"Development of Post-LEED Energy Management and Sustainability System Audits for High Occupancy Buildings"

By

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College of Engineering Studies

Submitted

TO

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

DEHRADUN, INDIA

March, 2012

ACKNOWLEDGEMENTS

I would like to acknowledge the support I received from my supervisors Dr. Parag Diwan (Vice-Chancellor, University of Petroleum and Energy Studies, Dehradun) and Dr. Charanjit Bambra (Professor, Centennial College, Toronto, Canada). I sincerely thank them for their valuable technical assistance and generative discussions on various topics related to the thesis, over the past two years.

I am also thankful to Centennial College leadership team for their support and especially Dr. Vicki Bismilla, Vice-President Academic, for providing me the mentorship and continuously inspiring me to finish the PhD.

I am grateful to my academic and professional colleagues for their advice, ideas, contribution and participation during various stages of this research project.

Finally, I have to thank my parents and I am sure that now they will be further proud of my educational accomplishments and my continued commitment to life-long learning.

DECLARATION BY THE AUTHOR

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

"Jagannathan Mohan/ March, 2012"

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **"Development of Post-LEED Energy Management and Sustainability System Audits for High Occupancy Buildings"** by **Jagannathan Mohan** in Partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Engineering) is an original work carried out by him under our joint supervision and guidance. It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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Date: March, 2012

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Date: March, 2012

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EXECUTIVE SUMMARY

The move to "Green Buildings" produced a number of third party building rating systems to certify buildings based on environmental performance. One system is "Leadership in Energy and Environmental Design" (LEED) developed by US Green Building Council which has been adopted by many countries including Canada and India.

People spend up to 90% of their time indoors and there is a growing recognition that poor indoor environmental (IEQ) impacts on health and productivity in high occupancy buildings. IEQ category has the intention of protecting health but the overall intent of the LEED approach is to combine energy efficiency, environmental impact reduction and high indoor environmental quality. Therefore, a certified building can achieve the total of 15 points in IEQ category from the possible total of 110 from all rating categories. Eight of these points can be awarded for lighting, daylight and views (3 points), thermal comfort (3 points) and IAQ management during construction (2 points). As the highest rating level only requires 80 points, LEED Certification is possible without earning credits in IEQ category. In Canada, on an average LEED certified buildings achieve only six per cent of the total points for "IEQ".

The focus of the current study is to evaluate IEQ in relation to health and wellbeing in LEED certified buildings in Canada and India and to develop framework for new post-LEED Audit tools for energy, building system, credit sustainability and occupant health.

Ongoing work clearly demonstrates that the LEED standard is biased towards energy conservation. Little attention is paid towards health and wellbeing. Moreover, similar LEED certified projects impact on occupant health differently.

There is very low emphasis on factors that relate to human health. Energy conservation makes buildings more airtight and effective in trapping the gases emitted by large numbers of chemicals used in today's building materials and furnishings. Even as this threat from indoor air pollution grows, LEED continues to ignore human health. A way forward is to modify the LEED scoring system within categories, by requiring minimum performance within each category that impacts health and comfort of occupants. This will provide a more accurate reflection of project performance and encourage builders to improve with in all categories. The current study proposes amendments and rationale for LEED related enhancements for high occupancy buildings while providing "Review and Analysis" tools for builders, regulators and end users for self-assessment and LEED re-certification.

LIST OF SYMBOLS

Bq – Becquerel

CO_2 – carbon dioxide

g/h – grams per hour

H_2S – hydrogen sulphide

Hr. - hour

O^3 – ozone

m^3 – cubic metre

$PM_{2.5}$ – particulate matter 2.5 microns

ppb – parts per billion

pt. – points

Rn – radon

µg – microgram

LIST OF ABBREVIATIONS

AIA - American Institute of Architects

AEUI - Annual Energy Use Index

ASHRAE - American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BREEAM - Building Research Establishment Environmental Assessment Method

BRI - Building-related illness

BEAM - Building Environmental Assessment Method

CAGBC - Canada Green Building Council

CANMET - Canada Centre for Mineral, Energy and Technology

CASBEE - Comprehensive Assessment System for Built Environment Efficiency

CBE - Centre for the Built Environment

CCBFC - Canadian Commission on Building and Fire Codes

CFC - chlorofluorocarbons

DE – Department of Energy

EA – Energy & Atmosphere

E & A - Energy & Atmosphere

EB - Existing Buildings

EPA – Environmental Agency

EPC - Energy Performance Coefficient

EPN - Energy Performance Norm

ETS - Environmental Tobacco Smoke

GBI - Green Building Initiative

GRIHA - Green Rating for Integrated Habitat Assessment

HVAC - heating, ventilation, and air conditioning

IAQ – Indoor air quality

ICC - International Code Council

Id - Innovation & Design

IRC - International Residential Code

IEQ - Indoor environmental quality

IGCC - International Green Construction Code

LEED - Leadership in Energy and Environmental Design

LOAEL - Lowest observed adverse effect level

MR – Material & Resources

NABERS - National Australian Built Environment Rating System

NREL - National Renewable Energy Laboratory

NC – New construction

NOAEL - No observed adverse effect level

NV – natural ventilation

OBC - Ontario Building Code

OSH - Canada's National Occupational Health and Safety Resource

PAQ – Perceived air quality

POE – post occupation evaluation

SBS - Sick Building Syndrome

UNEP – United nations Environmental Program

USGBC – United States Green Building Council

SS – Sustainable Sites

Tvoc - Total volatile organic compounds

VOC – volatile organic compound

WE – Water Efficiency

WHO – World Health Organization

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CHAPTER ONE: INRODUCTION

1.1 Problem statement & philosophy

Currently, the Green Building rating systems do not adequately emphasize on the occupant's health & comfort needs. Philosophically, "No green certified building should be able to sustain that status, without continued demonstrated efforts to improve occupant health & comfort".

1.2 Green building certification systems

Buildings play a significant role in energy consumption and environmental impact. CANMET Energy Technology Centre (CETC 2002) in Canada estimates that the building industry uses more than 50% of Canada's primary resources and currently is responsible for 35 – 40% of national energy consumption. In response to increasing public awareness, a number of reference documents have been produced to direct the decision makers to develop buildings with improved environmental performance. Many building assessment methods have been developed for use in the construction industry with the primary intent of increasing the market demand for green buildings. Benefits of such buildings include energy, water and other resource savings over the building life cycle (Bosch and Pearce, 2003). Green Buildings are expected to increase productivity, improve health and enhance human performance.

When compared to other sectors (such as transportation, manufacturing, forestry and agriculture), the building sector has the greatest potential for energy savings in all countries including Canada and India. The long life cycle of buildings, combined with persistent demand for public and private sector construction, will continue to increase energy needs. Therefore, in countries with fast growing economies such as Canada and India, incorporation of energy efficiency, conservation, systems automation and management concepts in Green Buildings are becoming very important.

The move to Green Buildings has resulted in a number of third party rating systems that have been specifically developed to “certify” buildings on their environmental performance. One such system – “Leadership in Energy and Environmental Design” (LEED) Certification system developed by the United States Green Building Council (USGBC) is currently the leading system in the North American market. It has been adopted in many countries including Canada and India. The current LEED-NC rating system uses a 100-point system to designate buildings LEED Certified, LEED Silver, LEED Gold or LEED Platinum. Previously, LEED-Canada and LEED-India systems were based on the original LEED system that rates a building using the 69 point system. These points are allocated for design and features that impact on sustainability (e.g. site planning, energy efficiency, water efficiency, indoor air quality, materials and resources). Continuous monitoring of the technical performance of buildings over their life cycle is important since these buildings undergo significant changes over time. These changes are a consequence of internal reorganization, refurbishments and degradation of technical systems.

There is a growing recognition that poor indoor environmental quality in high occupancy buildings has impacts on health and productivity. Social welfare and health are influenced by heat, light, acoustics, ventilation, chemicals and the availability of an outside view. A recent report from the United Sates National Institute of Standards and Technology presented an appraisal of the current state of research concerning neighborhood design and public health providing recommendations for integrating the knowledge into a LEED-ND (LEED for Neighbourhood Development) rating system to improve public health. Indoor air quality (IAQ) is an important occupational health and safety issue (Canada's National Occupational Health and Safety Resource - OSH). Recent energy conservation measures have resulted in airtight building construction using ventilation systems that minimize the amount of fresh air entry and circulation, thereby creating poor IAQ. People tend to spend a lot of time working in such buildings and have experienced symptoms such as headaches, shortness of breath, cough and nausea. These symptoms are classified as Sick Building Syndrome (SBS) or Building-Related Illness (BRI).

The certification systems used in major countries are as follows:-

1. USA, Canada and India ; USGBC developed certification system for the sustainable buildings – known as LEED v1.0 in 1997; LEED v3 in 2009 in Canada (CAGBC) & USA; LEED v1.0 in 2006 and LEED 2011 in India.
2. United Kingdom; Building Research Establishment's Environmental Assessment Method (BREEAM).
3. Australia, New Zealand and South Africa; Green Star is used for voluntary building assessment program.
4. India; In addition to LEED, also follows Green Rating for Integrated Habitat Assessment (GRIHA).
5. Japan; Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is used as a tool for assessing and rating the environmental performance of buildings.

6. Hong Kong; Building Environmental Assessment Method (BEAM) is used as a voluntary initiative to measure, improve & label the environmental performance of buildings.

1.3 LEED green building rating system

The Leadership in Energy & Environmental Design (LEED) is a third party certification program, and an internationally accepted benchmark for design, construction & operation of Green Buildings. The LEED system encourages & accelerates adoption of sustainable green building & development practices through the creation and implementation of universally understood and accepted tools & performance criteria. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health:

- sustainable site development
- water efficiency
- energy efficiency
- materials selection
- indoor environmental quality

Currently, LEED offers four levels of certification; Certified, Silver, Gold & Platinum.

Categories	**LEED v 2.2(Canada & USA)** **LEED 2006 (India)**	**LEED 2009(Canada & USA)** **LEED 2011 (India)**

Sustainable Sites	13	26
Water Efficiency	6	10
Energy & Atmosphere	17	35
Material & Resources	13	14
Indoor Environmental Quality	15	15
Innovation & Design	5	6
Regional Priority		4
TOTAL	**69**	**110**

Within each category, there are prerequisites & credits with associated points. The maximum achievable number of points in each category is listed above.

The points required for different levels of LEED certification are as follows:-

Level of Certification	**LEED v 2.2(Canada & USA)** **LEED 2006 (India)**	**LEED 2009(Canada & USA)** **LEED 2011 (India)**
Certified	26 – 32	40 – 49
Silver	33 – 38	50 – 59
Gold	39 – 51	60 – 79
Platinum	52 – 69	80 & Above

CHAPTER TWO: LITERATURE REVIEW

2.1 Green buildings vs. Healthy buildings – LEED certification perspective

There is a growing recognition that poor indoor environmental quality (IEQ) in high occupancy buildings has impacts on health and productivity. Social wellbeing and health are influenced by heat, light, acoustics, ventilation and the availability of an outside view. Indoor air quality (IAQ) is an important occupational health and safety issue (Canada's National Occupational Health and Safety Resource - OSH). Recent energy conservation measures have resulted in airtight building construction using ventilation systems that minimize the amount of fresh air entry and circulation, thereby creating poor IAQ. Canadians spend over 90% of their time indoors and a consequence of this life style is an increased susceptibility of individuals to indoor air pollutants with a concomitant increase in the incidence of respiratory diseases.

The contribution of each LEED category towards the total score within same LEED-certification level varied. The economic benefits of high indoor air quality are estimated to be in the range of billions of dollars. In some cases, better indoor air quality was found to increase work productivity up to 10%. These gains were due to employees reporting less adverse symptoms of respiratory diseases, lower number of absent hours, improved concentration, higher typing velocity and improved communication performance. Besides HVAC design characteristics, proper operation and system maintenance procedures impact on occupant health and energy consumption levels. The precise overall benefits of better indoor environmental quality for the average Canadian are not known. Many programs that promote the "green pathway" as a way of life usually emphasize on the benefits of the product in environmental protection. Additional Research on indoor air pollutants and their effect on health and well-being are required.

Many studies have mentioned benefits resulting from increased worker productivity associated with energy production (Lee *et al*, 2000; Katz *et al*, 2003 and Weber, 2004) and improved indoor environment (Fisk, 2000, 2002; Milton *et al*, 2000). This work reviewed the existing literature and reported that better working air quality reduced respiratory diseases and allergies. Similar results were reported in the 2005 Building Design Council Annual Report. A variety of studies have demonstrated productivity benefits in commercial and industrial settings. For example, according to the U.S. Green Building Council, office worker productivity increases between 2-18% on average in green buildings.

All sustainable design rating schemes award credits for actions that will improve IEQ. Limited small scale post occupancy surveys of LEED Certified buildings have been reported and all of these are case studies of small specialist buildings. No firm conclusions can be drawn. Heerwagen & Zagreus (2005) performed a post-occupancy evaluation on a single LEED building. Results showed that it rated third overall in general end-user satisfaction in the IEQ database maintained by the Centre for the Built Environment (CBE) at the University of California, Berkeley. Abbaszabeh *et al*. (2006) performed occupant surveys for 21 green-designed buildings, 15 of which were LEED rated. The results of the surveys compared the performance of the green buildings to conventional buildings in the CBE database. On average, occupants of green buildings were more satisfied with the building overall, and with air quality and thermal comfort compared to conventional buildings. Lighting and acoustic quality did not show any overall improvement in comparison with non-green buildings. Satisfaction scores for the green buildings for both of these components of the indoor environment clustered near the extremes of the satisfaction scale, implying that some buildings performed better while others performed poorly compared to other buildings in the CBE database. The top three complaints in green buildings for lighting were same as conventional buildings (i.e. not enough daylight, reflections in computer screens and the space being too dark). There is a substantial amount of evidence detailing the characteristics that office workers like in their work environment. Characteristics generally include views, natural light, natural ventilation and a high quality of air, as well as control over their environment (Leaman *et al*. 2007).

Certification under a green building program is possible without achieving points in the respective energy category (besides meeting the mandatory provisions), by accumulation of points outside of the energy category. Green buildings are often marketed with the expectation that there will be improved organizational productivity due to an improved indoor environment (Charles *et al*. 2004). However, the improvements in organizational productivity in green buildings will only result when the improvement to IEQ is delivered. For example the business case for the CH2 Building included a 4.9% improvement in productivity (Paevere *et al*. 2008). The results of a recent real estate survey suggest that the market is attaching substantial monetary value to green buildings (Fuerst *et al*. 2008). Clearly, this green premium cannot be maintained if in the long run these buildings do not deliver their assumed performance benefits in either indoor environment quality or energy consumption savings.

A clear trend exists with a decrease in acoustic satisfaction associated with green buildings. A decrease in acoustic satisfaction may be a logical consequence of the current LEED credit scheme, which offers credits for building design features such as low partitions to allow natural light to penetrate and allow views, and hard ceilings and floors to improve air quality. However both of these features have negative effects for acoustics (Bradley *et al*. 2001).

Sick building syndrome is the term used to describe all symptoms related to the time that individuals spend in a building. Use of synthetic materials, increased thermal insulation and technological complexity of the office work landscape (e.g., photocopiers, laser printers, computers) correlates positively with the frequency of people experiencing these symptoms (Bakó-Biró, 2004). However, these symptoms cannot be linked to any particular environmental source and are more likely the consequence of complex pattern of interactions between indoor air contaminants (Seppänen, 2004). Most frequent symptoms of SBS are: dryness and irritation of the eyes, nose, throat, and skin, headache, fatigue, and shortness of breath, hypersensitivity and allergies, sinus congestion, coughing and sneezing, dizziness, and/or nausea. Chemical, physical and biological analyses of air samples fail to reveal significant concentrations of any of the contaminants and the problem is often attributed to the combined effects of several pollutants at low concentrations, complicated by other environmental factors. Other factors besides IAQ may also affect indoor air quality (see Table 5.1) and it is better to use the term “Indoor Environmental Quality” (IEQ).

Changes in employees’ health and well-being can impact on asthma, respiratory allergy symptoms, depression and stress conditions following the movement from traditional to green (LEED-certified) office buildings (Table 5.2; Singh, 2010).

Using the minimum airflow rate design method, a productivity loss of 5–9% has been estimated (Kosonen, 2004). Displacement ventilation is a better strategy for providing good air quality in occupied spaces in a manner that significantly increases productivity.

“Energy and atmosphere” and “indoor environmental quality” are the two LEED categories which have a direct positive impact in the health and comfort of building occupants. With maximum points of 17 and 15 respectively they are also two of the four categories that provide more credits toward achieving LEED certification. The other two are “Sustainable sites” and “Material and Resources” both with a maximum of 14 points. LEED certification is an organic in that each category can impact other categories and it is very difficult to implement a LEED certification process without addressing all categories included in it. Due to prohibitive cost and tradeoffs it is virtually impossible to acquire all points in each category. The challenge for designers is to identify design models that create the maximum achievable synergy between credits to make the best decision for the building. In this way, the LEED system provides flexibility to support the fact that no two buildings are exactly alike.

2.1.1 Correlation between energy conservation and public health in high occupancy buildings in Canada

According to the Canadian Guidelines for Residential Indoor Air Quality (Health Canada, 1989) the main areas of concern are related to the presence and levels of formaldehyde, carbon monoxide, nitrogen dioxide, radon, indoor air pollutants including biological agents (e.g. mould, bacteria and dust mites) and chemical pollutants (gases and particles that come from combustion appliances, tobacco smoke, household and personal care products, building materials and outdoor air). These contaminants impact on the health and comfort of building occupants. The effects range from diseases such as asthma, allergies, cancer and sick building syndrome (SBS). Health Canada has produced documents describing physical, chemical and/or biological properties, origin, health effects and assessment under the 1999 Canadian Air Protection Act (Government of Canada, 1999). The Act also provides guidelines for exposure limits once these have been established.

Radon: Radon (86Rn) is a colorless, noble radioactive gas that occurs naturally in soil and rocks as the decay product of uranium. Its most stable isotope Radon (222Rn) has a short half-life of 3.82 days and its decay emits *alpha* particle. Alpha radiation presents no external hazard as it is unable to penetrate the skin. However, a synergistic effect between cigarette smoking and radon gas can lead to lung cancer. After smoking, radon gas is the leading cause of lung cancer. In 2006, OSH estimated 1,900 lung cancer deaths in Canada were due to radon exposure. Soil and drinking water are the main sources of indoor radon. Radon levels vary across different locations and the main factor affecting the amount of radon that enters a building include differences in soil's nature, building/home characteristics, foundation conditions, occupant lifestyle, and variations in weather (e.g., temperature, wind, barometric pressure and precipitation). In high rise buildings internal levels of radon are higher in upper floors (Bill Broadhead WPB Enterprises Inc.). The Canadian Commission on Building and Fire Codes approved the creation of Task Group on "Protection against Radon Ingress" and is currently discussing the proposed changes to 2010 National Building Code. In Canada radon's acceptable exposure level has been set at 200 Bq/m3 (Health Canada, 1989).

Mold: Mold (fungi) growth impacts on the air quality as both spores and mycelial fragments are dispersed into the air and can be inhaled. The depth of their penetration into the bronchial tree is inversely related to their size. Mold growth in buildings requires the presence of nutrients, an adequate temperature, and a sufficient amount of water. The first two requirements are met by indoor environments as fungal growth usually results from a moisture problem (CMHC, 2003). Molds impact on health (Health Canada, 2004, 2005) and an updated Residential Indoor Air Quality Guidelines for Moulds has been issued by Health Canada (Health Canada, 2007). Fungi are useful indicators of indoor air quality. Exposure to indoor mold is associated with an increased prevalence of symptoms such, headaches, sleepiness, tiredness, fatigue and asthma-related symptoms (Lee, 2003).

Significant amounts of indoor fungal growth are absent in buildings with low indoor humidity but prevalent in buildings with high indoor humidity. Adverse health symptoms are associated with chronic exposure to volatile organic compounds, spores and mycotoxins produced by *Penicillium sp, Aspergillus sp*, and *Stachybotrys sp* (Cabral, 2010). The development of symptoms such as cough, shortness of breath and chest tightness, and asthma-like symptoms have been documented in workers following mould exposure (Al-Ahmad, 2010). There is a significant correlation between building dampness and the risk of developing asthma (Wickman 2003, Jaakkola, 2005.)

Several models are available for predicting the likelihood of mould growth in buildings in different environmental, structural and climatic conditions. The "limit condition model" emphasizes on the minimum conditions for mold growth (Clarke *et al*, 1998). The "Mould Index: 0 to 6" can be used to estimate the risks for mould growth on any material's surface and can be used as criteria for moisture performance (Ojaanen, 1998). The "Mould Growth Model" is a numerical model developed to calculate mould growth in building envelopes under specific indoor/outdoor conditions (Viitanen, 1996).

Ozone: Ozone (O^3) is an allotrope of oxygen. The ozone layer in the upper atmosphere is beneficial, preventing potentially damaging ultraviolet light from reaching the Earth's surface. Sources of ozone indoors include any equipment that releases ozone either directly (such as ozone generators and any other types of air cleaners) or as a by-product (such as office equipment including printers and photocopiers). Outdoor ozone is also an important contributor to indoor ozone, depending on the concentrations outdoor and the air exchange rate with indoor environments. For the purpose of this study we are concerned with indoor O^3 levels.

Symptoms of ozone exposure include coughing, chest discomfort, reduced lung function, shortness of breath; and irritation of eye, nose and throat. Prolonged exposure (periods between 4 to 8 hours) to ozone in human controlled exposure studies had an effect on lung function (Seal, 1993, 1996; McDonnell, 1993). Ozone has been recently identified as a potential risk factor for cardiovascular disease (Urch, 2005) and exposure to increasing ozone concentrations has been linked to increased risk of death from respiratory causes (Bell, 2004; Jerrett, 2009).

Ozone is a very reactive and highly oxidant gas. Ozone started chemical reactions are an important source of indoor air pollutants. House surfaces such as carpets, and kitchen counters can produce formaldehyde and C3-C10 saturated aldehydes upon exposure to ozone (Wang, 2006; Weschle, 2006 and Hyttinen, 2006). Ozone exposure effects are dependent on concentration levels and time of the exposition. To describe these concentration dependent effects the following concepts have been established: No Observed Adverse Effect Level (NOAEL), Lowest Observed Adverse Effect Level (LOAEL). Based on experimental findings the

Residential Indoor Air Quality Guideline for Ozone (Health Canada, 2010) recommends a maximum exposure limit of 40 μg/m^3 (20 ppb) ozone, based on an averaging time of 8-hours. This exposure limit is still half of the NOAEL=40 ppb O^3 derived from a controlled human exposure study (Adams, 2002). The only study available for a Canadian city (a Toronto indoor ozone exposure study) illustrated that 95% of homes were below 22.6 ppb and 22.4 ppb respectively for daytime and night time 12-hour summer indoor ozone levels (Liu, 1995).

Carbon Monoxide: Carbon monoxide is a tasteless, odorless and colorless gas at room temperature. The main sources of carbon monoxide are both natural and anthropogenic processes. It is usually formed during the incomplete combustion of organic materials. In indoor environments carbon monoxide occurs directly as a result of emissions from indoor sources or indirectly as a result of infiltration indoors of outdoor carbon monoxide from vehicles. Use of specific sources can lead to increased carbon monoxide concentrations indoors. In the absence of an indoor source, carbon monoxide concentrations are generally equivalent to average outdoor concentrations. The sources and effect of carbon monoxide exposure are well documented (WHO, 1999; USA EPA, 2000).

Factors affecting the introduction, dispersion and removal of carbon monoxide indoors include (Health Canada, 2010):

- The type, the generation rate of carbon monoxide and number of sources.
- Source use characteristics;
- Building characteristics;
- Infiltration or ventilation rates;
- Air mixing between and within compartments in indoor spaces;
- Removal rates and potential remission or generation by indoor surfaces and chemical transformation;

- Existence and effectiveness of air contaminant removal systems; and
- Outdoor concentrations.

Carbon monoxide (CO) impacts on health and severity of the problems vary with the levels of CO present in the environment. Carbon monoxide acts by binding to hemoglobin and inhibiting the binding of oxygen as the affinity of carbon monoxide for hemoglobin is 230 times higher than that of oxygen. The health effects at higher levels are much more serious and can even lead to death. The recommended maximum exposure limits for carbon monoxide are 28.6 and 11.5 mg/m3 for 1hr and 24 hr. respectively. Symptoms of mild acute poisoning include headaches, vertigo, and flu-like effects; higher level exposures can lead to significant toxicity of the central nervous system and heart, and even death. A recent study has shown that early life exposition to CO can increase the risks of developing childhood asthma (Clark, 2010)

Formaldehyde: Emission sources of formaldehyde are well known. Sources that influence indoor levels of formaldehyde can be divided into two broad categories: combustion and off-gassing. Combustion sources include cigarettes and other tobacco products, and open fireplaces. Off-gassing sources include wood products such as particle board and other building materials made with adhesives containing formaldehyde, varnishes, paints, carpeting, drapes and curtains.

Formaldehyde may also be formed by the chemical reaction of ozone with some building and surface materials. A chamber study showed that the presence of ozone increased the release of formaldehyde from plaster, plywood and fitted carpet (Moriske *et al.* 1998). Formaldehyde is also formed through the oxidation of R-(+)-limonene, a VOC that is common in indoor environments, by ozone (Clausen, 2001).

Indoor ozone-releasing devices such as photocopiers and laser printers have been found to release formaldehyde, and this is thought to result from the reaction of ozone with aliphatic hydrocarbons. When a single dry-process photocopier was sent to four different laboratories for chamber experiments, formaldehyde emissions rates ranging from 1.3 to 4.7 g/h of operation were measured (Leovic *et al*. 1998). Emission from laser printers were also assessed, and were found to range from non-detectable to 0.3 g/h of operation (Tuomi *et al*. 2000).

Health effects at different levels of formaldehyde are presented in Table 5.3. Health Canada has developed an indoor air quality guideline for formaldehyde and the recommended maximum formaldehyde levels for two types of exposure:

- The short-term exposure limit protects against health problems that may arise from exposure to high levels over a short time period (e.g. one hour).
- The long-term exposure limit protects against health problems that may be caused by repeated exposure to lower levels of formaldehyde over a long period (days, weeks, months, etc.).

To avoid possible eye, nose and throat irritation from short-term exposure, indoor air levels of formaldehyde should be below 123 $\mu g/m^3$ (100 ppb). To prevent respiratory problems from long-term exposure, i.e. over days, months or years, indoor air levels should be kept below 50 $\mu g/m^3$ (or 40 ppb).

2.1.2 Energy conservation in LEED rating system in Canada and Public Health in Ontario

2.1.2.1 LEED Certification: Extent to which different categories affect HVAC systems

Site selection: There is no direct correlation to HVAC systems in this category. However, the credits for reducing site disturbance and heat island effects can have a positive impact on the HVAC system. Heat island is the thermal gradient difference between developed and undeveloped areas in a project. The heat island effect can impact local habitats because native plant and animal species may not be adapted to the increased temperature. Minimizing this impact can also help to reduce summer cooling loads, resulting in lower energy costs and capital cost requirements.

Water efficiency: In general, HVAC systems have little effect on water efficiency unless water-cooled technology such as cooling towers and evaporative condensers are used.

Energy and Atmosphere: Each of the prerequisites and credits in the "Energy and Atmosphere" category directly address the HVAC system and its impact on the environment. This category includes the percentage of energy consumed (minimum energy performance, optimize energy performance), the environmental impact of generating that energy (and of renewable energy), and the ozone reduction potential of the refrigerant (CFC) used in the equipment.

Materials and Resources: This LEED category encourages reuse and restoration of the existing building stock versus new building construction. The level of restoration can have a significant impact on the HVAC. For example, if an older building (1970s or before) is to be restored as part of a LEED project, it will be difficult to find indoor space to accommodate more modern HVAC equipment, ductwork and ancillary equipment. Restoration may require major structural changes to accommodate larger equipment.

Indoor Environmental Quality: Limiting pollutants in the building before, during and after construction provides cleaner air and reduce odors upon occupation; these actions will help reduce maintenance for the HVAC system by extending filter life and reducing cleaning requirements.

LEED gives a point for providing 2% daylight factor in 75% of all space occupied for critical visual tasks and an extra point for providing a direct line of sight from 90% of all regularly occupied spaces. By providing sunlight and views to the occupants of the building, the building occupants can be connected to the outdoor environment. However, careful balancing must be done as solar heat gain is one of the largest loads on the cooling system. Conversely, this can offset some of the heating load requirements in winter months if planned correctly.
The correlation analysis between different certification categories in platinum LEED Certified projects is provided in Table 5.4.

Table 2.1 Factors and Sources Affecting Indoor Air Quality and Comfort

Factor	Source
Temperature and humidity extremes	improper placement of thermosstas, poor humidity control, inaility of the Building to compensate for climate Extremes, tenant added office equipment and processes.
Carbon dioxide	People, combustion of fossil fuels
Carbon monoxide	Automobile exhaust, comustion and Tobacco smoke
Formaldehyde	Unsealed plywood, urea, insulation, fabrics, glues, carpets,
Partculates	Particulates Smoke, air inlets, duct insulation, water residue, HVAC filters, housekeeping
VOcs	furnisings, cleaners, smoke, paints
Inadequate ventilation	Energy saving measures, improper system design, HVAC system, poor office layout
Micrbial matter	Stagnant water in HVAC, humidity, poor placement of thermostats
Temperature and humidity extremes	Inability of building to compensate for climate extremes, tenant added equipment and processes

Adapted from Health Canada (1993)

Table 2.2 Impact on employee health and well-being following movement from traditional to green office building

Condition	Traditional Buildings	Green Buildings
	Mean Number of Hours	
Asthma and respiratory illness Self-reported hours absent per Month	16. 28	6.32
Depression and stress-related Self-reported hours absent per Month	20.21	14.06

Singh A (2010)

Table 2.3 Health effects at different levels of formaldehyde

Levels of Formaldehyde	Possible health effects
Low below 50 µg/m^3 (40ppb)	No adverse effects should be noticed
Moderate above 50 µg/m^3 (40ppb)	Long term exposure may result in respiratory symptoms such as coughing and wheezing, and allergic sensitivity, especially in children
High term exposure grows with Concentration above 123 µg/m^3	There is also an increased likely hood of respiratory symptoms and risk from Irritation or burning sensation in eyes, nose and throat from short term exposure

Adapted from Health Canada

2.2 Indoor environment and productivity

Both, U.S. Environmental Protection Agency (EPA) and the U.S. Consumer Product Safety Commission (1995), estimate that people spend up to 90 percent of their time indoors. "Indoor environmental quality" (IEQ) is the category most closely tied to health and is affected by the green building's design, construction, operation, maintenance, activities of occupants and the outdoor environmental conditions. On average LEED certified buildings in Canada achieve only 6 percent of the total points for "indoor environmental quality". It should be noted that some of these credits are given for lighting and thermal comfort.

The May 2010 report from Connecticut based Environment and Human Health, Inc., titled "LEED Certification: Where Energy Efficiency Collides with Human Health," raised concerns about indoor air quality in LEED (Leadership in Energy and Environmental Design) Certified buildings. This report notes that the LEED certification offers a total of 110 points in seven categories, and that it's possible to get the top rating—Platinum—while scoring zero points (out of 15) in "indoor environmental quality." The seven LEED categories include energy and atmosphere, sustainable sites, indoor environmental quality, materials and resources, water efficiency, innovation in design, and bonus credits. Of the 110 points, 35 are allocated to energy and atmosphere. As noted, on average LEED certified buildings in Canada achieve only 6 percent of the total points for "indoor environmental quality". It should be noted that some of these credits are given for lighting and thermal comfort.

Several studies have evaluated the impact of indoor environmental quality on human health and demonstrated the loss of millions of hours of productivity due to symptoms such as headaches, nausea, fatigue and eye irritation (Germguard, 2002; Heerwagen, 2002; Medallion healthy air, 2002; Office IAQ and productivity, 1999; Pearson, 2002; Solberg, 1999). Review of current literature clearly demonstrates a possible connection between indoor environmental quality and these symptoms.

Many studies have also mentioned benefits that result from increased worker productivity associated with energy production (Lee et al, 2000; Katz *et al*, 2003 and Weber, 2004) and improved indoor environment (Fisk, 2000, 2002; Milton *et al*, 2000). A review of the existing literature suggests that better working air quality reduced respiratory diseases and allergies. Similar findings were reported in the 2005 Building Design Council Annual Report.

The current LEED scoring system is biased towards energy conservation. The largest category of possible credits for new construction encourages energy conservation, either directly via use of renewable technologies (solar panels, geothermal wells, insulation) or indirectly through reduced water use, proximity to public transit, or use of locally produced materials. Moreover, LEED has no requirement for post-occupancy air quality monitoring for particulate matter or volatile organic compounds. These are primary threats to health, especially among those with respiratory and cardiovascular disorders.

The IEQ is affected by the building's design, construction, operation, maintenance, activities of occupants, and outdoor environmental conditions. Consequently, energy-efficiency measures may degrade IEQ, improve IEQ, or be IEQ neutral.

"Indoor Environmental Quality" is the rating category that has the intention of protecting health and a certified building can achieve a total of 15 points in the indoor environmental quality category from the possible total of 110 from all other rating categories. Eight of the fifteen possible points can be given for lighting, daylight and views (3 possible points), thermal comfort (3 points), and air quality management planning during construction (2 points). The highest possible building rating only requires a total score of 80 points and therefore LEED certification is possible at the highest "platinum" level, without earning credits in the indoor air quality category, the category that is most likely to protect human health.

The changes made to the "Indoor Environmental Quality" (IEQ) sections of LEED-NC Version 2.2 related to ventilation (Taylor, 2005) show that of the 15 points available for IEQ, two points are mandatory and 13 are optional.

