014).

6. Acoustic comfort

The acoustic comfort of buildings is the capacity to protect occupants from noise and offer an acoustic environment suitable for the purpose the building is designed for (Greek Legislation, 1989). There is a direct relationship between acoustic comfort and occupant productivity in commercial buildings (Landström et al., 1995). With growth in open plan offices, issues of acoustic comfort and privacy have been identified as significant issues impacting on occupant productivity (Sundstrom et al., 1994). Despite being recognised as an important parameter, research indicates that acoustic comfort is not considered high priority in building design leading to several post occupancy productivity related issues (Andersen et al., 2009; Anderson, 2008). Acoustic problems emanate from airborne sounds, outdoor noise, noise from adjacent spaces, noise from office equipment and sound of nearby facilities (ANSI, 2010). Acoustic problems in offices could be divided into two major categories: annoyance from various noises and lack of communication privacy. The level, the spectrum, and the variation with time of the noise may influence the level of disturbance. Noise from other people talking, telephones ringing, and other irregular sounds may create more annoyance and disturbance compared to the more continuous regular sounds (Veitch et al., 2002). Acoustic problems therefore need to be addressed at the design stages of the building. In order to address acoustic problems at design stages itself, it is important to assess what is going to happen indoors and outdoors (Bluyssen et al., 2011a,b). Speech Intelligibility Index is a measure of speech privacy and measures ease of verbal communication for office buildings. The three strategies for noise prevention are: (a) absorption of sound using ceiling tile; (b) blocking of sound using workstation panels and workspace layout; and (c) covering up of sound using electronic sound masking techniques (Loewen and Suedfeld, 1992). However, with all these techniques one has to achieve an optimal balance. For example noise masking can actually be so loud that occupants might have to speak louder than usual to be heard. This will lead to annoyance for everyone around them.

Despite our knowledge in this area, acoustic comfort is still lacking. Although, it is becoming popular and more and more buildings are being analysed for acoustical comfort we have a long way to go in this area (Fuerst and McAllister, 2011; Jakobsen, 2003; Kjellberg and Landström, 1994; Schultz and McMahon, 1971). Green building guidelines have started including acoustic comfort as one of the criteria but the overall priority for this is low. Leadership in Energy and Environmental Design (LEED) which is one of the most popular green building guidelines has included acoustic credits as an option but lots more need to be done to make it a mandatory element of green building guidelines (Schiavon and Altomonte, 2014). There are green building guidelines like Global Sustainability Assessment System (GSAS) which do incorporate acoustics in their calculation but all these calculations are submitted prior to occupancy of the buildings (British Standard, 1999; DoT et al., 2015; GORD, 2015). Post occupancy the internal layout of the building often changes and this might have impact on the overall plan. The overall impact of acoustics on occupant comfort and productivity is well established in the literature and hence being considered more in design of new buildings for offices, healthcare and schools these days (Passero and Zannin, 2012; Shafaghat et al., 2014).

7. Visual comfort

Visual comfort is very important for well-being and productivity of the occupants in buildings (Leech et al., 2002; Serghides et al., 2015). Several past studies have analysed the effect of visual comfort on occupant work performance, productivity, comfort and satisfaction (Veitch, 2001). Preference for windows and therapeutic impact of natural views is well established in the literature (Aries, 2005). Visual comfort defines lighting conditions and the views from ones workspace. Insufficient light and especially daylight or glare reduces the ability to see objects or details clearly (Leech et al., 2002). Architectural design has a direct impact on office lighting and office lighting has a direct impact on well-being and productivity. The access to natural lighting as well as artificial lighting is essential in order to ensure well-being of occupants in areas where natural lighting is missing or during evening when the natural lighting fades (Aries et al., 2010).

Visual comfort at work has an impact on comfort after work as well (Chang and Chen, 2005). There are studies that have looked at impact of visual comfort on sleep quality at home after work. These studies have documented differences in impacts by gender, age, and seasons on the overall discomfort levels and impacts on health (Serghides et al., 2015). Several visual comfort criteria such as view type, view quality and social density have an impact on physical and psychological health of the occupants (Chang and Chen, 2005). Densely laid offices and open plan offices have negative effect on visual comfort which leads to a negative impact on occupant well-being (Book in Greek, 2005). Geometry of windows, photometry of surfaces, amount of glazing etc., all have an impact on the illumination levels in a work area (McNicholl and Lewis, 1994). Visual comfort plays such a vital role in the overall productivity, comfort and well-being of the occupants that buildings need to avoid excessive use of artificial lighting yet still maintain some level of optimality (Yun et al., 2012). Therefore, one needs to study daylight, artificial lighting, glare and visual comfort together in order get a more holistic picture (Van Den Wymelenberg and Inanici, 2014; Huang et al., 2012).

8. Discussion

The triple bottom line of sustainability includes environmental, social and economic aspects (Steemers and Manchanda, 2010). Incorporating all these three elements in the design of buildings is becoming important to improve the performance of buildings (Kua and Lee, 2002). The sustainable building design has moved from energy efficiency centric to occupant experience centric approach (Steemers, 2003). New research has tried to link sustainability rating systems with comfort of occupants and conservation of natural resources (Liang et al., 2014). The research in the area of sustainable building design and the well-being of the user focus on energy performance, daylight, ventilation, acoustics and occupant feedback (GhaffarianHoseini et al., 2013; Paul and Taylor, 2008). However, well-being and comfort of occupant could be in conflict with the performance of the building. For example energy efficiency of a building is impacted positively by tighter building envelop and reduced ventilation rates, but for well-being of the occupants the ventilation rate should be higher in order to dispel PM. This is a conflict which is often decided in favour of building efficiency and not occupant well-being (Koponen et al., 2001; Lai et al., 2009).

