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Needs Assessment Study of BIM Tools for Indoor Environmental Quality Management

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Project & Report
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Abstract

Considering the existing scenario in AEC industry, where clients often set a fairly low budget for design stage, an incomplete design planning and assessment can cause extra cost and time in changing the design in the construction stage or during the occupancy over the lifetime of the building. It has been studied that most of the decisions which impact IEQ management of the building are done after the initial design phase which hinders their usefulness and suitability to the project. Through literature review and subsequent investigation, the author provided gap analysis in the current capabilities of BIM tools during the design phase which would ultimately enhance the IEQ management of the building. The purpose of the research was to use BIM to facilitate sustainability in the design and eventually, lifecycle of the building. To measure Indoor Environmental Quality, LEED Version 3.0 checklist was used. After an extensive literature review, a matrix was created which tabulated the LEED IEQ credits against the BIM tools capability. A subsequent detailed analysis, along with the findings of the matrix was then used to draw conclusions about the deficiencies and potential use of BIM platforms in the future. The outcome of this research was the identification of Indoor Environmental Quality performance measures not currently incorporated in the existing BIM models. Further recommendations were made for a more complete model which makes use of these measures during the design phase and ultimately the lifecycle of the building.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Building Information Modeling (BIM) is driving an unprecedented revolution in the Architecture, Engineering and Construction (AEC) industry. It involves digital engineering, modeling and simulation, sometimes referred to as "Virtual Design and Construction," used to predict and manage construction projects. However, BIM is much more than a software package or a digital model. It is a new methodology and process of data management, information distribution, risk mitigation and project delivery (Jacocks 2009). Alongside this transformation are other trends in the AEC industry. Construction projects are increasingly complex, owner expectations are increasing, and environmental consciousness is desired. Specifically, the green building or sustainability movement is rapidly gaining momentum (Jacocks 2009).

The importance of the this research is that considering the existing scenario in AEC industry, where clients often set a fairly low budget for design stage, an incomplete design planning and assessment can cause extra cost and time in changing the design in the construction stage or during the occupancy over the lifetime of the building. The crucial part is that the proposed materials are not normally analyzed thoroughly and this can cause a serious environmental impact for the next 60 years or longer.

Similar research has been done in the past in which attempts have been made to combine BIM to Sustainability. Kyle Jacocks (2009) in his research titled, "Leveraging BIM for Sustainability", used LEED credits as a measurement of sustainability and tracked the criteria which were compatible with specified BIM tools. One major weakness in Kyle's research was that the analysis was a high level overview of Leadership in Energy & Environmental Design (LEED) criteria based on literature review and resulting documentation. My research carries forward Kyle's investigation by focusing on Indoor Environmental Quality (IEQ) as a parameter and exploring the utility of BIM tools to satisfy the IEQ management of the building. A detailed analysis of two of the IEQ performance criteria has also been undertaken in order to better understand the capacity of

BIM tools. The detailed analysis done in the study also results in setting a framework for future research on similar lines which would further explore other credits in the field of Indoor Environmental Quality.

The importance of analyzing IEQ performance in a building has grown, but it is still often done using simple static calculations or estimates (Laine et al. 2007). Accurate IEQ simulation software has been available already for decades, but these tools are still not widely used by the stakeholders in building projects. The main barrier of wider usage of digital IEQ analysis methods has been the required big manual input work. By utilizing BIM as a data source for IEQ analysis, the data input will be more efficient and the existing data more reusable. BIM facilitates easier verification of its performance in different phases of the building process (Laine et al. 2007).

Over the past 20 years, research and experience have improved our understanding of what is involved in attaining high indoor environmental quality and revealed manufacturing and construction practices that can prevent many indoor environmental quality problems. The use of better products and practices has reduced potential liability for design team members and building owners, increased market value for buildings with exemplary indoor environmental quality, and boosted the productivity of building occupants. In a case study included in the 1994 publication, "Greening the Building and the Bottom Line," the Rocky Mountain Institute highlights how improved indoor environmental quality increased worker productivity by 16%, netting a rapid payback on the capital investment (Rocky Mountain Institute 1994).

Recent achievements in Building Information Modeling (BIM) technologies and interoperable software tools have made BIM-based performance analysis possible for exploitation in all building processes, especially during the design phase. The systematic use of analysis and automated performance monitoring for performance evaluation throughout the building life cycle, from early design through construction, commissioning, and operations and maintenance, has significant potential to improve the end use performance of buildings.

The importance of analyzing indoor comfort performance in building design has been recognized in the recent past, because of the increasing awareness of the role of Energy usage in building life cycle costs and environmental impacts and the role of indoor conditions in the personnel's productivity (Laine et al. 2007). However, the relevant BIM tools are still mostly used by researchers, not widely by practitioners in building projects. The main barrier of wider usage of dynamic IEQ analysis methods has been the required big manual input work (Loh et al. 2007).

Other barriers for wider utilization of BIMs in IEQ analysis have been the missing interoperable data interface implementations in the simulation tools and the lacking guidelines. The Industry Foundation Classes (IFC) provides today an open standard for description and exchange of information within the life cycle of a constructed facility. To use BIM effectively however, and for the benefits of its use to be released, the quality of communication between the different participants in the construction process needs to be improved (Loh et al. 2007).

By using BIM it is easier to verify the performance of the building truly in different phases of the building process. The experiences from many BIM based projects show that interoperable analysis software is not enough for the management of IEQ performance during the building process, but it requires also tools to manage different revisions of BIMs, to compare the performance of these revisions and to visualize this by easy-to-understand way (Bernstein 2007).
Therefore, the purpose of this paper is to identify the IEQ performance criteria not incorporated in the current BIM tools and then undergo a needs assessment study of BIM tools in order to analyze Indoor Environmental Quality Management.

