OCCUPANT PRODUCTIVITY AND INDOOR ENVIRONMENT QUALITY LINKED TO GLOBAL SUSTAINABILITY ASSESSMENT SYSTEM

Yousef Al Horr, Martha Katafygiotou and Esam Elsarrag

Gulf Organisation for Research and Development (GORD), Qatar

Mohammed Arif and Amit Kaushik*

School of Built Environment, University of Salford, United Kingdom

Ahmed Mazroei

Qatari Diar Real Estate Development Company, Qatar

ABSTRACT

Occupant productivity is gaining momentum in the field of sustainable built environment. Humans spend most of their time indoors, and the majority of the world's population lives in urban areas and work in an office environment. Different Indoor Environment Quality (IEQ) factors affect productivity in an office environment. This paper investigates Global Sustainability Assessment System (GSAS) rating system to identify criteria and submittals focusing different physical indoor environment quality factors that influence occupant productivity. It draws implicit links between the current state of sustainable research and indoor environment quality factors covered in the GSAS rating system. The study highlights that GSAS has focused one-third of its weightage to indoor environment quality factors. Most IEQ criteria like indoor air quality, thermal comfort, lighting and day lighting, Biophilia and views are well addressed in the GSAS. There is still room to focus on factors like office layout, look and feel, and location and amenities. This paper is a part of ongoing research endeavour to update GSAS to incorporate occupant productivity and well-being in rating system's focus to improve green buildings in the Middle East. The paper would help researchers and professionals who aim to understand the link between the GSAS rating system and indoor environment quality factors that affect productivity.

Keywords: *Green Building Rating System; Indoor Environment; Quality Occupant Productivity; Sustainability.*

1. INTRODUCTION

Humans spend most of their time indoors, and the majority of the world's population lives in urban areas and work in an office environment (ASHRAE, 1993). There has been a significant global shift in the economy from manufacturing sector towards service and knowledge-based sector, operating in indoor office environments (Haynes, 2008; World Green Building Council, 2014). Hence, it is becoming important to understand the indoor office environment and the effect it has on occupant well-being and performance. Office environment has a high level of influence on its occupants' well-being and performance (Leaman and Bordass, 1999; Frontczak *et al*., 2012 ; Roelofsen, 2002; Mawson, 2002; Van der Voordt, 2004). Past studies on sustainable buildings postulate that green design strategies and technologies enhance the indoor workplace environment. It enables to create an environment favouring occupants' comfort and performance in both newly built and retrofitted buildings (Romm and Browning, 1994). The majority of the building stock which will exist in 2050 has already been built (UNEP, 2009). Thus, there is a need to understand the quality of the indoor workplace environment, and its relation to

*Corresponding Author: E-mail - a.k.kaushik1@salford.ac.uk

occupant productivity and comfort. An extensive literature review was conducted to identify physical indoor environment quality factors that affect occupant productivity and comfort.

The study identifies eight physical components that affect occupant satisfaction and productivity in an office environment:

1. **Indoor Air Quality and Ventilation** (Vernon and Bedford, 1926; Wargocki *et al*., 2000; Fanger, 1988; Fisk *et al*., 2012)
2. **Thermal Comfort** (Fanger, 1970; De Dear *et al*., 1997; Tanabe *et al*., 2007; Djongyang *et al*., 2010)
3. **Lighting and Daylighting** (Hopkinson, *et al*. 1966; Alrubaih *et al*., 2013; Edwards, L. 2000)
4. **Noise and Acoustics** (Sundstrom *et al*., 1994; Banbury and Berry, 2005; Mui and Wong, 2006)
5. **Office Layout** (Brill *et al*., 1985; Laing *et al*., 1998; CABE, 2005; Haynes, 2009)
6. **Biophilia and Views** (Heerwagen and Orians, 1984; Grinde and Patil, 2009; Heerwagen, 2009; Bright, 2012)
7. **Look and Feel** (Mahnke, 1996; Kwallek *et al*., 1988; Ou *et al*., 2004; World Green Building Council, 2014)
8. **Location and Amenities** (Duffy *et al*., 1992; Gordon-Larsen *et al*., 2009; World Green Building Council, 2014)

This research paper investigates the Global Sustainability Assessment System (GSAS) rating system and its categories to identify criteria focusing the eight physical environmental factors identified above.