Mandatory points require indoor ventilation rates to perform to ASHRAE 62.1-2007 guidelines and to minimize the entrainment of tobacco smoke in occupied zones. The non-mandatory points include monitoring of CO_2 levels, increased ventilation, an indoor air quality management plan for the construction and pre-occupancy phases, the use of low emission materials, and the management of indoor chemical/pollutant source control. The rest of the points support indoor comfort and verification. There is no differentiation between the common indoor pollutants that include volatile organic compounds, aldehydes (including formaldehyde), and biologic agents including allergens, mold and endotoxins, ultrafine particulate matter (including combustion products such as gases like carbon monoxide or H_2S). LEED does not specify occupancy limits for each of these IAQ metrics and instead focuses on mitigating strategies such as the use of materials that emit low levels of Volatile Organic Compounds (VOC – USGBC-LEED, 2009), increased ventilation (30% over ASHRAE 60.1-2007 for mechanically ventilated buildings and [CIBSE] Applications Manual 10: 2005 guidelines for naturally ventilated buildings), air flush-out protocols for construction and pre-occupancy phases, basic guidelines to control indoor chemical dispersion, thermal comfort guidelines (ASHRAE 55-2004) and a Post-Occupancy Evaluation (POE) survey.

The overall intent of the LEED approach is to combine energy efficiency, environmental impact reduction, and high indoor air quality. One of the most pervasive building design strategies used to achieve these design goals is the use of natural ventilation (NV). NV buildings save energy by avoiding the use of motor driven air handling units (Emmerisch *et al.*, 2001). Not using forced air lowers fiber counts by reducing the entrainment of small particulate matter residing in air ducts. When compared to NV, mechanical systems can have up to four times higher number of suspended airborne dust particles (Paul *et al*., 2010). Natural ventilation mostly relies on small differential pressure differences between the outside air and interior spaces that are sensitive to local wind and temperature fluctuations that result in non-uniform spatial and temporal flow rates (Linden, 1999).

According to Storey and Bartlett (2010) naturally ventilated LEED NC buildings are a major step forward in terms of supporting high IEQ. However, the major weakness of the LEED IEQ points system continues to be the reliance on prescriptive approach. Without compulsory performance strategies and benchmark limits for VOC and other pollutants, high IEQ cannot be achieved.

2.2.1. Indoor environment quality

The LEED "Indoor Environmental Quality" section is divided into 10 categories: Minimum Indoor Air Quality Performance, Environmental Tobacco Smoke Control, Carbon Dioxide Monitoring, Ventilation Effectiveness, Construction Indoor Air Quality Management Plan, Low-Emitting Materials, Indoor Chemical and Pollutant Source Control, Controllability of Systems, Thermal Comfort, and Daylight and Views. Each of these items will now be considered in relation to health.

Minimum indoor air quality performance: Twelve LEED credits are directly or indirectly connected to indoor air quality. With a total of 100 base points, it is possible for a building to get "Platinum" Certification (80+ credits) without addressing any of the issues associated with IAQ.

The IAQ is considered as the most important environmental concern by Environmental Protection Agency (EPA) in US (Haymore & Odom, 1993;

Medallion healthy air, 2002) as it accounts for half of all illnesses that are reported. Moreover, in the United States up to 60% of the population is affected by poor IAQ and this is a major cause of employee absenteeism (‘‘Germguard’’, 2002) and this in turn reduces work productivity (Pearson, 2002). It is estimated that lost employee productivity costs United States $41.4 billion annually Haymore and Odom (1993). In another United States study carried out in 1997 by Department of Energy and Lawrence Berkeley National Laboratory (reported by Solberg, 1999) $12 - $125 billion was lost annually due to reduced employee productivity. According to ASHRAE (Office of IAQ and productivity, 1999) nearly $60 billion are annually lost by American business as a consequence of decreased productivity resulting from poor IEQ.

As expected, good IAQ improves employee productivity (Fisk, 2002; Heerwagen, 2002; Indoor air study, 1993; Pearson, 2002). Using sickness records provided by employers, a manufacturer of interior environments (CenterCore Inc.) conducted a baseline case study on IAQ and employee productivity and suggested that when air quality improved by 94%, there was a concomitant increase of 40% in employee self-reported productivity (Indoor air study, 1993). Pearson (2002) also reported that productivity could be increased by 6% to 7% when air quality improved. Fisk (2002) also reported that better IAQ promotes employee productivity that potentially saved employers $20 - $160 billion.

Several studies have pointed out the benefits of improved IAQ to building architects, designers, owners, and occupants (Fisk, 2002; Heerwagen, 2002; Monroe, 2002; Solberg, 1999). It is estimated that 50 – 70% of IAQ issues are related to design, operation, and/or maintenance of the building HVAC system (Spicer, 1997) estimated at 50% to 70% of IAQ problems.

Environmental tobacco smoke control: As a potentially major indoor particle and chemical source, Environmental Tobacco Smoke (ETS) is the second prerequisite in the IAQ category. The main aim of this is to prevent or minimize occupant, interior surface and HVAC exposure to ETS. The latest version of LEED (LEED, 2009) have changed the request for prevention of exposure to ETS "prevent or minimize". The easiest method of dealing with ETS is source elimination.

Environmental Tobacco Smoke (ETS) comprises of over 4,000 chemical compounds (including sulfur dioxide, ammonia, formaldehyde, and acrolein) that have health implications (see Eisner, 2002). ETS is also considered a Class A carcinogen by EPA and in the United States is responsible each year for 53,000 human deaths (Glantz and Parmley, 1991).

The relationship between ETS and impaired respiratory function, coronary heart disease, lung cancer and reduced breathing capacity is well known (Eisner, 2002; Mendell, et. al., 2002; Mizoue, *et al.*, 1999). For this reason laws empower public and private building owners to ban against smoking to protect nonsmokers from ETS.

Carbon dioxide monitoring: IAQ section directly addresses IAQ by requiring compliance with ASHRAE Standard 62.1 – 2007 'to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects". This standard presents a ventilation rate procedure to calculate the required amount of outdoor airflow based on occupancy and building area. This prescriptive method is specifically designed to remove CO_2 while the additional floor-based component is included to address other pollutants. The LEED rating system requires a permanent CO_2 monitoring system that provides feedback on space ventilation performance in a manner that allows operational adjustments. LEED suggests designing the HVAC system with CO_2 monitoring sensors and integrating them with the building's automation system.

Carbon dioxide (CO_2) is an excellent indicator for IAQ (Haghighat and Donnini, 1993). In adequate building ventilation the structure of accumulated air contaminates should be purged daily to reduce indoor CO_2 concentrations levels to those of outdoor air system (Bearg, 1998). .

Ventilation effectiveness: Once again the IAQ section directly addresses IAQ by requiring compliance with ASHRAE Standard 62.1 – 2007 'to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects". This standard also presents a ventilation rate procedure to calculate the required amount of outdoor airflow based on occupancy and building area. The standard assumes that all of gaseous pollutants typically found in indoor environments including volatile organic compounds (VOCs) will be sufficiently diluted. With an increased pollutant dilution rate as a goal, LEED Certification encourages designers to include additional supply of outside air when compared to the minimum ventilation requirements.

Buildings with inadequate ventilation systems have poor IAQ that affects occupant heath (Mendell *et al*., 2002). The Architects' Perceptions of LEED (Hepner *et al*., 2006) states that Institute on Safety and Health found that 53% of reported cases of sick building syndrome are caused by inadequate air ventilation. Indicators of sick building syndrome are eye irritation, headaches, and upper and lower respiratory ailments that are estimated cost U.S. employers $20 to $70 billion annually (Mendell *et al*., 2002).

Numerous studies have shown that inadequate ventilation systems negatively affect employee health, well-being, and productivity (Bearg, 1998; Fisk, 2002; Hedge *et al*., 1993; Kumar & Fisk, 2002; Mendell *et al*., 2002; Solberg, 1999). The main symptoms of an inadequate ventilation system are normally respiratory illness (Fisk, 2002) and buildings with higher ventilation rates show a 35% reduction in respiratory illnesses. The productivity gains estimated for decreasing respiratory illness alone range from 6 to 14 billion dollars. A review of 500 studies by the National Contractors demonstrated that if ventilation was improved by 2%, the return on investment for productivity alone would be $6.50 per square foot annually (Solberg, 1999).

2.2.2. Construction IAQ management plan, during construction, and before occupancy

Factors that affect the indoor environment include the design, material and contents of a building and according to Mendell and associates (2002) the following building practices impact on the indoor environment quality and occupant health: ‘‘(a) construction, commissioning, operation, maintenance, renovation and repair of the building, and ventilation system; (b) selection of materials in buildings and ventilation systems; and (c) protection of occupants from contaminants produced during construction and renovation’’. The intent of the LEED Construction IAQ Management Plan during construction is to maintain adequate air quality and hence the health and comfort of construction workers and building occupants during renovations (USGBC, 2002).

Many potential IAQ hazards are associated with construction and specific examples are keeping ETS out of the building no matter the phase of construction, protection of materials from moisture and keeping IAQ levels comfortable for current occupants during renovation. For this purpose one needs to develop and implement an IAQ Management Plan that concentrates on pre-occupancy. The IAQ Management Plan should include a minimum of two weeks to flush-out or a baseline IAQ test following EPA standards.

Low-emitting materials: Apart from moisture and mold concerns building enclosure and interior materials can potentially release VOCs into indoor environment. A recent EPA (2003) study provided the benchmark "Building Assessment Survey and (Base) case studies that established a database for 100 buildings that resulted in three databases: environmental measurements, occupant questionnaires and building survey. This data allowed linking of IAQ to human health outcomes and as an example demonstrated effect of VOC concentration on mucous membranes (Apte and Erdmann, 2002).

Many carpets, paints, adhesives, and other interior products emit extremely harmful volatile organic compounds (VOC's) such as formaldehyde that can be damaging to those directly in the area. Other sources of VOC's include ventilation systems, irritating aerosols, cleaning products, new computers, photocopiers, printers, and fresh paint. The symptoms normally associated with VOC emissions are similar to those associated with sick building syndrome (Mendell et al., 2002).

The intent of the LEED standard related to low-emitting materials is reduction of indoor air pollutants thereby improving health and safety of occupants. For adhesives and sealants, LEED requires that the VOC should be less than the current VOC content limits of South Coast Air Quality Management District Rule #1168. LEED also requires that all sealants that are used as fillers must meet or exceed the requirements of the Bay Area Air Quality Management District Regulation 8, Rule 51. In the paints and coating section, LEED specifies that all

VOC emissions from paints and coatings should not exceed the VOC and chemical component limits of Green Seals' Standard GS-11 requirements. Carpets must meet or exceeding the requirements of the Carpet and Rug Institute's Green Label Indoor Air Quality Test Program. The last item of the Low-Emitting Materials section specifies that composite wood cannot contain any added urea-formaldehyde resins (USGBC, 2002).

Indoor chemical & pollutant source control: The goal of LEED credit for Indoor Chemical and Pollutant Source Control (IEQ 5) is to minimize occupant exposure to potentially hazardous chemical pollutants. However, this credit does not cover the use of "Cleaning products" as these issues are not concerned with the building design phase but the operation and maintenance phases. Pesticides are also commonly found in indoor environments and in LEED these are a part of two different credits for operation and maintenance in buildings. The credits are "Integrated Pest Management, Erosion Control and Landscape Management Plan" and "Green Cleaning: Integrated Pest Management". Since pesticides are designed as toxic substances to kill pests, they will impact on human health and cause nervous system, endocrine system, skin and eye problems (EPA, 2010).

More than 3,000 pollutants contribute to the problem of contaminated indoor air (The Medallion Healthy Air of Texas, 2002). According to EPA, indoor air may be two to three times more contaminated than the outdoor air poor IAQ may cause or aggravate up to 50% of all illness. Effects of contaminated air include eye, nose, and throat irritation, headaches, dizziness, and fatigue. Controlling the quantity of indoor chemical and pollutant sources will improve IAQ and thereby provide occupants with a healthier environment, reducing illness and improving productivity that ultimately saves money (Medallion et al., 2002).

Strategies to comply with the LEED rating system (USGBC, 2002) must minimize pollutant cross-contamination. Design requirements include: (a) designating a permanent entryway system, (b) where chemicals are used, providing a separate area with deck to deck partitions, and an outside exhaust, and (c) providing drains that are appropriate for the disposal of liquid waste.

Controllability of systems: The Controllability of Systems section of the LEED Green Building Rating System is separated into two parts, perimeter spaces and non-perimeter spaces, with the intent of providing individual occupants or groups with a greater control of thermal, ventilation and lighting systems. (USGBC, 2002). Standards address the need for operable windows and lighting control zones within 15 feet of the building perimeter. LEED also specifies that in non-perimeter spaces, at least 50% of occupants should be provided with controls for individual airflow, temperature, and lighting. Some of the design strategies suggested by LEED include task lighting and under floor HVAC systems with individual diffusers.

Thermal comfort: The moisture content in indoor environment is important for thermal comfort and three criteria including controllability (IEQ 6.2), design (IEQ 7.1 and verification (IEQ 7.2) comprise ASHRAE Standard 55 – 2004 that defines air temperature and velocities, mean radiant temperature and humidity levels acceptable to building occupants. The occupants' local thermal comfort is expressed by draft, vertical air temperature differences, radiant temperature asymmetry, and surface temperature of the floor (Olesen, 2000). The unwanted heating or cooling of a specific body part often causes thermal dissatisfaction. Temperature difference can impact the speed or accuracy of workers in tasks such as typewriting and reading speed by 2% to 20%. (Fisk, 2002)

Daylight and views: Day-lighting allows buildings to benefit from sunlight that promotes occupant health and performance while reducing energy demands (Fisk, 2002; Leslie, 2002; Monroe, 2002). According to Leslie (2003) the improved occupant performance is due to ''elevated levels of melatonin, the hormone responsible for regulating the body's internal clock or rhythm, and is influenced by exposure to light. Day lighting and views are intended to provide building occupants with a link between the indoor environment and the outdoors (USGBC, 2002). There are two day lighting sections: (1) daylight for 75% of spaces and (2) views for 90% of spaces. To meet the requirements of the first section, a minimum daylight factor of 2% in 75% of all spaces occupied must be provided. In the second section, a direct line of sight in 90% of all regularly occupied spaces should be implemented. Some of the strategies that LEED suggested are considering building orientation, increased building perimeter, exterior and interior permanent shading devices, and maximum view opportunities.

2.2.3. The HVAC system

The main role of HVAC system is to provide a comfortable indoor environment for building occupants. The level of satisfaction with the HVAC operation can be measured through thermal comfort, indoor air quality (IAQ), and perceived air quality (PAQ). The proportion dissatisfied with the perceive air quality (PDPAQ) is a good predictor of productivity loss due to IAQ in different kinds of office work (Fauchoux, 2007). The amount of energy consumed by a HVAC system can be as high as 70% of the total building energy (Fauchoux, 2007). Therefore, energy savings in HVAC system will strongly impact on the overall performance of the building in terms of energy consumption. The design of HVAC system, operation and maintenance has effect on both the occupants' health and building's energy consumption levels.

Air filters: Air filters are an integral component of air conditioning systems and they work by blocking the entry of particulate matter (PM) into the buildings. The rates at which air-handling units become dirty have cost implications. However, these air filters need regular replacement to keep the HVAC system at optimal performance level (Beko, 2009). Furthermore, presence of used filters in HVAC systems has an adverse impact on the perceived air quality (PAQ), sick building syndrome symptoms and performance of office workers. (Wargocki, 2002; Mendell, 2008; Apte, 2000). An estimate of the aggregated benefits and cost of particle filtration from a social perspective predicts a 1% loss of productivity over 75% of the filter's lifetime (Beko, 2008). Replacement of air pre-filters in an office building with new ones increased productivity of office workers by 5.7% (Wyon, 2000). A similar study investigated work productivity in a call center. Outdoor air supply rate and supply air filters quality were shown to influence the workers' talk-time by as much as 10% (Wargocki, 2004). Other studies have established that employees with adverse health conditions (i.e. asthma, allergies and SBS) are absent more often, loose more work hours and are less productive than healthy employees (Burton WN, 2001, Newsham, 2009) and Seppänen, 1999).

Particle matter in IAQ depends on environment and human activity. These particle sizes are divided into three categories based on their aerodynamic diameters and include course particles with diameters from 2.5 to 10 microns, fine particles with diameters less than 2.5 microns, and ultrafine particles with diameters less than 0.1 microns. Ultrafine-fine size particles are the most abundant in the urban environment and $PM_{2.5}$ are up to 3 and 30 times higher than the ordinary levels during smoking and cooking, respectively. Organic carbon is the largest contributor to $PM_{2.5}$ (see Figure 5). Organic carbon contributes to bacteria propagation and spread and is an important source of secondary emissions from accumulations over hot surfaces (CO, CO_2, NO_X and NH_3)

The precise factors that contribute to the overall pollution from loaded filters are not yet clear. A few studies have ruled out microorganism as the main reason for deterioration of the air quality of used filters (Alm, 2001). Chemical reactions on the filter surface are the most likely sources of these secondary contaminants as organic compounds captured on the filter surface can react with ozone and create new oxidation products (Hyttinen, 2006) that are usually more dangerous than their precursors (Weschler, 2000; Wolkoff, 2001; Weschler, 2004 and Beko, 2009).

Epidemiological studies have confirmed that elevated particle concentrations have a positive correlation with number of deaths due to cardiopulmonary diseases and lung cancer (Dockery *et al*., 1993, Valavanidis *et al*., 2008). LEED certification for new construction addresses particles in two credits that includes “Construction Indoor Air Quality Management Plan – Before Occupancy” (IEQ 3.2) and “Indoor Chemical and Pollutant Source Control” (IEQ 5). The former credit is directed towards protection of construction workers. The latter is associated with particles in new construction. Both of these credits require building air handling units to use specific filters rated according to ASHRAE Standard 52.2 – 1999.

Design of HVAC systems: As expected, the design of HVAC systems impacts on the IAQ. Low height of outdoor air intake is associated with lower and upper respiratory symptoms, such as fatigue/difficulty concentrating, headache, and skin symptoms (Mendell, 2008). System maintenance is also a critical factor (Seppänen, 2004). Poorly performing humidification systems are associated with increased upper respiratory symptoms, fatigue/concentration difficulty, eye and skin symptoms, and headache. Dirty cooling and condensate drip pans are associated with different symptoms – lower respiratory symptoms and headache (Mendel, 2008). Therefore, HVAC designs that meet green building certification standards do not guarantee good IAQ (Niven, 2000).

The operation of the air-conditioning systems is also critical as it has been established that the quantity of reactive organic compounds on the filter surface increases during non-operating intervals. Under static conditions the rate of desorption of organic compounds from the filter surface decreases and the filter acts as a reservoir for these products. Desorption rate increases when the system is running. . The implication of this is that in case of intermittent operation of ventilation systems the air flow through the filters should be restarted ahead of time to purge odorous pollutants prior to occupancy (Beko, 2009).

PAQ and SBS symptoms: PAQ and SBS symptoms have been assessed for individuals exposed to indoor pollutants while performing simulated office work. The subject-rated acceptability of the PAQ in the office corresponded to 22% dissatisfied when the pollution source was present and to 15% dissatisfied when the pollution source was absent. In the former condition there was a significantly increased prevalence of headaches and significantly lower levels of reported effort during the text typing and calculation tasks, both of which required a sustained level of concentration. In the text typing task, subjects worked significantly more slowly when the pollution source was present in the office typing 6.5% less text than when the pollution source was absent from the office (Wargocki, 1999). In another study the performance of four simulated office tasks improved monotonically with increasing ventilation rates, and the effect reached formal significance in the case of text-typing. For each two-fold increase in ventilation rate, performance improved on average by 1.7%. (Wargocki,, 2000).

Air conditioning system innovation: Twofold benefits can be achieved by Innovation in the AC system. Introducing energy wheels (enthalpy wheel) can improve energy recovery by reducing the size of the HVAC system and thereby amount of energy consumed. Introduction of the energy wheel can cut down energy consumption by 2%. This approach is not universal since the energy savings depend on the geographical location. A recent study evaluated wheel enthalpy performance in different geographical locations such as Saskatoon, Phoenix, and Tampa and reported benefits from introduction of energy wheels. However no benefits occurred in a facility located in Vancouver. The life cycle costs were lower for Saskatoon, Tampa and Phoenix by 4%, 6%, and 6% respectively. Payback periods were also reduced with immediate payback in Saskatoon, and payback periods of 0.5 and 0.4 for Tampa and Phoenix respectively. Enthalpy wheels also remove contaminants from the air and they have helped lower cross-contamination from 4-6 % to 0.04%. (Kosonen, 2004)

2.3 Building design and human health

According to a recent review (Fisk, 2000) the three categories that impacted on IEQ were communicable respiratory illnesses, allergies and asthma and SBS.

Communicable respiratory diseases: Strong evidence suggests that building characteristics and indoor environment are correlated with the occurrence of respiratory diseases (Fisk, 2000) and building characteristics can contribute to the number of aerosols containing virus or bacteria, (e.g., droplet nuclei from coughs and sneezes). In this regard the following building characteristics are important:

- efficiency or rate of air filtration;
- rate of ventilation (air supply per occupant);

- amount of air recirculation in ventilation systems,
- separation between individuals (occupant density);
- air temperature and humidity and
- Mold levels since molds increase susceptibility to illness.

From this it follows that relatively simple building technologies may theoretically reduce exposure to aerosols and these include:

- increased ventilation;
- reduced air recirculation;
- improved air filtration;
- ultraviolet disinfection of air;
- reduced space sharing (e.g., shared office) and
- reduced occupant density

Allergies and asthma: Allergy symptoms are triggered by allergens present in indoor air and those that originate from house dust mites, pets, fungi, insects, and pollens (Committee on Health Effects of Indoor Allergens 1993). As reviewed by (Fisk, 2000), good evidence exists to support the fact that building characteristics and indoor environment cause allergy and asthma symptoms. The building factors that are associated with asthma and allergic respiratory symptoms include moisture problems, indoor tobacco smoking, house dust mites, molds, cats and dogs, and cockroach infestation (Committee on the Assessment of Asthma and Indoor Air 1999, Committee on Health Effects of Indoor Allergens 1993). There are three potential ways of reducing allergy and asthma simples through changes in buildings and indoor environment and they involve:

- controlling indoor sources of agents causing symptoms (e.g. restricting indoor tobacco smoking to designated separately-ventilated areas);
- using air cleaning systems or increased ventilation to decrease the indoor airborne concentrations of the pollutants and
- Modifying the buildings in the ways indicate above that will reduce viral respiratory infections among occupants.

2.3.1 Sick building syndrome: SBS symptoms include irritation of eyes, nose, and skin, headache, fatigue, and difficulty with breathing. Other psychosocial factors such as job stress may also influence SBS symptoms. The main building factors (as reviewed by Fisk, 2000) that are known to influence SBS include: types of ventilation system; rate of outside air ventilation; level of chemical and microbiological pollution; and indoor temperature and humidity. Changes that may be made to buildings and indoor air quality to reduce or prevent SBS are not well understood. Some of the responses to SBS analysis carried out so far have had serious financial implications that have included replacement of carpeting or removal of wall coverings to remove molds and changes in the building ventilation systems.

2.3.2 Building ventilation. Increased rates of outside air ventilation lead to improvements in perceived air quality, satisfaction with air quality, and health (Seppanen *et al*. 1999). However, higher ventilation rates will increase building energy use and peak energy demands.

Moisture and humidity problems. Most moisture problems are a result of water leaks in building envelopes, particularly roofs. Others come from condensation of water vapor in walls or from inadequate humidity control by HVAC systems in humid climates. The extent of mold contamination resulting from a moisture problem depends on the selection of building materials. Apart from impacting on health, moisture problems affect the thermal performance of building envelopes, increase energy use, and cause extensive materials damage requiring costly repairs. In Canada, prevalence and severity of moisture problems is poorly understood. Higher indoor humidities are known to increase house dust mite levels (Committee on the Assessment of Asthma and Indoor Air 1999). Very high indoor humidities, (e.g., above 80%) also cause growth of molds indoors (Alm, 2001).

2.4 Building rating systems

With the building industry's move to sustainability, a number of third party rating systems have been developed to certify buildings based on their environmental performance. Most countries, including Canada and India, have developed their own standards for green buildings. Examples include Building Research Establishment's Environmental Assessment Method (BREAM) in the United Kingdom; Leadership in Energy & Environmental Design (LEED) in the United States (US), National Australian Built Environment Rating System (NABERS), The BCA Green Mark Scheme was launched in January 2005 as an initiative to drive Singapore's construction industry towards more environment-friendly buildings.

The LEED building rating system was developed by the United States Green Building Council (USGBC) in 1998. USGBC released LEED Green Building

System version 1.0 in 1999. It is currently the main system in United States (US) and has been adapted to other countries worldwide. The LEED system uses a 100 – point system to designate buildings LEED certified, LEED Silver, LEED Gold or LEED Platinum. A building must satisfy several prerequisites before it can earn points. Under contract with the United States Department of Energy (DE) the USGBC developed and released the LEED Rating System version 2 in 2001. Some of the credits were changed and increased with Certificate level replacing the Bronze certification level. The credits related to water conservation were changed in accordance with the plumbing fixtures requirement of the Environmental Protection Act (EP) of 1992. The energy efficiency credits were related to annual energy cost reductions in comparison to the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) 90.1 standard. The USGBC produced the LEED Green Building Rating System for New Construction and Major renovation (LEED-NC) Version 2.1 in 2002. The same standards of comparison were retained and minor changes were made to credits associated with certification. The points required for each level of certification remained the same, 26-31 for Certification, 32-38 for Silver, 39-51 for Gold and 52-69 for Platinum (USGBC, 2002). Most recent changes to certification are contained in the USGBC 2005 document. The main change was the removal of existing buildings from new construction category and updating the energy efficiency standard to the latest ASHRAE 90.1 standard (USGBC, 2005).

The Canada Green building Council administers the LEED certification system in Canada, while the Indian Green Building Council administers the LEED – India certification system. The LEED – Canada and LEED – India systems are based on the original LEED system that rates a building using a point system. The points are earned for design features that improve overall sustainability, and include site planning, energy efficiency, water efficiency, indoor air quality, materials and resources.

Energy simulation and actual consumption

Detailed whole building performance information on "High Performance Buildings" is maintained by the DOE. In addition the National Renewable Energy Laboratory (NREL) completed evaluation on six buildings constructed in 1990s but not designed using LEED criteria (Deru et al, 2005, 2006; Griffith et al, 2005; Ples & Torcellini, 2004; Torcellini, et al. 2005). These studies were reviewed by Torcellini, et al. (2006) who demonstrated that even though all six buildings consumed energy 25-70% below code requirements all were performing significantly below simulation predictions.

The USGBC system relies on energy simulation for efficiency certification and two studies have specifically compared building utility performance with LEED submitted simulation data. Turner (2006) evaluated 11 out of 30 LEED certified buildings in Cascadia in US and determined that one building was affected by major problems with heating ventilation and air conditioning, and in the remaining five buildings the energy used was 99% of modeled predicted value. Only two of these buildings consumed more water than the predicted simulation. In contrast, Diamond et al. (2007) examined the performance of first generation LEED certified commercial buildings and found that 18 buildings averaged 27% energy savings over the ASHRAE baseline building while the Turner study mirrored actual use at 99% of the modeled values. It is noteworthy that both these studies had a small sample size.

Energy performance assessment toolkits

Energy efficiency is influenced by building age, occupancy, operations and maintenance, and equipment. 11 LEED Certified buildings in the Cascadia Region of USA were assessed by Turner (2006) where the author compared utility usage in three different metrics (design, energy use and code compliance) and found that all buildings performed better than their baseline. A recent study done in the US (Turner and Frankel, 2008) concluded that LEED buildings on average performed better than similar non LEED buildings, but one-third of LEED buildings performed less efficiently than their peers. In contrast, a study done in India showed that all four LEED facilities in Bangalore had high energy efficiency and were among the top third facilities of 26 samples for both energy efficiency metrics, though this may have been an artifact of the small sample size.

The following methods exist for energy criteria ranking and the rating of a building's energy consumption and production:

- Energy Star – Since January 1999 the Environmental Protection Agency (EPA), in collaboration with the US Department of Energy (DOE) has provided the public with a means to benchmark energy efficiency in commercial buildings. After normalizing for the most significant drivers of energy consumption, buildings with highest energy performance among the nation's top 25% (a score greater than 75 on a scale of one to 100), while also maintaining a healthy indoor environment, qualify for the ENERGY STAR label for buildings. An online software tool that makes benchmarking energy performance simple and accessible is available.(www.energystar.gov)

- LEED – Existing Buildings (EB) – Has been developed by the US Green Building Council (www.usgbc.org) in order to use as a design guideline sustainability indicator. LEED is a voluntary, consensus-based market-driven building rating system based on existing proven technology that evaluates environmental performance from a building. LEED – EB rates the environmental aspects of a building and the behavior of occupants to arrive at a final score that results in platinum, gold, silver or bronze Certificate rating.

- Energy Performance Norm (EPN) - Was developed to regulate the total energy use of commercial buildings in the Netherlands. Application of the EPN results in a single number - the Energy Performance Coefficient (EPC value) and this is comparable to the LEED rating system.
- Energy Standard for Buildings except Low-Rise Residential Buildings (ASHRAE/IESNA 90.1 – 200) - Covers the building envelope, HVAC (Heating Ventilation and Air Conditioning), water heating, power, lighting and other equipment. It offers only minimal energy standards.
- Annual Energy Use Index (AEUI) – Most common energy performance indicator that normalizes energy use by floor area.

Only half the variation in energy use between commercial buildings is due to the design of the building and its services (Baird *et al.* 1984), and the building user is responsible for the rest. The calculation of energy use for a building may be made at different levels of accuracy and complexity (Park, 2002). An energy performance assessment tool kit for existing buildings has been developed for energy audits, measures of energy performance, and tracking improvements in deterioration in building efficiency. The toolkit identifies three phases, including an energy audit, a building system audit and a system and plant audit.

New software developed within a framework of a collaborative European Union project is used for energy performance assessment for existing European Dwellings (EPA-ED - Poel *et al*. 2007). Innovative intelligent decision supporting models for identification of intervention and evaluation of energy saving measures in European existing buildings are also under development (Doukas *et al.* 2009).

Legislative and design code requirements

The design and construction of high occupancy buildings in Ontario is covered by Ontario Building Code (OBC – 2006) and this is based on the model National Building Code and model National Plumbing Code. However, compared to the model codes, OBC has more advanced energy provisions. Ontario's Green Energy Act (1997) requires the creation of a Building Code Energy Advisory Council to advice on the Code's energy provisions every five years. This means that changes to the OBC will come into force in 2012 and these will strengthen energy efficiency requirements, promote renewable energy generation and climate change adaptations.

The OBC follows internationally accepted good engineering practices related to building energy systems and these include:

- "Energy Standard for Buildings except Low-Rise Residential Buildings" (.ANSI/ASHRAE/IESNA 90.1). For Toronto, OBC follows American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) design standards for Climate Zone 6, designated as "Zone B" in Canadian Terminology.
- ANSI/ASHRAE 62.1 "Ventilation for Acceptable Indoor Air Quality"
- Canadian Commission on Building and Fire Codes (CCBFC) "Model National Energy Code for Buildings".

Other regulations are effective when alternative energy resources are used and an example would be, "Design and Installation of Earth Energy Systems for Commercial and Institutional Buildings (CAN/CSA-C448.1)

IAQ is implied in most building codes as design and operation criteria. Building codes in Canada refer to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 62.1-2004 "Ventilation for Acceptable Indoor Air Quality (1999 version).

<u>Building costs and benefits</u>

In the United States the EPAct (1992) requires the federal authorities to determine the cost of efficient design features that will provide benefits in less than 10 years. This requires determining both the cost and benefits of sustainable design.

The review of literature indicates a few studies that have tried to quantify costs and benefits of sustainable design although there are no conclusive studies available. Three state-owned buildings were studied to determine the projected costs and benefits if modifications were made to achieve LEED Certification (Lee et al. 2000) and the authors concluded that the final costs would have increased up to 2% and most of the benefits would be associated with increases in worker productivity. A similar report was created for the State of California on 33 sustainable design buildings (Kats *et al*. 2003) that made several conclusions on the cost premiums for achieving LEED Certification and net present value of the resulting benefits. The average Green Cost Premium was 1.84%. The productivity and health benefits accounted for 70% of the net present value of Silver LEED Certification while utility savings represented only 12%. In comparison, 82% of the net present value of Gold or Platinum LEED Certification was the result of health and productivity benefits and energy savings accounted for 9% of the value. Even though the sample size is small, the trend suggests an increasing trend in cost premiums associated with higher LEED Certification. Interestingly, all 33 buildings were either designed to LEED standards or registered for certification but only five actually achieved the LEED certification (Kats et al. 2003, Certified Project List, 2007). A report released by DOE (2003) that included a hypothetical 20,000 square foot building constructed in the State of Maryland described why sustainable design in construction made business sense, supported the findings of Kats et al. (2003). In this document utility savings from the use of energy efficient designs and emissions accounted for 12% and 4% respectively with a majority of the benefits (75%) coming from incorporation of design features that minimized costs associated with personal turnover and work area layout (DOE, 2003).

The GSA contracted Steven Winters Associates (2004) to conduct a cost study on achieving LEED certification for a new construction building and a major renovation to determine whether 2.5% facility budget authorized for buildings seeking LEED Certification was an effective policy. The authors estimated that the premiums increased from 0.4 to 8.1% savings for low Certified to Gold Certificate. A recent studies of the LEED building rating system done by doing a credit-by-credit cost analysis (Mattheissen and Morris, 2004, 2007) and comparison of 138 and 221 LEED (N= 45, N= 83) and non-LEED buildings reported that cost premiums to achieve LEED Silver, Gold and Platinum Certification were similar to those reported by Kats et al (2003) and ranged from 1– 0.3%.

Water conservation

The reduction of water consumption and protection of water quality are key indicators of sustainability. The World Building Design Guide (http://www.wbdg.org/design/conserve_water.php) estimates that in United States expenditures for water and sewer range between 0.5 – 1.0 Bullion dollars. For this reason there is a need for facilities to increase their dependence on water that is collected, used, purified or reused on site.