1.2 PROBLEM STATEMENT & OBJECTIVES

The objective of the research was to identify BIM tools' capability to analyze Indoor Environmental Quality strategies. It has been studied that most of the decisions which impact IEQ management of the building are done after the initial design phase which hinders their usefulness and suitability to the project. Through literature review and a detailed study, the author has provided gap analysis in the current capabilities of BIM tools during the design phase, which would result in further research in the area, ultimately enhancing the IEQ management of the building.

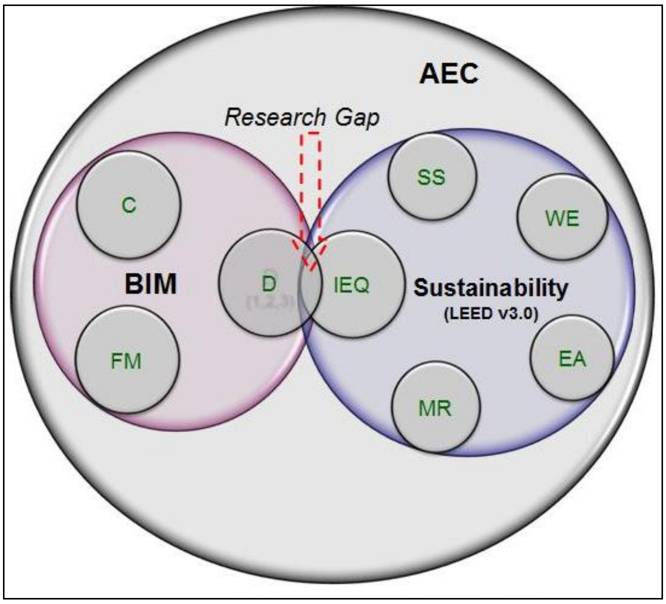

Fig. 1: Research Gaps in the AEC Industry

The author hopes that after the conclusion of this research, future researchers will be able to use BIM to facilitate sustainability in the design and ultimately, lifecycle of the building. To measure Indoor Environmental Quality, LEED Version 3.0 checklist was used. The reason for using LEED Version 3.0 as an assessment tool is because it is a widely accepted and federally mandated measurement tool for sustainability and in turn, IEQ (Jacocks 2009). Figure 1 above reflects the gaps in the industry after overlapping the spheres of Building Information Modeling and Sustainability.

1.3 RESEARCH QUESTION

After identifying the problem areas and the research gaps in the industry, it was important to form a research question for the purpose of this project & Report.

Research Questions:

- Can the specified IEQ performance measures, measured here as LEED credits, be monitored using the existing BIM platforms in a building design?
- How are the platforms going to accomplish this task?

1.4 SCOPE DEFINITION

Amongst all the stakeholders in the construction industry, the scope of this research has been limited to the designers who are involved in the design phase of the building's lifecycle. This is done to narrow down the vast literature and the research already done in the fields of sustainability and BIM.

Also, as described above, Indoor Environmental Quality has been chosen to link with the designers and the design aspect of Building Information Modeling. It needs to be mentioned here though, is that the research also takes forward the study done by also focusing on the construction and the facilities management phases of the building. Fig. 3 below charts out the scope definition of this research.