The comprehensive GSAS rating system measures and evaluates every project on eight key aspects or categories that have a direct impact on environmental stress mitigation (refer Figure 1). Each category is assigned a weight based on Analytical Hierarchy Process (AHP). The categories are then broken down into specific criteria that measure and define these individual issues. A score is then awarded to each criterion based on the level of compliance.

GSAS indicated that the impacts resulting from limited control and design of the indoor environment include are mainly the following:

- Climate Change
- Fossil Fuel Depletion
- Air Pollution
- Human Comfort and Health

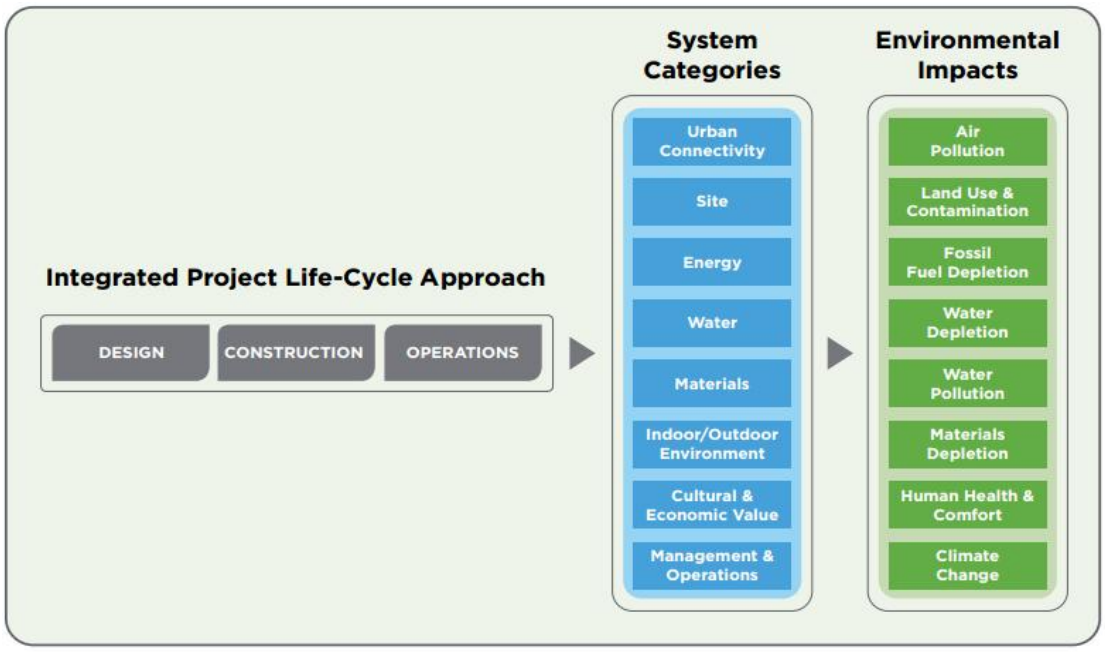

Figure 1: GSAS Categories and Environmental Impacts

The GSAS green building rating system divides its criteria and submittals into eight categories (refer Figure 2). The indoor environment has its category with 16% weightage. However, this document analyses all the categories in GSAS to identify criteria related to the identified eight aspects affecting occupant productivity.