LEED Certification Credits are currently aimed at water use reduction and use of waste water technologies. No prerequisites exist for this category and use of high efficiency irrigation technology, rainwater use for irrigation and use of high efficiency plumbing fixtures provide up to five points. Only the last category is applicable to high occupancy buildings. Emerging technologies that include increased grey water recovery and use, rain water harvesting, low irrigation green roofs, and other emerging green water strategies also need to be included in the overall grading system. There will also be a parallel need to recommend enforceable building code changes to encourage the use of these new technologies in designing new Green Buildings.

Impact of indoor environment quality on sick building syndrome

People in developed and developing countries spend 90% and 70% of their time indoors (Jones, 1999) and for this reason increasing attention is being paid towards understanding and improving IEQ since it is known to impact on human health. In India, people spend more time indoors in very hot or cold climates. Therefore, occupant exposure to airborne materials is closely related to indoor pollution (Dales *et al.*, 2008). The components of IEQ include physical environment (temperature, humidity, noise, work station design), chemical environment (chemical and biological agents), and social environment (management and organization of work). Elements of physical and chemical environment contribute to the overall internal air quality (IEQ). The IAQ contains high levels of outdoor pollutant levels, pollutant sources and sinks and movement of air between the building's exterior and interior (Burrows *et al.,* 2008). As a consequence the importance of human exposure to air pollutants has shifted from outdoor to indoor (Hui, Mui and Wong (2007). For this reason an assessment of IAQ is critical for developing IEQ control strategies for acceptable environment. IAQ is becoming an important occupational health and safety issue.

International standards for attaining appropriate IAQ have been established by Canada, Japan, Korea, Singapore, Sweden, UK and USA (Crandall and Sieber, 1996; Malkin, Wilcox and Sieber, 1996; Sietz, 1988; USEPA, 1991 and WHO, 2000).

Previous work on IEQ was mainly concerned with indoor air contents (aerosols, chemicals and particles) and comfort factors (temperature, air flow and humidity; Samer *et al.*, 1998). Currently, researchers are more interested in investigating the complex interrelationship between the built environment and occupant's (their role in the environment) and an array of physical, chemical and design factors (Mitchell *et al.*, 2007). A key reason for this shift is the fact that there is now both an increased awareness and concern that sustainable green design and human well-being are both integral elements of the building performance. This fact is supported by a recent review where up to 60% of US office workers chose improving air quality as the thing they would most like to improve (Obesity, Fitness and Wellness Week, Atlanta April 16, 2005).

The terms SBS, tight building syndrome and building related illnesses (such as nausea, skin irritation and allergies) are used describe the relationship between poor IAQ and wellbeing. However, the symptoms of SBS involve an array of little understood sensory reactions and this makes diagnosis very difficult (Berglund and lindvall, 1986). It has been demonstrated that SBS symptoms are influenced by sex, allergy, job nature, psychosocial factors and room parameters (Sundell, 1996). General SBS symptoms that have so far been recorded include eye irritation, blocked nose and throat, headache, dizziness, sensory discomfort from odors, dry skin, fatigue, lethargy, wheezing, sinus and skin rash (WHO, 1984). Hedge (1996) demonstrated that IAQ complaints and SBS are a product of many complex issues that are started by several stressful entities that cause personal stress. The term SBS defines acute health effects that are experienced by building occupants and are linked to the time spent in buildings and for which no specific illness or underlying condition may be identified (Sterling *et al.*, 1985). Acceptable IAQ is the air that has no known contaminants at harmful concentrations and when 80% of the people exposed to this air express satisfaction with it (ASHRAE, 2001).

2.5 Gaps in research

The LEED Rating Certification System has been very effective in mobilizing the green building industry. However, it has been challenged for its lack of scientific robustness, especially in regard to lack of credits dealing directly with practices that influence climate change (Stein And Reiss, 2004), and incorporating newer emerging technologies for building automation, reduction of carbon footprint and impact on public health. In parallel and directly related to the LEED Certification System is the urgent need for a thorough review of building codes and municipal by-laws on ways in which these can be enforced.

LEED focuses on impact and thereby rewards incremental solutions but fails to recognize step-change or paradigm-shifting advances. As an environmental rating system LEED does not specifically deal with economic or social issues (Zimmerman and Kilbert, 2007). The performance of sustainable technologies in buildings is not assessed in totality and evaluated only from single issue perspective, either financially or environmentally. Such an approach ignores the interaction of technologies, within the physical building itself as expressed through life cycle costs, impact on surrounding environment, design objectives of the project and conflicting interests of stakeholders (Nelms *et al*, 2005).

Both in Canada and India the builders satisfy the minimum requirements for LEED certification to assist in their marketing and property evaluation appreciation. However once the building is commissioned there are no mandated regulatory requirements or incentives for further periodic audits for performance and comfort, that are critical for high occupancy buildings with long life cycles. The research will attempt to analyze and recommend methodologies to add relevant continuing or alternate credits in recognition of updated energy systems to suit new technologies, building automation mechanisms, advanced measurement processes, infrastructure enhancement, post-construction innovation and periodic audits for health and sustainability.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Objectives

The topic of this thesis is "Development of Post-LEED Energy Management and Sustainability System Audits for High Occupancy Buildings". It will have the following objectives:

1. To review the current status of green building certification systems and the impact on human health and quality of life.
2. To evaluate the LEED Certified green buildings in Canada and India based on credit distribution in various categories with specific emphasis on IEQ in the context of Health and Comfort of occupants in High Occupancy Buildings.
3. To survey building occupants with Health & Comfort questionnaire and conduct an analysis to establish Performance Index measure for sustainability of certification.
4. To develop a framework for Post-LEED energy audit for sustainability of LEED certification.
5. To develop a framework to specifically address the issue of tradeoff between energy conservation and public health.

3.2 Scope of the study

The purpose of the study is to identify LEED certified buildings in new construction category (LEED – NC), specifically, limited to high occupancy buildings. The study will focus on the categories impacting health & comfort of the occupants, i.e., Indoor Environmental Quality (IEQ), Indoor Air Quality (IAQ) and Energy & Atmosphere (E & A).

Currently, buildings are responsible for 30 - 40% of global energy use as well as 30% of carbon dioxide emissions (UNEP, 2007; World Business Council for Sustainable Development, 2007). Recent studies have demonstrated that around 80 - 90% of the total energy that a building uses in its life cycle is used during operation phase for heating, cooling, lighting and other appliances (Keoleian et al, 2001; Scheuer et al, 2003 and Utama and Gheewala, 2008).

The relationship between energy conservation and public health in high occupancy buildings was evaluated and current areas of concern are noted. Selected LEED certified projects in the Province of Ontario, Canada and various states in India were reviewed to analyze the contribution of health related categories toward the certification process.

The main purpose of this study is to evaluate the effectiveness of IEQ in LEED certified buildings by comparing IEQ in relation to occupant wellbeing and provide framework for improving the IEQ standards in future design of LEED-certified buildings and recertification process.

The study will focus on the Leadership in Energy and Environmental Design (LEED) for new construction (LEED – NC) certified high occupancy buildings. LEED – NC has gone through four versions. To capture comparable energy data and the greatest number of buildings in Canada and India, this study will use buildings that were certified under LEED – NC v2.0 or v2.1 rating systems (USGBC, 2001, 2002). The new LEED Canada NC 2009 rating system applies to new construction and major renovations of buildings defined within Part 3 of the National Building Code (The National Building Code of Canada, 2005). As of

January 2012, over 3,000 projects have been LEED registered and 573 buildings are LEED certified in Canada. The equivalent rating system in India is LEED India NC v1.0 (Indian Green Building Council). As of January, 2012 there were 223 certified buildings and 1,505 buildings were registered for certification. The buildings in Canada and India will be matched according to the equivalent LEED point system, population density and area in square feet.

3.3 Grounded theory

The study also attempts to determine whether the current LEED rating systems in high occupancy LEED certified buildings in Canada and India promote wellbeing (including occupant health and comfort) of the building occupant. To understand this, the study addresses several aspects in a stepwise manner to narrow down the focus of the study. These in turn generated qualitative and quantitative data that in turn influenced other following research items. The term grounded theory has been used to describe this form of questioning and analysis (Glaser. 1995a; 1995b and 1998). In his explanation of grounded theory Glaser (1995a) points out “that in writing grounded theory methodology the goal is to empower researchers with an open, generative, emergent methodology. The goal was not to tell researchers what to find or how to force it out of the data, but to do research that allows the emergence of what is going on. This is designed to produce an integrated set of conceptual hypothesis of multivariate set of ever moving facts, which continually resolve a main concern of the participants in a substantive area.

The end product of the grounded theory is the evolution of a theory from qualitative and quantitative data generated through a systematic enquiry. This data is used to generate a prospective theory instead of using an established theory and working through deduction to prove it. Grounded theory is a method of enquiry

used by the researcher to evaluate the experiences involved in the phenomenon and attempting to explain this by identifying the key elements (Strauss and Corbin, 1975, 1990) and allowing the author to explore current LEED rating systems in high occupancy LEED certified buildings in Canada and India to see whether they promoted occupant wellbeing via exploring hypothesis, collecting data, analysis and arriving at conclusions.
Taking into account that both in Canada and India, builders satisfy the minimal LEED Certification requirements to assist in their marketing but once the building is commissioned there are no regulated requirements or incentives for further energy audits for performance and comfort, the grounded theory is a reasonable way to determine whether the current LEED rating systems in high occupancy LEED certified buildings in Canada and India promote occupant's wellbeing.

Ensuring trustworthiness is an important aspect of qualitative research and Shenton (2004) outlines Guba's (1981) constructs and points out that in addressing credibility the researcher must satisfy four criteria. For credibility the researcher tries to illustrate a true picture of the research investigation. For transferability, sufficient details must be presented for the reader to conclude that prevailing and a different situation are identical. For dependability, other investigators should be able to replicate the study. To attain conformity, researchers must show that their findings emerge from the data and not their own predispositions.

In determining whether the current LEED rating systems in high occupancy LEED certified buildings in Canada and India promote occupant's wellbeing qualitative and quantitative analysis of IAQ/IEQ and E & A categories in Canadian and Indian buildings were used to test the hypothesis that

I. “Differences exist in how the six LEED categories are used in obtaining Silver, Gold and Platinum LEED Certification”.
II. “The six LEED categories used in obtaining silver, gold and platinum certification are used differently in Canada and India”
III. “Higher certification levels do not translate into delivery of better improved building occupant wellbeing”

LEED certification is based on a point system and is adaptable to countries like India and Canada, notwithstanding the climate, location and socio-economic conditions. This study examined LEED certification in Canada & India and conducted surveys on the population of certified Green Buildings in Canada & India and to perform a comparative analysis. Canada, India and United States are the three countries in the world that use LEED rating system. This study focused on Canada and India. India has recently adopted the LEED system and all LEED certified buildings are relatively new. This provided an opportunity to study new LEED certified buildings in India and compare these with Canada (country of residence of the author) where older certified buildings are present. Since LEED rating systems used in Canada and India are similar the survey of occupant wellbeing in Silver, Gold and Platinum LEED certified high occupancy buildings was restricted to India and following additional hypothesis were explored

IV. “Occupants experience sick building syndrome (SBS) in silver, gold and platinum LEED certified buildings”
V. “There is no statistically significant difference in SBS score between silver, gold and platinum LEED-NC certified high occupancy buildings”
VI. “There is a gender bias for SBS score and percentage of SBS symptoms”

VII. “There is no difference in the occupant’s responses to satisfaction for building, thermal comfort, air quality and noise level between silver, gold and platinum LEED certified buildings”

3.4 Research approach

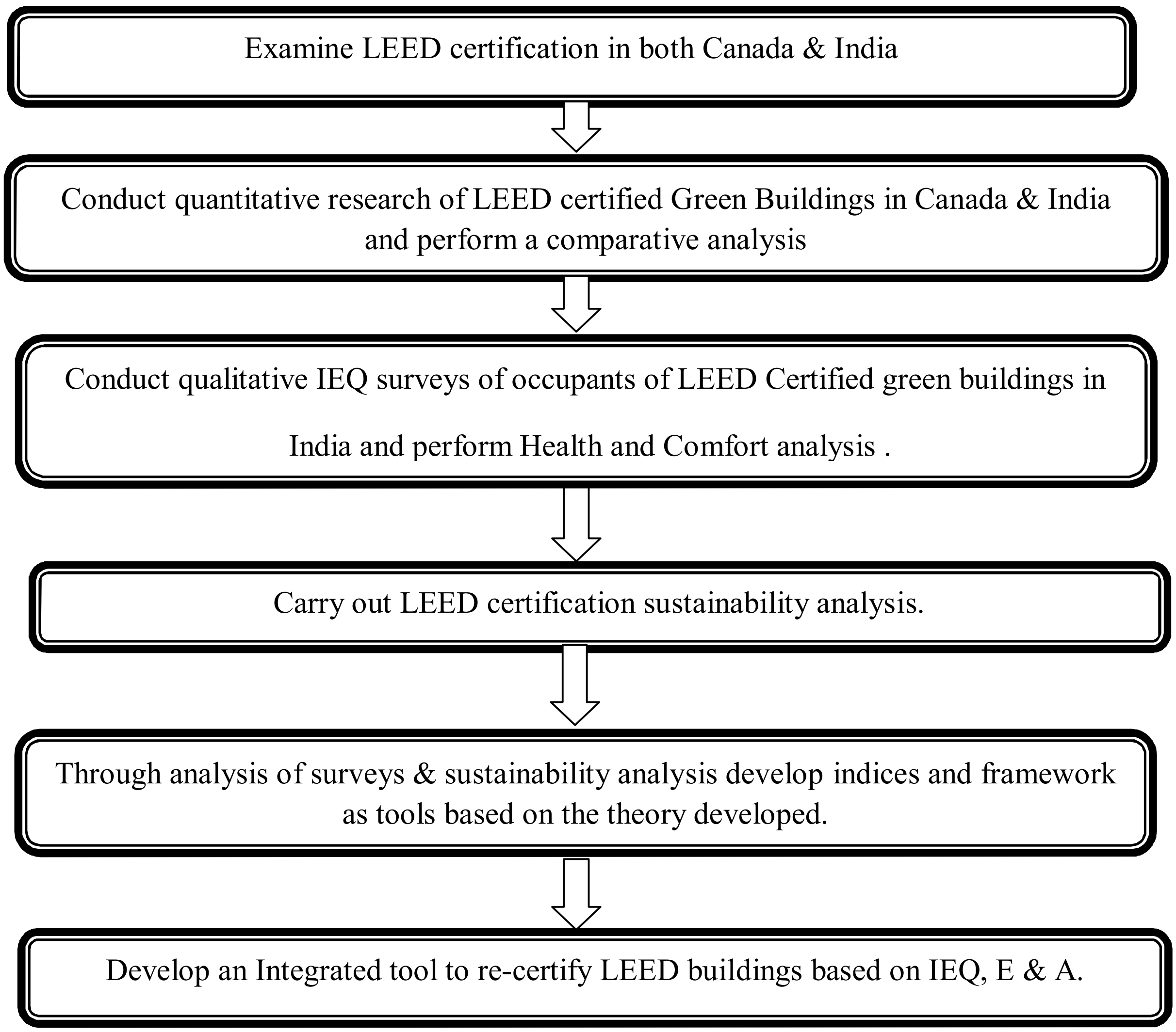
A qualitative research is best suited when the researcher wants to transform a fact or problem which has been observed, reported or registered into written words not statistical numbers. A qualitative research is based on detailed descriptions of events by people. A qualitative research is often conducted for small-scale researches due to its inability to handle a large research problem which is necessary to be solved through statistical tools.

In this thesis, quantitative research is used as the type of research approach because the nature of the study is inductive; it means that, a theory will be developed based on the data collected with the help of the surveys. In the surveys, the information collected will be recorded and analyzed, to identify conclusions for the research problem.

The aim of this thesis is to highlight the gaps in the currently used Green Building certification systems like LEED, India & Canada and GRIHA, India. Through the surveys, it is clear that IEQ has not been given adequate emphasis while certifying the buildings.

3.5 Research strategy

The flowchart depicted below presents an abstract picture of the thesis:



3.6 Sample data

A representative sampling from silver and gold LEED – NC certified high occupancy buildings will be collected and a database that includes relevant variables impacting on Indoor Environment Quality and health outcomes created.

Selected items will be included in the database to ensure that the data will provide meaningful information on contributions of various categories impacting these variables. The study will gather relevant information on indoor environmental quality from various levels of LEED-certified buildings in India and Canada. The extent to which the buildings embrace the credits within the "Indoor Environmental Quality" category towards LEED certification will be analyzed to understand the potential opportunities for addressing current energy conservation, building codes and design, and occupant comfort. Relevant literature will be reviewed and any key studies that specifically link building envelope with occupant comfort and health outcomes will be evaluated. The Canada Green Building Council (CaGBC) and Indian Green Building Council and United States Green Building Council online database of LEED-certified projects, and information from builders and designers will be used as primary source of data for this analysis. Data from LEED-certified projects will be extracted from project`s score cards and analyzed to understand the contribution of each category to the total project score.

3.7 Collection of data on IAQ and working environment

The study was done in 33 LEED certified buildings in silver (N = 5), gold (N = 16) and platinum (N = 11) categories located in various Indian cities as shown in Table 3.1. Questionnaires were issued to 314 occupants between October 2011 and January 2012. To understand the occupant's perception a questionnaire taking into account all relevant IAQ (see Appendix 1) within LEED-NC system was prepared. Different components of the questionnaire are given in Table 3.3. The main symptoms used to evaluate the SBS score included eye irritation, nose irritation, throat dryness, tiredness/lethargy, headaches and skin dryness.

3.8 Correlation among different parameters and mean SBS symptoms/person

The questionnaire responses were utilized to establish the correlation between mean SBS symptoms/person and different parameters including age, sex and perceived IEQ.

3.8.1 SBS Score

To evaluate the total levels of SBS, an integrated index – as described by Gupta *et al.* (2006) the SBS score was calculated. This score described the total number of SBS symptoms that included eye irritation, nose irritation, throat dryness, tiredness/lethargy, headaches and skin dryness. The SBS score directly indicated number of different types of SBS symptoms. As suggested by Gupta *et al*. (2006) and Seppanen and Jaakola (1989) the questions in part VI (see Table 2) asked for information about SBS symptoms that was analyzed on a scale of 0-6 (WHO, 1984). The expected answers were 'often', 'sometimes' or 'never' and these were assigned the scores of 1.0, 0.5 and 0 respectively. The questions on health were used to calculate the score prior to occupying the building ("Pre SBS Score"). The SBS analysis was restricted to five LEED NC buildings. However, responses to questions about medical condition and six SBS symptoms and signs were insufficient for platinum level LEED-NC buildings and four LEED-CS buildings were used instead.

3.9 Data analysis

Satisfaction from temperature comfort, satisfaction from IAQ, satisfaction from noise level and satisfaction from workplace were subjected to standard statistical tests, including chi square and "T" tests for paired samples to see whether any differences existed between silver, gold and platinum LEED certification levels.

In analyzing the SBS symptoms, standard statistical test chi square was used and comparison of samples between buildings with different levels of certification was done using 'T' test for paired samples.

<u>One-way ANOVA</u>

One-way ANOVA analyses were performed for LEED projects with Silver, Gold and Platinum certification levels to understand the contribution of IEQ and AE to the accreditation level obtained. For analysis of the LEED data from Canada silver, gold and platinum level projects were used. For analysis of the LEED projects from India gold and platinum level projects were used.

<u>MANOVA Analysis</u>

The multiple (two-way ANOVA) analysis will be performed for two certification levels (silver and gold) in the case of Canada, and across all six LEED categories. In both cases 5 building projects were used. The reason for this is that Excel doesn't support the analysis of unbalanced data (only four building in the case of platinum). For India the analysis will be done only for gold and platinum projects. Web based tools on the Canadian Centre for Occupational Health and safety will be used to analyze the "IAQ and Working Environment" questionnaire.

Table 3.1 Study Buildings

Sr. No	Name of Building	Level of LEED Certification	Year of Certification	Location
1	Thermax[a]	Silver	2009	Pune
2	Rajiv Gandhi Airport[a]	Silver	2008	Hyderabad
3	LOGIX CYBER PARK	Silver	2009	Noida, Uttar Pradesh
4	DUPONT[a] Knowledge Centre	Silver	2010	Hyderabad
5	CDPL[a] Creamline Dairy Products Ltd.	Silver	2010	Hyderabad
6	HITAM[a] Hyderabad Institute of Technology and Mnagement	Silver	2007	Hyderabad
7	Ishanya Mall[a]	Gold	2009	Pune
8	Symantec[a]	Gold	2008	Pune
9	Commer Zone[a]	Gold	2010	Pune
10	Fortune[a]	Gold	2009	Lavasa
11	Nirlon Knowledge Park-2[b]	Gold	2010	Mumbai

12	WIPRO-1[a]	Gold	2008	Pune
13	WIPRO-2[a]	Gold	2009	Pune
14	Nirlon Knowledge Park-1[b]	Gold	2009	Mumbai
15	Kohinoor City Mall[a]	Gold	2010	Mumbai
16	ING Vysya[a]	Gold	2010	Mumbai
17	NOKIA[b] Nokia Siemens Networks	Gold	2010	Noida, Uttar Pradesh
18	MAX[a] Max Super Speciality Hospital	Gold	2010	New Delhi
19	WIPRO[a] Fast Track Building	Gold	2009	Gautam Budh Nagar
20	UNITECH[a] Commercial Tower	Gold	2011	Gurgaon
21	ASHOK LEYLAND[a] Corporate Office	Gold	2006	Chennai
22	Express Avenue[a] Mall	Gold	2011	Chennai
23	SPACE MATRIX[b]	Platinum	2010	New Delhi

24	HCL[b] Green Data Centre	Platinum	2010	Noida, Uttar Pradesh
25	HSBC-Hyderabad[b]	Platinum	2011	Hyderabad
26	HSBC-Gurgaon[b]	Platinum	2009	Gurgaon
27	PAHARPUR[b] Business Centre	Platinum	2010	New Delhi
28	PATNI[a] Knowledge Centre	Platinum	2008	Noida, Uttar Pradesh
29	GREEN BOULEVARD[b]	Platinum	2009	Noida, Uttar Pradesh
30	Suzlon One Earth[a]	Platinum	2010	Pune
31	Kirloskar Brothers[a]	Platinum	2009	Pune
32	Hiranandani BG[a]	Platinum	2009	Mumbai
33	Kohinoor Hospital[a]	Platinum	2009	Mumbai

[a] LEED NC, [b] LEED CS and LEED EB

Table 3.2 Components of the LEED –IEQ?SBS Questionnaire

Part I	Purpose and background information
Part II	Questions about the workplace and workplace conditions
Part III	Questions about bothering factors at the workplace
Part IV	Questions about job satisfaction
Part V	Questions about rating of workplace
Part VI	Questions about medical condition and six SBS symptoms and signs

CHAPTER FOUR: DATA ANALYSIS AND RESULTS

4.1 Correlation between energy conservation and public health in high occupancy buildings in Canada

For silver, gold and platinum level LEED-certified projects the contribution of each LEED category to the total score is variable (Table 4.1). This is expected as each LEED project is unique (Fig. 4.1, 4.2 and 4.3).

The contributions of "Indoor Environmental Quality" (IEQ) and "Energy and Atmosphere" (A&E) varies for each project. This fact means that projects with a similar LEED certification level will have a different impact on the occupants` health (see Appendix 4.1: Tables 4.1 – 4.5). For instance, in LEED projects with gold and silver certification level the magnitude of contribution *of IEQ* and *A&E* categories move between 10% and 30%, respectively of the total project score.

There is higher variability in the contribution of the *Energy and Atmosphere* and *Indoor Environmental Quality* categories associated with a lower degree of LEED-certification. Intuitively we should expect less variability on the contribution of each category toward the certification level only because a higher level of certification has less room for variability (see Appendix 4.1: Tables 4.1 – 4.5).

There are differences among the more and less frequently awarded credits within the *IEQ* category (see Appendix 4: Tables 4.1 – 4.5). For gold LEED-certified projects the two credits topping the list are construction IAQ management and daylight view: daylight 90% of spaces. For silver LEED-certified projects the two top credits more frequently awarded are "*low-emitting materials adhesive and sealants"* and low-emitting materials carpets. For both levels of certification less credit is awarded within the *IEQ "controllability of system: non-perimeter spaces"*.

Comparing the two levels of certification also provides evidence of the trade-off approach in the LEED-certification process. In gold and silver level projects there is a clear trade-off between the "*daylight view: daylight 90% of spaces"* and the "*thermal comfort compliance"* and "*monitoring"* credits.

Table 4.1 Correlation analysis between certification categories in Platinum LEED Certified Projects

	Sustainable Sites	Water Efficiency	Energy & Atmosphere	Material & Resources	IEQ	Innovation & Design
Sustainable Sites	1.00					
Water Efficiency	0.78	1.00				
Energy & Atmosphere	0.72	0.93	1.00			
Materials & Resources	-0.56	-0.33	0.00	1.00		
IEQ	-0.54	0.00	-0.19	0.00	1.00	
Innovation & Design	NA	NA	NA	NA	NA	1.00

<u>Figure 4.1 Contribution of each category to *silver* level LEED certified projects.</u>

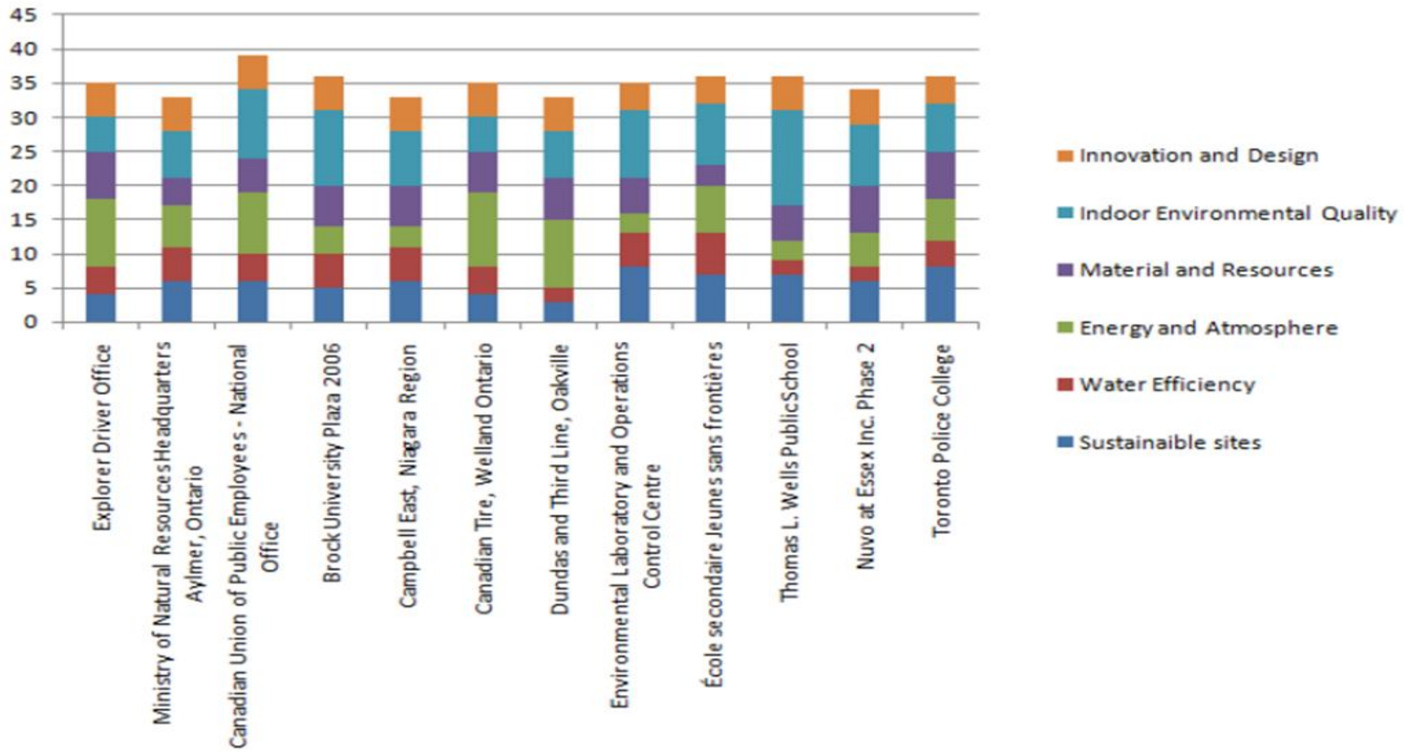


Figure 4.2 Contribution of each category to gold level LEED certified projects.

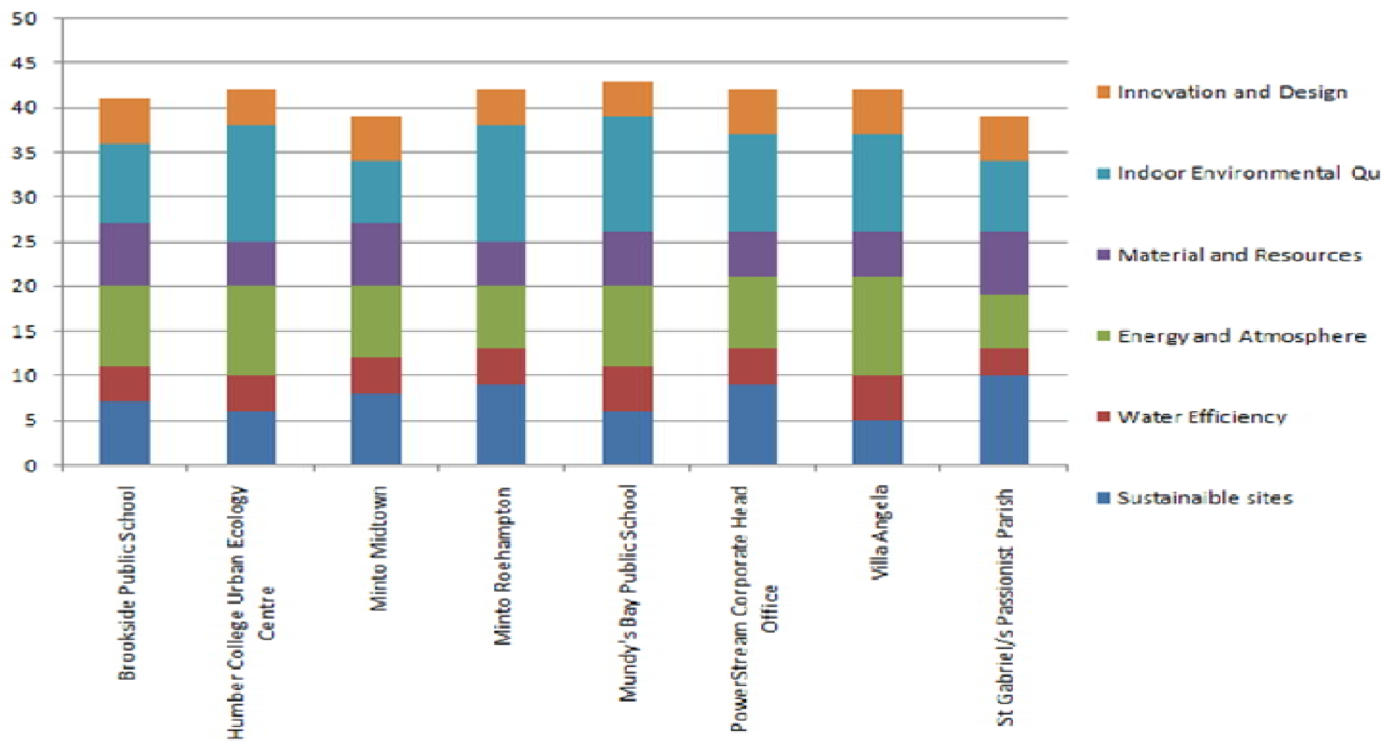
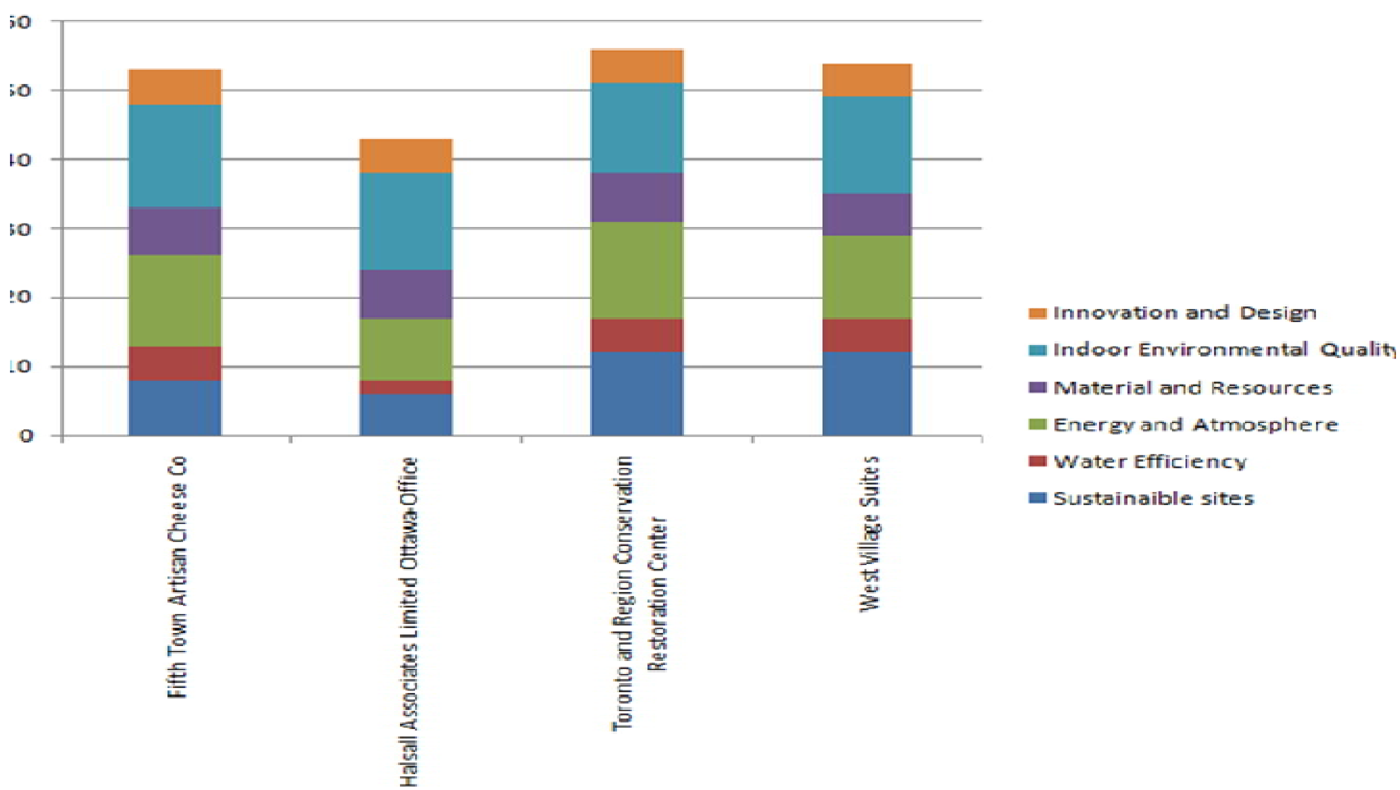


Figure 4.3 Contribution of each category to platinum level LEED certified projects



4.2 Indoor environment and productivity: An audit of LEED certified buildings in Canada and India

Buildings

A total of 24 Canadian (12 Silver, 8 Gold and 4 Platinum, see Table 4.2) and 28 Indian (8 Silver, 10 Gold and 10 Platinum, see Table 4.3) buildings were sampled.