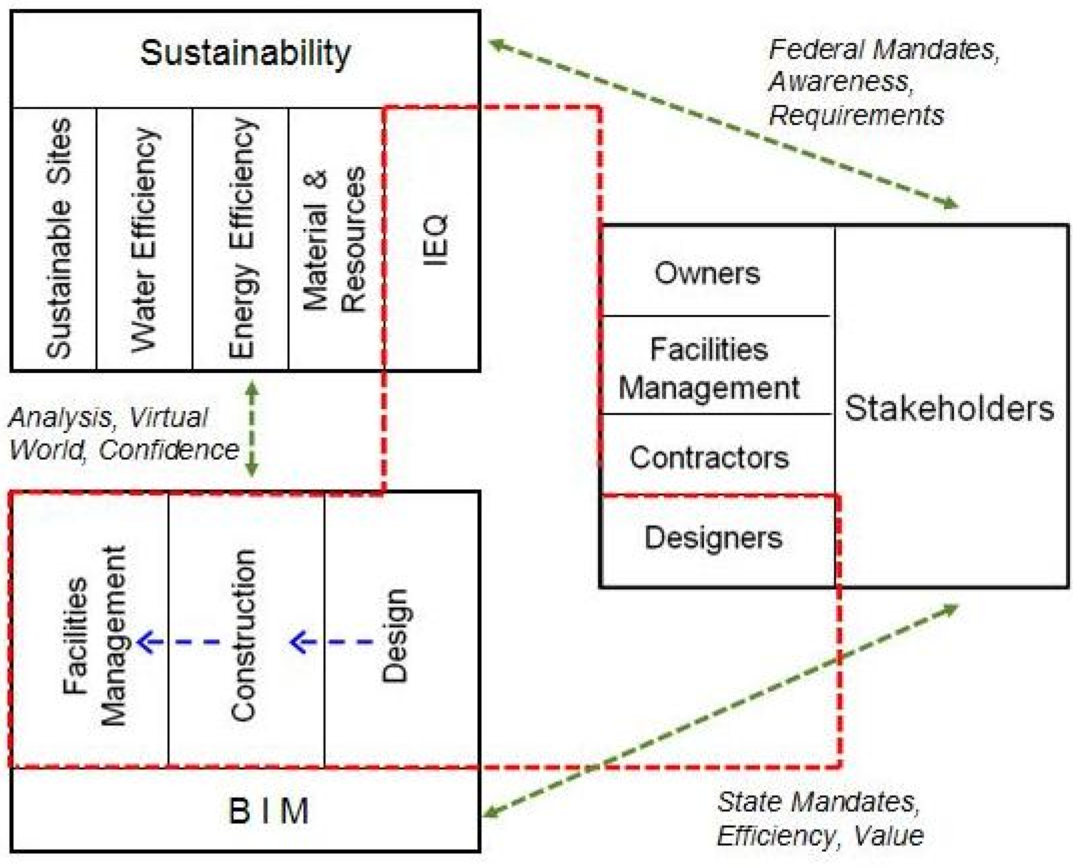

Fig.2: Scope Definition

1.5 METHODOLOGY

The research objective of correlating the identified Indoor Environmental Quality performance measures to the current BIM models and finding solutions to enhance existing models is best understood through the use of literature review, and a subsequent detailed analysis. The steps outlined for successful completion of the research were:

- *Understand BIM technology and IEQ management through Literature Review*

  Through Literature review, the two main objects of research needed to be studied and analyzed in order to understand the strengths and weaknesses of both and perform a gap analysis for the purpose of this study.

- *Develop a Hypothesis after creating definitions of BIM and IEQ with respect to the research*

  After the literature review, the relation between IEQ and BIM was identified, following which a hypothesis was developed which would be tested after a detailed analysis on the subject.

- *Develop a matrix of what BIM tools apply to specific IEQ LEED 3.0 credits*

  For the purpose of the study, it was required that a matrix be created that would tabulate the IEQ performance criteria against the process through which those criteria would be evaluated on and the BIM tools capability to track those criteria. The BIM knowledge used for the purpose of this study was two-fold: first, was the literature garnered through various journals and conference papers and secondly, the author's prior experience of using different BIM tools in the field. The list of software and the projects worked on has been attached as Appendix A. The creation of matrix helped the author understand the deficiencies of BIM tools with respect to the IEQ credits.

- *In-depth analysis of Credits 3.1 & 3.2: IAQ Construction Management Plans*

  To make the research more meaningful, two credits from the matrix were chosen for a more detailed analysis. The two credits chosen; Credit 3.1: Construction IAQ Management Plan-During Construction and Credit 3.2: Construction IAQ Management Plan-Before Occupancy, were examined in detail along with their reference standards to find out how and which BIM tool could be utilized to achieve the credit. The reason for choosing these two credits, despite them being construction phase credits, was the fact that the author realized that very little research has been done on these two credits in order to correlate them with BIM tools. Other IEQ design phase credits like credits 7 & 8 could have been chosen for the study but the fact that a lot of background research has been done in the past was a major deterrent in choosing them. For instance, Krygiel & Nies discuss in detail the collaboration between BIM & Daylighting in their book, "Green BIM" (Krygiel & Nies 2008). Actual examples of the IAQ plans from live projects were used during the course of the in-depth analysis. An interview with the sustainability manager of Hess Constructions provided valuable insights as well.

- *Study IFC data structures to check how they apply to the above mentioned credits.*

  The next step in the research was to correlate the performance criteria needed to achieve the above mentioned credits to BIM technology available in the market. Background literature also reflected the lack of the current software and the need to use IFC data structures for optimization of the building performance. This section gave the author a thorough understanding of the exact requirements needed by the tools/software. This section also laid the foundation for conclusions and the future research section.

- *Recommendations to apply the identified measures to successfully incorporate Indoor Environmental Quality in BIM technology*

The final step of this study was to outline the areas needed by BIM tools to successfully integrate the technology into IEQ management. The recommendations and areas for future research were identified to improve the efficiency of the facilities over their lifecycle.