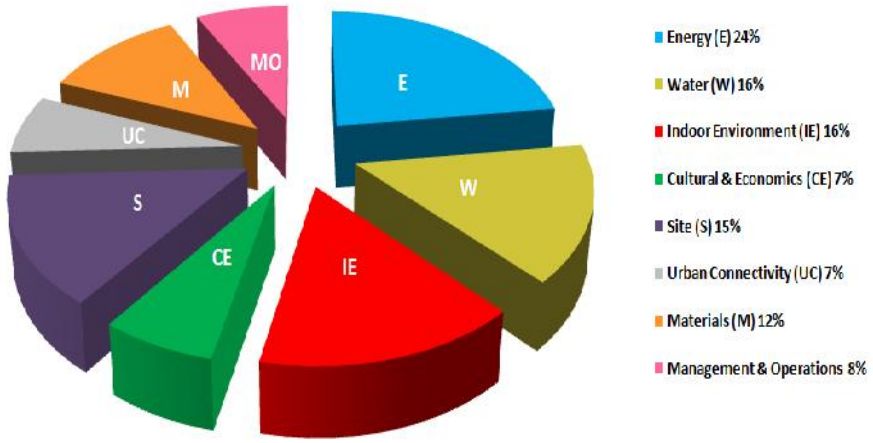

Figure 2: GSAS Categories and Weights V2.0

2. RESEARCH METHODOLOGY AND PROCESS

This study aims to identify the current gap in the GSAS rating system's focus towards employee productivity. The study was conducted by desktop analysis/study. The research process was divided into two steps:

1. The first step was literature review. It was done by looking at journal articles, conference articles and books to establish a firm base for the research findings. The keywords used were: occupant productivity, workplace satisfaction, indoor environment quality, occupant comfort. The authors used the University library's online search engine and Google Scholar, Science Direct and Elsevier for the literature search.

2. The second step of the study was to draw links between eight IEQ factors identified in the literature review and GSAS rating system. The analysis was done using desktop study to identify current gap in the GSAS rating system based on the literature review findings.

The rest of the study is divided into nine sections. First eight sections discuss each identified IEQ factor and GSAS criteria and submittals focusing that IEQ factor. The last section presents the conclusion of the study.

3 INDOOR AIR QUALITY

Indoor air quality is covered by two categories in the GSAS guidelines. In energy category, criterion (E.5) focuses on the nitrogen and sulphur gases in the indoor environment. The criterion defines two submittals with 2.05% weightage of the overall scoring. The indoor environment category has four criteria focusing indoor air quality. These criteria focus on ventilation design (IE.2, IE.3) of the building and indoor air pollutant source (IE9, IE.10) in the buildings. These four criteria have 16 submittals with 7.12% weightage of the overall scoring. Overall indoor air quality has 15 points with 9.17% weightage of the overall scoring.

Table 1: Details of Indoor Air Quality

Category	Criterion	Submittals	Max Score	Weightage
Energy	E.5 - NOx, SOx, and Particulate Matter	Energy Calculator (one for all 5 criteria below)	3	2.05%
		Horizontal work plan area calculations		
Indoor Environment	IE.2 - Natural Ventilation	Natural Ventilation Calculator	3	1.13%
		Occupancy calculations		
		Floor plans highlighting all occupied spaces		
		Elevations highlighting operable parts of windows, or drawings for controlled direct air supply system		
	IE.3 - Mechanical Ventilation	Calculations for fresh outdoor air delivery	3	2.33%
		Equipment Schedule		
		Report showing comparison between Fresh air calculations based on minimum required outside air for each zone as per ASHRAE 62.1-2010 recommendations, and Fresh air as per design		
		Report showing equipment efficiency compared to ASHRAE 90.1-2007		
	IE.9 - Low-Emitting Materials	Low-Emitting Materials Calculator	3	1.83%
		Material Safety Data Sheet listing VOC content for all indoor materials and finishes		
	IE.10 - Indoor Chemical and Pollutant Source Control	Floor plans to demonstrate the locations of contaminant sources in the project	3	1.83%
		Wall sections or other drawings to demonstrate how source of contamination spaces are sealed and isolated		
		Mechanical drawings showing dedicated exhaust system for those spaces		
		Doors specifications illustrating self-closing doors are provided for those spaces		
		HVAC specifications and equipment schedules to demonstrate the scope of filtration systems		
		Floor plans showing permanent entryway system provided at main entrances		

4. THERMAL COMFORT

Thermal comfort is an important aspect of indoor environment quality. GSAS system has one dedicated criterion for thermal comfort in the indoor environment category. The criterion outlines six submittals with 1.57% weight of the total score. Energy category has energy demand performance (E.1) criterion that focuses on the energy efficiency of the building for thermal comfort. This criterion has nine submittals with 7% weightage of the overall scoring. The site category has heat island effect (S.7) criterion focusing on the heat island effect generated by the neighbouring building. Heat island effect also influences the thermal comfort of the occupants. This criterion has six submittals with 0.78% weightage of the overall scoring. Overall, thermal comfort aspect has nine points and 9.35% weightage of the total scoring.