Data evaluation

The Contribution of each category in silver, gold and platinum LEED Certified Canadian Buildings in Canada is depicted in Figures 4.4, 4.5 and 4.6 respectively. The equivalent data for five gold and platinum Indian LEED certified buildings is provided in Figures 4.7 and 4.8 respectively. The comparative data for Canadian and Indian LEED Certified buildings in silver, gold and platinum categories is presented in Fig. 4.9, 4.10 and 4.11 respectively. For silver, gold and platinum level LEED-certified Canadian projects the contribution of each LEED category to the total score is variable. It is interesting to note that in India, for gold and platinum level LEED-certified projects the contribution of each LEED category to the total score is fairly consistent. The contributions of IEQ A&E varied for each project.

It will also be evident that, for both Gold and Silver Certified buildings, the spread of credits for the same category also varied between the different buildings in Canada. An analysis of the number of times a particular credit was given for a particular category demonstrated a clear bias towards construction IAQ management and daylight view: daylight 90% of spaces or low-emitting materials adhesive and sealants and low-emitting materials carpets for both Gold and Silver Certified buildings respectively. As is also apparent from this analysis, there are country differences in the utilization of the various category credits in achieving LEED certification.

Data for credit distribution for IEQ for four silver and gold and platinum LEED Certified Canadian Buildings is presented in Fig. 4.12 and 4.13 respectively. The platinum category has only four buildings. Equivalent data for India is presented in Fig. 4.14, 4.15 and 4.16, respectively. Comparative data for Canadian and Indian LEED Certified buildings in silver and gold levels is illustrated in Fig. 4.17

and 4.18 respectively. There are differences among the more and less frequently awarded credits within the three certification levels. Comparing any two levels of certification clearly indicates a trade-off approach in the LEED-certification process. For instance in gold and silver level Canadian projects there is a clear trade-off between the "*daylight view: daylight 90% of spaces* and the *thermal comfort compliance* and *monitoring* credits".

The comparative data on frequency distribution of credits in the E&A category for silver and gold LEED Certified buildings for Canada and India is provided in Figures 4.19 and 4.20, respectively. This analysis suggests that there are significant country differences in the utilization of the various category credits towards achieving the LEED certification. The contributions of IEQ and A&E in Indian buildings were consistent at country level but different from those in Canadian buildings.

Statistical analysis

The analysis for Canada clearly show that for both E&A ($F = 8.42 > F_{crit} = 3.49$) and IEQ ($F = 8.56 > F_{crit} = 3.49$) categories analyzed there is a significant difference between the three accreditation levels Silver, Gold and Platinum. The same conclusion holds for India (E&A, $F = 10.08 > F_{crit} = 5.32$; IEQ, $F = 8.80 > F_{crit} = 5.32$) but E&A values are lower.

Two main sources of variability are the number of projects per certification level and the fact that Canadian building are from Ontario; while the data from India covers a wider geographical area.

MANOVA analysis for Canada show that when the six categories are analyzed together no differences are detected across silver and gold LEED accreditation levels and between LEED categories ($F = 2.23$; $F_{crit} = 2.56$). The opposite is true for the data from India LEED projects and a significant difference is observe across categories and projects and gold and platinum accreditation levels ($F = 36.93 > F_{crit} = 2.41$).

Table 4.2 Canadian Buildings

Silver	Gold	Platinum
Explorer Driver Office	Humber College Urban Ecology Centre	Fifth Town Artisan Cheese
Ministry of Natural Resources Headquarters	St. Gabriel's Passionist Parish	Halsall Associates Ltd Ottawa Office
Brock University Plaza	Minto Roehampton	West Village Suites
Campbell East, Niagara	Minto Midtown	Toronto and Region Conservation Centre
Canadian Tyre, Welland, On	Villa Angela	
Dundas and Third Line, Oakville	Power Stream Head Office	
Environmental Laboratory and Operations Control Centre		

Ecole Secondaire Jeunes Sans				
Silver	**Gold**	**Platinum**		**Gold**
Thomas Wells Public School				
Nuva at Essex Inc				
Toronto Police College				

Table 4.3 Indian Buildings

Silver	Gold	Platinum
Motorola Manufacturing Facility	Grundfos Pumps India	CII Godrej Green BC
The Rajiv Gandhi Intl Airport	Vimta Labs	ITC Green Centre
L&T EDRC – 1	Tamil Nadu Legislative Assembly	Wipro Technologies Development Centre
SNQZ International	General Electrics	Spectral Services Consultants
DuPont Knowledge Centre	Inspector General of Police Complex	Patni Knowledge Centre
Hyderabad Institute Technology	Anna centenary Library	Turbo Energy
Thermax Corporate House	Cement House	L & T Hazira

The World Bank	Mudra House	Suzlon One Earth
	Aquamall Water Solutions	Infosys Technologies Ltd
Silver	**Gold**	**Platinum**
	YCH Logistics Private Limited	Great Lakes Institute of Management

Figure 4.4 The Contribution of each category in 11 Silver LEED Certified Canadian Buildings

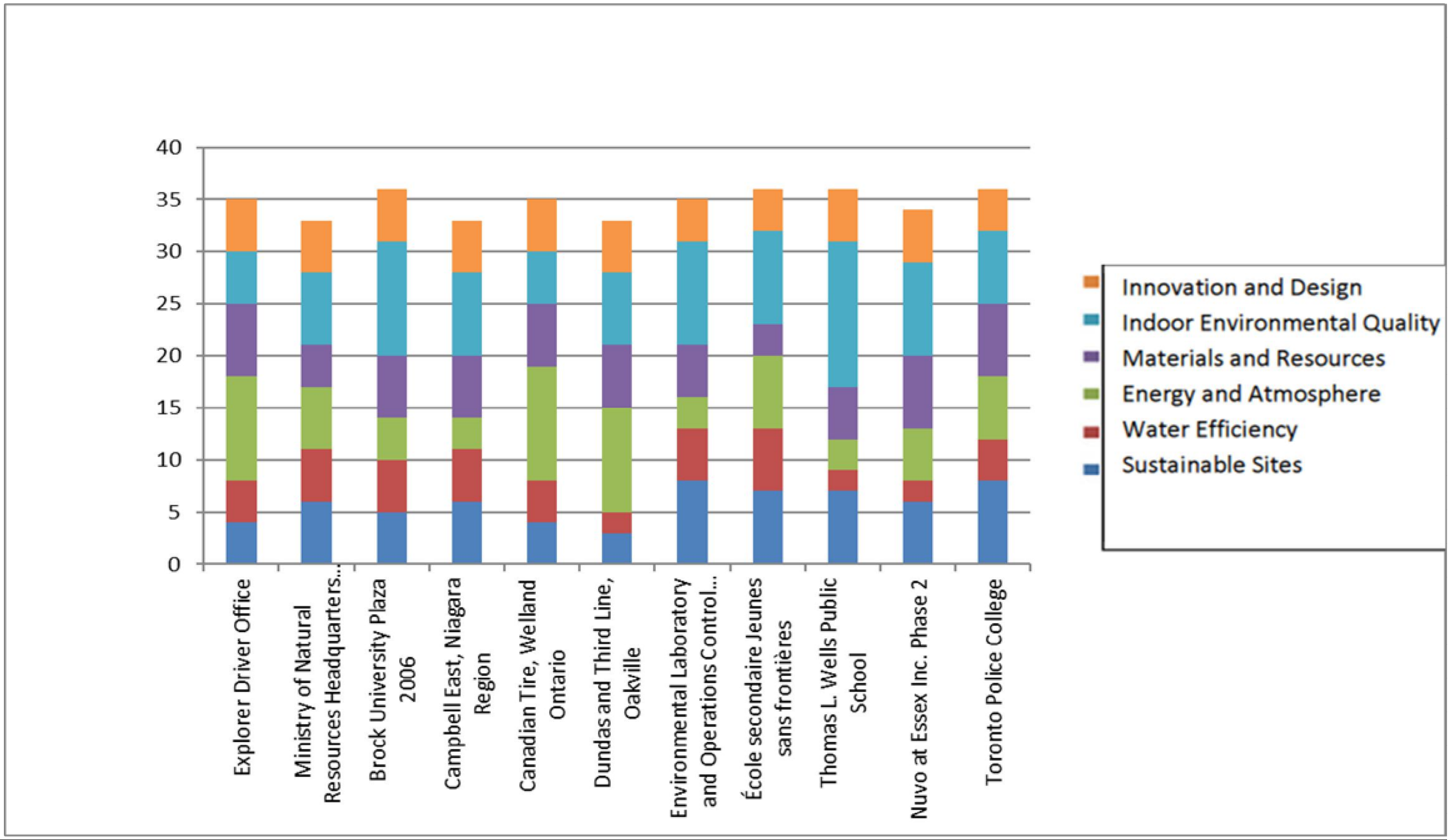


Figure 4.5 The Contribution of each category in 7 Gold LEED Certified Canadian Buildings

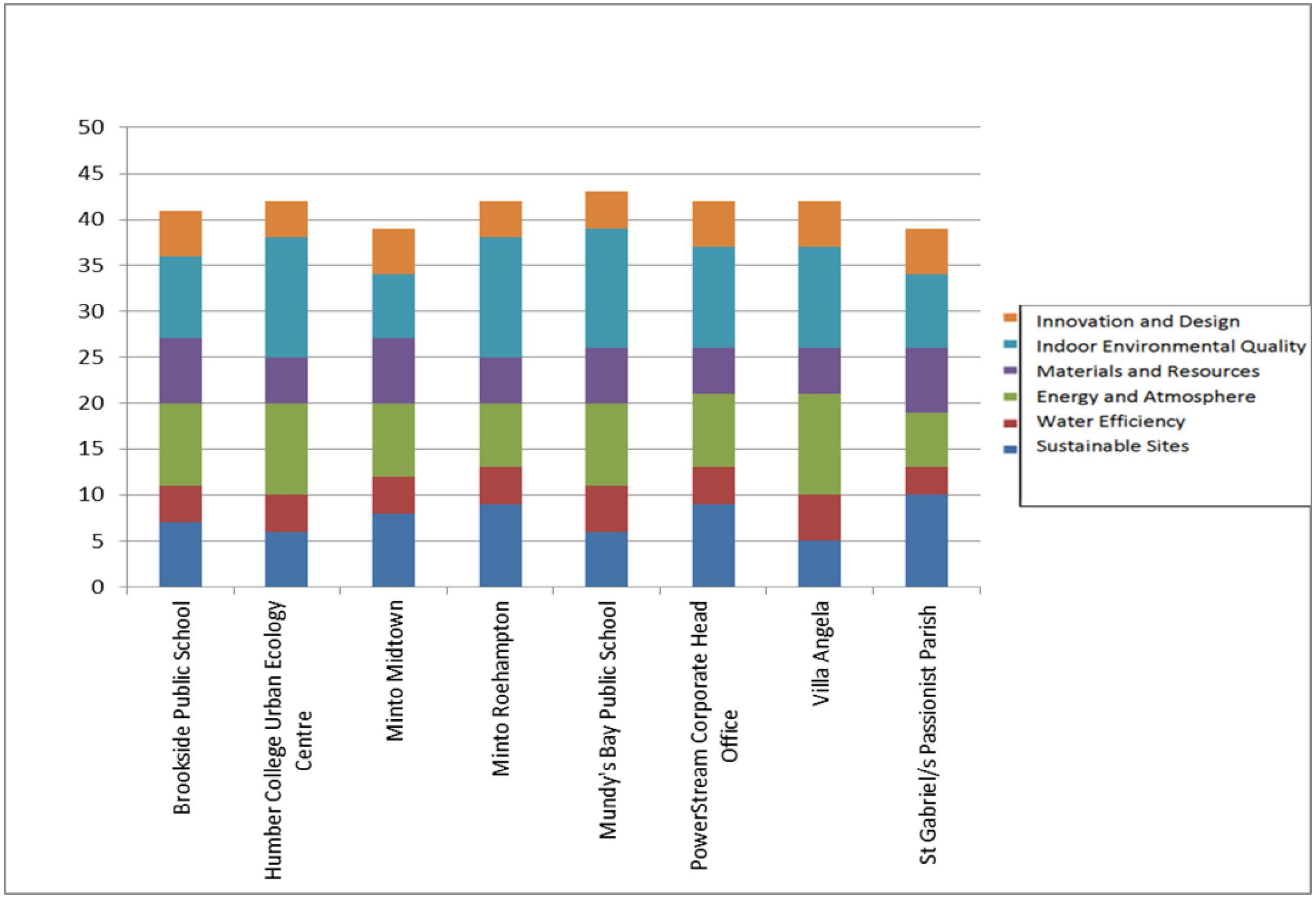


Figure 4.6 The Contribution of each category in 4 Platinum LEED Certified Canadian Buildings

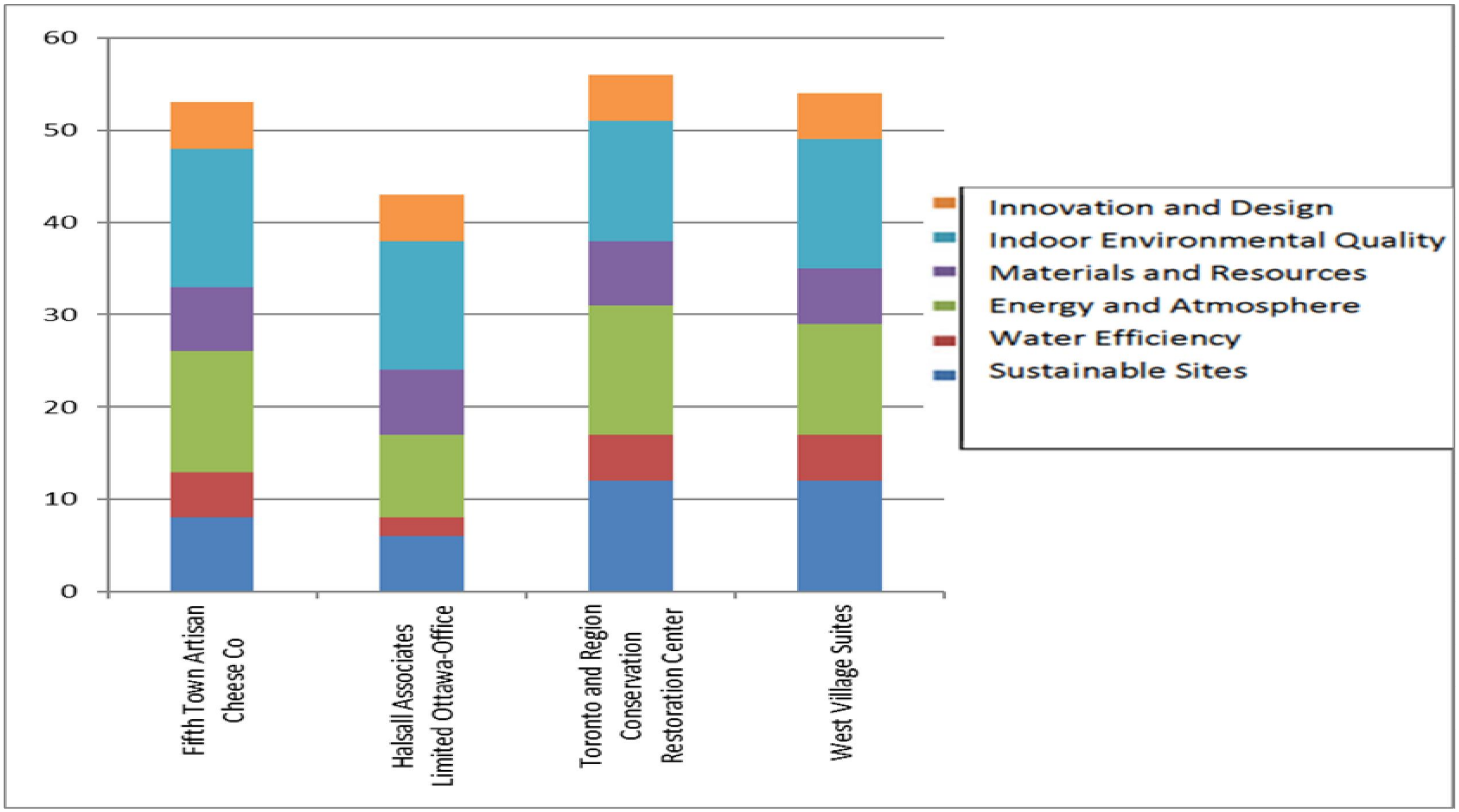


Figure 4.7 The Contribution of each category in 5 Gold LEED Certified Indian Buildings

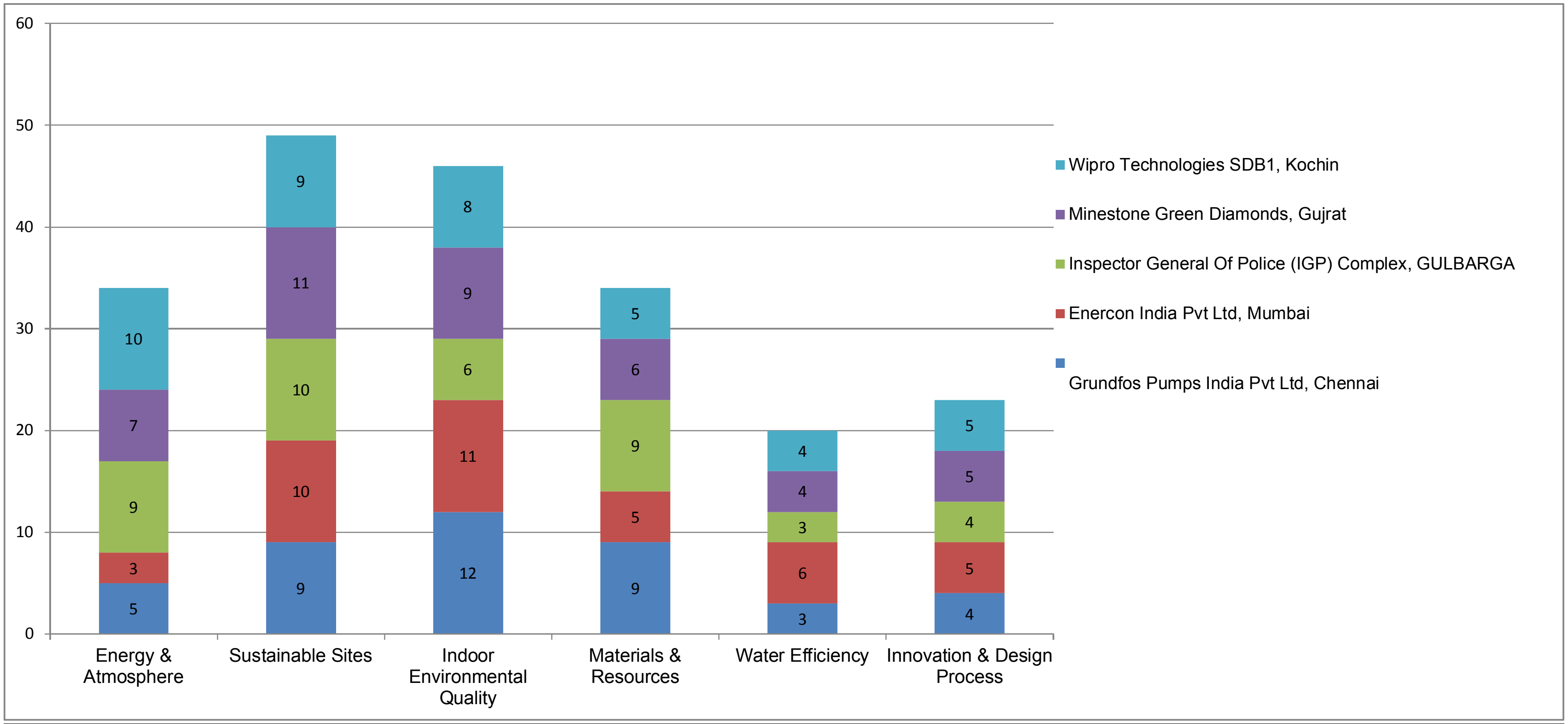


Figure 4.8 The Contribution of each category in 5 Platinum LEED Certified Indian Buildings

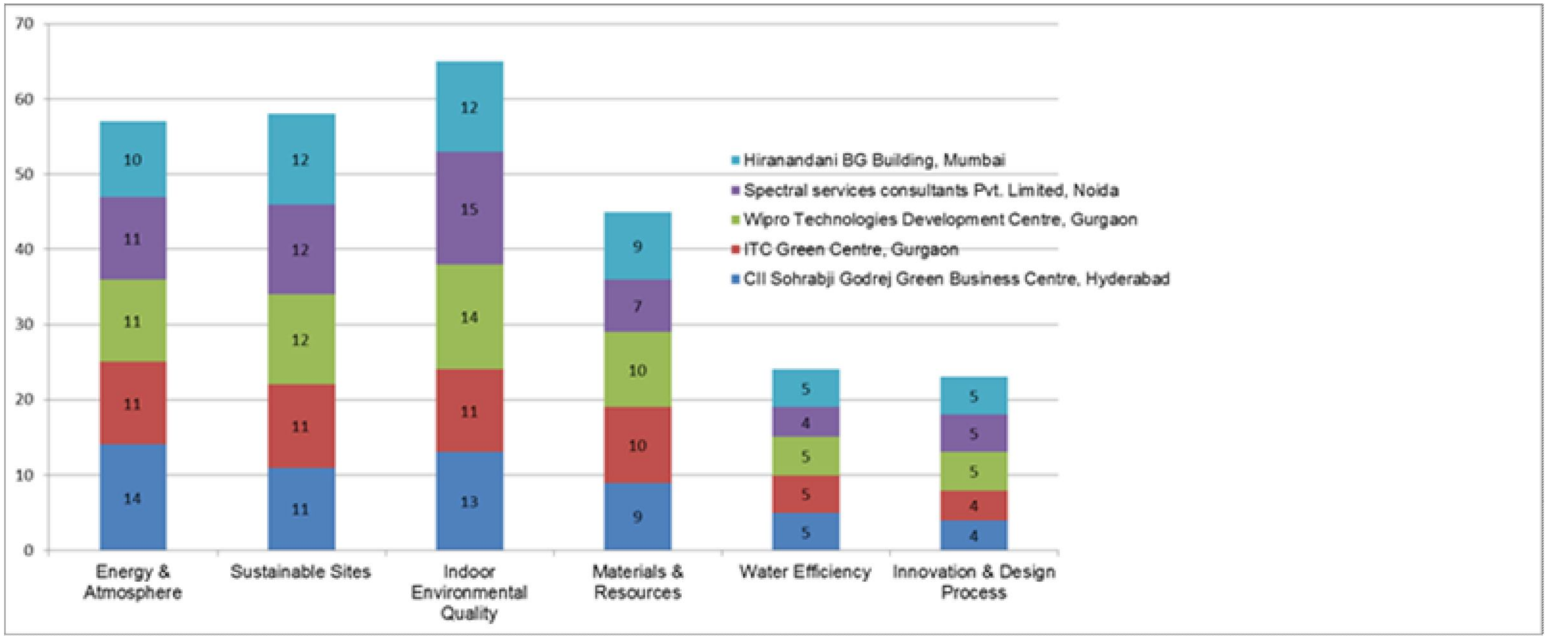


Figure 4.9 Average Value of Credits Attained in Each Category for LEED Silver Buildings in Canada and India

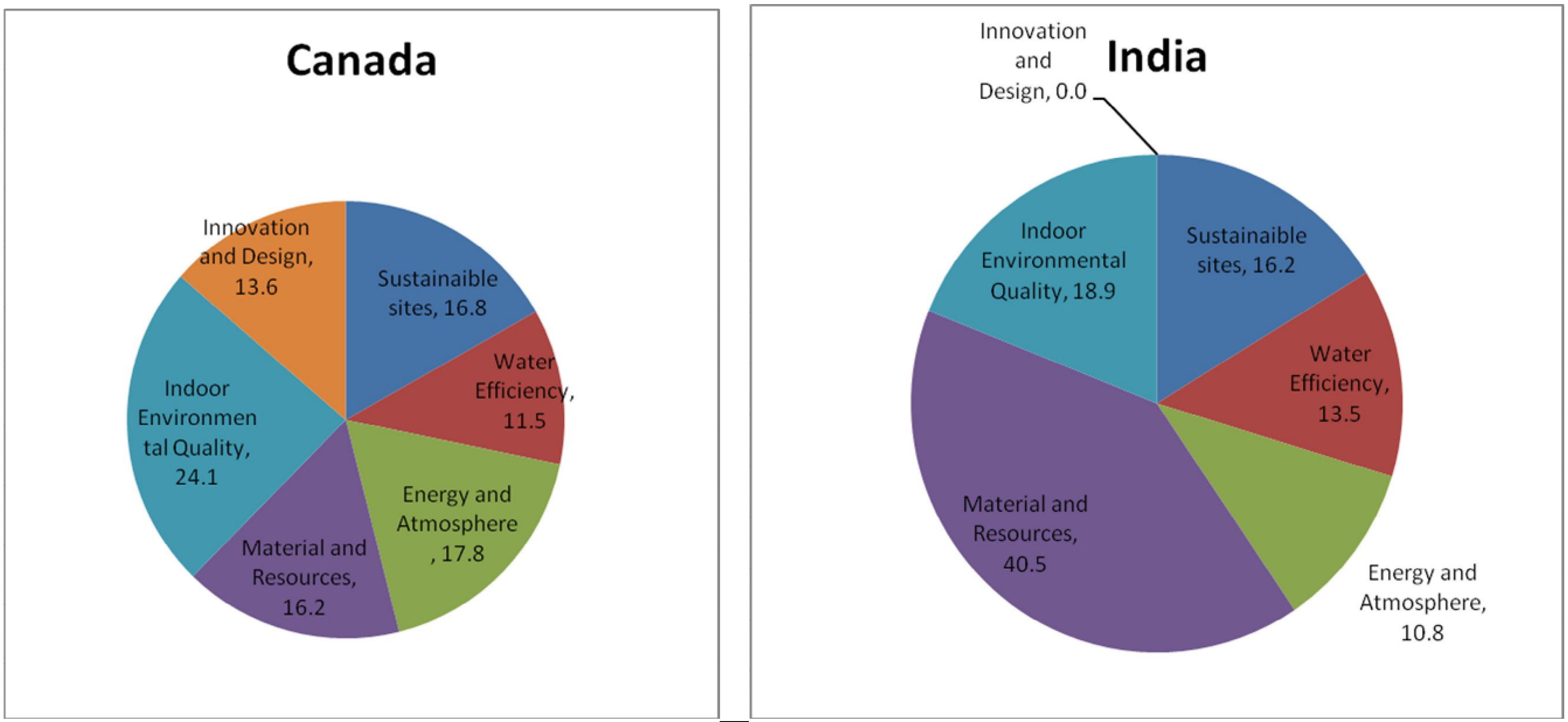
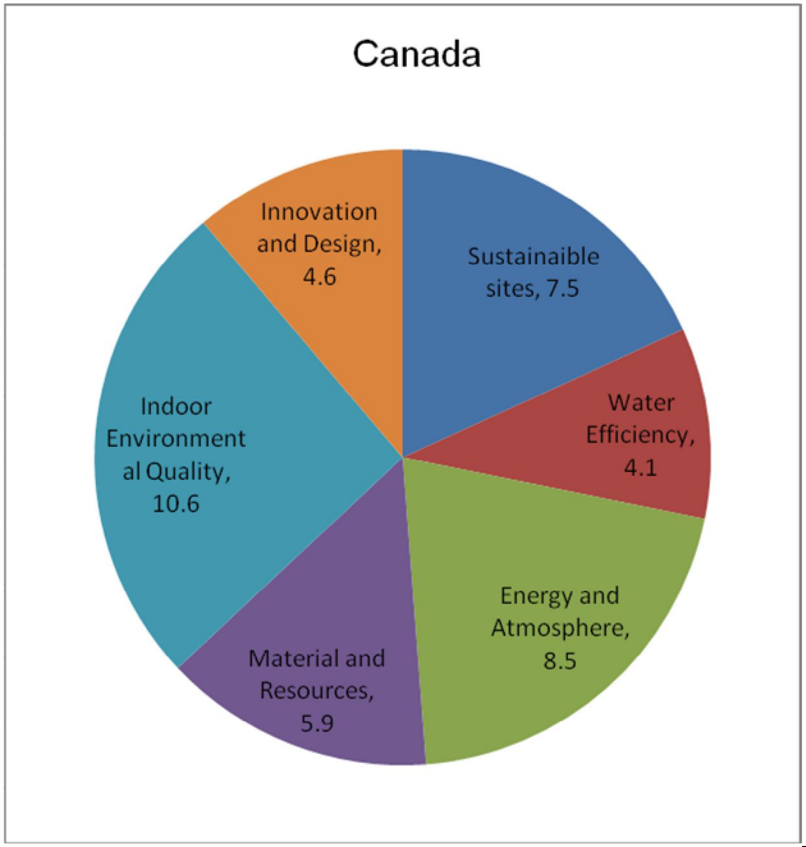


Figure 4.10 Average Value of Credits Attained in Each Category for LEED Gold Certified Buildings in Canada and India



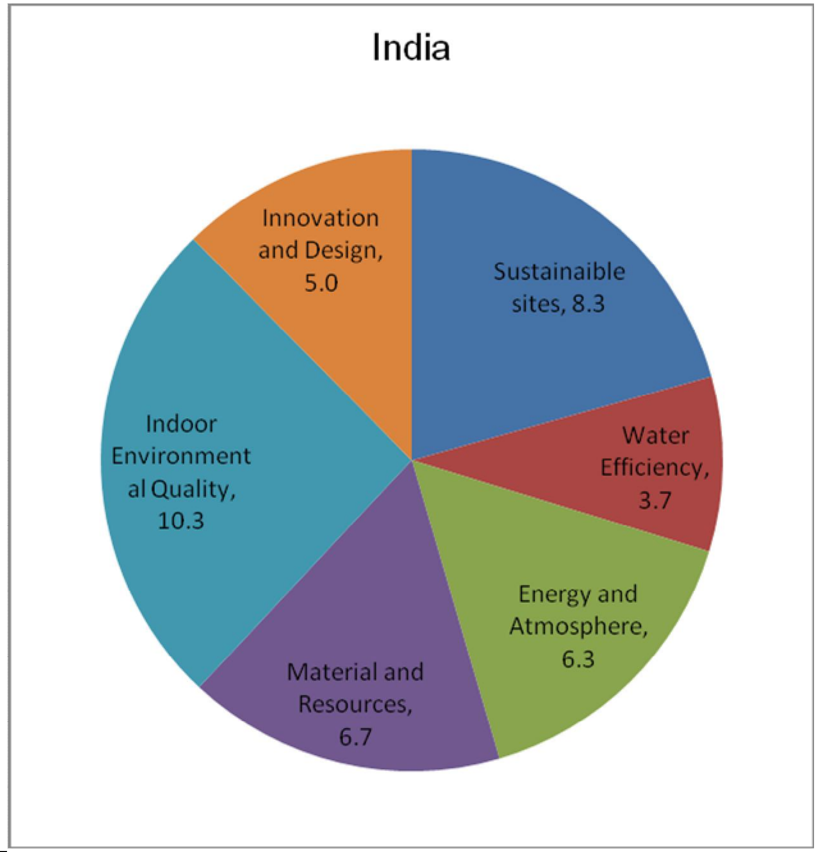


Figure 4.11 Average Value of Credits Attained In Each Category for LEED Platinum Certified Buildings in Canada and India