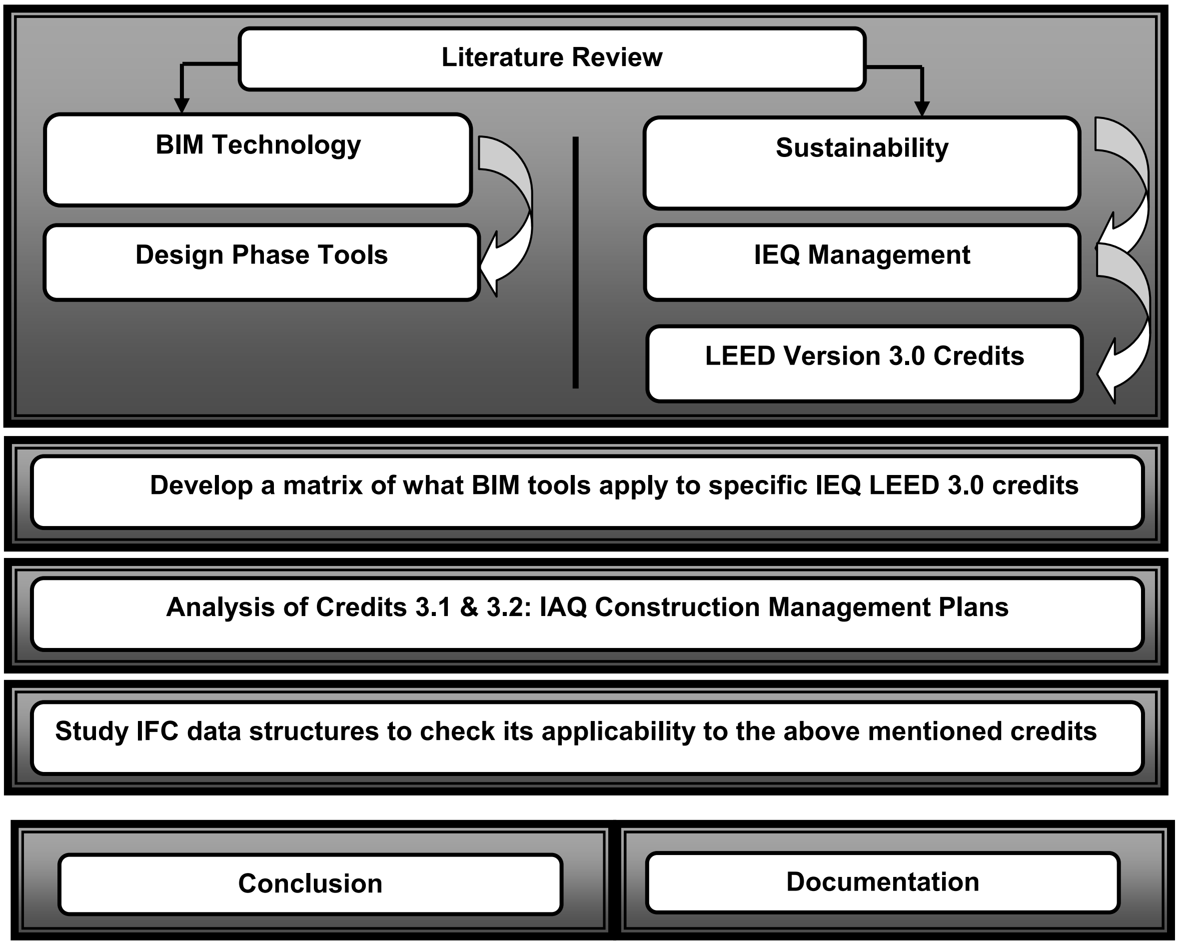

Fig. 3: Methodology of the Research

1.6 EXPECTED OUTCOMES & IMPACTS

The outcome of this research was the identification of Indoor Environmental Quality performance measures not currently incorporated in the existing BIM models. Further recommendations are going to be made for a more complete model which makes use of these measures during the design phase and ultimately the lifecycle of the building. This research was significant because IEQ forms an important part of any building's performance and the fact that BIM is the future of the construction industry and an excellent tool to facilitate sustainable design and IEQ management, it is important to understand and optimize the relationship between them.

Thus, the author hopes that through the gap analysis of BIM tools with respect to IEQ management and the recommendations suggested, the software could be improved upon and utilized better to improve the building's performance over its lifecycle.

CHAPTER 2: LITERATURE REVIEW

2.1 INDOOR ENVIRONMENTAL QUALITY

Indoor Environmental Quality (IEQ) includes the quality of the air within a building environment along with occupants' health, safety and comfort, energy consumption etc. (NIOSH 2010). Indoor environments are highly complex and building occupants may be exposed to a variety of contaminants (in the form of gases and particles) from office equipments, cleaning products, indoor & outdoor construction activities, carpets and furnishings, perfumes, cigarette smoke, water-damaged building materials, microbial growth (fungal/ mold and bacterial), insects, and outdoor pollutants (NIOSH 2010). Americans spend an average of 90% of their time indoors, so the quality of the indoor environment has a significant influence on their well-being, productivity, and quality of life (USEPA 2001). The U.S. Environmental Protection Agency (EPA) reports that pollutant levels of indoor environments may run 2 to 5 times—and occasionally more than 100 times higher than outdoor levels (USEPA 2001).

Our understanding of health effects related to the indoor environment has evolved over the past decade. In the past, discussions of IEQ focused on indoor air constituents (which included particles, bioaerosols, and chemicals), and comfort factors (temperature, air flow, and humidity) (Samet et al. 1998). More recently, we have begun to look at the relationship between the built environment and humans as a complex interplay between building occupants and an array of physical, chemical, biological, and design factors. This evolution in understanding has profound implications for the design and operation of buildings, how the buildings are used, and the prevention and management of health problems that occur in building occupants.

It is increasingly apparent that indoor environments are unique and contain significant exposures that can affect the health of occupants. The exposures are the result of complex interactions between the structure, building systems, furnishings, the outdoor environment, and the building occupants and their activities (Mitchell et al. 2007). As people spend more time indoors, the opportunities increase for significant health effects resulting from these exposures.

Recent increases in building-related illnesses and "Sick Building Syndrome," (SBS) as well as an increasing number of related legal cases, have further heightened awareness of indoor air quality (IAQ) among building owners and occupants (USEPA 1987). Other factors such as indoor temperatures, relative humidity, and ventilation levels can also affect how individuals respond to the indoor environment. Understanding the sources of indoor environmental contaminants and controlling them can often help prevent or resolve building-related worker symptoms.

2.1.1 Productivity

Indoor air quality and thermal comfort are two important aspects of indoor environmental quality that receive considerable attention by building designers. International and regional standards prescribe conditions intended to foster environments that are acceptable to occupants. Although there is considerable field data on air quality and thermal comfort, there is far less data that assesses occupant satisfaction across a large number of buildings using a systematic method, and using occupant opinions as a measure of building performance is still far from standard practice (Huizenga et al 2006).

In addition to health and liability concerns, productivity gains also drive indoor environmental quality improvements. With employees' salaries a significant cost in any commercial building, it makes good business sense to keep staff healthy and productive by improving and maintaining the quality of the indoor environment. The potential annual savings and productivity gains from improved indoor environmental quality in the United States are estimated at $6 billion to $14 billion from reduced respiratory disease, $1 billion to $4 billion from reduced allergies and asthma, $10 billion to $30 billion from reduced sick building syndrome symptoms, and $20 billion to $160 billion from direct improvements in worker performance that are unrelated to health (IAQ Fact Sheet 2006).