Table 2: Details of Thermal Comfort

Category	Criterion	Submittals	Max Score	Weightage
Indoor Environment	IE.1 Thermal Comfort	System operation specifications	3	1.57%
		Floor plans highlighting spaces under assessment		
		Glazing data sheet		
		HVAC drawings showing nominal air supply for spaces under assessment		
		Equipment Schedule		
		Diffuser data sheet		
Energy	E.1 Energy Demand Performance	Energy Calculator (one for all five criteria below)	3	7%
		Architectural drawings.		
		Relevant MEP drawings.		
		Area, volume and envelope calculations		
		Roof and Walls U-value calculations		
		Glazing data sheet		
		SEER Calculations		
		Lighting calculations for the whole building		
		Fan efficiency calculations or data sheet		
Site	S.7 Heat Island Effect	Heat Island Effect Calculator	3	0.78%
		Site plan including neighbouring buildings within the 200 m radius, illustrating required coordinates and Selector Indicator calculations		
		Landscape plan highlighting different types of site finishes		
		Roof floor plans illustrating coordinates		
		Construction material specifications for building envelope and site finishes		
		Simulation results for irregular shape buildings		

5. LIGHTING AND DAY LIGHTING

Lighting and day lighting is covered by indoor environment category. There are three criteria focusing lighting and day lighting aspect of the indoor environment. These are illumination levels (IE.4), daylight (IE.5) and glare control (IE.6). They have 15 submittals with nine points and 4.57% weightage of the total score.

Table 3: Details of Lighting and Day Lighting

Category	Criterion	Submittals	Max Score	Weightage
Indoor Environment	IE.4 Illumination Levels	Illumination Levels Calculator	3	1.37%
		Electrical drawings highlighting spaces being measured		
		Lighting simulation results for all typical spaces		
		Lighting manufacturer's data sheet		
	IE.5 Daylight	Daylight Input Calculator	3	1.83%
		Daylight Scoring Calculator		
		Daylight Simulation results		
		Drawings identifying measuring point locations		
		Boundary conditions for daylight simulation		
	IE.6 Glare Control	Glare Control Input Calculator	3	1.37%
		Glare Control Scoring Calculator		
		Simulation boundary condition template		
		DGI simulation result		
		Relevant drawings including elevations, plans and site map with surrounding buildings		
		Diagram identifying the measuring point location		

6. NOISE AND ACOUSTICS

Three GSAS categories cover noise and acoustics aspect. Urban connection category has an acoustic condition (UC.6) criterion that highlights submittals focusing urban level acoustic conditions around the site. Noise pollution (S.9) criterion under site category identifies submittals focusing neighbouring noise pollution sources and design mitigation strategies. Acoustic quality (IE.8) criterion under indoor environment category identifies seven submittals focusing noise sources, acoustic quality of material used in the building and acoustic analysis in and around the building. Noise and acoustic factor has nine points and 2.21% weightage of the total score.

Table 4: Details of Noise and Acoustics

Category	Criterion	Submittals	Max Score	Weightage
Urban Connection	UC.6 Acoustic Conditions	Acoustic Condition Calculator	3	0.26%
		Traffic report for each road		
		In case an airport exists in proximity to the site, provide site DNL if current DNL contours are available, or a report		
		Drawings or diagrams showing the distance between the site and any major road or airport		
Site	S.9 Noise Pollution	Noise Pollution Calculator	3	0.58%
		Site plan including neighbouring buildings within the 500 m radius, specifying building types		
		Report for hourly sound pressure level measurements at the 4 test positions on an operational day		
		Plans and elevations for outdoor HVAC equipment location		

		HVAC equipment manufacturer sound data		
Indoor Environment	IE.8 Acoustic Quality	Acoustic Quality Calculator	3	1.37%
		Floor plan and elevation highlighting space under assessment (worst case selection)		
		Site plan showing road under assessment		
		Report for road traffic input data and measurements		
		Building material specifications illustrating absorption coefficients		
		HVAC drawings		
		Noise source sound power levels		

7. OFFICE LAYOUT

There is no criterion focusing office layout in the GSAS commercial building guidelines.

