SAVING ENERGY IN OFFICE BUILDINGS WITHOUT COMPROMISING THEIR INDOOR ENVIRONMENTAL QUALITY

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ABSTRACT

The concept of Internal Environmental Quality (IEQ) has emerged as a determinant of the performance of built environments due to its direct impact on the health, comfort and satisfaction of the occupants of the buildings and also due its role in ensuring a productive work environment. However, IEQ indicators such as thermal comfort, indoor air quality, and lighting level are associated with the most energy consuming utilities, namely HVAC and lighting. While IEQ and energy efficiency have been researched extensively, there is no published research on energy saving strategies that will optimize the IEQ in office buildings. Therefore, the aim of this study was to identify energy efficient strategies that will optimize the IEQ in office buildings. The research problem was approached through a case study analysis of four office buildings. The study identified energy efficient strategies that can be practiced without compromising the IEQ of a building. However, findings also asserted that there is no common platform to optimize the IEQ performance while achieving the best energy performance of a building. Energy efficient strategies to be adopted can depend on various internal and external factors of a facility. The findings will be useful for building managers who manage office buildings.

Keywords: *Built Environment; Energy Efficient Strategies; Indoor Environmental Quality; Office Buildings.*

1. INTRODUCTION

Due to economic and environmental reasons, organizations around the world are constantly under pressure to reduce their energy consumptions. As energy cost is one of the major cost factors of businesses, a reduction in their energy consumptions leads to a reduction in their operating costs thereby helping to improve their profitability (Jayamaha, 2006). The energy in office buildings is mainly utilized for heating, cooling, and lighting purposes while a significant portion of it is consumed by office equipment (Santamouris, 2002). Managing a building's energy efficiency may soon be an integral component of managing its operational and financial performance (Landsberg, Lord, Carlson, and Goldner, 2009). The energy consumption of buildings depends significantly on the criteria used for the design and operation of their indoor environments as well as the buildings themselves (Bluyssen, 2002).

A majority of people carry on their lives inside buildings which have to satisfy the objective and subjective requirements linked to vital functions of the occupants (Wolkoff, 2012). Therefore, the Indoor Environmental Quality (IEQ) plays a major role in the overall performance of a building (Quang *et.al*,. 2014). In today's world, people spend more than 90% of their time in built environments such as residences, workplaces and similar buildings (Levin and Emmerich, 2013). The built environment or indoor environment of a building should be at an acceptable IEQ level for the comfort and satisfaction of the occupants and for a productive work environment (Bluyssen, 2011).

The cost of energy used to maintain acceptable standards is often high. (Abbaszadeh *et al*., 2006) On the other hand, a good IEQ could improve the overall work performance of workers by minimizing building related illnesses and absenteeism (Brimblecombe, 2002)., Thermal comfort and IAQ are two dominant factors among IEQ parameters, while indoor air temperature and indoor CO2 concentrations are the

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control parameters of environmental control systems of many air-conditioned office buildings (Bluyssen, 2011).

A good energy policy for indoor environment should respond to the needs of both energy conservation and a desirable healthy indoor environment by users of the built environments (Abbaszadeh *et al*., 2006). Several studies have addressed the requirement of optimizing the energy performance in buildings and also their IEQ. However, there is little research that has addressed both energy efficiency and IEQ optimization within a single paradigm. Thus, there exists a research gap in coupling energy performance with IEQ optimization.

AIM

The aim of this research is to identify strategies to save energy in office buildings without compromising their indoor environmental quality.

OBJECTIVES

- To identify IEQ indicators and problems related to them in office buildings
- To identify currently practiced energy efficient strategies in office buildings
- To investigate energy saving strategies that will optimize IEQ in office buildings

2 LITERATURE SYNTHESIS

The Building Performance (BP) of a built environment addresses a set of coordinated strategies that are mainly aimed at assessing the quality of that built environment, in terms of the extent to which all requirements of performance such as safety in operation, air quality, energy performance, acoustics, thermal comfort and visual comfort are satisfied (Hapurne, Baran and Bliuc, 2012). The BP of a built environment depends upon consumer satisfaction including users' needs such as those of physiological, physical, sociological and psychological nature and mental health. These have to be satisfied together with users' spatial ergonomics and their thermal, air, acoustic and visual quality needs which are interrelated with user satisfaction related to BP (Frontczak *et al*., 2012).