Characteristics of buildings and indoor environments have been linked to the prevalence of acute building-related health symptoms, often called sick-building syndrome (SBS) symptoms, experienced by building occupants. SBS symptoms include irritation of eyes, nose, and skin, headache, fatigue, and difficulty breathing (Fisk 2000). Although psychosocial factors such as job stress influence SBS symptoms, many building factors are also known or suspected to influence these symptoms including: type of ventilation system; rate of outside air ventilation; level of chemical and microbiological pollution; and indoor temperature and humidity.
The estimate of the productivity loss from SBS symptoms is based on the limited information available. The reports suggest a productivity decrease, averaged over the entire work population, of approximately 4% due to poor indoor air quality and physical conditions at work (Fisk 2000).

2.1.2 IEQ Analysis Methods

Throughout the world economy, many industrial sectors are beginning to recognize the impacts of their activities on the environment and to make significant changes to mitigate their environmental impact. The construction and property sector is also starting to acknowledge their responsibilities for the environment - causing a shift in how buildings are designed, built, and operated (Crawley and Aho 1999).

Even though IEQ assessment methods are not originally intended to serve as design guidelines it seems that they, in the absence of better alternatives, are increasingly being used as such.

The primary benefit from these methods is that they can provide a structured means of incorporating performance targets and criteria into the design process. One method for IEQ analysis is the nesting principle in the Green Building Assessment (GBA) method, which enables overall criteria to be determined and evaluated during the design-assessment process. (Crawley and Aho 1999). Therefore, the common denominator of design guidelines and performance assessment systems is materialized in performance indicators or criteria. For building design these represent targets, objectives and (or) requirements, whereas for performance assessment they represent the basic output of analysis. The major drawback of GBA method and the reason that it is not well known as an analysis method is that it is a manual process which takes up a lot of time and effort on the part of the evaluators.

Ventilation systems form a big part of the IEQ management, It is thus important to handle effective ventilation systems in order to obtain and to maintain a good quality of indoor air. Ventilation efficiency can be experimentally and numerically analyzed (Akoua et al 2007).

The numerical analysis is useful to deals with details of the internal flow and contaminant distribution. In so doing, Computational Fluids Dynamics (CFD) constitutes one of the best numerical tools. Computational fluid dynamics has been used for many years as a research tool for room air movement. It is important to consider the quality of CFD predictions because of the widespread use of the method. It is concluded that numerical schemes with a second or third order of accuracy should be used whenever it is possible instead of schemes with first order of accuracy, but in some situations it can be difficult to obtain converged solutions by the last mentioned schemes (Nielson 2004).

Also, CFD tools are widely used in the study of indoor air quality, indoor and outdoor thermal comfort, fire safety, and smoke extraction apart from the building ventilation systems (Hong et al 1999). Building simulation using CFD software is gaining popularity due mainly to new standards on health and comfort in the built environment and the need to design internal spaces and HVAC systems that meet the required standards criteria.CFD software like Fluent, CFX and FIDAP among many others are being used in the industry today for the purposes of IEQ analysis.

2.2 BUILDING INFORMATION MODELING

The construction industry is in the early stages of an historic shift in its methods, due to the advent of a new information technology known as Building Information Modeling (BIM). With this technology, the information needed for a project's design, construction and operation is contained in digital models. The advantages that are offered by BIM to the building industry provide strong premises to overcome the fragmented nature of the industry. This technology will enable better collaboration between design information and fabrication and construction processes. As a result the industry is likely to see new emerging processes that replace the traditional separation of design, construction and facilities management (Mokbel 2006).

In the 21st century, every evolution in technology has been achieved with advances in computer science. The result of each evolution is to provide more information to attain objectives easily. This technical evolution is also reflected in the Architecture, Engineering, and Construction (AEC) Industry. In the past 10 years, design tools in the AEC industry have been improved from 2D modeling to 3D modeling. Today, some software companies such as Autodesk claim that they produce new design software based on the concept of Building Information Modeling (Yan 2007).

BIM combines information needed for a project's design, construction and operation into a digital form. BIM is importantly defined as the development and use of a technology to simulate the construction and operation of a facility from which views and data appropriate to various users' needs can be extracted and analyzed. These data are then used to generate information for making decisions that improve the process of delivering the facility (Ernstrom et al 2006). BIM's advantage to the industry is in its tendency to overcome the fragmented nature, thus reducing risk and cost while increasing quality. BIM also enables better collaboration between design information and the fabrication processes of construction, resulting in newly emerging processes that replace traditionally separated design, construction and facilities management (Mokbel 2006).

BIM originated in the late 1990s, when improvements in hardware speed and performance allowed for the development of intelligent 3D design software. These developments meant that CAD software was now capable of storing detailed parameters of the building elements rather than simple graphic representation of those elements (Howell 2005). BIM was known as an "object-oriented model," a collection of building objects in model form that were previously a series of lines and planes. Newer technologies began to accommodate multiple disciplines, as a result, into a single form of communication. The new software helped detect conflicts in building components, minimized undetected construction problems that were costly when undetected. An example might be piping that penetrates ducting. BIM also provided all intelligent building objects in a single "project database;" a "virtual building" associated with a single, logical, consistent source for all physical building information (Howell 2005).

Confusion surrounds around the central definition of BIM. The following are the various definitions of BIM as recorded in literature:

Building Information Modeling is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility (Ernstrom et al 2006).