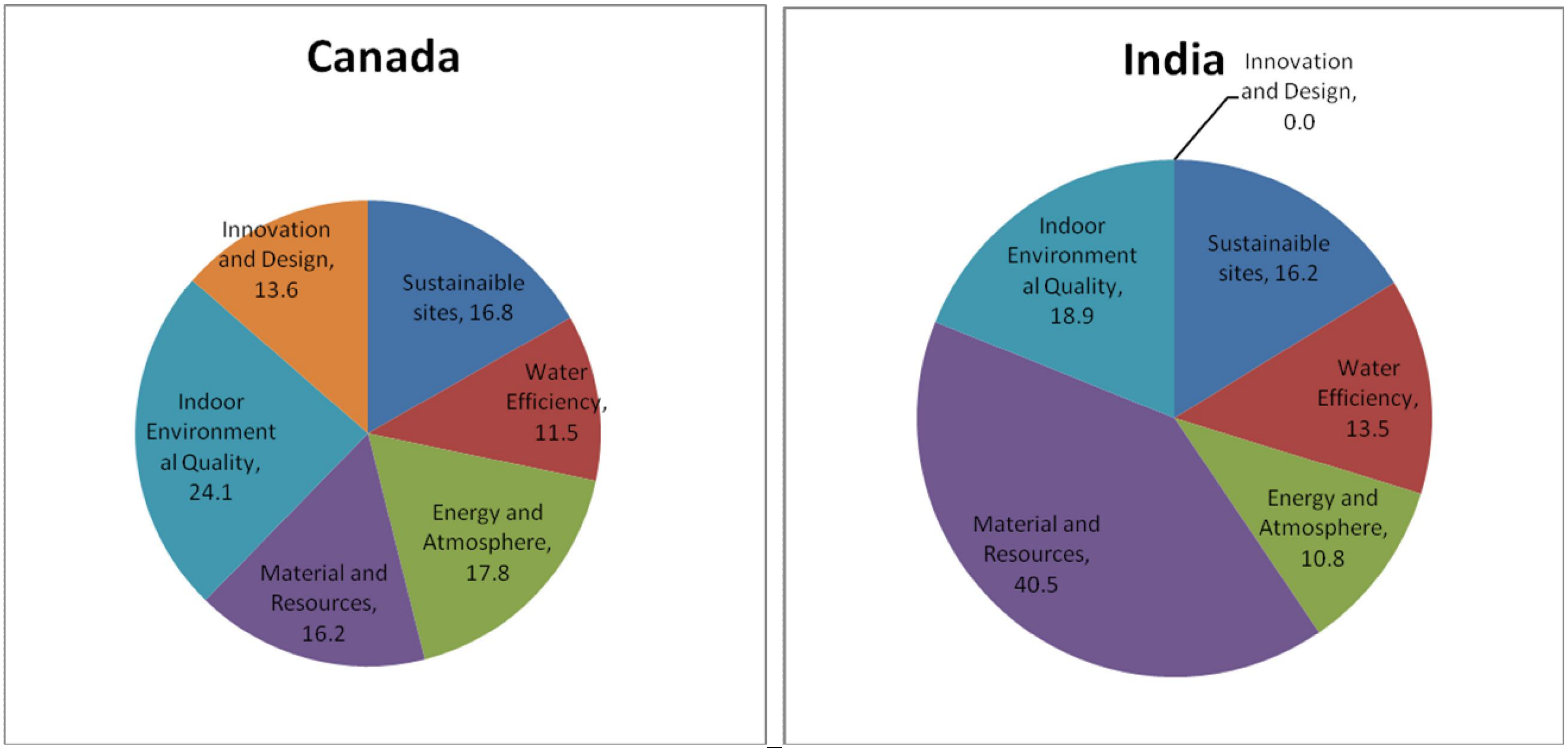


Figure 4.12 The Contribution of each credit within the IEQ category in 11 Silver LEED Certified Canadian Buildings

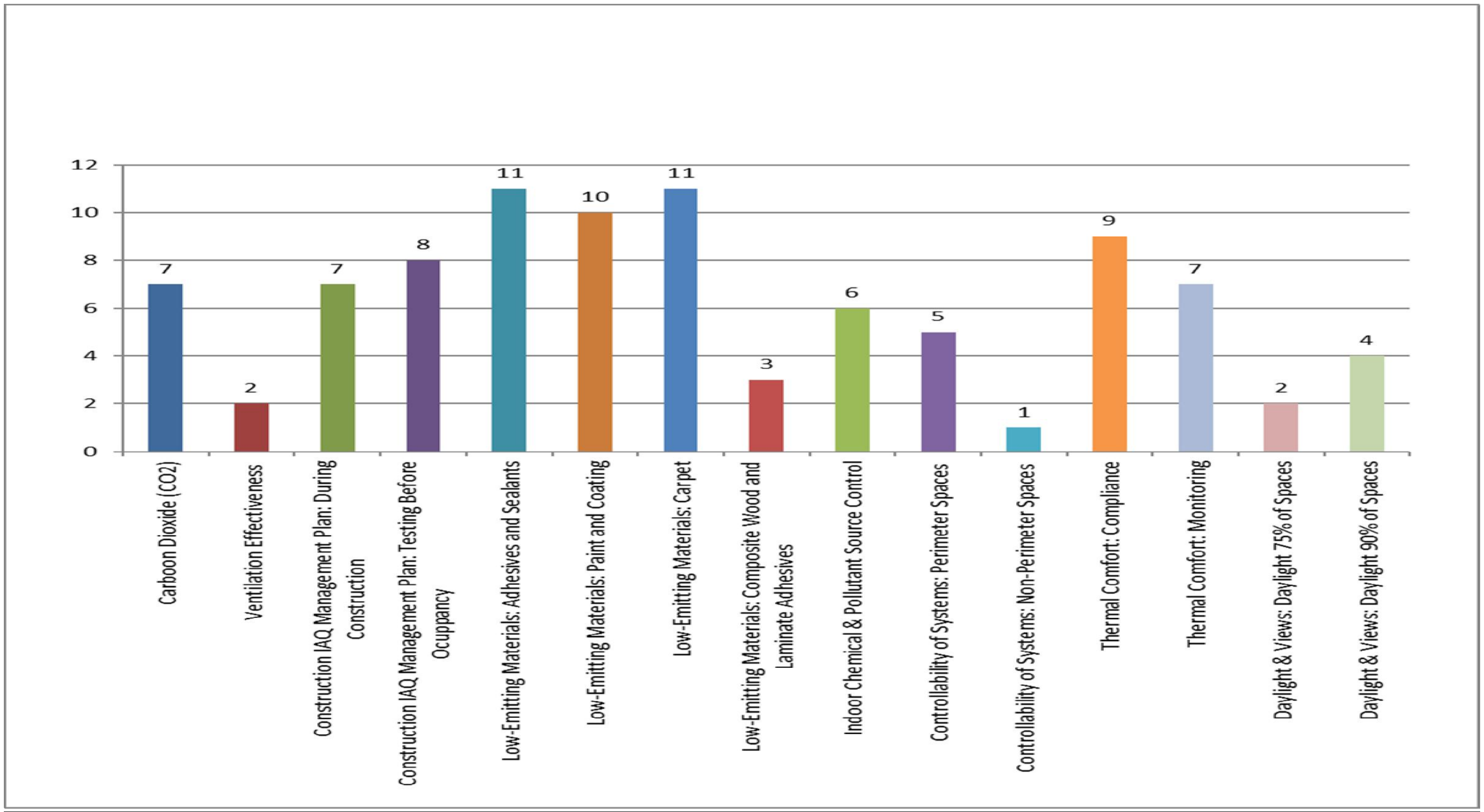


Figure 4.13 The Contribution of each credit within the IEQ category in 7 Gold LEED Certified Canadian Buildings

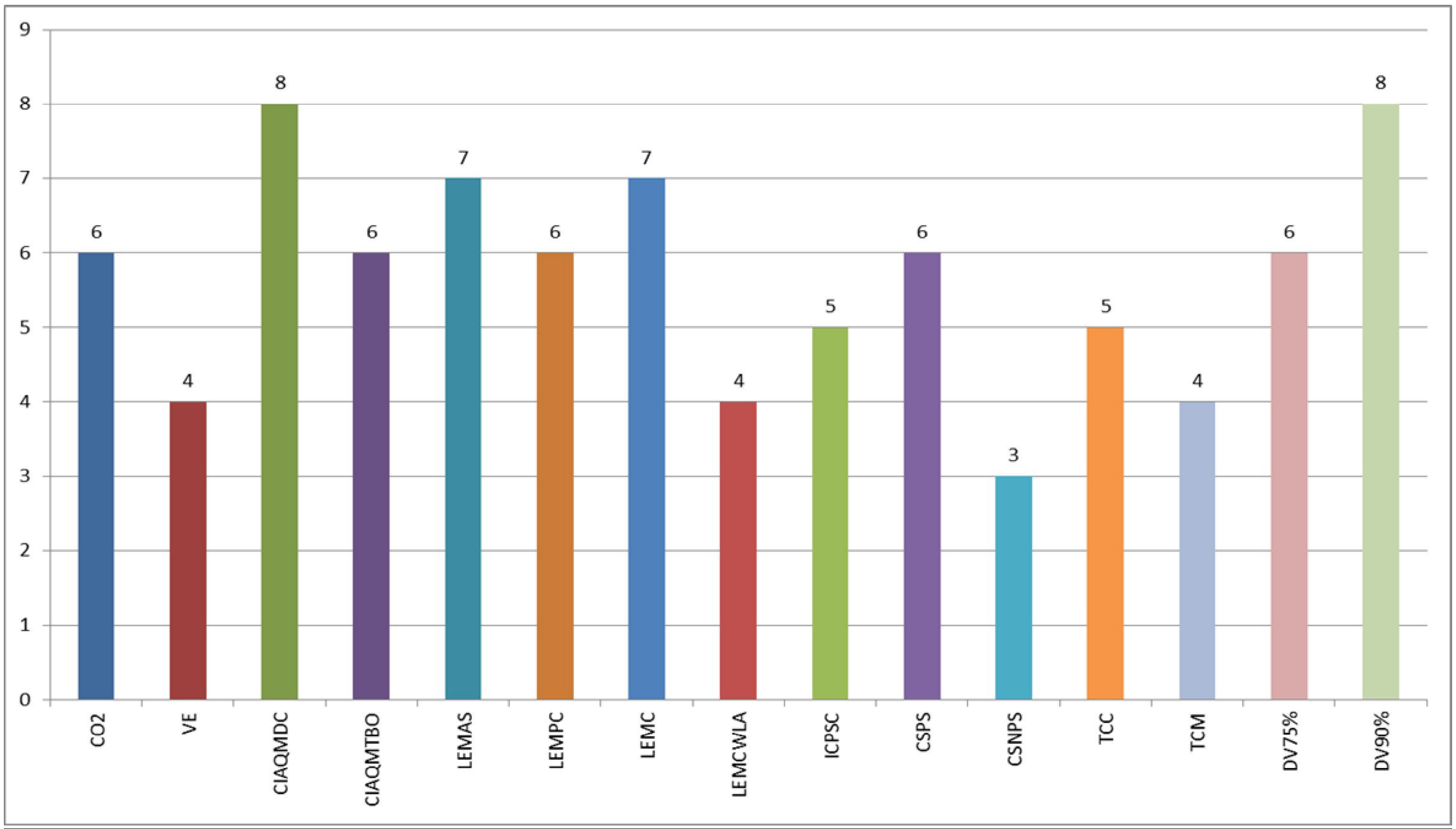


Figure 4.14 The Contribution of each credit within the IEQ category in 8 Silver LEED Certified Indian Buildings

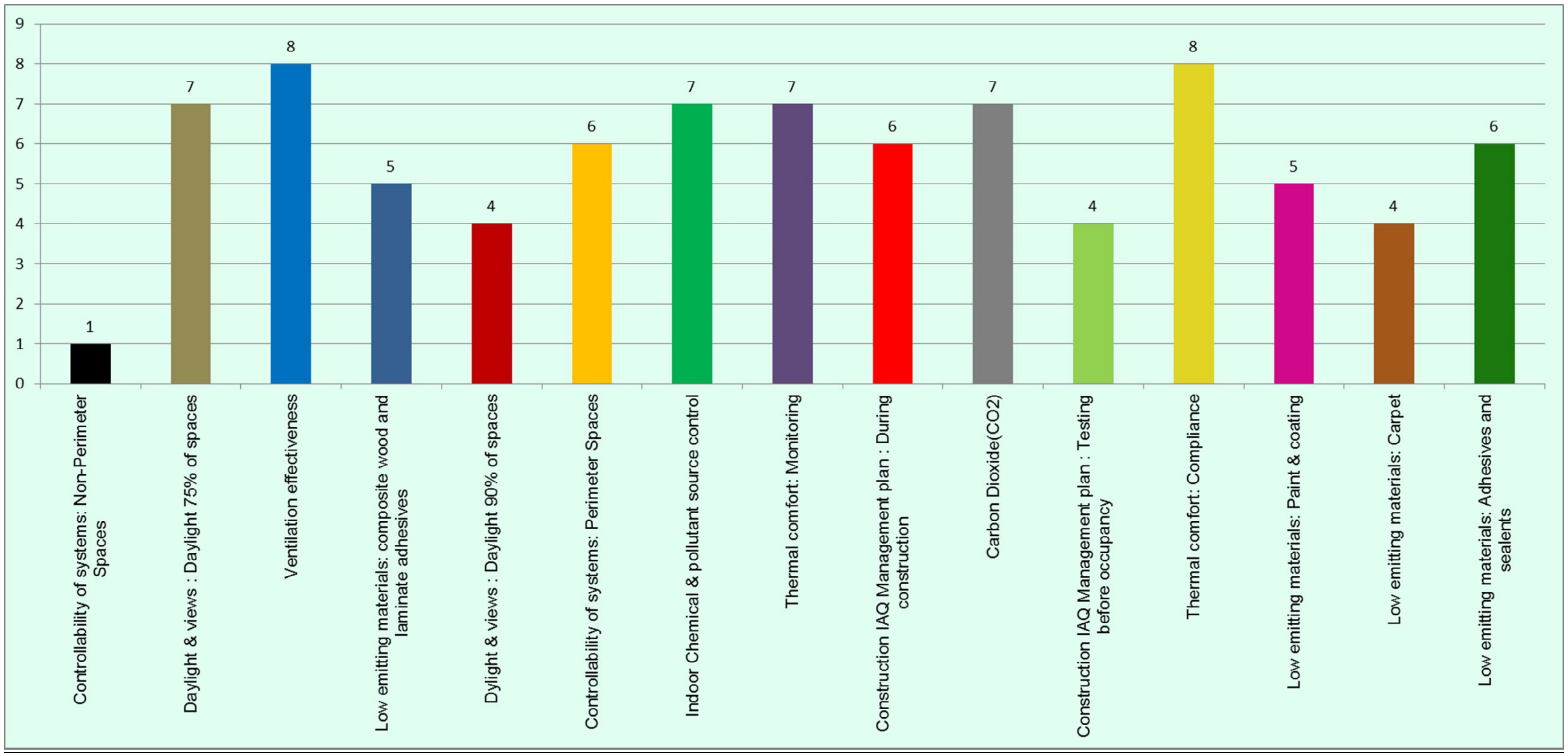


Figure 4.15 The Contribution of each credit within the IEQ category in 10 Gold LEED Certified Indian Buildings

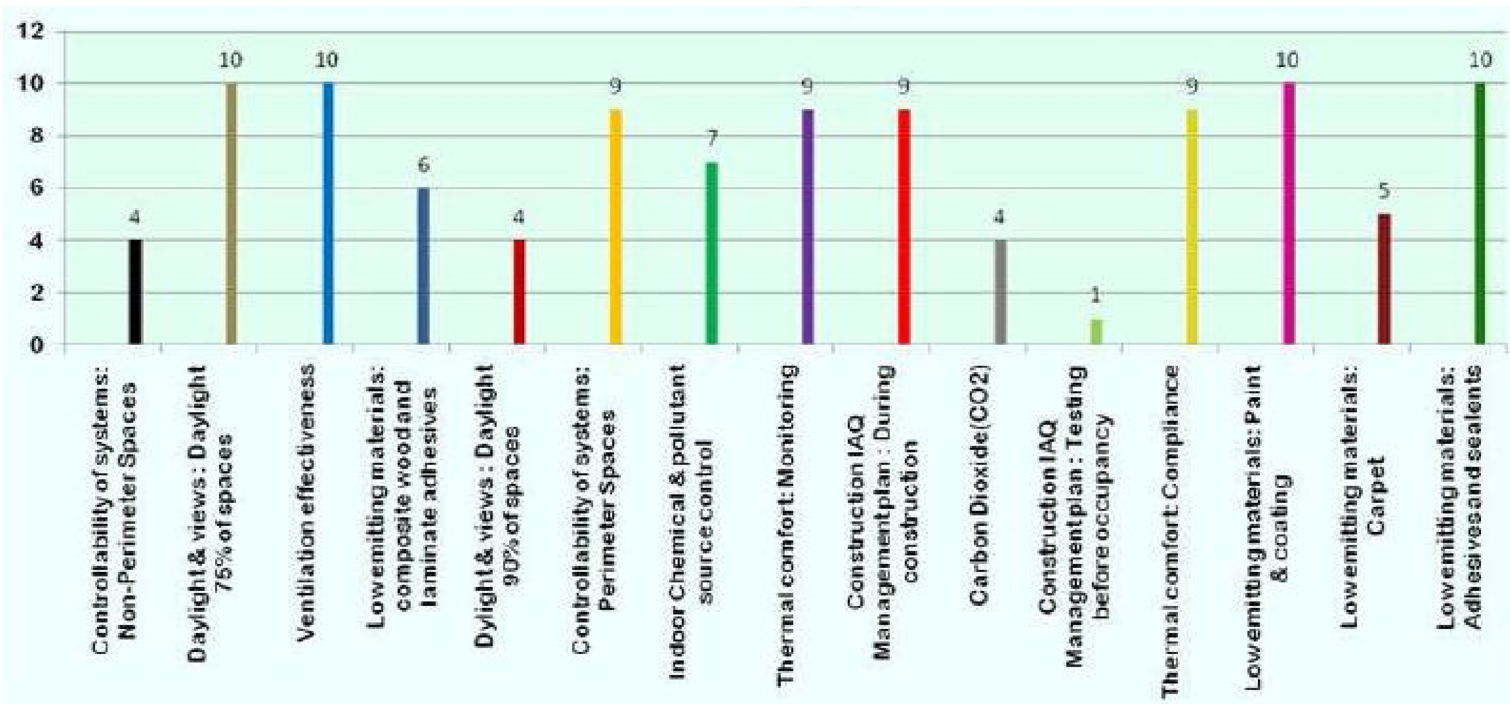


Figure 4.16 The Contribution of each credit within the IEQ category in 10 Platinum LEED Certified Indian Buildings

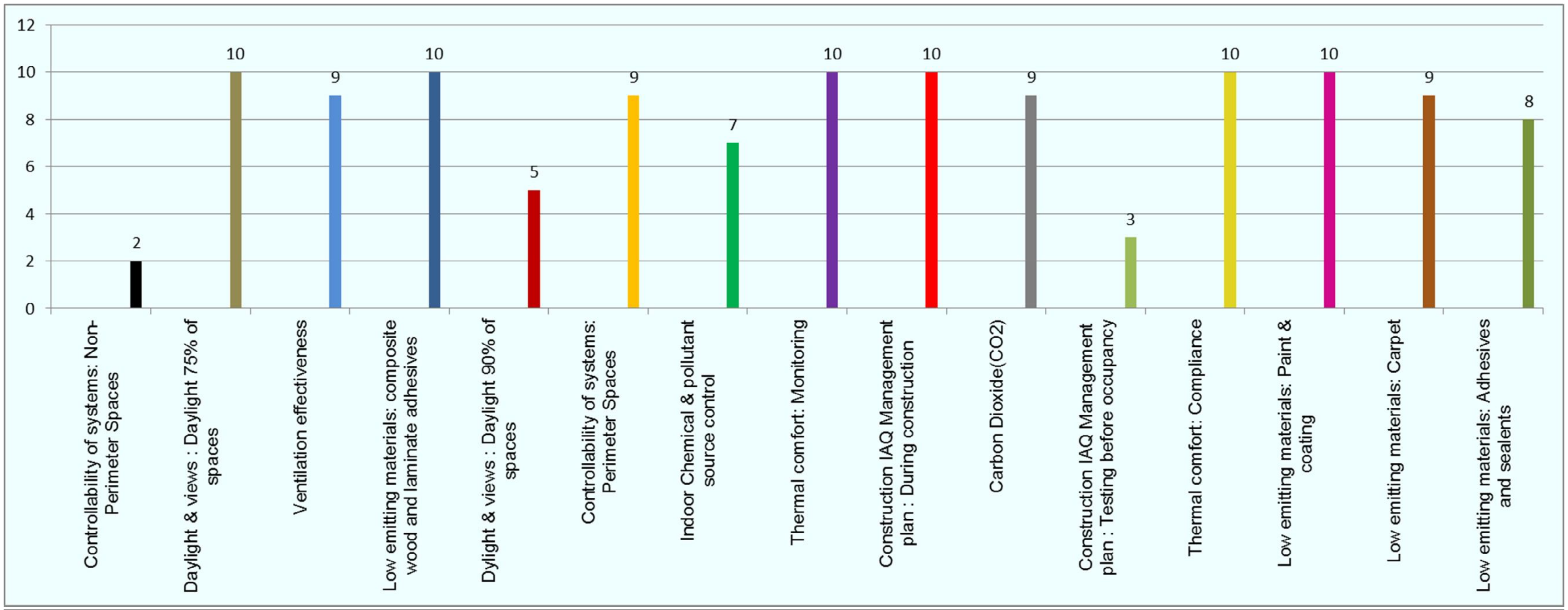


Figure 4.17 Distribution of IAQ Credits for Silver LEED Buildings in Canada and India

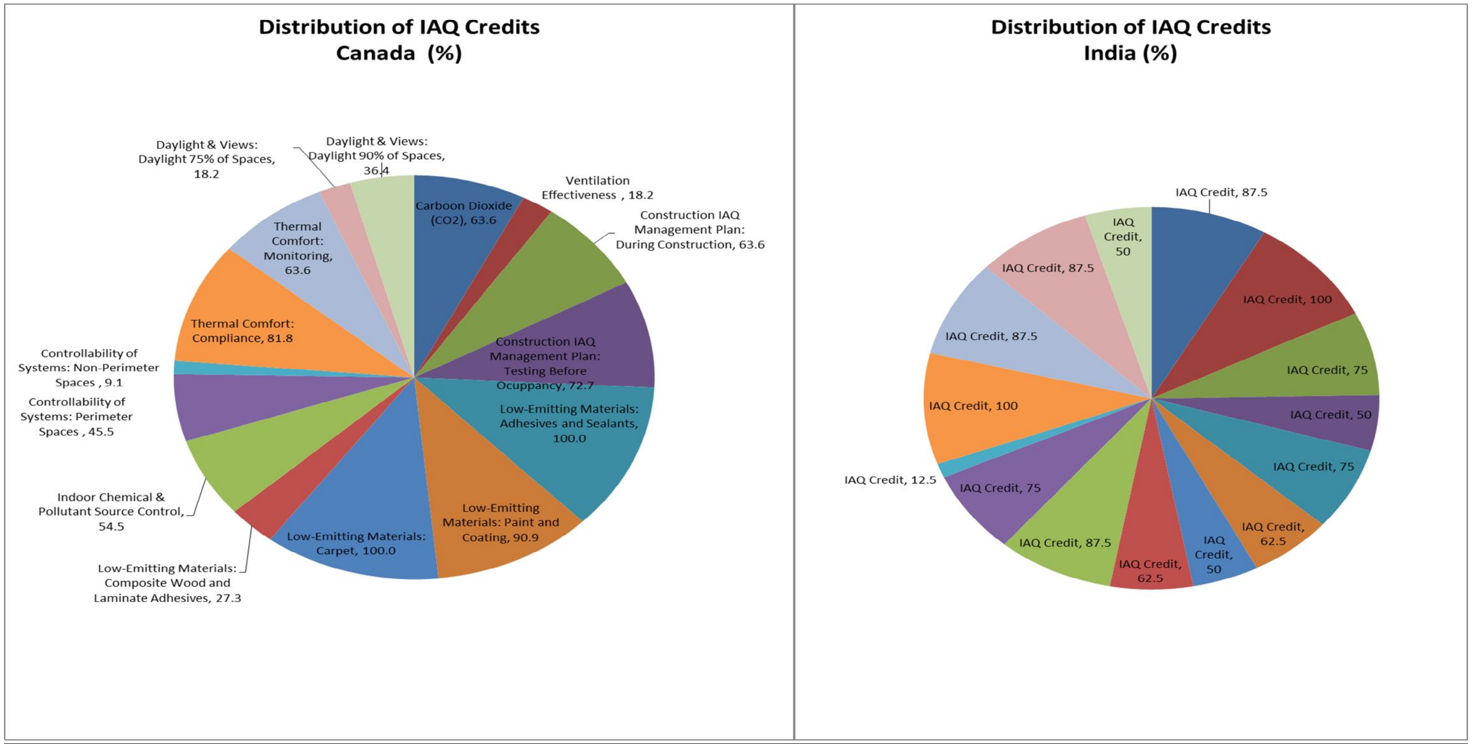


Figure 4.18 Distribution of IAQ Credits for Gold LEED Buildings in Canada and India

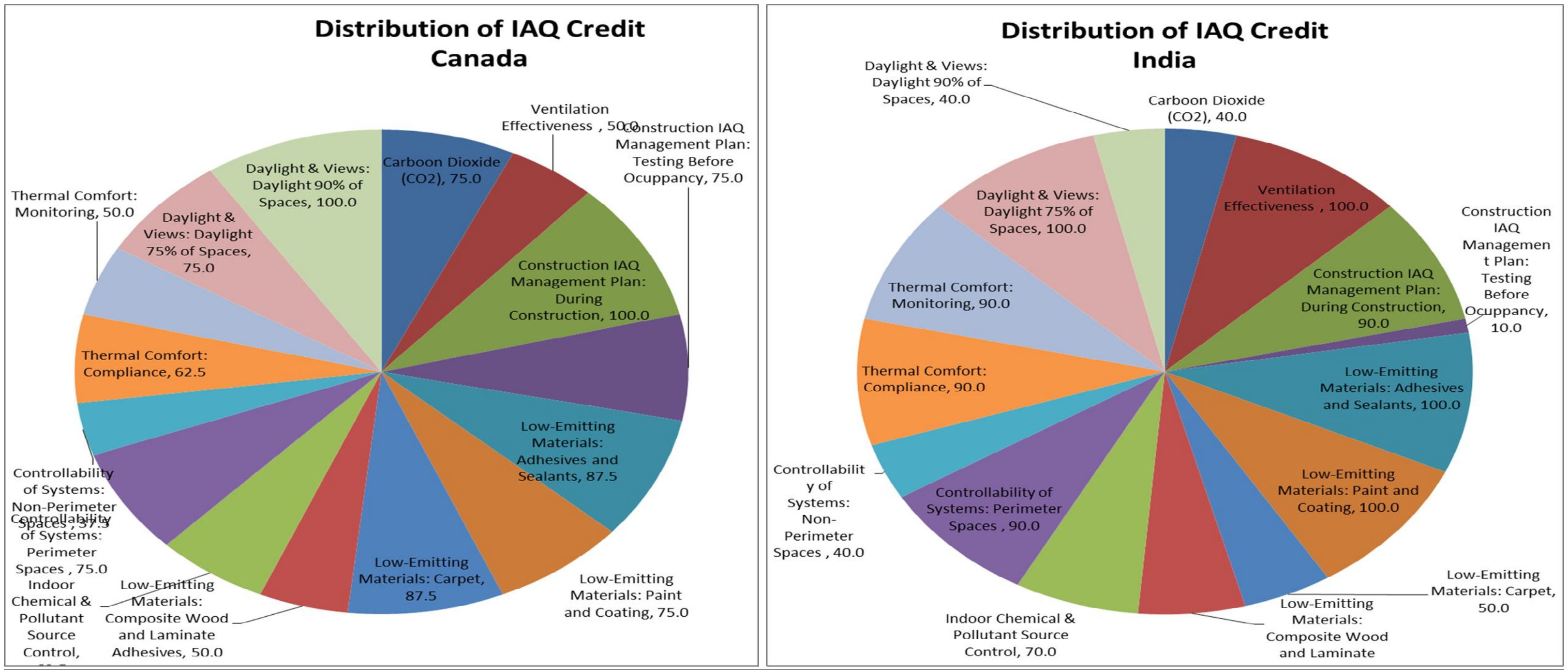


Figure 4.19 Distribution of E&A Credits for Silver LEED Buildings in Canada and India

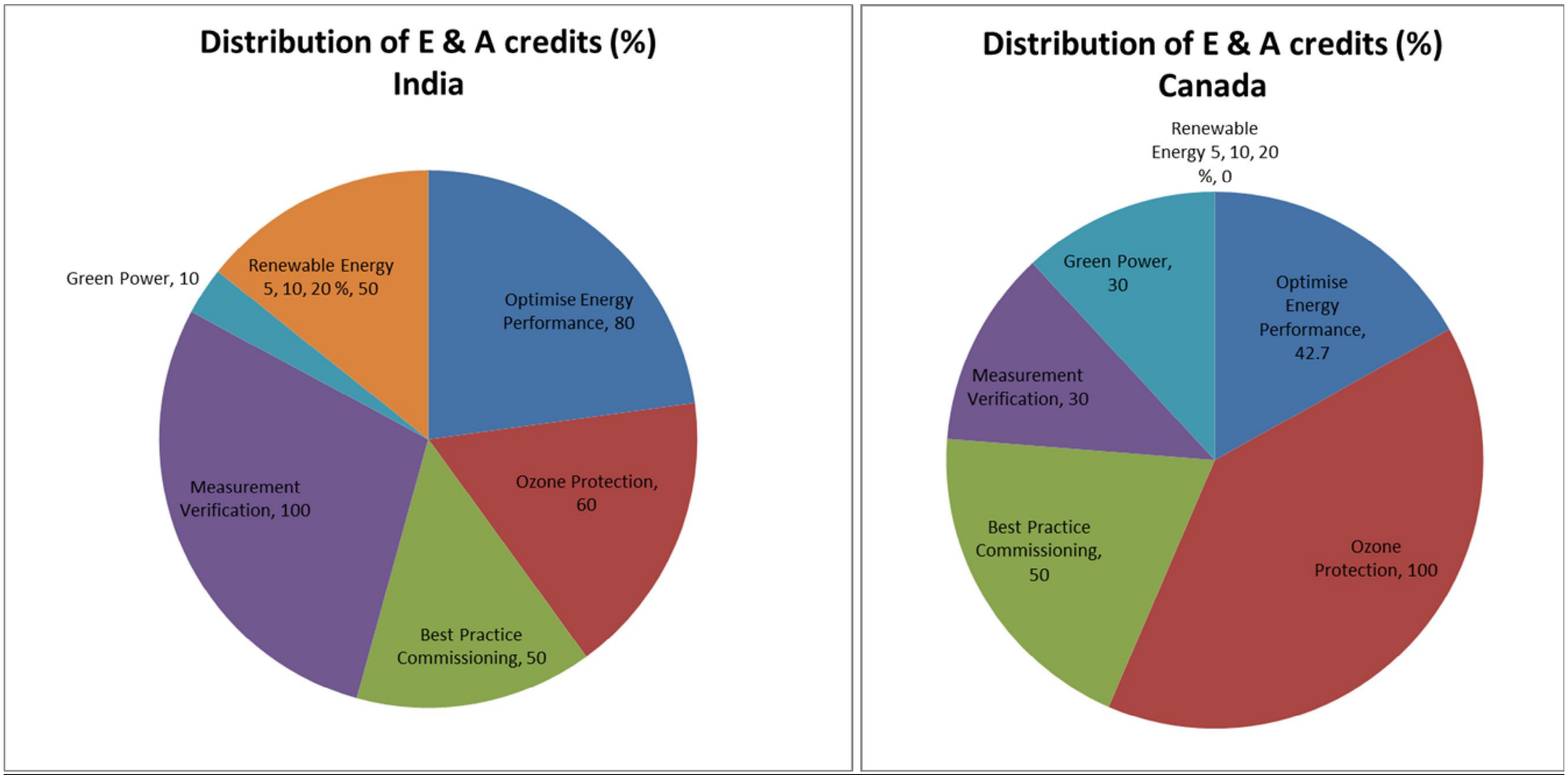
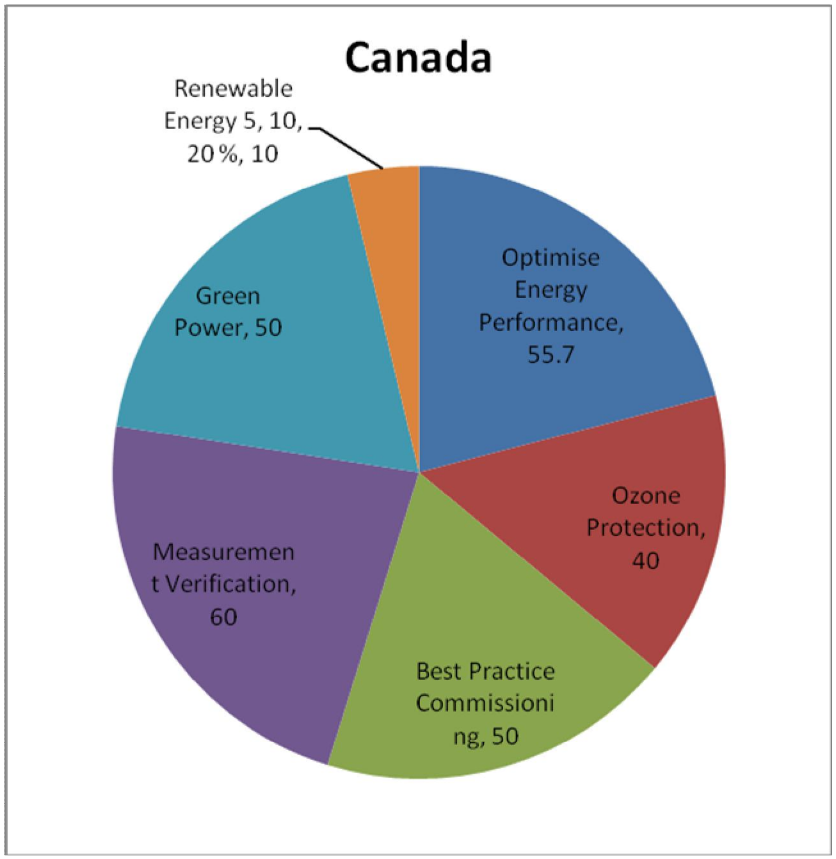
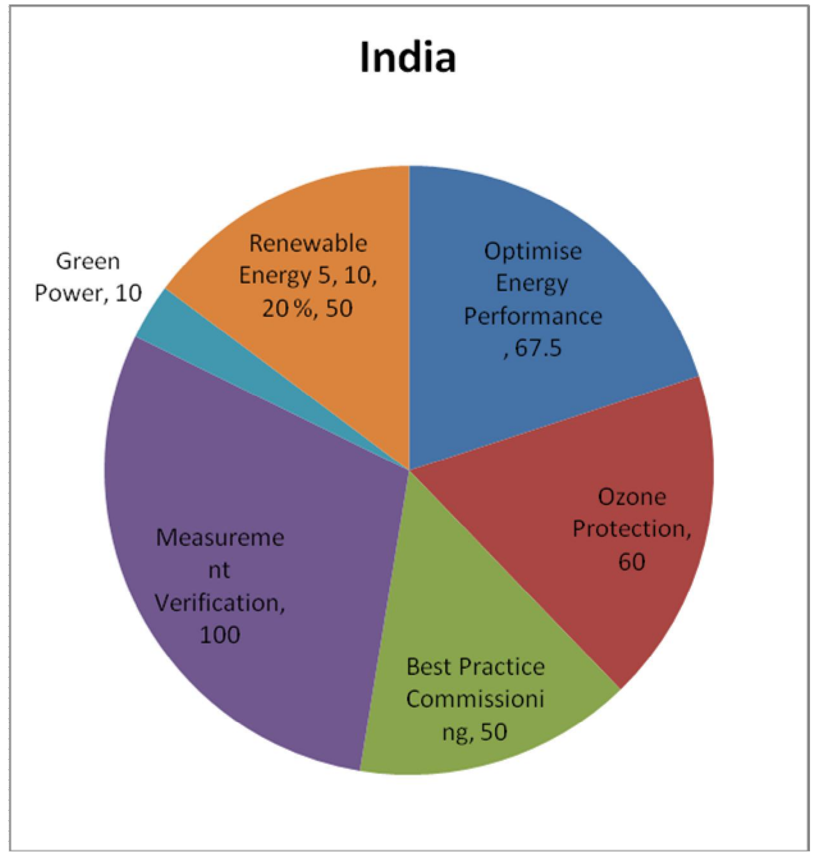


Figure 4.20 Distribution of E&A Credits for Gold LEED Buildings in Canada and India





4.3 Impact of indoor environment quality on sick building syndrome in Indian LEED certified buildings

IEQ and IAQ in silver, gold and platinum certified LEED buildings

Analysis of satisfaction for building, thermal comfort, air quality and noise level for all silver level LEED certified buildings is given in Figure 4.21. Comparative results for the gold and platinum certified buildings are provided in Figures 4.22 and 4.23, respectively.