2.1 INDOOR ENVIRONMENTAL QUALITY INDICATORS

The concept of IEQ is growing as a new and very useful concept of building performance and quality (Catalina *et al*., 2011). It is because people spend most of their time inside buildings with various aspects of the indoor environment affecting their wellbeing and performance (Prakash, 2005). Furthermore, the quality of the indoor environment reflects health, comfort and productivity of occupants of building environments (Singh, 1996). Moreover, it has been emphasized that IEQ parameters are important and that a better IEQ would improve existing working conditions while minimizing complaints from occupants (Catalina *et al*., 2011). Therefore, the increasing interest in this IEQ concept has placed additional pressure on professionals such as architects, facility managers, building investors, engineers and health officials. Occupants also seek practical guidelines on creating a safe, healthy, and comfortable built environment (Kumar and Fisk, 2002).

Past research has identified thermal comfort, lighting quality, acoustic quality and indoor air quality and workspace as the most important indicators of IEQ (Mahbo *et al*., 2011). Figure 1 illustrates the main indicators relating to IEQ performance.

Figure 1: IEQ Indicators
Source: Mahbob *et al.* (2011)

However, out of the above mentioned five indicators of IEQ, only thermal comfort, IAQ, and lighting level make a measurable impact on energy consumption of a building (Catalina *et al*., 2011). Thus, only those three indicators were taken in to consideration in this study.

3. RESEARCH METHODOLOGY

The research was initiated with a literature synthesis to identify common issues relating to the indoor environmental quality in office buildings. A case study was undertaken using a mixed approach, the best suitable method for the research. A case study examines existing phenomenon within a real life context especially when boundaries between phenomenon and context are not clearly evident (Yin, 2009). Hence, in a case study, data is gathered from real life practices. Furthermore, different cases offer multiple sources of evidence and a possible replication of findings. Therefore, four multi-storey buildings providing similar services were selected as case studies. All four cases had central air conditioning systems, glazed windows and 20-25 floors.

A questionnaire survey and semi-structured interviews were selected as the data collection method. Office workers usually spend many working hours at their desks. Therefore, they become more sensitive to the working environment. Thus, their opinions about the IEQ were sought through a questionnaire survey in each case. Twenty office workers were selected from each case and thus the sample consisted of a total of 80 workers. Data was processed using simple statistics (weighted average).

The questionnaire survey was focused on three main indicators of IEQ identified from literature as having a significant impact on energy efficiency, i.e. IAQ, thermal comfort and lighting level. The five point Likert scale was used to collect occupants’ responses. The scale was 1 - Unbearable, 2 - Not pleasing but bearable, 3 - Moderate, 4 - Good, and 5 - Very pleasing.

A separate five point Likert scale was used to collect occupants’ responses for disease symptom analysis as well as for subsections under thermal comfort. This scale was 1 - Never, 2 - Rarely, 3 - Occasionally (few times a month), 4 - Often (few times a week) and 5 - Very frequent (almost daily).

Semi structured interviews were carried out with the managements involved in the energy management of the selected cases and content analysis was used to analyse the collected data. Table 1 denotes the interviewee profile.

Table 1: Interviewee Profile

Case Study	Interview Code	Designation	Experience
A	A_1	Manager, O & M Division	10 years
	A_2	Manager, HVAC	20 years
B	B_1	Chief Engineer	15 years
	B_2	Assistant Engineer	8 Years
C	C_1	Head, FM division	25 Years
	C_2	Facilities Manager	20 Years
D	D_1	Chief Engineer	25 years
	D_2	Assistant Engineer	18 years

4. Research Findings and Analysis

4.1 Importance of IEQ in Office Buildings

Building owners and managers during the past few decades have become increasingly knowledgeable about the importance of a good indoor environmental quality (IEQ) in their buildings (Landsberg *et al*., 2009). Building owners and managers may have heard about how good IEQ in a building can help their occupants to improve their productivity, Tenants may wish to judge IEQ on absentee rates and create productivity rates specific to their businesses. However from a building-industry perspective, it is difficult to nail down productivity specifics as studies done are not that definitive (Bluyssen *et al*., 2011).

Office workers spend most of their time in commercial buildings for carrying out their daily work as well as for having meals and entertainment. These buildings in modern cities are typically fully air conditioned high-rises in which the indoor environmental quality essentially lies in the proper operation and management of their facilities such as the air conditioning systems, electrical lighting and, sanitary and drainage systems (Joseph and Francis, 2007). The research by Gensler (2005) identified the impact an office working environment has on improving the productivity and job satisfaction of employees. Therefore, maintaining an acceptable IEQ would enable better occupant comfort in built environments.