Building Information Modeling refers to the creation and coordinated use of a collection of digital information about a building project. The information is used for design decision-making, production of high-quality construction documents, predicting performance, cost estimating, and construction planning, and eventually, for managing and operating the facility (D'Agostino 2007).

Building Information Modeling is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward (*NBIMS).*

BIM has been suggested as a solution to the fragmented nature of the AEC industry (Ernstrom et al 2006; Howell 2005; Mokbel 2006*)*. BIM, as a concept, is relatively simple and theorizes that data required from all AEC stakeholders to design and construct a project may be entered and developed within a collective system, thus constructing the project in the virtual world first.

The use of BIM for architects and engineers facilitates communication of design intent to contractors, fabricators and subcontractors. BIM use by contractors, fabricators and subcontractors facilitates successful implementation of the design intent. BIM reduces risks to the owner as well through effective delivery of design intent and implementation, thus reducing legal exposures. Further BIM is a great tool for the owners for the facility management of the project over its complete lifecycle.

Different types of BIM tools are available in the industry today. These tools serve different functions and are inter-operable with each other which maximizes the utility of BIM as a methodology in the industry. The different types of BIM tools are:

- **Authoring Tools:** Software like Revit, Microstation etc. fall under authoring tools because the primary function of these tools is to create a 3D model which would be later utilized for a variety of purposes.

- **Analysis Tools:** After a complete 3D model has been made, an authoring tool might combine with an analysis tool such as Ecotect, Green Building Studio etc. which analyze the model for daylighting, thermal comfort etc. Ususally an analysis tool uses simulation techniques to perform the analysis

- **Validation Tools:** Lastly, tools like Solibri Model Checker and Navisworks are an important cog in the wheel of BIM as they provide authenticity and accuracy to the 3D model platform. These tools check for different aspects in different phases of the building lifecycle such as code compliance, clash detections, construction sequencing etc.

Douglas (2005) discussed one example as an ideal scenario for BIM as wireless access to a central database for all participating entities. This scenario might include (Douglas 2005):

- Accepting an architect's initial sketch.

- Facilitating the initial sketch being transformed into an intelligent 3D computer model with increasing building component detail.

- Enabling creation of timelines and status reports that are knowledgeable about the design objects.

- Compiling materials lists, costs, and vendors, derived using the information about the intelligent design objects.

- Accepting and reconciling changes anywhere along the way to the design, materials, vendors, timeline or budget using bidirectional reconciliation between all construction drawing types.

- Electronically ordering and receiving all construction material on site and on schedule.

- Providing automated query at any time into any facet of the building project.

BIM scenarios would go beyond the construction of the facility as well to "Building Lifecycle Management (Dillon 2005)."

At first glance, BIM technology appears to have opened a door of new possibilities which the industry cannot ignore (Thomson and Miner 2006). Still, application of this new methodology has been a significant challenge for industry stakeholders. Among others, the two largest challenges to implementation being that technology developers and end-users experience interoperability of existing BIM programs and a lack of accurate technologies to fulfill specific purposes (Thomson and Miner 2006).

2.3 NEED FOR IEQ AND BIM TO COME TOGETHER

During the past few decades, the field has evolved beyond the traditional area of heating and cooling of building interiors to include topics such as health, economics, and aesthetics. Especially, concerns with indoor environmental quality (IEQ) have increased since energy conservation measures were instituted in office buildings minimizing the infiltration of outside air and contributing to the buildup of air contaminants (Yana et al 2006). As a result, the parameters considered by the HVAC system designers are not only the indoor temperature, but also the indoor humidity and many IEQ related parameters. On the other hand, current engineering design tools do not have an integrated consideration of the above variables. For example, the building ventilation type and fresh air rate from energy conservation viewpoint may be contrary to those from IEQ perspective (Yana et al 2006). This calls for design tools that can simultaneously take into account various key factors in the simulation process.

According to Krygiel and Nies, the fundamental tenet of true sustainable design is the integration of all the building systems within themselves as well as with the external economic and environmental realities of the project. We can imply the same for IEQ management as unless all the systems associated with the building take into account the human factor and integrate it into the building, it's very difficult to have a truly energy efficient building.

As mentioned above, the want to integrate the building systems with each other can be answered with a complete BIM model which would act as a database of information of all the building systems during post-occupancy, after maximizing its utility of improving upon the design parameters during the design and construction phase of the project.

2.4 HYPOTHESIS

The literature review gave the author an understanding on the areas of BIM and IEQ and the need to bring the two together. With the help of this literature, the areas of concern were identified and a hypothesis developed. This hypothesis, given below, was then tested through a detailed analysis of the IEQ credits:

- BIM tools do not cater to some of the IEQ Performance Criteria
- Possible Links between BIM tools and IEQ data requirements can be determined through a detailed analysis

CHAPTER 3: INVESTIGATION OF BIM TOOLS

3.1 LEED 3.0 IEQ CREDITS

LEED Version 3.0 IEQ checklist was used as IEQ performance measures. The reason for using LEED Version 3.0 as an assessment tool is because it is a widely accepted and federally mandated measurement tool for sustainability and in turn, IEQ (LEED NC Reference Guide 2009).

Leadership in Energy & Environmental Design (LEED) is an internationally recognized green building certification system, providing third-party verification that a building or community was designed and built using strategies aimed at improving performance across all the metrics that matter most: energy savings, water efficiency, CO2 emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts.

Developed by the U.S. Green Building Council (USGBC), LEED provides building owners and operators a concise framework for identifying and implementing practical and measurable green building design, construction, operations and maintenance solutions.