Fifty nine per cent of the sliver LEED Certified occupants were satisfied with the working space and gave a rating of 6. Ratings of 7 and 4 were provided by 13% AND 2% of the occupants respectively. In contrast 22% of the occupants were satisfied with the working space in gold LEED certified buildings and a rating of 7 was given by 26%. No one gave a rating of less than 4. In platinum LEED certified buildings, 62% of the occupants were satisfied with the working space and 33% gave a rating of 7 and only 5% or less gave rating lower than 5.

Sixty four per cent of the occupants were satisfied with the environmental temperature in silver LEED certified buildings and 15% gave a rating of 7. None gave a rating of less than 4. The number of satisfied occupants in gold certified buildings (58%) was slightly less and gave a rating of 7. Only 17% of the respondents gave a rating of 7 and less than 1% gave a rating of 4 or less. The number of satisfied occupants in platinum certified buildings was lower (50%) than in gold certified buildings and rated thermal satisfaction at 6. Ratings of 7 and 5 were given by 35% and 11% of the occupants.

Fifty two per cent of the occupants were satisfied with the air quality in silver LEED certified buildings and gave a rating of 6. Only 5% of the occupants gave a rating of 4 or less. Ratings of 7 and 5 were given by 21% and 20% of the respondents. In gold level LEED certified buildings 63% and 16% gave a rating of 6 or 7, respectively and were satisfied with the air quality. Eighty eight per cent of the occupants were satisfied with the air quality in platinum level LEED certified buildings and gave a rating of 6 (43%) or 7 (45%).

Sixty two per cent of the occupants were satisfied with the environmental noise levels in silver LEED certified buildings and gave a rating of either 6 (42%) or 7 (20%). Ratings of 4 and 5 were given by 5% and 31% of the occupants respectively. The number of satisfied occupants in gold level buildings was slightly higher (73%) and 58% and 15% gave a rating of 6 and 7 respectively. The same number (73%) of occupants was satisfied with the noise levels in platinum buildings and ratings of 6 and 7 were provided by 54% and 19% of the occupants respectively.

A similar trend was evident even if only the data collected for just LEED NC certified buildings was analyzed. Analysis of satisfaction for building, thermal comfort, air quality and noise level for all silver level LEED-NC certified buildings is given in Figure 4.24. Comparative results for the gold and platinum certified buildings are provided in Figures 4.25 and 4.26, respectively.

No significant difference was found between silver, gold and platinum LEED certified buildings when occupant's responses to satisfaction for building, thermal comfort, air quality and noise level were analyzed.

SBS score

The SBS Score for silver, gold and platinum LEED certified buildings is given in Table 4.4. The gold LEE certified buildings had a SBS score of 1 suggesting that on an average, the occupants of these buildings had at least one SBS symptom out of 6. There was no statistically significant difference between SBS score in either Silver or Gold (P = 0.39), Gold and Platinum (P = 0.40) or Silver and Platinum (P = 0.16) LEED Certified buildings. There was no significant differences in the SBS score between genders (Table 4.5). The main SBS symptoms prevailing were tiredness/lethargy and headaches as shown in Table 4.6. Only those response that chose 'often' and 'sometimes' as alternative to the health questions were considered in the analysis. The silver LEED certified building occupants had the highest incident of tiredness/lethargy (54.1%) while platinum building occupants had the highest incidence of headaches. Gold certified building occupants experienced equal amounts of tiredness/lethargy (48.8%) and headache (48.9%) symptoms.

Table 4.7, 4.8 and 4.9, demonstrates the SBS score in silver, gold and platinum LEED certified buildings respectively. A general worsening in SBS symptoms was evident when "Pre SBS" and "SBS" scores were compared. This difference was significant for two buildings at silver and gold levels, and for one building at the platinum certification levels. For silver certification level buildings this difference was highly significant for HITAM (P = 0.001) and significant for Rajiv Gandhi Airport (P = 0.01). For gold certification level the difference was significant for WIPRO (P = 0.005). For platinum certification levels the difference was significant for Green Boulevard.

Table 4.4 SBS Score in Silver, Gold and Platinum Buildings

	Silver	**Gold**	**Platinum**
Number of Buildings	4	5	5
Surveys Completed	40	50	50
Number of Males	31	40	33
Number of Females	9	10	17
SBS Score	0.88 ± 0.14	1.0 ± 0.13	0.90 ± 0.12

Table 4.5 Gender and SBS Score

	Men	Women
Total Number	114	36
Total Showing SBS	63 (55.2%)	22 (61.1%)
Mean SBS Score	1.51 ± 0.05	1.50 ± 0.10

Table 4.6 Prevalence of SBS Symptoms in Silver, Gold and Platinum Buildings

	Silver	Gold	Platinum
Number of surveys	40	50	50
Eye irritation %	0.02	0.02	0.05
Nose irritation %	0	0	0
Throat dryness %	0	0.02	0.07
Tiredness/lethargy %	54.1	48.8	31.7
Headaches %	43.2	48.9	56.1
Skin dryness %	0	0.02	0

Table 4.7 SBS Score in Silver LEED Certified Buildings

	Pre Mean SBS Score	Post Mean SBS Score	
Thermax	-	-	
Rajiv Gandhi Airport	0.50 ± 0.16	1.20 ± 0.29	P = 0.01
DUPONT	0.60 ± 0.16	0.80 ± 0.29	P = 0.20
CDPL	0.30 ± 0.15	0.20 ± 0.13	P = 0.30
HITAM	0.50 ± 0.17	1.30 ± 0.26	P = 0.001

Table 4.8 SBS Score in Gold LEED Certified Buildings

	Pre Mean SBS Score	Post Mean SBS Score	
MAX	0.60 ± 0.16	0.80 ± 0.32	P = 0.50
WIPRO	0.30 ± 0.15	1.60 ± 0.37	P = 0.05
UNITECH	0.60 ± 0.16	0.90 ± 0.23	P = 0.04
Ashok Leyland	0.90 ± 0.10	1. 0 ± 0.15	P = 0.50
Express Avenue	0.60 ± 0.16	0.70 ± 0.13	P = 0.30

Table 4.9 SBS Score in Platinum LEED Certified Buildings

	Pre Mean SBS Score	Post Mean SBS Score	
PATNI	0.80 ± 0.13	1.20 ± 0.33	P = 0.08
HSBC-Hyderabad	0.70 ± 0.15	0.90 ± 0.23	P = 0.16
HSBC- Gurgaon	0.30 ± 0.13	0.70 ± 0.21	P = 0.02
SPACE MATRIX	0.50 ± 0.16	0.20 ± 0.13	P = 0.33
Green Boulevard	0.70 ± 0.21	1.50 ± 0.21	P = 0.01

Figure 4.21 Satisfaction for building, thermal comfort, air quality and noise level for all silver level LEED certified buildings

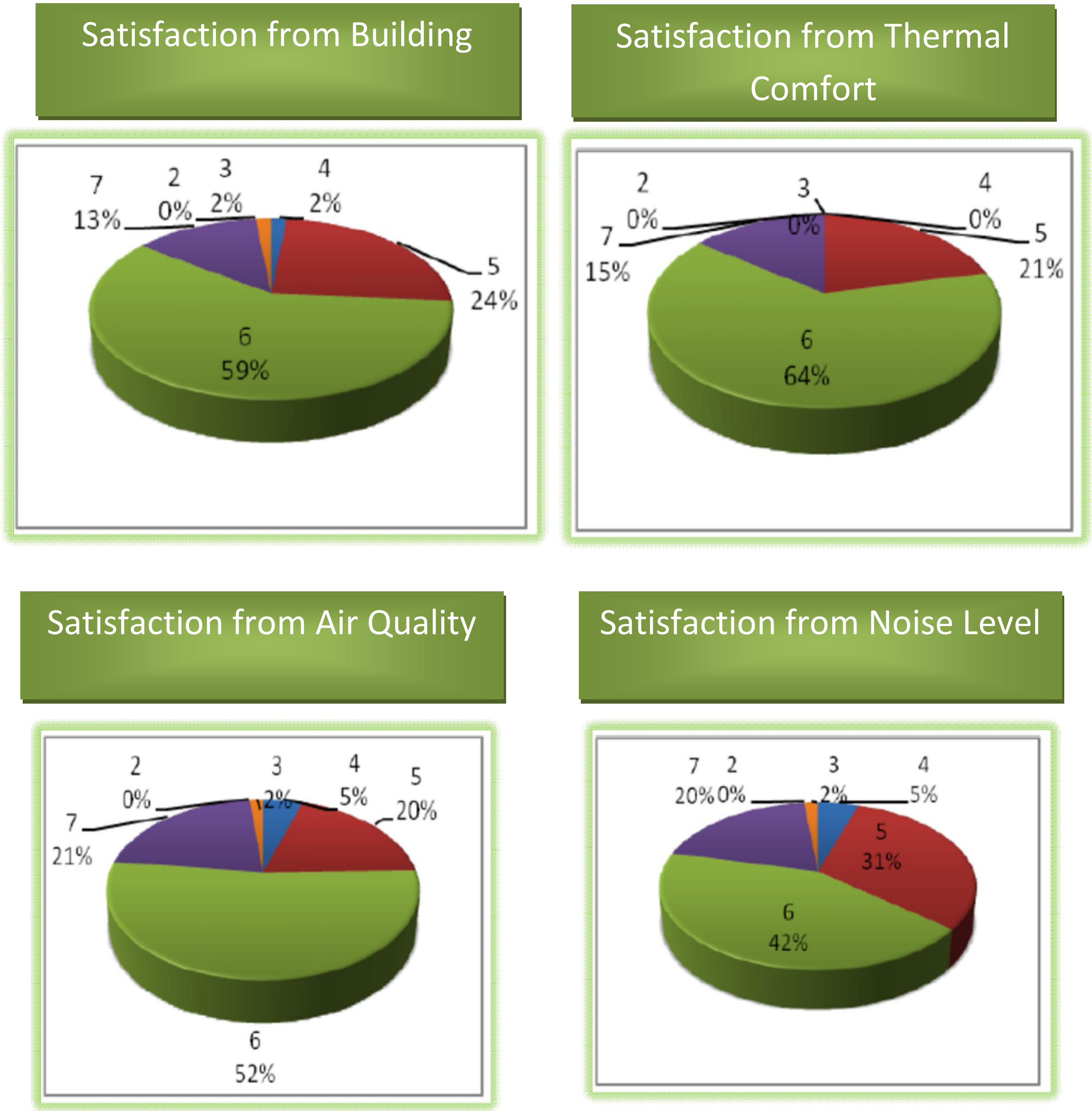


Figure 4.22 Satisfaction for building, thermal comfort, air quality and noise level for all gold level LEED certified buildings

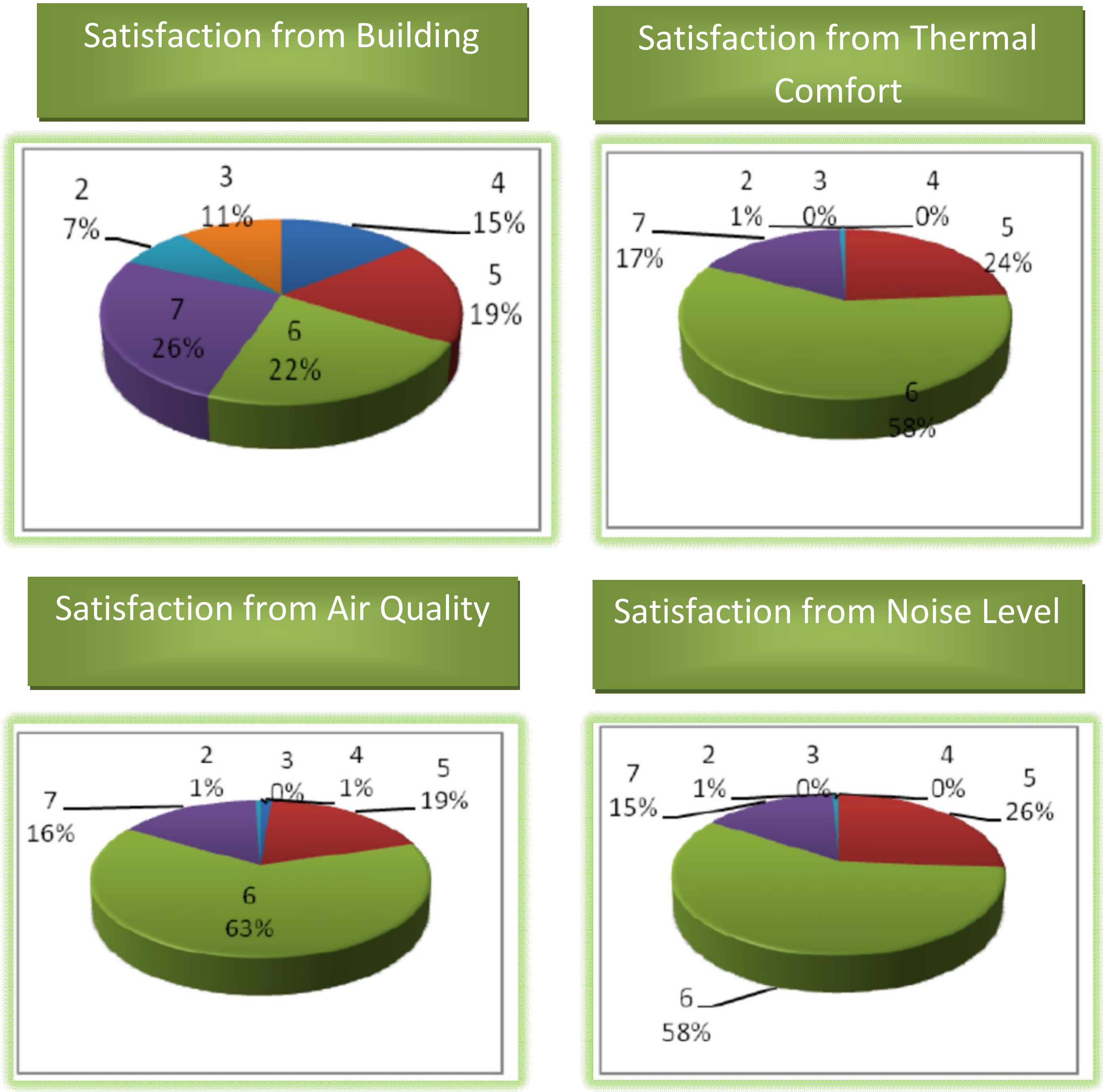


Figure 4.23 Satisfaction for building, thermal comfort, air quality and noise level for all platinum level LEED certified buildings

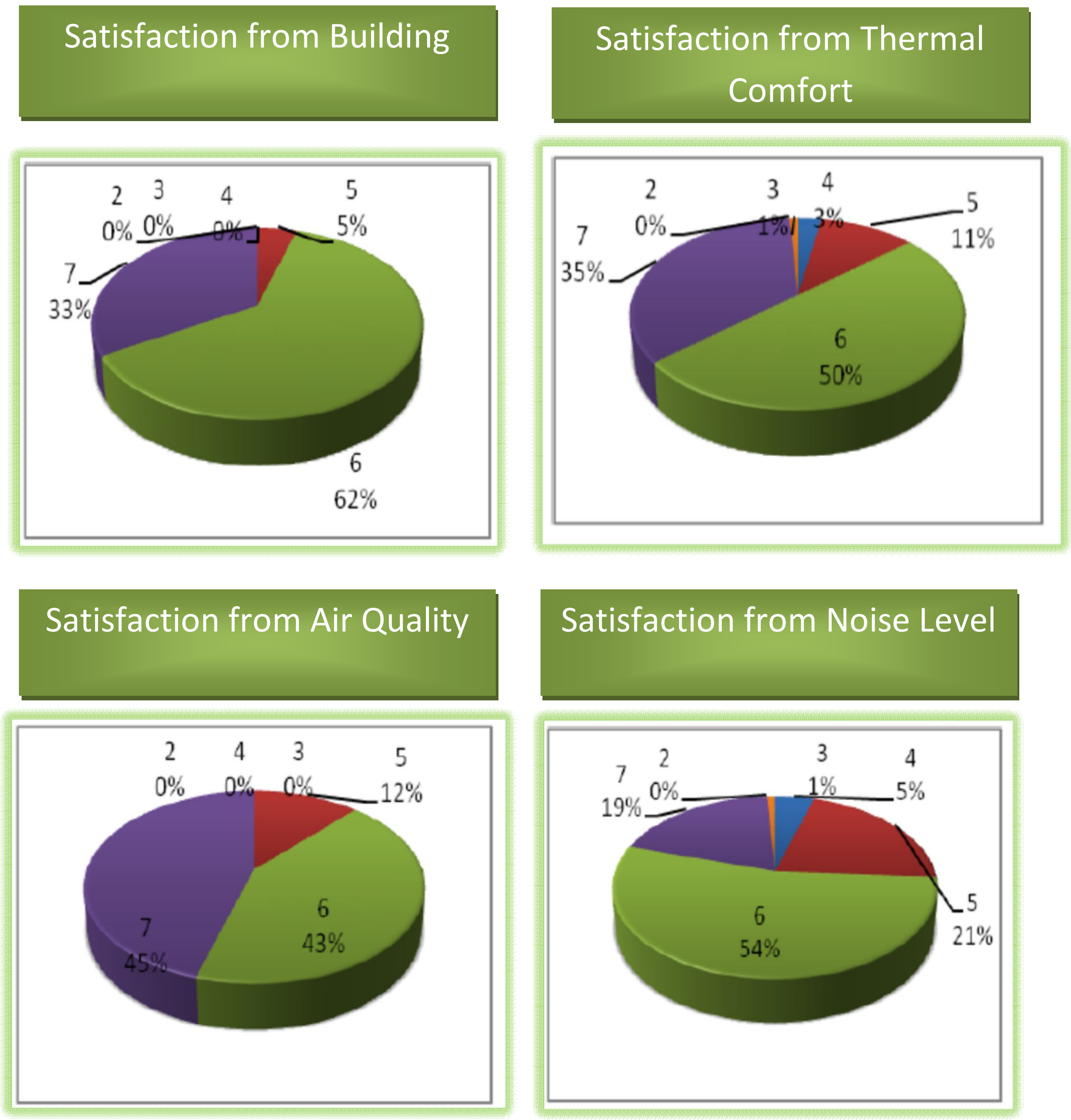


Figure 4.24 Satisfaction for building, thermal comfort, air quality and noise level for silver level LEED-NC certified buildings

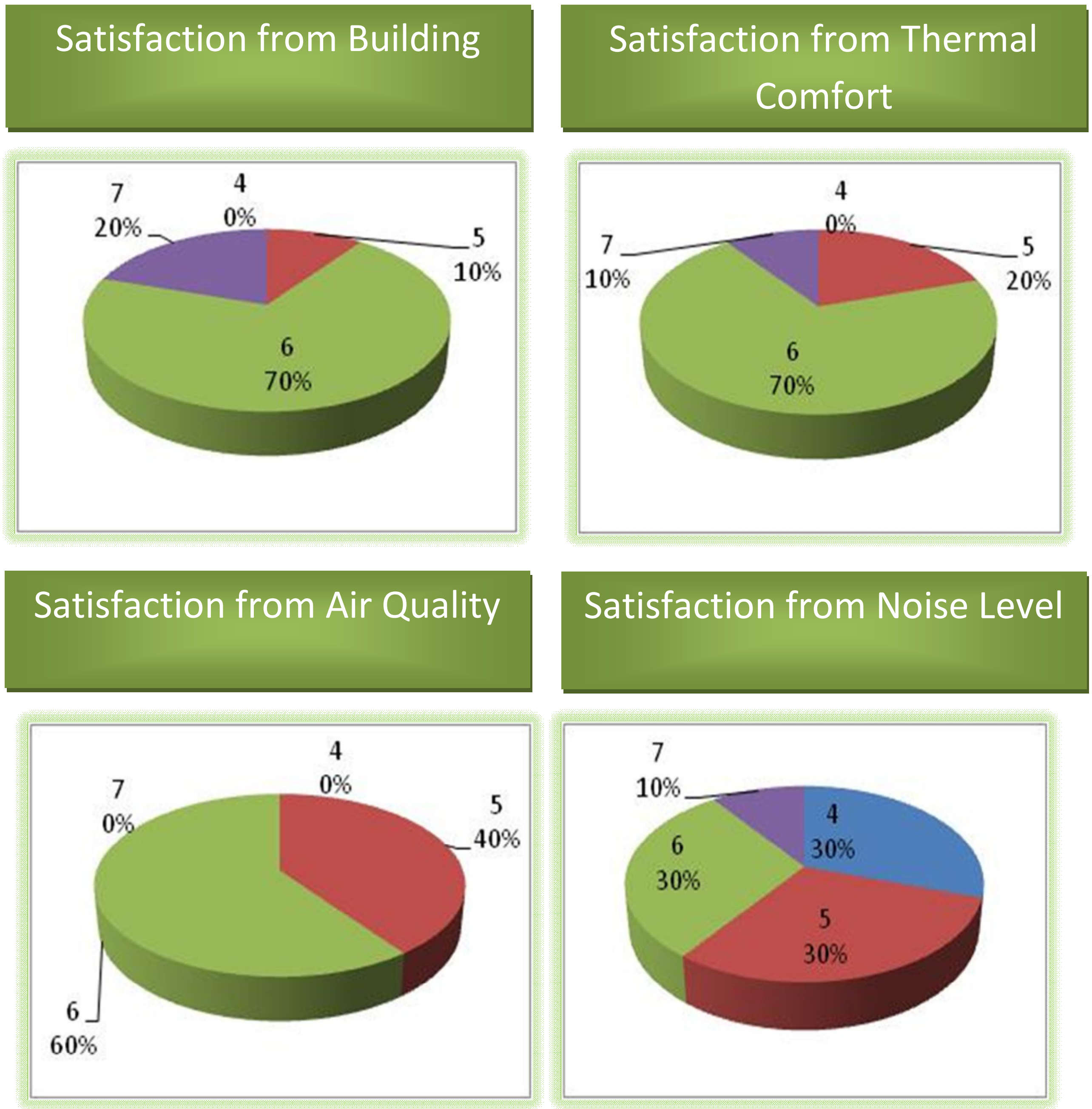


Figure 4.25 Satisfaction for building, thermal comfort, air quality and noise level for gold level LEED-NC certified buildings

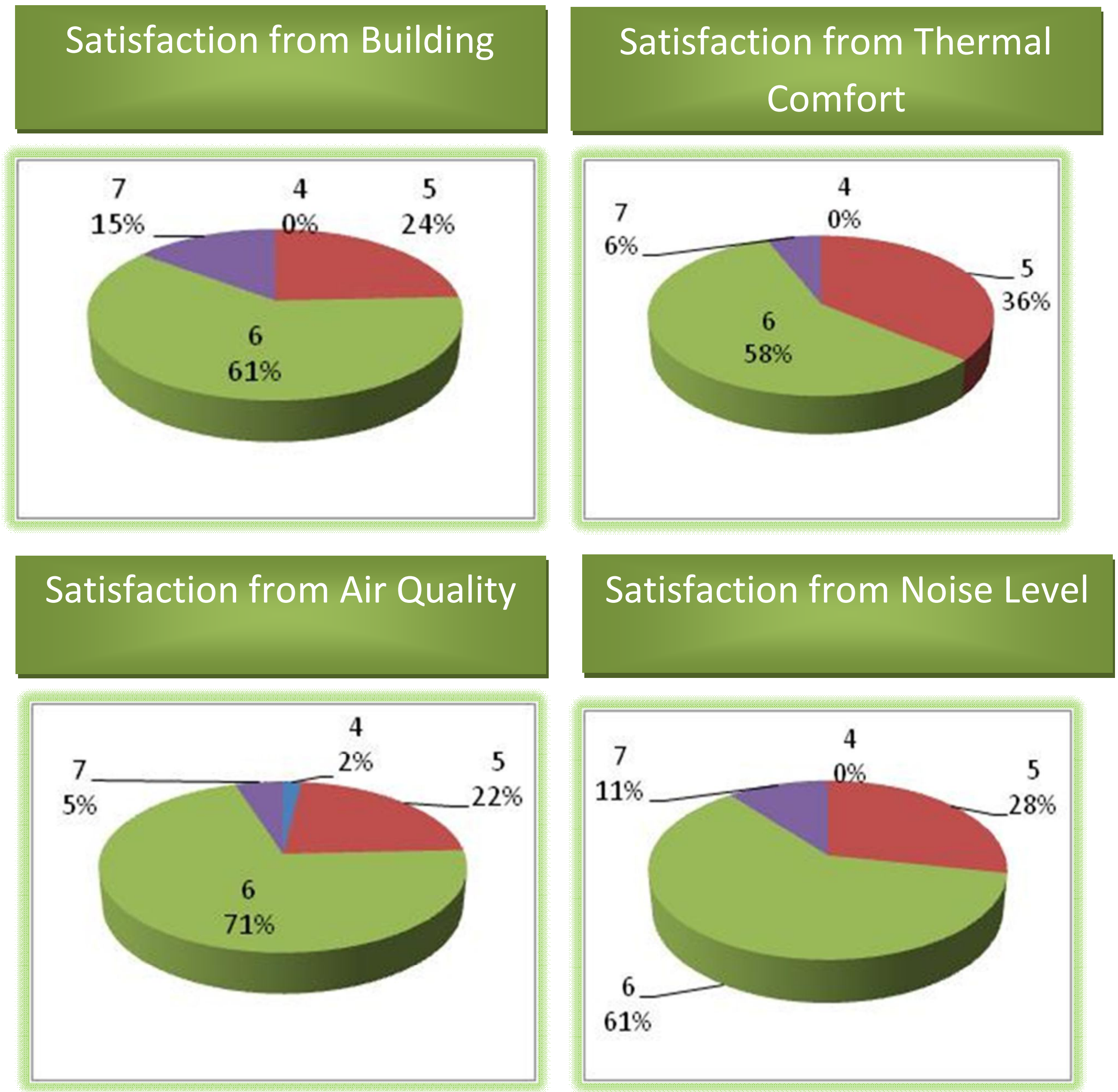
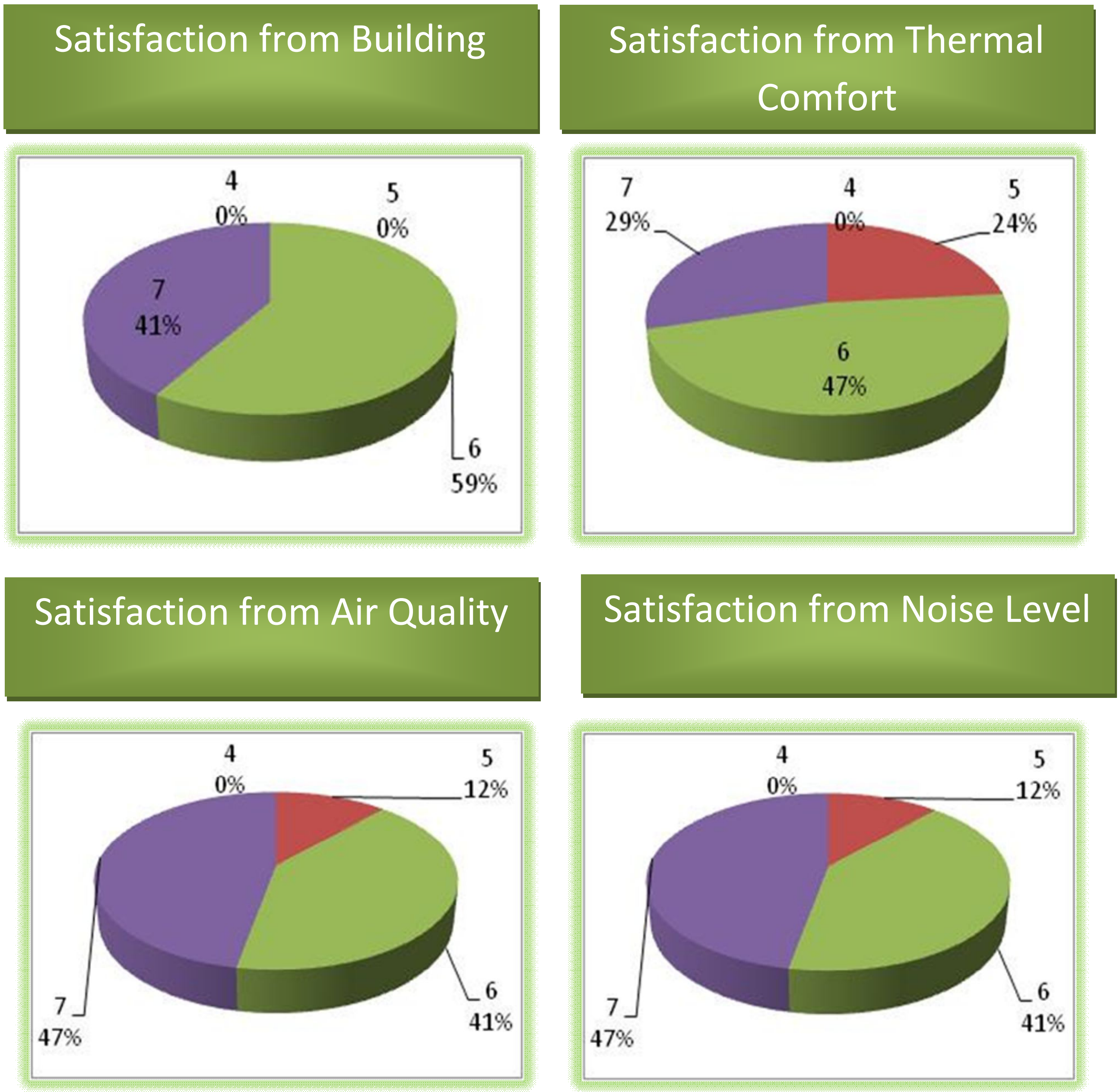


Figure 4.26 Satisfaction for building, thermal comfort, air quality and noise level for platinum level LEED-NC certified buildings



CHAPTER FIVE: LEED CERTIFICTION SUSTAINABILITY AUDIT FRAMEWORK

Introduction

The LEED rating system provides a framework for understanding what makes the building green and for evaluating its performance. Post-certification, the owners of such buildings are always concerned about added value of their properties and continued LEED status. A review of literature clearly shows that presently, the attention is focused on energy performance of buildings. Currently, there is no re-certification process for such buildings and post-occupancy audit for occupant health, comfort and productivity. The data obtained from post-occupancy evaluation in 33 LEED certified buildings spread in various Indian States clearly indicates additional requirements that must be met by the builders to ensure consistent monitoring and improvements of workspace, lighting, thermal comfort, air quality and acoustic levels.

This chapter presents a framework for re-certification process that is developed based on the findings of the present study and literature review.

Introduction to International Green Construction Code (IGCC)

The International Green Construction Code (IGCC) provides a comprehensive set of requirements intended to reduce the negative impact of buildings on the natural environment. It is a document which can be readily used by manufacturers, design professionals and contractors; but what sets it apart in the world of green building is that it was created with the intent to be administered by code officials and adopted by governmental units at any level on a *mandatory* basis. It is designed to drive green and sustainable building significantly beyond the market segment that has been transformed by *voluntary* rating systems. The IGCC has been developed by the International Code Council (ICC) in association with cooperating sponsors ASTM International (ASTM) and the American Institute of Architects (AIA). Other organizations indicating their support include the U.S. Green Building Council (USGBC), producers of the LEED green building rating systems, and The Green Building Initiative (The GBI), producers of the Green Globes green building rating system.

The IGCC was developed with the intent to be consistent and coordinated with the ICC family of Codes & Standards: the I-Codes. It is applicable to the construction of high performance commercial buildings, structures, and systems, including existing buildings subject to alterations and additions, utilizing both traditional and innovative construction practices. It also applies to residential occupancies other than low-rise residential buildings that fall under the scope of the *International Residential Code* (IRC).