Within the comfort and well-being parameters there could be conflicts. For example natural ventilation or higher rate of ventilation may also have an adverse effect on acoustic comfort of occupants since it might allow more exterior background noise to come inside the building (Deuble and de Dear, 2012). There are studies that also highlight the relationship between the buildings' envelop and visual as well as thermal comfort of occupants (Liang et al., 2012; Theodosiou and Ordoumpozanis, 2008; Weschler et al., 1996). Studies on acoustic comfort reveal that the overall comfort and satisfaction of occupants with acoustic comfort is lower in green buildings than buildings that are not green rated (Altomonte and Schiavon, 2013). Some of the common green building strategies result in poor acoustics. Strategies in green buildings that provide fewer barriers between the sources of noises and occupants lead to poor acoustic comfort (Brill et al., 2001).

Office layouts are designed to balance between daylighting, natural ventilation and acoustics. Open plan environments with sufficient daylighting could be really productive workspaces as long as acoustic design is not ignored. To increase daylighting and natural ventilation green buildings often feature very high percentage of open plan spaces. However, this ends up eliminating key acoustical control methods in the form of physical barriers (Lee and Guerin, 2010). There is also an impact of geometry on acoustic comfort. If the area is square then the acoustic comfort is higher. However, when one has a long and narrow kind of space then acoustically one creates a bowling alley kind of effect where sound bounces between the two walls creating noise for the occupants as stated from American Speech-Language-Hearing Association (2005). There are several other practices in green building design that negatively impacts acoustic comfort. Use of underfloor heating leads to elimination of carpets which tend to absorb the sound (Jana Madsen, 2014). The use of harder material for floor and walls in order to help with cleaning is also an important issue. The harder the material, the lesser is its capability to absorb noise. Therefore, use of harder material results in more noise in the interior space (Field, 2008).

All these issues will eventually have an impact on occupant health and well-being. The examples above have demonstrated that it is possible that green building parameters and practices will have an impact on occupant health and well-being. The concept of passive design does attempt to combine thermal comfort and sustainable design (Elsarrag and Alhorr, 2012). Several strategies such as providing control to the occupants and providing them training and raise their awareness has an impact on the overall satisfaction of occupant from the building. Buildings in urban areas can have a higher level of natural ventilation at night as there is lower noise and pollution at night due to lower traffic and other outdoor activities around buildings.

IEQs have to be considered throughout the lifecycle of the building. Decisions made at design, construction, commissioning and maintenance stages have an impact throughout the lifecycle of the building. Design of exterior entrances with permanent entryways captures dirt particles and avoids them from appearing in the indoor space. Collaborative work with the mechanical engineer can create a balance between energy efficiency and optimal amount of fresh air. Adequate IEQ is easiest to achieve when source control is practiced during the operation of each building since the indoor conditions or even the neighbourhood conditions may change frequently (Abbaszadeh et al., 2006).

Materials have a crucial role to play on building performance and their selection requires special attention. Materials used in a building affect thermal performance, indoor pollution, visual comfort and acoustical comfort. Architects and designers can select materials that do not produce irritating odour or VOCs. Choice of material can also help maximise sound absorbing ability. In addition, good sound masking system can totally eliminate other acoustic problems post-occupancy.

Design of buildings may also benefit from views and interaction of occupants with their natural environment. It is beneficial to use natural lighting and at the same time use shading devices to reduce direct glare in the field of view. The use of light colours in walls may also improve visual comfort. In addition, if occupants could be given control of lighting through dimming controls then it might further help achieve visual comfort (Newsham et al., 2004).

Balancing between green credentials of buildings with well-being of its occupants are quite important and there is a higher level of emphasis on monitoring and control to ensure that buildings are delivering what they are designed for (Al Nasa'a, 2015; Azhar et al., 2011). Considering occupants whilst designing buildings is quite important (Iwaro and Mwasha, 2013). The principles of building design now need to incorporate occupant needs, comfort and well-being (WBDG, 2015; Hua, Y, 2014).

9. Limitations and future recommendation

This literature review study analysed direct and indirect relations between indoor environment quality and occupant health and well-being. The study limited its focus on occupant's health and well-being. However, indoor environment quality also has a high-level impact on occupant productivity and occupant behaviour. The study also limited its focus on office buildings. This study opens up various research threads for researchers focusing on indoor environment quality. The researchers can concentrate study on indoor environment quality and its relation to occupant productivity and occupant behaviour and behaviour change. This state of art study also presents an example for researchers to develop a state of the art study of indoor environment's impact on health and wellbeing in school, retail and residential buildings. This study can also be taken forward by connecting the findings to various green building rating systems like LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Methodology), and GSAS (Global Sustainability Assessment System).

10. Conclusions

This paper has documented how occupant comfort and well-being are affected by IEQ. The review of literature has highlighted that the relationship between IEQ and well-being of occupants and relationship of IEQs amongst themselves is quite complex. However, given that we spend more than 90% of our life indoors, it is important to understand it and act accordingly.

Based on the literature, it is important that designers and engineers need to take into account a range of factors such as sick building syndrome, thermal, visual and acoustic comfort. Literature suggests that green building designs don't automatically guarantee that the building designed will be comfortable and ensure occupant well-being. More specific and in-depth considerations on occupant well-being is required along with the impact on building efficiency and sustainability. Just designing a potentially comfortable building is not enough. One also needs to monitor building and occupant performance during its operations.

This paper has presented state of the art knowledge on occupant well-being and comfort and their relationship with IEQ. This paper can act as an important starting point for future researchers who are trying to study the relationship between occupant well-being and comfort and IEQ.

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