LEED addresses both commercial and residential building types. It works throughout the building lifecycle – design and construction, operations and maintenance, tenant fitout, and significant retrofit. For the purpose of this research, LEED NC (New Construction) was used because of its wide spread applicability to the new construction across the country. The requirement of LEED Schools is more arduous but the criteria for IEQ study was the same for this particular research.

The IEQ credits in LEED reference guide address extensively environmental concerns relating to indoor air quality; occupants' health, safety, and comfort; energy consumption; air change effectiveness; and air contaminant management. Therefore, it was apt that these credits were defined as performance measures for my research.

LEED addresses the different project development and delivery processes that exist in the U.S. building design and construction market, through rating systems for specific building typologies, sectors, and project scopes allocation of points between credits is based on the potential environmental impacts and human benefits of each credit with respect to a set of impact categories. The impacts are defined as the environmental or human effect of the design, construction, operation, and maintenance of the building, such as greenhouse gas emissions, fossil fuel use, toxins and carcinogens, air and water pollutants, indoor environmental conditions (LEED NC Reference Guide 2009).

The impacts defined above play a very important role for the purpose of this research as IEQ performance criteria pay special emphasis to the environmental and human impact on the building design.

The IEQ credit checklist has been listed below in Table 1 with the intent of each credit briefly described. These credits are explained more in detail in the matrix later on in the chapter.

	CREDITS	INTENT
Prereq.1	Minimum Indoor Air Quality Performance	To establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.
Prereq.2	Environmental Tobacco Smoke(ETS) Control	To prevent or minimize exposure of building occupants, indoor surfaces and ventilation air distribution systems to environmental tobacco smoke (ETS).
Credit 1	Outdoor Air Delivery Monitoring	To provide capacity for ventilation system monitoring to help promote occupant comfort and well-being.
Credit 2	Increased Ventilation	To provide additional outdoor air ventilation to improve indoor air quality (IAQ) and promote occupant comfort, well-being and productivity.

	CREDITS	INTENT
Credit 3.1	Construction IAQ Management Plan, During Construction	To reduce indoor air quality (IAQ) problems resulting from construction or renovation and promote the comfort and well-being of construction workers and building occupants.
Credit 3.2	Construction IAQ Management Plan, Before Occupancy	To reduce indoor air quality (IAQ) problems resulting from construction or renovation to promote the comfort and well-being of construction workers and building occupants.
Credit 4.1	Low Emitting Materials - Adhesives & Sealants	To reduce the quantity of indoor air contaminants that is odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.
Credit 4.2	Low Emitting Materials - Paints & Coatings	To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.
Credit 4.3	Low Emitting Materials - Flooring Systems	To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.
Credit 4.4	Low Emitting Materials - Composite Wood & Agrifiber Products	To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.
Credit 5	Indoor Chemical & Pollutant Source Control	To minimize building occupant exposure to potentially hazardous particulates and chemical pollutants.
Credit 6.1	Controllability of Systems, Lighting	To provide a high level of lighting system control by individual occupants or groups in multi occupant spaces (e.g., classrooms and conference areas) and promote their productivity, comfort and well-being.
Credit 6.2	Controllability of Systems, Thermal Comfort	To provide a high level of thermal comfort system control by individual occupants or groups in multi-occupant spaces (e.g., classrooms or conference areas) and promote their productivity, comfort and well-being.

	CREDITS	INTENT
Credit 7.1	Thermal Comfort, Design	To provide a comfortable thermal environment that promotes occupant productivity and wellbeing.
Credit 7.2	Thermal Comfort, Verification	To provide for the assessment of building occupants' thermal comfort over time.
Credit 8.1	Daylight & Views - Daylight	To provide for the building occupants with a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.
Credit 8.2	Daylight & Views - Views	To provide building occupants a connection to the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Table 1: LEED 3.0 IEQ Credits (Source: LEED NC Reference Guide 2009)

3.2 EXPLANATION OF MATRIX

As discussed in the previous sections, the main purpose of this study was to analyze the BIM tools' capability to supplement IEQ management in the design, construction and eventual lifecycle of the building.

For this purpose, it was required that a matrix be created that would tabulate the IEQ performance criteria against the process through which those criteria would be evaluated on and the BIM tools capability to track those criteria.

The matrix, attached as Appendix B, has each of its rows represented by the LEED IEQ credits (IEQ performance criteria for our study). The first column discusses the evaluation process of the credit, which is basically defining the intent of the credit while the second column of the matrix, 'potential sustainable solution' elucidates how that particular credit might be achieved and what the general requirements are. This column is followed by the specific criteria for the completion of the credit; it mentions the codes and regulations that have to be catered to. ASHRAE codes form an important part of the IEQ requirements and are generally the minimum threshold for the ‘sustainabilization’[1] of the credit. It needs to be mentioned here that the primary source of the columns ‘evaluation process’ and ‘Criteria for Certification’ has been the LEED NC Reference Guide 2009 while the ‘Potential Sustainable Solution’ has been derived from the Reference Guide and includes author’s interpretations in it. The next column, Utility of BIM Tools, specifies how the credit in question might be achieved with the help of BIM tools. . The BIM knowledge in this column was based on the literature garnered through various journals & conference papers and secondly, the author’s prior experience of using different BIM tools in the field

For example, Credit 6.1, ‘Controllability of Systems, Lighting’ requires that lighting systems controllability be integrated into the overall lighting design of the building and providing ambient and task lighting. For this credit to be satisfied, it is mandated that the lighting controls be provided for min 90% of building occupants and provide lighting system controllability for all shared multi-occupant spaces. Based on author’s prior experience, it has been found out that the combination of Revit Architecture and Ecotect software has the capability to simulate daylighting of the building and give accurate results to the designer so that informed decision can be made about changing the design of the building, if necessary.