The IGCC also allows jurisdictions to choose ASHRAE Standard 189.1 as an alternative compliance path. ASHRAE Standard 189.1, Standard for High-Performance Green Buildings except Low-Rise Residential Buildings, is an American National Standards Institute (ANSI) standard developed by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) in association with the Illuminating Engineering Society (IES) and the U.S. Green Building Council (USGBC).

5.1 Re-certification process

The framework is divided into two phases, namely certification and audit phases. Both phases have intermediate steps. The current LEED certification system allows buildings to be certified provided they meet a certain range of total points available (certification on the basis of points accumulated). For the audit phase the building will be evaluated to see whether a building has retained or differs from LEED certified points. For buildings that retain similar points (1 - Figure 5.1) within their categories, and exceeds the benchmark of a minimum of 80% on IEQ points, re-certification audit may be scheduled for the coming evaluation period (every five years).

Buildings that do not achieve the effective points (excluding the construction phase – 2 – Figure 5.1) during the certification process could be evaluated on the basis of sustainability and IEQ indices.

Sustainability index

Three priorities, low, medium and high will be considered under the sustainability index (3 – Figure 5.1). The building is considered a low priority when a building earns more points required in the certification under the same category. For example, silver certified building can earn between 50-59 points under LEED Building NC-2009 and if 59 points are earned, 9 could be used as a buffer. On the other hand if a building achieves only 50 points, it will be considered a high priority. Therefore both IEQ and Energy audits will be essential for satisfying the re-certification requirements.

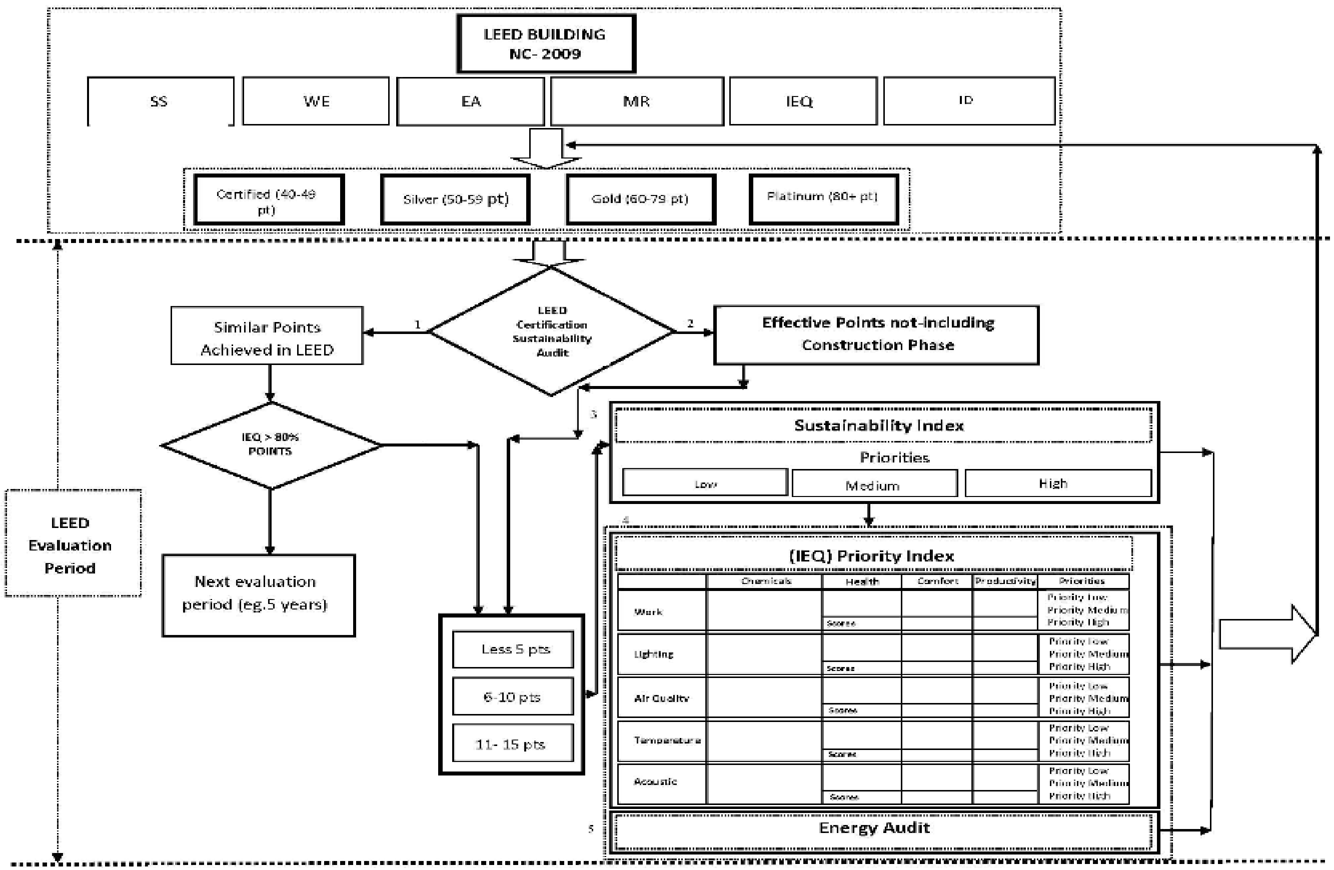
Indoor environmental quality (IEQ) index

IEQ will consist of a scoring matrix (4-Figure 5.1) that will evaluate variables including workspace, lighting, air quality, temperature and acoustics and their impact on health, comfort and productivity. Weights are given according to either higher or lower impacts weighted on a three point scale of low, medium and high. A chemical audit will be done to evaluate impact on wellbeing.

A priority index will be drawn from these audit scores that will also be organized on a three point scale of low, medium and high priority. The highest score will be assigned as a lower priority. A variable will be considered to be a lower priority when the score/index is high and *vice versa*.

An audited building that has lowest priority sustainability index and the highest IEQ priority score will require minimal auditing. The highest priority sustainability index and a low IEQ priority score will require mandatory additional IEQ and Energy audits to gain adequate points on IEQ items for the required re-certification.

Figure 5.1: LEED Certification Sustainability Audit



5.2 Chemical audit framework for occupant health and comfort in LEED certified green buildings

A thorough chemical audit will ensure that the occupants inside the LEED certified high occupancy buildings meet the basic comfort benchmarks and the impact of chemicals consumed do not adversely affect their wellbeing. The template developed is primarily to measure the comfort factor as well as the health factor for the occupants.

The Template will focus on the IEQ items identified in LEED documents including work space factor, thermal comfort, air quality factor and acoustics. The lists of chemicals identified in the template are commonly present in buildings like the printers, computers, laptops, paints, flooring, carpet cleaners etc. The health priority is based on information provided in the MSDS (Material Safety Data Sheet) and takes into consideration the health hazard factor for that particular chemical. The comfort factor is based on the few surveys that were conducted and the paper (A professional Paper from: American Society of Interior Designers Armstrong World Industries, Inc. Dynasound, Inc. Milliken & Co. Steelcase Inc.) on acoustics. Most of these chemicals did not affect the comfort factor of the occupant so are represented with the lowest impact in case of the comfort.

The Productivity factor was calculated taking into consideration the "Health priority" as well as "Comfort factors". From the template (Appendix 5), it is evident that the "Thermal Factor" affects the productivity most. When compared individually, "Biological Allergens" and "Concentration of the Gases" released from various chemicals in high occupancy buildings have the most impact on productivity.

Three different types of testing methods that include surveys, testing and sampling have been used. These methods are carefully assigned to each of the factor that has to be tested taking into consideration how they may affect the occupant's productivity. Some of these factors can be felt or seen by the occupants and can be rated by them and analyzed.

Using surveys, testing and sampling one can find whether the exposure to chemicals falls under permitted levels. If they are not, then contingency plans can be prepared to nullify effects on wellbeing. Such audits provide a greater return on investment and ensure a healthier IEQ. These audits not only ensure that there an excellent IEQ and wellbeing maintained. Such audits can also prevent the usage of toxic building materials in furnishings, paints, adhesives and carpets. This audit also looks at the many chemicals that are present in painting materials, cleaning agents and carpets that are used. This audit also takes care of the factors like acoustics, which directly affects the productivity of the Occupant. The smallest factors such as the Printer whirring running and the keyboards clicking might seem to be really small things but they disturb the occupants in many different ways.

Thermal comfort is another important factor that influences productivity and has to be addressed. This factor can be taken care off by maintaining satisfactory indoor climate, temperature and humidity levels. Timely checks for moisture excess in any part of the building as well as checking for water leaks are the most important factors for reducing biological allergens that growing in the building. These can cause several allergies to the building occupants. Restrictions like no Tobacco smoking within 20 metres of the building can also reduce the levels of this dangerous air pollutant.

Good ventilation systems require air filters that can filter the ultrafine particles from the air. Equipment to check the concentrations of ozone and concentrations of carbon monoxide in the air exists. Growing plants in the building can also help in eliminating carbon dioxide emissions. Air pollutants can also be reduced by using low emitting VOC's and using the cleaners that have low or no formaldehyde content. Detection and control of "Total Volatile Organic compounds (Tvoc)" and "Semi Volatile Organic Compound (Svoc)" is very important since these compounds present everywhere and they can be emitted from many source including computers, printers, cleaning agents and wall paints. These compounds may be reduced but cannot be avoided completely as computer usage emits these. The emission of these compounds is reduced by using adhesives and sealants, paints and coatings, floor covering materials, composite wood and agrifiber products and cleaning agents, that have very low, or no concentrations of VOC. Measures for testing cleaning product emissions and performance of VOC is required. Stricter guidelines for using such products and controlling their emissions are needed. A perfect blend of the materials should be used when cleaning agents and materials used in the carpets and flooring are considered since their combination should not worsen the situation.

The particulate materials (usually considered an atmospheric pollutant) are the smallest particles that are present in air that can be eliminated through use of air purifiers or filtration process. It is preferable to avoid using turf. Emissions from the computers can be reduced by setting the standards like turning off the computers when not in use, using low EMF emitting monitors and cables. All the laptops should not be used for more than 3-4 years and desktops not more than 4-5 years as emission levels increase as these age.

Acoustics problem can be addressed by using better insulating materials (Foam insulation, rubber foams or melamine sponges) as these can be used without harming the indoor air quality for the occupants. Frequent surveys such as occupant noise levels, room size, and room comfort need to be carried out. All such questions asked from the occupants get an immediate response. Timely checks of acoustic panels, sound absorption, sound transmission class; and reverberation time would be useful in determining the quality of the acoustics in the building. The most important factor that one can concentrate in acoustics is the speech privacy for the occupants, as this is considered the single most important factor by the occupants.

CHAPTER SIX: DISCUSSION

Indoor environment and productivity: An analytical audit of LEED certified buildings in Canada

Indoor environmental quality (IEQ) can negatively affect occupant`s physical health through poor air quality, extreme temperatures, excess humidity, and excess ventilation. Common manifestations are asthma exacerbation, and communicable respiratory illnesses. IEQ and more specifically, indoor air quality (IAQ) is a dynamic element within the building environment. As the level of indoor air pollution varies so does the level of indoor air quality. More importantly, secondary air pollutant s can be produced within the building due to indoor chemical reactions between primary pollutant and building surfaces (Mitchel, 2007). It is difficult to quantify the impacts of specific components of the indoor environment on productivity, because individual and group work effectiveness is linked to different factors that include compensation levels, management practices, and environmental comfort. Similarly, it is difficult, if not impossible, to isolate individual physical factors, such as the presence or absence of team rooms, day lighting or control over the environment. This problem is exacerbated in the case of white-collar workers whose "production" is in terms of knowledge that cannot be easily quantified. In spite of this limitation some estimation is possible. In spite of the difficulties in obtaining quantitative estimate of the effect of IAQ over work productivity some studies suggest that improvement of IAQ can lead to gains in productivity up to 10% (Beko, 2008; Pasanen, 1994). In terms of absolute monetary value poor IAQ can cost tens of occupant's health and comfort (Mitchel, 2007; Health Canada, 1989) removal of contaminants from indoor air is important.

A correlation analysis to look for a correlation between all the LEED categories *and IEQ* was performed. The results showed the existence of a negative correlation between "*Water Efficiency"* and the rest of the categories in silver level LEED-certified projects. The result was less dramatic for gold level LEED certified projects as only two LEED categories showed this correlation with "*Water Efficiency"*.

Some initiatives included on the *IEQ* categories such as a construction indoor air quality management plan during construction (credit 3.1) and testing before occupancy (credit 3.2) can impact on the level of pollutants in the building before, during and after construction. This in turn affects the capacity of the HVAC system to provide cleaner air and reduce odors upon occupation. If implemented, these actions (credit 3.1 and 3.2, *IEQ*) help reduce maintenance for the HVAC system by extending filter life and reducing cleaning requirements.

All negative correlations in LEED projects can be explained as the result of a tradeoff approach followed during the project's development. As each category contains various points it is difficult to establish with accuracy where the connections lie. At the same time the existence of more complex (and less obvious) relations between categories cannot be ignored. This may be the case for the negative correlation coefficient (-0.70) between IEQ and "*Energy and Atmosphere* (EA)" in the silver level LEED-projects. However, for the gold level LEED-certified projects there is a positive correlation coefficient (0.35). This value may merely indicate less flexibility in term of trading-off between categories at the higher level of certification as this requires a more uniform approach to the LEED certification.

The negative correlation between "*Sustainable Sites* and *Material and Resources"* (-0.56) can be explained in terms of constraints put on sustainable credits by implementing the "*Material and Resources"* LEED category. Significant negative correlations also exist between *Sustainable Sites* and *Energy and Atmosphere* in both Gold and Silver level LEED-certified projects (-0.73 and -0.95 respectively).

Site selection (credit 1, "*Sustainable Sites"*) influences building design. Opportunities to orient the building for optimum solar exposure, for instance, can enhance the power of day lighting. The site selection can therefore impact on the HVAC system (Indoor Environmental Quality) and significantly affect the energy efficiency of the building.

The immediate question with regard to these results is whether the sample size is enough to provide meaningful statistically valid results. One should also be aware that the presence of correlation doesn't necessarily imply the existence of a cause-effect relationship between categories. A correlation analysis requires that the underlying relationship between the two variables under consideration is linear. If the relationship is known to be linear, or the observed pattern between the two variables appears to be linear, then the correlation coefficient provides a reliable measure of the strength of the linear relationship. If the relationship is known to be nonlinear, or the observed pattern appears to be nonlinear, then the correlation coefficient is not useful, or at least questionable. There is no reason why we should expect a linear relationship between LEED categories. Following recommendations are made:

a) In order to assess the statistical significance of the correlation analysis between the LEED-certification categories the sample size should be increased.

b) Since many Ontario LEED projects have no scorecards in the CaGBC database it is important to contact project stakeholders to get detailed information on the rationale behind the certification process and an explanation on results obtained.

c) Perform principal component analysis (PCA) with the data sets to uncover more complex relationships.

d) Reduce levels of indoor air pollutants as several studies have shown that resultant benefits for health, comfort and productivity of ventilation at rates are well above the minimum levels prescribed in existing standards and guidelines.

e) Encourage and support additional research on indoor air pollutants and their effect on health and well-being.

Green buildings vs. healthy buildings - LEED certification perspective

The LEED rating system does not pay sufficient attention to potential health effects of chemicals and other compounds used in building materials. The rating system assigns credits for building products that may contaminate indoor air and the environment, such as insulation materials or other materials that may contain flame retardants (USGBC, 2009), PVC materials containing phthalates, and artificial turf containing multiple contaminants.

A maximum of 110 credit points are available for new construction or renovation projects and of these only 15 credits are for meeting LEED standards for indoor environmental quality – seven are associated with thermal comfort and lighting. This means that a building may earn no credits for air quality assurance but still be awarded the highest level of certification.

Several factors including outdoor air pollution that flows into buildings contribute to poor indoor air quality. The indoor air itself has pollutants from cleaning products, pesticides, formaldehyde from furniture and insulation, paints and other wood finishes, cleaning agents, waxes and polishing compounds, fragrances, plasticizers in wallpaper, rugs, components of building structures (such as sealants, plastics, adhesives and insulation materials), animal and insect allergens, molds, fumes from household gas appliances and tobacco smoke. Carbon monoxide, fine carbon particles, and polycyclic aromatic hydrocarbons emitted from poorly vented fireplaces, wood stoves, furnaces, water heaters and idling vehicles in garages also contaminate indoor air.

Many studies have shown that leukemia and neoplasms of the brain and colon are associated with formaldehyde exposure. A positive correlation exists between formaldehyde exposure and childhood asthma (McGwin *et al*., 2009 and Rumchev *et al*., 2002). Sources of formaldehyde in buildings include off-gas from pressed wood products, such as plywood, particleboard and fiberboard; insulation, durable press drapes, textiles and glues. High concentrations of formaldehyde are associated with lower fresh air exchange. LEED grants one point for documentation that composite wood and agrifiber products used on the interior of the building do not contain urea-formaldehyde resins (EQ Credit 4.4, Low-Emitting Materials: Composite Wood & Agrifiber Products).

Since the LEED rating systems for new construction and existing buildings allows smoking within designated rooms that exhaust the smoke outdoors when a separate heating and ventilation system prevents smoke from entering other parts of the building, there is an assumption that ventilation and air filtration techniques can remove secondhand smoke from the air thereby protecting people from secondhand smoke. However according to the U.S. Surgeon General and the

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) it is not possible for ventilation systems to eliminate secondhand smoke (ETS). Secondhand smoke is a known human carcinogen. It contains over 4,000 chemical compounds, more than 60 of which are known to or suspected to cause cancer (American Cancer Society, 2009). The workplace is a major source of secondhand smoke exposure for adults and secondhand smoke exposure has been linked to an increased risk for heart disease and lung cancer (US Department of Health and Human Services, 2007).

Brominated flame retardants (BFRs) are a large chemical group that includes tetrabromobisphenol A (TBBPA), polybrominated diphenyl ethers (PBDEs), polybrominated biphenyls (PBBs) and hexabromocyclododecane (HBCD or HBCDD). Articles treated with the flame retardant PBDE include carpets, upholstery fabric, cushions, and plastics used as components in electrical appliances and equipment. Current literature suggests that flame retardants are present in bodies of most people and that they are ubiquitous in the environment. Low-level exposures can cause liver toxicity, thyroid toxicity, neurodevelopmental toxicity and fertility problems (USEPA, 2010 and Harley et al., 2010). Environmental monitoring programs have found traces of PBDEs and HBCD not only in wildlife, but also in human breast milk and body fluids.

There is no law in the United States or Canada that requires labeling of chemical ingredients in plastics, and their use is not restricted in LEED-certified buildings. Plastics now comprise nearly 70 percent of the synthetic chemical industry in the U.S., where each year more than 100 billion pounds of resins are formed into building materials, window and door casings, furnishings, electrical wiring, piping, insulation, water and waste conduits, floor coverings, wood sealants, wallpaper, paints, packaging materials, appliances, countertops, lighting fixtures and electronics (Environment and Human Health, 2010).

B i s p h e n o l -A (B PA) a primary component of hard and clear polycarbonate plastics and epoxy resins, are used in a wide range of building materials, including paints, sealants, adhesives and fillers (caulk, grout, mortar, and putty). The resins are used as lacquers to coat metal products and water supply pipes. The Centers for Disease Control and Prevention (CDC) found that over 90 percent of human urine samples tested have measurable BPA levels. BPA has also been detected in human serum, breast milk, maternal and fetal plasma, amniotic fluid and placental tissue at birth. PVC plastics pose a problem at least as serious as BPA, but they are also neglected by LEED standards. Products that contain PVC can be used in LEED-certified buildings—and no credits are available for avoiding them.

Since the CDC began testing human tissues to determine the presence of some chemical ingredients of building materials most individuals whose tissues were tested carried dozens of these chemicals in their hair, blood or urine. Children often carry higher concentrations than adults. Chemicals released by building materials to indoor environments may be inhaled, ingested or absorbed through the skin.

These findings imply that design components and concepts that comprise the LEED IEQ checklist can be linked to employee health, comfort, and well-being to productivity. One way to understand the relationship between specific items in the IEQ checklist and employee productivity would be to survey occupants. Very few such studies have been able to identify specific items in the interior environment that are most associated with employee productivity gains. Building owners, therefore, have received little information that would justify increased investment in improved building interior environments.

A recent study (Hepner and Boser, 2006) investigated architects' perceptions of 17 components that comprise the LEED IEQ checklist on employee productivity. Although this study was based on the LEED Version 2.1, the components of the Construction Version 2.2 (2005) are essentially the same. The IEQ elements of day lighting, views, low-emitting interior finish materials, thermal comfort and control, and a smoke-free environment were perceived by architects as the ones most associated with employee productivity gains and were also considered to provide the best value for the budgeted cost. Although the estimated dollar value of employee productivity gains from improved IEQ varied widely, the research clearly showed that building features can affect workers' health and hence impact productivity, positively or negatively. Another study (Lee and Kim, 2008) assessed the IEQ of LEED-certified buildings by comparing seven IEQ criteria in relation to occupant's satisfaction and performance between LEED-certified buildings and non-LEED-certified buildings in the U.S. In the comparison of the seven IEQ criteria between two building groups, LEED-certified buildings presented more positive occupant's evaluations in four criteria including office furnishings quality, thermal comfort quality, indoor air quality, and cleanliness and maintenance quality. However, LEED certified buildings were rated lower in office layout quality, lighting quality, and acoustic quality.

As the LEED standard is weighted very heavily toward energy conservation and pays little attention toward health protection the green-design criteria is skewed (Environmental and Human Health, Inc. - a Connecticut-based nonprofit dedicated to protecting human health from environmental harms). It places very low emphasis on factors that relate to human health, even as the list of largely unregulated potentially toxic building materials continues to expand. One major accomplishment of LEED, that of saving energy by making buildings more airtight only results in effectively trapping the gases emitted by the unprecedented number of chemicals used in today's building materials and furnishings. Even as the threat from indoor air pollution grows LEED continues to ignore human health factors when certifying whether the building meets its environmental and social goals or not. These issues need to be addressed urgently.

As suggested by Environment and Human Health, Inc. (2010) one easy way forward would be to modify the LEED Scoring System and the US/Canada Green Building Council (GBC) should simplify the LEED scoring system within categories instead of issuing awards of "platinum," "gold" and so on. The GBC should require performance within each category (health, energy, sites, neighborhoods, etc.) on a 0–100 scale. These scoring changes would provide a more accurate reflection of project performance, while encouraging developers to improve within all categories—and scoring standards would be more easily understood. The Certification Categories (Environment and Human Health, Inc., 2010) should also be diversified and separate certifications should be offered in the fields of health, energy, sites and neighborhoods. Currently, all of these categories are grouped together, and some are more heavily weighted than others in the overall scoring system. If the GBC judged and scored a project's performance in separate categories, the developers would have an incentive to score high in all categories. This requirement would also correct the current and common misimpression that certified LEED buildings perform well in all categories.

Several alternative rating processes are under development. The challenge of conforming to ASHRAE Standard 62.1-2004 in an energy efficient manner has led some HVAC practitioners to the conclude that using dedicated outdoor air systems (DOAS) in conjunction with sensible cooling at terminal units offers the best solution. The DOAS approach, as advocated on their web site, has the potential to generate up to 21 Green Building Rating points, up to 80% of the minimum points needed for Certification.

The most effective way to achieve long-term environmental results is through the use of a consistent set of metrics and decision making framework. The U.S. EPA has developed TRACI, the Tool for the Reduction and Assessment of Chemical and other environmental Impacts to assist in impact assessment for Sustainability Metrics, Life Cycle Assessment, Industrial Ecology, Process Design, and Pollution Prevention.

LEED should encourage the use of building materials made from chemicals that are known to be made from safer chemicals. Credits should be offered for the use of products made from chemicals known to be safe, while credits should be deducted for use of products containing known hazardous substances.

Impact of indoor environment quality on sick building syndrome in Indian LEED certified buildings

Poor IEQ is recognized as an important public health risk all over the word, including India. In most societies (and India), occupants spend more than 90% of their time in indoor environments (Leech *et al.,* 2002) and for this reason it has a significant impact on health and well-being. Indoor hazards include biological and chemical contaminants, as well as poor ergonomics, lighting and physical design. These factors can exacerbate a number of health effects in building occupants including SBS (Wu *et al.*, 2007).

In spite of the fact that poor IEQ harms human health, the contributing building parameters are difficult to regulate and of little concern to the public (Wu *et al.*, 2007). There are several reasons for this. Economics play a key role in political inaction and passive public attitude. The policymakers also lack motivation to act on IEQ. Individual building owners lack incentives for greening since other building issues may be more pressing than IEQ.

The occupant IEQ surveys have been found to be useful tools for assessing the performance of green buildings (Zagreus *et al.,* 2004) and such surveys can be used together with physical measurements in buildings. The present study used this tool (Appendix 1) to study the correlation between mean SBS symptoms/person and different parameters including age, sex and perceived IEQ (satisfaction from temperature comfort, satisfaction from IAQ, satisfaction from noise level and satisfaction from workplace). A recent study (Steemers and Manchanda, 2010) that used surveys to determine overall occupant satisfaction showed that, both in India and England, occupants indicated light, job satisfaction, thermal comfort and noise as the top factors dominating the responses to structured questions. Detailed textual analysis placed thermal comfort, IAQ and control as the most important environmental variables.

An earlier Indian study done in multistory centrally air-conditioned buildings in Delhi showed that the main SBS symptoms were headache (51%), lethargy (50%) and dryness (Gupta *et al.*, 2007). The current study done in LEED certified buildings supported these earlier findings. In our study we found that silver LEED certified building occupants had the highest incident of tiredness/lethargy (54.1%) while platinum building occupants had the highest incidence of headaches. Gold certified building occupants experienced equal amounts of tiredness/lethargy (48.8%) and headache (48.9%) symptoms. The level of LEED certification level had no correlation with the SBA symptoms and making the buildings "green" did not reduce the SBS symptoms.

As previously shown by Gupta *et al.* (2007) and Seppanen and Jaakkola (1989), analyzing the SBS symptoms on a scale of 1 – 6 and developing a SBS score, was also a useful tool for understanding the syndrome in LEED certified buildings. Differences in SBS score in different floors of multistory Indian buildings have been previously (Gupta *et al.* (2007). However, our limited data for high occupancy multistory LEED certified buildings did not appear to support this as the incidence of SBS symptoms looked similar.

A clear gender difference in SBS score has been reported in an earlier Indian study that sampled 34% females and 66% males in multistory centrally air-conditioned buildings in Delhi and found that the female occupants showed 50% more SBS symptoms (Gupta *et al.* 2007). Our study that sampled 24.5% females and 77.6% males in LEED certified buildings showed no such gender bias with both genders having both a similar SBS score and percentage of related symptoms (see Table 4).

In conclusion the present questionnaire based analysis done in Indian LEED certified buildings showed that:

- Building occupants experienced SBS symptoms that occurred "often" or "sometimes". The main symptoms prevailing were tiredness/lethargy (54.1%, 48.8% and 31.7% for silver, gold and platinum LEED certified buildings respectively) and headaches (43.2%, 48.9% and 56.1% for silver, gold and platinum LEED certified buildings respectively).

- There was no gender bias for either the SBS score or the percentage of SBS symptoms.

- There was no statistically significant difference between SBS score in either Silver or Gold ($P = 0.39$), Gold and Platinum ($P = 0.40$) or Silver and Platinum ($P = 0.16$) LEED Certified buildings.

- No significant difference was found between silver, gold and platinum LEED certified buildings when occupant's responses to satisfaction for building, thermal comfort, air quality and noise level were analyzed.

Re-certification process

The current research contributes to the knowledge on creating better workplace environment for the occupants while pursuing the LEED certification and sustainable design. The proposed framework has many benefits; it could be used as a benchmark for new and existing LEED buildings and as an audit and evaluation tool by building owners, real estate agencies, designers and building managers.

From the perspective of building owners; the framework could be used to evaluate buildings in term of IAQ and their impacts on occupants. Government agencies and organizations would be more interested in using this framework and the chemical audit to create a healthy work environment, to achieve their organizational goals to increase their organizational performance to complement Energy Audits. The use of this framework could also help in identifying premiums and develop incentives to encourage the LEED re-certification process. Such a framework could also be used to improve building regulations, norms and codes. The builders and investors could use the Sustainability Index and IEQ

Index, as factors in determining the Green Building Market Value as opposed to the Conventional Building Market Value.

From the perspective of Engineers/Architects and LEED consultants, this framework could be used to enhance LEED IEQ as a design criteria to provide better indoor environments for occupant comfort, productivity and wellbeing. It could also be used by designers to provide more flexible and ergonomic designs for occupants' satisfaction such as the ability to adjust their own furniture, to organize their interior partitions to meet their needs, to decide on the color and texture of interior flooring, furniture and healthy surface finishes.

This framework could also help in accommodating client's needs, in enhancing IEQ criteria and achieving a comfortable and productive work environment in sustainable buildings. The building managers could also use the framework to evaluate maintenance costs, develop operational guidelines and also built a reserve to fund studies.

Future research

Numerous current publications have focused on sustainability from an objective (physical) point of view, mainly as a set of problems to be resolved through advanced technology and progressive innovations. The authors of these publications believe that there are many other important objective aspects in terms of people's subjective preferences, and satisfaction that could contribute to sustainable and LEED buildings. Therefore, only focusing on mechanical aspects of the indoor environment may not be effective in increasing people's satisfaction and performance, even if the indoor environment meets indoor environmental sustainability. One area of future research could be the testing the proposed framework on new LEED buildings and re-evaluate the framework to identify strengths and weaknesses for improving efficiency. Additional research could focus on adapting and testing similar frameworks on existing LEED buildings.

Among the three LEED certification levels tested in the present study, platinum buildings showed the least overall building satisfaction level. The study also identified some factors that impact on comfort level, productivity and occupants' wellbeing. Future research could investigate the reasons for this dissatisfaction. Do office furnishing positively affected levels of satisfaction? Which IEQ chemicals influence the level of satisfaction?

It is necessary for designers and architects to understand the importance of the IEQ criteria that are not included in the LEED IEQ category. New policies are necessary to ensure that buildings pursuing LEED certification provide adequate indoor environment quality. The current LEED certification system allows building to be certified when they meet a certain range of total points available, and this is possible even without achieving any credits in the LEED IEQ category. Future research could therefore focus on incorporating mandatory IEQ points in the certification process.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the present work carried out to find out whether the current LEED rating systems in high occupancy LEED certified buildings in Canada and India promote wellbeing (including occupant health and comfort) of the building occupant.

- LEED certification based on point system for rating is adaptable in countries like Canada and India notwithstanding the climate, location and socioeconomic conditions.
- The literature review clearly showed that high occupancy LEED certified buildings in Canada have health and comfort concerns.
- A maximum of 110 credit points are available for new construction or renovation projects and of these only 15 credits are for meeting LEED standards for indoor environmental quality – seven are associated with thermal comfort and lighting. This means that a building may earn no credits for IEQ but can still be awarded the highest level of certification.
- Analysis of IEQ and E&A show a significant difference between Silver, Gold and Platinum certification levels for buildings in Canada and India.
- No difference was evident between Silver, Gold and Platinum levels for Canada in the use of the six certification categories but the opposite was true for India, and a significant difference was observed.
- The LEED rating system does not pay sufficient attention to potential health effects of chemicals and other compounds used in building materials.
- As the LEED standard is weighted very heavily toward energy conservation while paying little attention towards wellbeing the green-design criteria is skewed.
- Building occupants experienced SBS symptoms that occurred “often” or “sometimes”. The main symptoms prevailing were tiredness/lethargy (54.1%, 48.8% and 31.7% for silver, gold and platinum LEED certified buildings

- respectively) and headaches (43.2%, 48.9% and 56.1% for silver, gold and platinum LEED certified buildings respectively).
- There was no gender bias for either the SBS score or the percentage of SBS symptoms.
- There was no statistically significant difference between SBS score in either Silver or Gold ($P = 0.39$), Gold and Platinum ($P = 0.40$) or Silver and Platinum ($P = 0.16$) LEED Certified buildings.
- No significant difference was found between silver, gold and platinum LEED certified buildings when occupant's responses to satisfaction for building, thermal comfort, air quality and noise level were analyzed.
- The LEED certification level cannot be a measure of energy and IEQ efficiency,

The following recommendations are made.

- In order to assess the statistical significance of the correlation analysis between the LEED-certification categories the sample size should be increased.
- Since many LEED certified and registered projects have no scorecards in the CaGBC/IGBC database, it is important to contact project stakeholders to get detailed information on the rationale behind the certification process and an explanation on results obtained.
- Perform principal component analysis (PCA) with the data sets to uncover more complex relationships.
- Reduce levels of indoor air pollutants as several studies have shown that resultant benefits for health, comfort and productivity of ventilation at rates are well above the minimum levels prescribed in existing standards and guidelines.
- Encourage and support additional research on indoor air pollutants and their effect on health and well-being.

- LEED should encourage the use of building materials made from chemicals that are known to be made from safer chemicals. Credits should be offered for the use of products made from chemicals known to be safe, while credits should be deducted for use of products containing known hazardous substances.

- In LEED certified buildings, all energy conservation measures and improvements to technology in building systems shall be subjected to chemical and sustainability audits to meet a pre-established minimum IEQ enhancement threshold, benchmarked through indices per proposed framework.

- Government regulations to protect "green buildings" investors from unfavourable variance in market value should be in place, by establishing mandatory valuation measures at pre-registration, certification, post-occupancy and re-certification phases.

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APPENDICES

Appendix 1: LEED Certified Buildings – Health and Wellbeing Questionnaire

Purpose of this questionnaire

The purpose of this survey is to obtain data for research purposes and study the performance of LEED certified buildings in terms of occupant satisfaction with the indoor environmental quality (IEQ). The four key IEQ related factors that impact workspace and productivity in LEED Certified buildings include thermal comfort, lighting, air quality and acoustics. The Questionnaire attempts to gather relevant feedback from the occupants and measure how the IEQ conditions affect their productivity, health and wellbeing in such LEED Certified buildings.