8. BIOPHILIA AND VIEWS

The GSAS system has views (IE.7) criterion under indoor environment category that highlights five submittals focusing outside views from the indoor environment of a building. The criterion has 1.37% weightage of the total score. Biophilia has two elements, the biophilia features outside the building and the features inside the building. GSAS building guidelines system indirectly addresses the biophilia features outside the building in the site category. The habitat preservation (S.3) and vegetation (S.4) criteria outline eight submittals highlighting strategies for preserving local ecosystem and vegetation and landscape design for the site. These criteria have six points with 1.68% weightage of the total score. GSAS system does not recommend any indoor biophilia design strategy. Overall, biophilia and views aspect has nine points with 3.05% weightage of the total score.

Table 5: Biophilia and Views

Category	Criterion	Submittals	Max Score	Weightage
Indoor Environment	IE.7 Views	Views Input Calculator	3	1.37%
		Views Scoring Calculator		
		Floor plans showing all occupied areas, and areas within 7 meters of the perimeter		
		Building elevations highlighting window area		
		Interior partitions specifications, if any		
Site	S.3 Habitat Preservation	Ecologist Site Assessment Report and preservation plan	3	0.65%
		Drawing identifying habitats pre and post-development		
		List of endangered plant and animal species		
		Strategies for preserving ecosystem interaction within the site and adjacent areas		
	S.4 Vegetation	Vegetation Calculator	3	1.03%
		Landscape plan highlighting total landscape area		
		Landscape plan highlighting lawn area		
		Landscape material data sheet		

9. LOCATION AND AMENITIES

Location and amenities aspect is partially covered in the GSAS building guidelines system. Urban connection category has three criteria that focus on the location and transportation aspect of the building site. Proximity to infrastructure (UC.1), public transportation (UC.3) and private transport criteria (UC.4) outline nine submittals highlighting the transportation options and facilities for the building occupants. The research indicates that amenities can help increase occupant productivity and recommends employers to provide few amenities on site or around the site. Proximities to amenities (UC.7) only focus on locating nearby amenities. It does not provide extra points for incorporating amenities in the design of the commercial buildings. It would be helpful to introduce a criterion or submittal that encourages employers/owners to include amenities like gym, childcare inside or near the site in case these facilities are not available. Location and amenities aspect has 12 points with 3.43% weightage of the total score.

Table 6: Details Location and Amentities

Category	Criterion	Submittals	Max Score	Weightage
Urban Connection	UC.1 Proximity to Infrastructure	Proximity to Infrastructure Calculator	3	1.22%
		Site map showing all available connection for existing infrastructure		
	UC.3 Public Transportation	Public Transportation Calculator	3	1.15%
		Authorized public transportation site plan, showing bus/rail stops within 240, 320, 400 and 480m from site		
		Transportation plan for shuttle services, connecting occupants to public transportation if provided		
	UC.4 Private Transportation	Private Transportation Calculator	3	0.38%
		Building floor plans highlighting all provided facilities		
		Transportation plan for shuttle services or alternative, if provided		
		Occupancy calculations		
	UC.7 Proximity to Amenities	Proximity to Amenities Calculator	3	0.68%
		Sitemap, using interactive map such as Google maps, showing locations and types of amenities within 480, 720, and 960 m from the site		

10. LOOK AND FEEL

Look and feel aspect of the indoor environment is indirectly covered in the heritage and cultural identity (CE.1) criterion in the cultural and economic value category in the GSAS system. The criterion defines a submittal to outline design strategies to incorporate design features that address the heritage and cultural identity of Qatar. The criterion addresses the Qatar's cultural identity in design. However, it does not recommend any strategy to incorporate potential occupant's perspectives and opinion about interior design's look and feel. The look and feel aspect has three points and 3.12% weightage of the total score.