4.2 Issues Related to IEQ in Office Buildings

Epidemiological studies such as the European Audit Project, the WHO study in Europe, and the BASE-study in the US have all shown how complex the relationships between building conditions (thermal comfort, lighting, indoor air quality and noise) and human well-being are (Bluyssen *et al*., 2011). Leea and Brand (2005) have illustrated that a majority of respondents believed that the office environment had a direct influence on their well-being and self-assessed productivity. When dissatisfaction with the environment and job were high, there was a low level of self-assessed productivity. Table 2 provides IEQ related issues that are most common in office buildings.

Table 2: Identified IEQ Issues in Office Buildings

IEQ Indicators	Causes	Issues in Office Buildings
Thermal Comfort	▪ Operating air temperature	▪ Common cold ▪ Heavy headed feeling ▪ Dry nose ▪ Dry lips ▪ Dry skin

Indoor Air Quality	▪ Ventilation problems with insufficient fresh air ▪ A high concentration of CO_2. ▪ Recirculation of air	▪ Headaches ▪ Fatigue (tiredness, lack of energy and mental fatigue) ▪ Shortness of breath ▪ Stuffiness ▪ Irritation
	▪ Low relative humidity & warm temperatures	▪ Skin problems – Dryness – Itching ▪ Drying of the mucous membranes and skin
	▪ High air velocity	Difficulty in breathing
Lighting Comfort	▪ Poor luminance ▪ Lack of exposure to day light	▪ Fatigue (tiredness, lack of energy and mental fatigue) ▪ Drowsiness ▪ Nausea ▪ Eye irritations

Sources: Ncube and Riffat (2012)

4.3 ENERGY EFFICIENT STRATEGIES IN OFFICE BUILDINGS

Building Orientation

With regard to energy saving strategies, all of the interviewees agreed that the control of solar radiation that comes into the building would have a significant effect in controlling the consumption of energy within a building since HVAC systems had the highest energy requirement in office buildings. With respect to energy saving strategies, all interviewees agreed that proper building orientation and the building location and layout at the site would highly influence the consumption of energy within the building. Interviewee B1 stated that the building orientation has a significant impact on the energy consumption. Interviewee further said that if the building is receiving direct sunlight, it will be hard to maintain the indoor temperature as well as the natural lighting supply and that therefore, it is important to design the building properly. Managements of Cases A and C stated that when constructing buildings, special building orientation factors were considered to reduce their energy consumptions.

Internal Shading Methods

Another important feature stated by many interviewees was that internal shading methods are used to control solar radiation coming into office buildings. Most of the interviewees stated that they were using “curtains”, “blinds” and “tinted glasses” in their building to control solar radiation. Interviewees D1 and D2 stated that in the morning, the building is directly exposed to direct sunlight and that therefore in order to control the solar radiation coming into the building, they install blinds at each floor. All of the occupants in the building have the freedom to adjust internal shadings to suit their requirements. Interviewee D1 stated that blinds were installed in some parts of the buildings to automatically adjust the luminance level at each floor level. These types of blinds help in controlling the solar radiation coming into the building.

HVAC System

All buildings had central air conditioning systems and several methods were being used to cool the inside of the buildings. Except Case D, all other buildings used Air Handling Units (AHU) to cool and dehumidify air at each floor. Case D used a fan coil unit at each level. The Variable Air Volume (VAV) method is used to control the air floor volume in ducts especially in areas where occupancy loads could vary considerably depending on the time of the day. The building in Case B did not have VAV installed and a constant air flow rate was provided through the duct line in each of the floors at all times. Variable Speed Drives (VSDs) had been successfully installed on fan and pump motors for a range of variable load applications. According to interviewee C1, the use of variable speed drives has caused energy savings of

35 to 50% in comparison to conventional constant speed applications. All four buildings had VSDs installed.

Lighting Systems

The types of lighting lamps presently used in the selected cases are fluorescent lamps, Halogen bulbs, CFL bulbs and LED bulbs. Fluorescent lamps were being used in all four buildings. All the interviewees stated that most of the office buildings still use fluorescent lamps. Halogen bulbs were used only in Case B and Case C to light up the outdoor garden. LED lights were being used only in Case C and Case D.

To control lighting, several methods can be used such as manual handling and the use of sensors, timers and building management systems. In most of the buildings, lights were controlled manually by the occupants and workers themselves. Except Case B, all other buildings used timers to control lighting systems. Every building under study used metering to measure the consumption of the HVAC system. Table 3 shows the energy consumption of the HVAC systems during the past three months.