Building Details

Building Name: ____

Address: ____

City: ___________________________ State/Province: ________________

Level of LEED Certification: _______________________

Year of Certification: ____________________________

Respondent Information

Name: ______________________________ Gender: Male ☐ Female ☐

(Optional)

Date: ______________________________

Background

How many years have you worked in this building?

Less than 1 year ☐ 1 – 2 years ☐

3 – 5 years ☐ More than 5 years ☐

How long have you been working at your present workspace?

Less than 1 year ☐ 1 – 2 years ☐

3 – 5 years ☐ More than 5 years ☐

In a typical week, how many hours do you spend in your present workspace?

Less than 10 ☐ 11 – 20 ☐

21 - 30 ☐ More than 30 ☐

Location

On which floor is your workspace located?

First Floor ☐ 2 - 5 ☐

6 – 10 ☐ 11 – 20 ☐

> 20 ☐

In which area of the building is your workspace located?

East ☐ West ☐

North ☐ South ☐

Core ☐

To which direction do the windows closest to your workspace face?

East ☐ West ☐

North ☐ South ☐

No Windows ☐ Don't know ☐

Are you near an exterior wall (within 15 feet)?

Yes ☐ No ☐

Are you near a window (within 15 feet)?

Yes ☐ No ☐

How satisfied are you with your building location?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

If dissatisfied, state the reasons below:

____

____

____

Overall, does the building location affect your ability to get your job done?

Yes ☐ No ☐ Neutral ☐

How satisfied with the floor plan/layout of the building?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Workspace

Which of the following best describes your personal workspace?

Enclosed Office – private ☐

Enclosed Office – shared with other people ☐

Cubicles with high partitions (> 5 feet) ☐

Cubicles with partitions (< 5 feet) ☐

Open office, no partitions ☐

How satisfied are you with your workspace?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

If dissatisfied, tick on the reasons below:

☐ Visual privacy

☐ Comfortable amount of space

☐ Ease of Interacting

☐ Other: ______________________________

Overall, does the Office Location affect your ability to get your job done?

Yes ☐ No ☐ Neutral ☐

Office Furnishings

How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

If dissatisfied, tick on the reasons below:

☐ Furnishings are old

☐ Makes a lot of Noise

☐ No proper care being taken

☐ Other: ______________________________

How satisfied are you with your ability to adjust your furniture to meet your needs?

Very Dissatisfied ☐ Dissatisfied ☐

Neutral ☐	Satisfied ☐
Very Satisfied ☐	

How satisfied are you with the colors and textures of flooring, furniture and surface finishes?

Very Dissatisfied ☐	Dissatisfied ☐
Neutral ☐	Satisfied ☐
Very Satisfied ☐	

Overall, do the furniture and their layout affect your ability to get your job done?

Yes ☐ No ☐ Neutral ☐

Please describe any other issues related to office furnishings that are important to you.

____

____

____

Thermal Comfort

How satisfied are you with the temperature comfort in your workspace?

☐ ☐ ☐ ☐ ☐ ☐ ☐
Low High

If dissatisfied, tick on the reasons below:

- ☐ Too much air movement
- ☐ Incoming Sun
- ☐ Drafts from windows/vents
- ☐ Inaccessible thermostat
- ☐ Too cold in warm weather
- ☐ Too cold in cold weather
- ☐ Too warm in cold weather
- ☐ Too warm in cold weather
- ☐ Other: ______________________________

Which of the following do you personally adjust or control in your workspace? (Check all that apply)

Windows blinds or shades	☐	Operable window	☐
Thermostat	☐	Portable heater	☐
Permanent heater	☐	Room air-conditioning unit	☐
Portable fan	☐	Ceiling fan	☐
Adjustable air vent in wall or ceiling	☐	Adjustable floor air vent	☐

Door to interior space ☐	None of these ☐

How would you best describe the source of this discomfort? (Check all that apply)

Humidity too high (damp) ☐	Humidity too low (dry) ☐
Air movements too high ☐	Air movements too low ☐
Incoming sun ☐	Hot/cold surrounding surfaces (Floor, ceiling, windows, walls) ☐
Heat from office equipment ☐	Drafts from windows ☐
Drafts from vents ☐	My area is hotter/colder other areas ☐
Thermostat is inaccessible ☐	Thermostat is adjusted by other people ☐
Heating/cooling system does not ☐	Clothing policy is not flexible ☐
Respond quickly too thermostat ☐	

Other

Please describe any other issues related to being too hot or too cold in your workspace.

____

____

____

____

Air Quality

How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

If you have said that you are dissatisfied with the air quality in your workspace. Please rate the level of each of the following problems:

Air is stuffy / stale

Major Problem ☐ Minor Problem ☐ No Problem ☐

Air is not clean

Major Problem ☐ Minor Problem ☐ No Problem ☐

Air smells bad (odors)

Major Problem ☐ Minor Problem ☐ No Problem ☐

If there is an odor problem, which of the following contribute to this problem? (Check all that apply)

Tobacco smoke ☐ Photocopier ☐

Printers ☐ Food ☐

Carpet or furniture ☐ Other people ☐

☐

Perfume	☐	Cleaning products	
Outside sources (car exhaust, smog)	☐	Other	☐

Overall, does the air quality in your workspace affect your ability to get your job done?

Yes ☐ No ☐ Neutral ☐

Please describe any other issues related to the air quality in your workspace that are important to you.

____

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Lighting

Which of the following controls do you have over the lighting in your workspace? (Check all that apply)

Light switch	☐	Light dimmer	☐
Window blinds or shades	☐	desk (task) light	☐
None of the above	☐	Other	☐

How satisfied are you with the amount of light in your workspace?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

If dissatisfied, Kindly tick on the reasons below

☐ Too Dark

☐ Too Bright

☐ Not Enough Day light

☐ Too much Day light

☐ Not enough electric lighting

☐ Too much electric lighting

☐ Electric light flickers

☐ Electric light is undesirable colour

☐ Reflections in the computer screen

☐ Others: ______________________________

Overall, does the lighting quality affect your ability to get your job done?

Yes ☐ No ☐ Neutral ☐

Please describe any other issues related to lighting that are important to you.

____

____

____

____

Acoustics

How satisfied are you with the noise level in your workspace?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

If dissatisfied, tick on the reasons below:

☐	People talking on the phone	People talking in neighbouring areas	☐
☐	People overhearing my private Conversations	Office equipment noise	☐
☐	Office lighting noises	Telephone ringing	☐
☐	Mechanical (HVAC) system noise	Excessive echoing	☐
☐	Outdoor office noise	Other outdoor noise	☐
☐	No Privacy	Others:	☐

Overall, does the acoustic quality in your workspace affect your ability to get your job done?

Yes ☐ No ☐ Neutral ☐

Please describe any other issues related to acoustics that are important to you.

____

____

____

____

Cleanliness and Maintenance

How satisfied are you with general cleanliness of the overall building?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

If dissatisfied, Kindly tick on the reasons below

☐ No regular maintenance is done

☐ Office maintenance staff is not well trained

☐ Cleaning service provider does not work proper

☐ General Building maintenance is not proper

☐ Other:

Does the cleanliness and maintenance of this building affect your ability to get your job done?

Yes ☐ No ☐ Neutral ☐

Building Features

Considering energy use, how efficiently is this building performing in your opinion?

Very Efficiently ☐ Efficiently ☐

Neutral ☐ Inefficiently ☐

Very inefficiently ☐

For each of the building features listed below, please indicate how satisfied you are with the effectiveness of that feature:

Floor air vents

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Thermostats

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Light switches

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Automatic daylight controls

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Occupancy sensors for lighting

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Window blinds

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Roller shades

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Exterior shades

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Please describe any other issues related to the design and operation of the above mentioned features that are important to you.

____

____

____

____

____

General Comments

All things considered, how satisfied are you with your personal workspace?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Please estimate how your productivity is increased or decreased by the environmental conditions in this building (e.g. thermal, lighting, acoustics, cleanliness):

Increased ☐ Neutral ☐ Decreased ☐

How satisfied are you with the building overall?

☐ ☐ ☐ ☐ ☐ ☐ ☐

Low High

Any additional comments or recommendations about your personal workspace or building overall?

____

____

____

Health Status

When did you have your last medical check-up?

Within the last six months	☐	Within the last year	☐
Within the last two years	☐	More than two years ago	☐

Have you ever had any of the following conditions?

Sinus infection	Yes ☐	No ☐
Asthma	Yes ☐	No ☐
Eczema	Yes ☐	No ☐
Hay fever	Yes ☐	No ☐
Allergy to dust	Yes ☐	No ☐

While working at your current location, do you experience any of the following symptoms?

Eye irritation	Often ☐	Sometimes ☐	Never ☐
Nose irritation	Often ☐	Sometimes ☐	Never ☐
Throat dryness	Often ☐	Sometimes ☐	Never ☐
Tiredness/lethargy	Often ☐	Sometimes ☐	Never ☐
Headaches	Often ☐	Sometimes ☐	Never ☐
Skin dryness	Often ☐	Sometimes ☐	Never ☐

Appendix 2 Table 1 Distribution of credits within the Indoor Environmental Quality category in silver level LEED-certified projects

Indoor Environmental Quality	EDO[1]	MNR[2]	Brock University Plaza 2006	Campbell[3]	Canadian Tire[4]	Dundas and Third Line, Oakville	ELOCC[5]	École secondaire[6]	Public School[7]	Nuvo	TPC[8]	FQ[9]
Storage and Collection of Recyclables	Required											
Environmental Tobacco Smoke (ETS) Control	Required											
Low-Emitting Materials: Adhesives and Sealants	1	1	1	1	1	1	1	1	1	1	1	11
Low-Emitting Materials: Carpet	1	1	1	1	1	1	1	1	1	1	1	11

[1] Explorer Driver Office

[2] Ministry of Natural Resources Headquarters Aylmer, Ontario

[3] Campbell East, Niagara Region

[4] Welland Ontario

[5] Environmental Laboratory and Operations Control Centre

[6] Jeunes sans frontières

[7] Thomas L. Wells Public School

[8] Toronto Police College

[9] Frequency with which the credit has been awarded

Low-Emitting Materials: Paint and Coating		1	1	1	1	1	1	1	1	1	1	10
Construction IAQ Management Plan: Testing Before Occupancy		1	1	1		1	1	1	1	1	1	9
Thermal Comfort: Compliance	1	1	1	1		1	1	1		1	1	8
Carbon Dioxide (CO_2)	1		1	1	1		1	1	1			7
Construction IAQ Management Plan: During Construction			1	1	1		1	1	1			7
Thermal Comfort: Monitoring		1	1				1	1	1	1	1	7
Indoor Chemical & Pollutant Source Control		1	1		1		1	1		1		6
Controllability of Systems: Perimeter Spaces		1	1			1			1	1		5
Daylight & Views: Daylight 90% of Spaces	1						1		1	1		4
Ventilation Effectiveness				1					1			3
Low-Emitting Materials: Composite Wood and Laminate Adhesives			1						1		1	2
Daylight & Views: Daylight 75% of Spaces						1			1			2
Controllability of Systems: Non-Perimeter Spaces									1			1

Appendix 2 Table 2 Distribution of credits within the Energy and Atmosphere category in silver LEED-certified projects

Energy and atmosphere	**EDO**[10]	**MNR**[11]	**Brock University Plaza 2006**	**Campbell**[12]	**Canadian Tire**[13]	**Dundas and Third Line, ELOCC**[14]		**École secondaire**[15]	**Public School**[16]	**Nuvo**	**TPC**[17]	**FQ**[18]
Fundamental System Building Commissioning	Required											
Minimum Energy Performance	Required											
CFC Reduction in HVAC & R Equipment	Required											
Ozone Protection	1		1	1	1	1	1	1	1	1	1	10

[10] Explorer Driver Office

[11] Ministry of Natural Resources Headquarters Aylmer, Ontario
[12] Campbell East, Niagara Region
[13] Welland Ontario

[14] Environmental Laboratory and Operations Control Centre

[15] Jeunes sans frontières
[16] Thomas L. Wells Public School
[17] Toronto Police College

[18] Frequency with which the credit has been awarded

Best Practice Commissioning	1	1			1	1	1	5
Measurement Verification	1		1			1		3
Green Power			1	1			1	3
Renewable Energy 5%								0
Renewable Energy 10%								0
Renewable Energy								0

Appendix 2 Table 3 Distribution of credits for the credit optimization of energy performance within the Energy and Atmosphere category in silver LEED certified projects

	EDO[19]	MNR[20]	Brock University Plaza 2006	Campbell[21]	Canadian Tire[22]	Dundas and Third Line,	ELOCC[23]	École secondaire[24]	Public School[25]	Nuvo	TPC[26]	Arithmetic Media	SD[27]
Optimize Energy Performance (1 to 10)	7	5	3	2	8	8	2	5	2	2	3	7.83	2.45

[19] Explorer Driver Office

[20] Ministry of Natural Resources Headquarters Aylmer, Ontario
[21] Campbell East, Niagara Region
[22] Welland Ontario

[23] Environmental Laboratory and Operations Control Centre

[24] Jeunes sans frontières
[25] Thomas L. Wells Public School
[26] Toronto Police College

[27] Standard Deviation

Appendix 2 Table 4 Contribution in percent of Energy and Atmosphere, Indoor Environmental Quality toward total project score. Silver level LEED-certified projects

LEED Categories	% Contribution toward total score													
	EDO[1]	MNR[2]	Brock University Plaza 2006	Campbell[3]	Canadian Tire[4]	Dundas[5]	ELOCC[6]	École secondaire[7]	Public School[8]	Nuvo	TPC[9]	Arithmetic Media	SD[10]
Energy and Atmosphere	28.6	18.2	11.1	9.1	31.4	30.3	8.6	19.4	8.3	14.7	16.7	17.9	8.8
Indoor Environmental Quality	14.3	21.2	30.6	24.2	14.3	21.2	28.6	25.0	38.9	26.5	19.4	24.0	7.2

[1] Explorer Driver Office

[2] Ministry of Natural Resources Headquarters Aylmer, Ontario

[3] Campbell East, Niagara Region

[4] Welland Ontario

[5] Dundas and Third Line, Oakville

[6] Environmental Laboratory and Operations Control Centre

[7] Jeunes sans frontières

[8] Thomas L. Wells Public School

[9] Toronto Police College

[10] Standard Deviation.

Appendix 3 Table 5 Distribution of credits within the Indoor Environmental Quality category in gold LEED certified projects

Indoor Environmental Quality	**Humber College Urban Ecology Centre**	**Minto Midtown**	**Minto Roehampton**	**Mundy's Bay Public School**	**Power Stream Corporate Head Office**	**Villa Angela**	**St Gabriel/s Passionist Parish**	**FQ**
Storage and Collection of Recyclables	Required							
Environmental Tobacco Smoke (ETS) Control	Required							
Construction IAQ Management Plan: During Construction	1	1	1	1	1	1	1	8
Daylight & Views: Daylight 90% of Spaces	1	1	1	1	1	1	1	8
Low-Emitting Materials: Adhesives and Sealants	1	1		1	1	1	1	7
Low-Emitting Materials: Carpet	1		1	1	1	1	1	7
Carbon Dioxide (CO_2)	1	1	1	1	1			6
Construction IAQ Management Plan: Testing Before Occupancy	1	1	1	1	1		1	6
Low-Emitting Materials: Paint and Coating	1			1	1	1	1	6

Controllability of Systems: Perimeter Spaces	1	1	1		1	1		6
Daylight & Views: Daylight 75% of Spaces	1	1	1	1		1	1	6
Indoor Chemical & Pollutant Source Control	1		1	1	1			5
Thermal Comfort: Compliance			1	1	1	1		5
Ventilation Effectiveness	1	1	1					4
Low-Emitting Materials: Composite Wood and Laminate Adhesives	1			1		1	1	4
Thermal Comfort: Monitoring				1	1	1		4
Controllability of Systems: Non-Perimeter Spaces	1			1		1		3

Appendix 5: The MSDS of the Chemicals considering the health Factor

Primary I.D	Label	Health Priority	Comfort Priority	Productivity Impact	Type Of Test
Work Space					
	Emissions from Carpet , Flooring				
	1-Methyl-2-Pyrrolidinone	3	5	4	B,C
	2-Ethylhexanoic Acid	4	5	4	B,C
	4-Phenylcyclohexene	5	5	5	B,C
	Acetaldehyde	2	5	3	B,C
	Ammonical Copper Arsenate	4	5	4	B,C
	Ammonical Copper Quat	5	5	5	B,C
	Ammonical Copper Zinc Arsenate	4	5	4	B,C
	Benzene	1	5	3	B,C
	Caprolactam	5	5	5	B,C
	Chromated Copper Arsenate	4	5	4	B,C
	Copper Napthenate	4	5	4	B,C
	Nonanal	4	5	4	B,C
	Octanal	4	5	4	B,C
	Pentachlorophenol	3	5	4	B,C
	Polyurethanes	2	5	3	B,C
	Vinyl Acetate	4	5	4	B,C
	Total Average Impact from Carpet , Flooring	3	5	4	
	Emissions from Adhesive				
	2-Ethyl-1-Hexanol	3	5	4	B,C
	Acrylic Emulsion Latex	4	5	4	B,C
	Benzothiazole	4	5	4	B,C
	Butyl Rubber	4	5	4	B,C
	Isooctylacrylate	5	5	5	B,C
	Methyl Biphenyl	2	5	3	B,C
	Naphthalene	3	5	4	B,C
	Neoprene	4	5	4	B,C
	Nitrile	5	5	5	B,C
	Oleoresinous	4	5	4	B,C
	Phenol	2	5	3	B,C
	Polysulfide	5	5	5	B,C

Polyurethane	3	5	4	B,C
Styrene	3	5	4	B,C
Styrene Budadiene Rubber	5	5	5	B,C
Toluene	3	5	4	B,C
Vinyl Acetate	4	5	4	B,C
Vinyl Cyclohexene	3	5	4	B,C
Xylenes (M-,O-,P-)	3	5	4	B,C
Total Average Impact	3	5	4	
Cushion products				
Tvoc	3	5	4	B,C
4-Phenylcyclohexine	4	5	4	B,C
Butylated Hydroxytoluene	3	5	4	B,C
Formaldehyde	2	5	3	B,C
Trichoroethylene	3	5	4	B,C
Total Average Impact	3	5	3	
Emissions from Desktop and Notebook Computers				
2-Butoxyethanol	3	5	4	B,C
Acetophenone	4	5	4	B,C
Bdp	5	5	5	B,C
Benzaldehyde	3	5	4	B,C
Cyclohexanone	3	5	4	B,C
Cyclohexyl Benzene	4	5	4	B,C
Dbp	3	5	4	B,C
D-Limonene	3	5	4	B,C
Ethyl Benzene	3	5	4	B,C
Ethyl Carbonate	3	5	4	B,C
Hexabromo-Benzene	3	5	4	B,C
Methyl Carbonate	3	5	4	B,C
PBDE 100 (A BFR)	3	5	4	B,C
PBDE 47 (A BFR)	3	5	4	B,C
PBDE 99 (A BFR)	3	5	4	B,C
Pentadecane	4	5	4	B,C
Tbbpa	3	5	4	B,C
Tcpp	5	5	5	B,C

Tpp	3	5	4	B,C
Trimethyl Cyclohexenone	4	5	4	B,C
Total Average Impact	3	5	4	
Emissions from Printers and Copiers				
1,2,4-Trichloro-Benzene	3	5	4	B,C
1,2-Dichloro-Benzene	3	5	4	B,C
1,3-Dichloro-Benzene	4	5	4	B,C
1,4-Dichloro-Benzene	3	5	4	B,C
123-Trimethylbenzene	3	5	4	B,C
13-Diethylbenzene	4	5	4	B,C
1-Hexadecanol	3	5	4	B,C
1-Hexanol, 2-Ethyl-	3	5	4	B,C
1-Methyl Naphthalene	3	5	4	B,C
1R-.Alpha.-Pinene	4	5	4	B,C
3-Carene	3	5	4	B,C
Arsenic	2	5	3	B,C
(2-Methylpropyl)-	3	5	4	B,C
Benzene, 1,2,3-Trimethyl-	3	5	4	B,C
Butyl- Benzene	3	5	4	B,C
Propyl- Benzene	3	5	4	B,C
Bromated Flame Retardants	2	5	3	B,C
Chloroform	3	5	4	B,C
Cydic Siloxanes	3	5	4	B,C
Hexamethyl- Cyclotrisiloxane	4	5	4	B,C
D3-Siloxane	4	5	4	B,C
D4-Siloxane	4	5	4	B,C
D5-Siloxane	4	5	4	B,C
Decamethyl-Cyclopentasiloxane,	4	5	4	B,C
Dodecane	3	5	4	B,C
Freon 11	4	5	4	B,C
Freon 12	4	5	4	B,C
Hexachloro-Butadiene	3	5	4	B,C
Hexadecane	3	5	4	B,C
Hexanal	3	5	4	B,C

I-Butyl Benzene	3	5	4	B,C
Low-Molecular-Weight Carbonyls	3	5	4	B,C
Mesitylene	5	5	5	B,C
Methyl Chloride	3	5	4	B,C
Methylene Chloride	2	5	3	B,C
N-Propylbenzene	4	5	4	B,C
Ozone	3	5	4	B,C
Tetrachloroethene	3	5	4	B,C
Tetradecane	3	5	4	B,C
Txib	4	5	4	B,C
Texanol	4	5	4	B,C
Tridecane	4	5	4	B,C
Total Average Impact	3	5	3	
Emissions from Tobaco smoke				
Acetic Acid	2	5	3	B,C
Acetone	3	5	4	B,C
Ammonia	2	5	3	B,C
Arsenic	2	5	3	B,C
Butane	2	5	3	B,C
Cadmium	2	5	3	B,C
Carbon Monoxide	1	5	3	B,C
DDT/Dieldrin	2	5	3	B,C
Ethanol	4	5	4	B,C
Hexamine	3	5	4	B,C
Hydrogen Cyanide	1	5	3	B,C
Methane	3	5	4	B,C
Methanol	4	5	4	B,C
Napthalene	3	5	4	B,C
Nicotine	2	5	3	B,C
Nitrogen Dioxide	2	5	3	B,C
Stearic Acid	4	5	4	B,C
Total Average Impact	2	5	3	
Lighting Systems				
Amount Of Light	3	1	2	A

Are People Comfortable With Lighting System Provided	5	1	3	A
Are The Lights Exactly Located As Per The Occupants Comfort	5	2	3	A
Color Rendering Index	5	3	4	B
Color Temperature	5	5	5	B
Consideration Of The Shadows Cast By Equipment	5	2	3	A
Contrasts In Light Levels	4	2	3	A,B
Interior Of The Room Reflecting Light Properly	5	3	4	A,B
Is The Lighting System Too Bright Or Too Dull For The Occupants	4	3	3	A
Local Control Of Lighting	5	3	4	A
Radiation From The Lighting System	3	5	4	B
Reflective Surfaces	5	2	3	B
Total Average Impact	4	2	3	
Thermal Comfort				
Air Temperature Stratification	3	3	3	C,B
Air Velocity	4	3	3	A,B
Are Some Of The Regions Cooler/Hotter Than Others	4	3	3	A
Are The Occupants Comfortable With The Temperatures Inside	4	2	3	A
Cooling Or Heating Devices	4	3	3	A,B
Floor Surface Temperatures	4	4	4	C,B
Flooring Used	4	5	4	B
Fresh Air Rate	2	2	2	A,B
Heat Balance	3	3	3	C,B
How Often Are There Extremes In Room Temperature	2	3	2	A,B
Humidity Levels	3	2	2	A,B
Is The Indoor Climate Satisfactory	4	2	3	A
Is There Individual Control For Temperature In A Particular Room	5	2	3	A
Number Of People Accommodated In Given Space	2	1	1	A,B

Personal Control	5	3	4	A
Radiant Asymmetry	4	2	3	C,B
Radiant Temperature	5	2	3	A,B
Relative Humidity	3	2	2	A,B
Room Temperature	3	2	2	A,B
Thermal Radiation	3	2	2	C,B
Under Floor Air Distribution	3	3	3	C,B
Use Of Fiber Glass For Thermal Comfort	2	5	3	C,B
Ventilation	1	1	1	A,B
Total Average Impact	3	2	2	
Air Quality				
Biological Allergens				
Bacteria	2	4	3	B,C
Dust Mites	2	2	2	B,C
Fungal Spores	2	2	2	A,B,C
Legionella	2	4	3	A,B,C
Moulds	2	2	2	A,B,C
Viruses	2	5	3	B,C
Total Average Impact	2	3	2	
Volatile Organic compounds				
1,1,1-Tricholoroetane	3	5	4	B,C
1,2-Dichloroetane	3	5	4	B,C
1-Butanol	4	5	4	B,C
1-Octen-3-Ol	3	5	4	B,C
1-Octene	3	5	4	B,C
2,4-Dihydroxybenzophenone	4	5	4	B,C
2-Heptanone	3	5	4	B,C
2-Hexanone	3	5	4	B,C
2-Nonanone	3	5	4	B,C
2-Octen-1-Ol	4	5	4	B,C
2-Pentanol	3	5	4	B,C
3-Methyl Furan	4	5	4	B,C
3-Methyl-1-Butanol	4	5	4	B,C

3-Methyl-2-Butanol	2	5	3	B,C
3-Octanol	4	5	4	B,C
3-Octanone	3	5	4	B,C
Aliphatic Hydrocarbons	4	5	4	B,C
Anthracene	5	5	5	B,C
Benzyl Butyl Phthalate	3	5	4	B,C
Bisphenol A	3	5	4	B,C
Borneol	4	5	4	B,C
Butyl Benzyl Phthalate	2	5	3	B,C
Decabromodiphenyl Ether	4	5	4	B,C
Dichlorodiphenyltrichloroethane	2	5	3	B,C
Dimethyl Phthalate	5	5	5	B,C
Di-N-Octyl Phtalate	4	5	4	B,C
Dioctyl Phthalate	4	5	4	B,C
Ethyl Acetate	3	5	4	B,C
Glycol Ethers	4	5	4	B,C
Heptachlor	2	5	3	B,C
Hexabromocyclododecane	3	5	4	B,C
Hexavalent Chromium	4	5	4	B,C
Isoprene	3	5	4	B,C
Methyl Ethyl Ketone	3	5	4	B,C
Ophenylphenol	4	5	4	B,C
Paradichlorobenzene	3	5	4	B,C
Polybrominated Diphenyl Ether	5	5	5	B,C
Tetrabromobisphenol A	3	5	4	B,C
Tetrabromobisphenol A Bis	3	5	4	B,C
Thujopsene	5	5	5	B,C
Triphenyl Phosphate	3	5	4	B,C
Vinyl Chloride	3	5	4	B,C
Total Average Impact	3	5	4	
Other Chemicals and gases				
Aluminum Oxide	3	5	4	B,C
Ammonium Sulphate	3	5	4	B,C
Antimony	3	5	4	B,C

Asbestos	2	5	3	B,C
Barium	3	5	4	B,C
Boric Acid	3	5	4	B,C
Carbon Black	4	5	4	B,C
Carbon Nanotubes , Coated	3	5	4	B,C
Carbon Nanotubes , Single Wall	3	5	4	B,C
Carbon Nanotubes, Multi-Wall	3	5	4	B,C
Chlordane	4	5	4	B,C
Chlorophene	3	5	4	B,C
Chromium	3	5	4	B,C
Cyanide	3	5	4	B,C
Dust	2	2	2	B,C
Lead	4	5	4	B,C
Pesticides	3	5	4	B,C
Phthalates	4	5	4	B,C
Radon	3	5	4	B,C
Second-Hand Smoke	2	5	3	B,C
Silica	4	5	4	B,C
Silicon Carbide	3	5	4	B,C
Sodium Borate	3	5	4	B,C
Titanium Dioxide	4	5	4	B,C
Triclosan	3	5	4	B,C
Total Average Impact	3	4	3	
Particulate Materials				
PM10	5	4	4	B,C
PM2.5	5	4	4	B,C
Total Average Impact	5	4	4	
Concentration of the Gases				
Carbon Monoxide Concentrations	3	3	3	B,C
Ozone Concentration Concentrations	2	2	2	B,C
Volatile Organic Compound Concentrations	2	4	3	B,C
Total Average Impact	2	3	2	

Acoustics

People				
Conversation Distraction	5	3	4	A,B
Excessive echoing of sounds	3	4	3	A,B
HVAC noise	4	4	4	A,B
Individual Workspaces	3	2	2	A
People talking on the phone	5	2	3	A,B
Proximity To One Another In Open Offices	3	2	2	A
Speech Audibility	5	2	3	A
Speech Privacy For Occupants	5	2	3	A
Total Average Impact	4	2	3	
Equipment				
File Drawers Sliding Open	5	4	4	A,B
Floor Machines And Burnishes	5	4	4	A,B
Impact Insulation Class	5	3	4	A,B,C
Keyboards Clicking	5	4	4	A,B
Phones Ringing	5	2	3	A,B
Printer Whirring	5	4	4	A,B
Propane Floor Equipment	5	2	3	A,B
Total Average Impact	5	3	3	
Other Factors Involved				
Are Acoustic Panels Good Enough?	4	3	3	B
Background Noise	5	2	3	B
Distribution Of Noise Levels	4	2	3	B,C
How Good Is The Speech Intelligibility	5	2	3	B
Noise Reduction Coefficient	3	3	3	B
Noise Isolation From Adjacent Spaces	5	2	3	A,B,C
Noise Isolation From The Exterior	5	2	3	A,B,C
Reverberation Time	5	3	4	B
Size Of The Room	3	2	2	A,B
Sound Absorption	5	3	4	B
Sound Reduction.	4	3	3	B
Sound Transmission Class	5	2	3	B
Total Average Impact	4	2	3	

Ref:
The Health Priority rating were from The MSDS of the Chemicals considering the health Factor
http://www.ee.ryerson.ca/~jkoch/MSDS_Sheets/835-liquid.pdf
A professional Paper from: American Society of Interior Designers Armstrong World Industries, Inc. Dynasound,

SHORT BIOGRAPHY

J. (JAG) MOHAN

M.Eng. (Carleton), Dip.Eng.Mgt. (Ottawa), B.Eng. (Madras), P.Eng. (Ontario), FEC (Canada)
Dean, School of Engineering Technology and Applied Science
Centennial College of Applied Arts and Technology, Toronto, Ontario, Canada

EDUCATION

- Bachelor of Engineering (Civil), University of Madras, India 1976
- Master of Engineering (Civil), Carleton University, Ottawa, Canada, 1981
- Post-graduate Diploma in Engineering Management, University of Ottawa, Canada (Completed through part-time studies), 1988

CURRENT PROFESSIONAL & TRADE AFFILIATIONS

- Board Member (elected), Centennial College Board of Governors, Ontario, Canada
- Board Member, Rouge Valley Health System hospitals (Scarborough, Ajax, Pickering – Canada)
- Board Member, Canadian Technology Accreditation Board
- Member, Canadian Information Processing Society
- Member, Ontario Sustainable Energy Association
- P.Eng. - Professional Engineer & Designated Consulting Engineer, Province of Ontario, Canada
- Sc.T – Certified Applied Science Technologist, Province of Ontario, Canada
- Associate member, Canadian Standards Association Committee on "Energy Efficiency and Renewables"

KEY RECOGNITIONS AND ACHIEVEMENTS

- “Fellow” of Engineers Canada (FEC), a designation bestowed in honour of exceptional contributions to the engineering profession in Canada.

- "Distinguished Service Award", Ontario Association of Certified Engineering Technicians & Technologists (OACETT), for outstanding contributions to the profession.
- Ontario Volunteer Service Award, Ministry of Citizenship & Immigration.
- Presented papers at international conferences and participated as an invited keynote speaker (topic: "*Role of Technology in the evolution and transformation of post-secondary education"*) at professional seminars and international education events.
- In April 2011, represented the Canadian Delegation at the "World Renewable Energy Technology Conference" at New Delhi, India as a speaker representing Canadian colleges.
- Doctor of Science (Honoris Causa), awarded by PRIST University in South India, where I was born, for outstanding contribution to engineering education over the past three decades.

POST-SECONDARY ACADEMIC EXPERIENCE IN CANADA (22 YEARS)

CENTENNIAL COLLEGE OF APPLIED ARTS AND TECHNOLOGY
TORONTO, ONTARIO, CANADA
www.centennialcollege.ca Aug 2006 – Present (5-1/2 years)

- Dean, School of Engineering Technology & Applied Science, Aug 2006 – present
- Director, Centennial Energy Institute , Oct 2006 – Present

SHERIDAN COLLEGE OF APPLIED ARTS AND TECHNOLOGY
BRAMPTON, ONTARIO, CANADA
www.sheridaninstitute.ca Oct 1989 – Aug 2006 (17 years)

- Associate Dean, School of Science and Technology (Aug 1999 – Feb 2003)
- Professor, School of Science and Technology (Oct 1989-Aug 1999, Mar 2003-Aug 2006)

OTHER ACADEMIC EXPERIENCE

- Research Assistant, University of Guelph (part-time during PhD Course work)
- Research/Teaching Assistant, Carleton University (during M.Eng. studies)

- Associate Lecturer, Civil Engineering, Madras University (1976-1979, until departure to Canada)

NON-ACADEMIC CANADIAN EXPERIENCE – PROFESSIONAL ENGINEERING & CONSULTING BUSINESS (30 YEARS)

- President & CEO, Jag Mohan & Associates Ltd., (www.jagmohan.ca) a multi-disciplinary consulting engineering firm located in Ontario, Canada offering consulting engineering and project management services to the building industry. Managed a team of engineers and project leaders towards completion of over 300 small/medium size new building construction and renovation projects, 1990 – Present

- Manager of CAD division & Senior Engineer, Adjeleian Allen Rubeli Ltd., consulting engineering firm located in Ottawa, 1984 – 1989

- Structural Engineer, Stanley Associates Engineering Ltd. (currently Stantec), a multi-disciplinary consulting engineering firm located in Edmonton, Albert, 1981 – 1983