Table 7: Look and Feel

Category	Criterion	Submittals	Max Score	Weightage
Cultural and Economic value	CE.1 Heritage and Cultural Identity	Concept brief outlining design strategies that meet the criteria along with supporting design drawings or renderings	3	3.12%

11. CONCLUSION

This research study has analysed the current GSAS green building rating system and its categories along with various indoor environment quality factors that affect occupant productivity. The study establishes the implicit links between eight indoor environment quality factors and GSAS building rating system. Indoor air quality and thermal comfort have the highest weightage allotment among the eight IEQ factors. Indoor environment quality and thermal comfort have high impact on occupant comfort and productivity and they are well addressed in the GSAS. The medium impact IEQ factors like lighting and day lighting, noise and acoustics, and Biophilia and view have been taken into account carefully as well. However, the study indicates that office layout and location and amenities can be addressed more appropriately. GSAS can include criteria on office design to reduce disruption and distraction caused due to inefficient office layout in the office buildings. Overall, the analysis presents that GSAS guidelines have 34.90% weightage towards both indoor and outdoor environment aspects that influence occupant productivity. GSAS rating system has a well-balanced approach towards occupant comfort and productivity. The study findings would help architects, engineer designing building under GSAS to also include office layout strategies to increase occupant productivity in their buildings. This study can also be used a model study to investigate other international green building rating system and their focus on occupant comfort and productivity.

Table 8: Details of Analysis

IEQ Aspect	Category	Criteria	Submittals	Total score	Weightage
Indoor Air Quality	2	5	15	15	9.17%
Thermal Comfort	3	3	21	9	9.35%
Lighting and Day Lighting	1	3	15	9	4.57%
Noise and Acoustics	3	3	16	9	2.21%
Office Layout	Nil	Nil	Nil	Nil	Nil
Biophilia and Views	2	3	13	9	3.05%
Location and Amenities	1	4	11	12	3.43%
Look and Feel	1	1	1	3	3.12%
Total			92	66	34.90%

12. ACKNOWLEDGEMENT

This research is supported by the Qatar National Research Funding under the project “GSAS Guidelines for Occupant Performance, Health and Environmental Realization of Sustainability” under the acronym GOPHERS and NPRP No.: 7 - 344 - 2 – 146.

13. REFERENCES

Alrubaih, M. S., Zain, M. F. M., Alghoul, M. A., Ibrahim, N. L. N., Shameri, M. A. and Elayeb, O., 2013. Research and development on aspects of daylighting fundamentals. *Renewable and Sustainable Energy Reviews*, 21, 494-505.

ASHRAE, 1993. *ASHRAE Fundamentals - Handbook*. Atlanta: ASHRAE

Banbury, S. and Berry, D., 2005. Office noise and employee concentration: Identifying causes of disruption and potential improvements. *Ergonomics*, 48, 25-37.

Bright, G. T., 2012. *The economics of Biophilia. Why designing with nature in mind makes financial sense*. New York (NY): Terrapin Bright Green.

Brill, M., Margulis, S. T. and Konar, E., 1985. Using office design to increase productivity, *Workplace Design and Productivity*, 2.

CABE, 2005. *The impact of Office Design on Business Performance*. London: Commission for Architecture and Built Environment and the British Council for Offices.

De Dear, R., Brager, G. and Cooper, D., 1997. *Developing an Adaptive Model of Thermal Comfort and Preference*. Atlanta: ASHRAE

Djongyang, N., Tchinda, R. and Njomo, D., 2010. Thermal comfort: A review paper. *Renewable and Sustainable Energy Reviews*, 14, 2626-2640.

Duffy, F., Laing, A. and Crisp, V., 1992. The responsible workplace. *Facilities*, 10, 9-15.

Fanger, P. O., 1970. *Thermal Comfort. Analysis and applications in environmental engineering*. Copenhagen: Danish Technical Press.

Fanger, P. O., 1988. Introduction of the olf and the decipol units to quantify air pollution perceived by humans indoors and outdoors. *Energy and Buildings*, 12, 1-6.

Fisk, W. J., Black, D. and Brunner, G., 2012. Changing ventilation rates in US offices: Implications for health, work performance, energy, and associated economics. *Building and Environment*, 47, 368-372.