Table 3: Energy Consumption of the HVAC Systems

Energy Bill (kWh)	**Case A**	**Case B**	**Case C**	**Case D**
June	249429	690208.4	344516	182325
July	260564	693703.2	327969	187707
August	234954	698194.4	319846	169420
Average energy consumption by HVAC	248316	694035.3	330777	179817
Number of square feet in the building	300930	598421	750000	179686
KWh required to cool 1 square foot of floor area	0.83	1.16	0.44	1.00

Case C needed only 0.44 kWh to cool one square foot of the building. When compared to other buildings, it had the lowest energy consumption. Case A needed 0.83 kWh to cool one square foot of the building which is the second lowest energy consumption. Case D and Case B required the highest amount of energy to cool one square foot of their respective buildings. Case D required 1.00 kWh and Case B required 1.16kWh.

4.4 ENERGY EFFICIENT STRATEGIES THAT WILL OPTIMIZE IEQ

Occupant survey and management interview findings were analysed to identify IEQ related problems and the type of energy saving strategies currently practised in buildings. Results obtained by simple statistical analysis and cross case analysis were compared to achieve more relevant data. Through this the final objective of the research, the investigation of energy saving strategies that will optimize indoor environmental quality in office buildings, was achieved. Figure 2 denotes the occupants' perception of IEQ in the four cases.

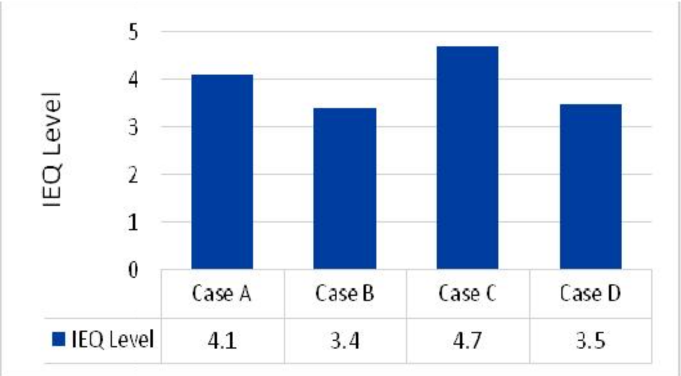
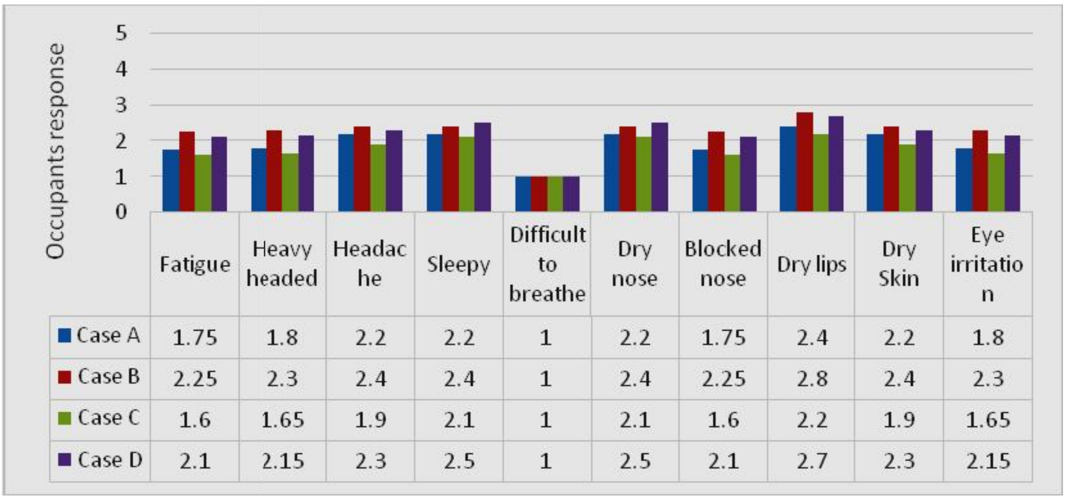


Figure 2: Occupants' Perception of IEQ in the Four Cases

Case A has obtained an average of 4.1 for IEQ level satisfaction. This indicates that its occupants perceive the quality of the indoor environment to be between the levels, good and very pleasing. Occupants of the building in Case B had rated its IEQ with an average of 3.4 which falls between moderate and good levels. Case C indoor environment conditions have been rated as 4.7, indicating that its occupants are very pleased with the quality of the indoor environment. An average of 3.5 was achieved by Case D regarding IEQ levels denoting that occupants perceive the IEQ to be between the levels of moderate and good.