Frontczak, M., Schiavon, S., Goins, J., Arens, E., Zhang, H. and Wargocki, P., 2012. Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. I*ndoor Air*, 22(2), 119-131.

Gordon-Larsen, P., Boone-Heinonen, J., Sidney, S., Sternfeld, B., Jacobs, D. R. and Lewis, C. E., 2009. Active commuting and cardiovascular disease risk: the CARDIA study. *Archives of Internal Medicine*, 169, 1216-1223.

Grinde, B. and Patil, G. G., 2009. Biophilia: does visual contact with nature impact on health and well-being?. *International Journal of Environmental Research and Public Health*, 6, 2332-2343.

Haynes, B. P., 2008. The impact of office layout on productivity. *Journal of Facilities Management*, 6, 189-201.

Haynes, B. P., 2009. Research design for the measurement of perceived office productivity. *Intelligent Buildings International*, 1, 169-183.

Heerwagen, J., 2009. *Biophilia, health and well-being. Restorative Commons: Creating Health and Well-being through Urban Landscapes*, Pennsylvania: USDA Forest Service.

Heerwagen, J. H. and Orians, G. H., 1984. *Humans, habitats, and aesthetics. The biophilia hypothesis*, Washington, DC: Island Press.

Hopkinson, R. G., Petherbridge, P. and Longmore, J., 1966. Day lighting, London : Heinemann.

Kwallek, N., Lewis, C. M. and Robbins, A. S., 1988. Effects of Office Interior Color on Workers' Mood and Productivity. *Perceptual and Motor Skills*, 66, 123-128.

L Edwards, P. T., 2000. *A literature review of the effects of natural light on building occupants*. USA: U.S. Department of Energy.

Laing, A., Duffy, F., Jaunzens, D. and Willis, S., 1998. *New Environments for Working: The Re-Design of Offices and Environmental Systems for New Ways of Working*, London; Construction Research Communications.

Leaman, A. and Bordass, B. 1999. Productivity in buildings: the 'killer' variables. *Building Research and Information*, 27, 4-19.

Mahnke, F. H., 1996. *Color, environment, and human response: an interdisciplinary understanding of color and its use as a beneficial element in the design of the architectural environment*. USA: John Wiley and Sons.

Mawson, A., 2002. *The Workplace and Its Impact on Productivity*. London: Advance Workplace Associates.

Mui, K. and Wong, L., 2006. A method of assessing the acceptability of noise levels in air-conditioned offices. *Building Services Engineering Research and Technology*, 27, 249-254.

Ou, L. C., Luo, M. R., Woodcock, A. and Wright, A., 2004. A study of colour emotion and colour preference. part II: colour emotions for two-colour combinations. *Color Research and Application*, 29, 292-298.

Roelofsen, P., 2002. The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement. *Journal of Facilities Management*, 1, 247-264.

Romm, J. and Browning, W., 1994. Greening the Building and the Bottom Line - Increasing productivity through energy-efficient design. USA: Rocky Mountain Institute.

Sundstrom, E., Town, J. P., Rice, R. W., Osborn, D. P. and Brill, M., 1994. Office noise, satisfaction, and performance. Environment and Behavior, 26, 195-222.

Tanabe, S.-I., Nishihara, N. and Haneda, M., 2007. Indoor Temperature, Productivity, and Fatigue in Office Tasks. *HVACandR Research*, 13, 623-633.

UNEP, 2009.]. *Buildings and Climate - Summary for Decision Makers*. USA:United Nations Environment Programme.

Van Der Voordt, T. J., 2004. Productivity and employee satisfaction in flexible workplaces. *Journal of Corporate Real Estate*, 6, 133-148.

Vernon, H. M. and Bedford, T., 1926. *A Physiological Study of the Ventilation and Heating in Certain Factories. Medical Research Council. Indust.* London: H.M.S.O.

Wargocki, P., Wyon, D. P., Sundell, J., Clausen, G. and Fanger, P., 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, 222-236.

World Green Building Council, 2014. Health, Wellbeing and Productivity in Offices. USA: World Green Building Council.