	Fatigue	Heavy headed	Headache	Sleepy	Difficult to breathe	Dry nose	Blocked nose	Dry lips	Dry Skin	Eye irritation
Case A	1.75	1.8	2.2	2.2	1	2.2	1.75	2.4	2.2	1.8
Case B	2.25	2.3	2.4	2.4	1	2.4	2.25	2.8	2.4	2.3
Case C	1.6	1.65	1.9	2.1	1	2.1	1.6	2.2	1.9	1.65
Case D	2.1	2.15	2.3	2.5	1	2.5	2.1	2.7	2.3	2.15

Figure 3: Distribution of Issues Caused by IEQ

Accordingly, issues related to the level of IEQ in each case were surveyed and apparently Case C had the lowest probability of occurrence of issues that can be caused by a bad IEQ. Figure 3 depicts the distribution of issues related to IEQ in the four cases.

The study investigated energy saving strategies used in four cases and calculated the energy consumed in cooling a unit space in each of the four cases. Table 4 presents the findings.

Table 4: Energy Saving Strategies Used in the Four Cases

Cases	**kWh consumed to cool 1 square foot of the floor area**	**Energy Savings Strategies**		**IEQ Perceived by Occupants**
		HVAC	**Lighting**	
Case A	0.83	- Building Orientation - Heat Gain Reduction Strategies – External Strategies ▪ Tinted Glasses ▪ Blind Walls – Internal Strategies ▪ Curtains ▪ Blinds - Variable Air Volume - Variable Speed Drives - Chiller Optimizde Start - Chilled Water Reset	- Use of Lighting Types ▪ Fluorescent Lamps ▪ CFLs - Lights Switching Method ▪ Manual ▪ Sensors ▪ Timers	4.1

Case B	1.16	Heat Gain Reduction Strategies – External Strategies ▪ Tinted Glasses ▪ Blind Walls – Internal Strategies ▪ Curtains ▪ Blinds – Variable Speed Drives	- Using Lighting Types ▪ Fluorescent Lamps ▪ Halogen Bulbs - Lights Switching Method ▪ Manual	3.4
Case C	0.44	- Building Orientation - Heat Gain Reduction Strategies - External Strategies ▪ Tinted Glasses ▪ Blind Walls - Internal Strategies ▪ Curtains ▪ Blinds - Variable Air Volume - Variable Speed Drives - Chiller Optimize Start - Electrical Demand Limiting - Chilled Water Reset - Fan Cycling	- Use of Lighting Types ▪ Fluorescent Lamps ▪ Halogen Bubs ▪ LEDs - Lights Switching Method ▪ Manual ▪ Sensors ▪ Timers	4.7
Case D	1.00	- Heat Gain Reduction Strategies - External Strategies ▪ Tinted Glasses ▪ Blind Walls - Internal Strategies ▪ Curtains ▪ Blinds - Variable Speed Drives	- Use of Lighting Types ▪ Fluorescent Lamps ▪ CFLs ▪ LEDs - Lights Switching Method ▪ Manual ▪ Sensors ▪ Timers	3.5

5. CONCLUSION AND RECOMMENDATIONS

With a growing number of hours being spent in built environments today, the indoor environmental quality is becoming a major consideration among building occupants. In office buildings, energy is mainly consumed for heating, cooling and lighting purposes. These activities are directly related to the Indoor Environmental Quality (IEQ) indicators. Four objectives were formed to achieve the aim of the study and as the research progressed, these objectives were achieved from literature and empirical studies.

This study evaluated IEQ issues that emerged in each case along with different energy performance strategies employed in those buildings. It was found that in cases which were able to minimize the energy consumption, it was also possible to provide its occupants with comfortable working conditions. Higher energy consumptions were seen in cases which had been unable to provide a comfortable indoor environment to their occupants. Proper building orientation, internal and external heat gain reduction methods such as the use of tinted glass, blind walls, curtains and blinds, use of VAV, VSD in HVAC systems, electrical demand limiting, chilled water resetting, fan cycling, use of energy efficient lamps such as fluorescent lamps, Halogen bulbs and LEDs and the use of sensors to control lighting were identified as successful strategies. The strategies identified can be applied depending on the nature of the building and the status of its utilities. This makes it evident that the effectiveness of an energy performance strategy of a building will depend on the inherent features of that respective building.

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