Similar analysis has been done for the other credits in the matrix which gives us an idea of how BIM tools correlate with the IEQ credits and relevant conclusions can be drawn from the matrix. During the course of the plotting of the matrix, the question of how many of the above mentioned credits actually are used in the design, construction or lifecycle phase of the building came up. To clarify this, another table, Appendix C was drawn up which reflects the phase in which these credits fall under. The basis for selecting the credit phase was again, the LEED NC Reference Guide 2009 and the author’s analysis of the topic. Also, how BIM tools can be used for the facilities management in relation to the IEQ was an important consideration. This has been discussed in detail in the next section.

[1] The term ‘Sustainabilization’ has been coined by the author in order to stress upon the fact that the achievement of the LEED credit ultimately results in improving the sustainability of the building. In this case, meeting the requirements of ASHRAE codes, which act as a benchmark, is necessary for the achievement of the credit.

The creation and a subsequent analysis of the matrix resulted in the need for a more thorough investigation of these credits as the author realized that the matrix, though extensive in its breakdown, is restricted to a high level overview of each of the credits. The matrix gives the reader a fundamental idea of what the requirements of each credit are, how they can be satisfied, and the basic utility of BIM tools in achieving of those credits.

3.3 IN-DEPTH ANALYSIS

However, to make the research more meaningful, two credits from the matrix were chosen for a more detailed analysis. The two credits chosen; Credit 3.1: Construction IAQ Management Plan-During Construction and Credit 3.2: Construction IAQ Management Plan-Before Occupancy, were examined in detail along with their reference standards to find out how and which BIM tool could be utilized to achieve the credit. As mentioned before, the reason for choosing these two credits, despite them being construction phase credits, was the fact that the author realized that very little research has been done on these two credits in order to correlate them with BIM tools. Other IEQ design phase credits like credits 7 & 8 could have been chosen for the study but the fact that a lot of background research has been done in the past was a major deterrent in choosing them. For example, for credits 8.1 & 8.2, after setting natural daylight and views in design, a BIM model can be used with a variety of daylight simulation software packages like IES Virtual Environment among others (Krygiel & Nies 2008, Schlueter & Thesseling 2009).

Also, for the purpose of getting actual credit information to compare it to BIM tools, information from *Barack Obama Elementary School,* MD was used for this section. The school, currently under construction, is being built by *Hess Construction+Engineering Services* located in Gaithersburg, MD. It is also needs to be mentioned that the author worked on this particular project during his internship with the company which resulted in easy access to the IAQ

Management plans[2] and other project data. The direct observation of the project on the part of the author also made the analysis easier and more thorough.

Further in this chapter, after the IAQ plans have been discussed, an overview of SMACNA standards has been given along with the a section on IFC data structures which talks about the applicability of BIM tools in the market along with the potential of IFC data structures to link with the IEQ data and requirements. Also, The IFC data structures were studied with respect to the detailed analysis, i.e. the IEQ credits 3.1 & 3.2.

3.3.1 Construction Indoor Air Quality Plans

The Credits information, reproduced from the LEED NC Reference Guide 2009, has been described in detail below for the purpose of better understanding of the credits

<u>Credit 3.1: Construction IAQ Management Plan-During Construction</u>

The intent of this credit is to reduce indoor air quality (IAQ) problems resulting from construction or renovation and promote the comfort and well-being of construction workers and building occupants. According to the LEED NC Reference Guide 2009, The main requirement of achieving this credit is to develop and implement an IAQ management plan for the construction and preoccupancy phases of the building as follows:

- During construction, meet or exceed the recommended control measures of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines For Occupied Buildings under Construction, 2nd Edition 2007, ANSI/ SMACNA 008-2008.

[2] Hess Constructions' IAQ Management Plans contain all the required documentation to achieve credits 3.1 & 3.2. For the purpose of credit 3.2, recommendations for multiple paths have been attached as Appendices E &F. These recommendations do not imply that both the scenarios were used during the course of the project.

- Protect stored on-site and installed absorptive materials from moisture damage.
- If permanently installed air handlers are used during construction, filtration media with a minimum efficiency reporting value (MERV) of 8 must be used at each return air grille, as determined by ASHRAE Standard 52.2-1999 (with errata but without addenda). Replace all filtration media immediately prior to occupancy.

Analysis: An example of IAQ Management plan (attached as Appendix D) is being used to demonstrate the requirements of this credit. The IAQ Management plan which follows the SMACNA guidelines (explained in detail in the next section) primarily deals with the areas of concern that the general contractor faces during the construction of the building. The IAQ management plan is then distributed to the management personnel of all the concerned stakeholders on the project and efforts made to meet the goals mandated in the plan.

<u>Credit 3.2: Construction IAQ Management Plan-Before Occupancy</u>

The basic intent of this credit is same as Credit 3.1. The intent is to develop an IAQ management plan and implement it after all finishes have been installed and the building has been completely cleaned before occupancy.

The two options available to achieve the credit are:

OPTION 1: Flush-Out

Path 1: After construction ends, prior to occupancy and with all interior finishes installed, install new filtration media and perform a building flush-out by supplying a total air volume of 14,000 cubic feet of outdoor air per square foot of floor area while maintaining an internal temperature of at least 60° F and relative humidity no higher than 60%.

OR

Path 2: If occupancy is desired prior to completion of the flush-out, the space may be occupied following delivery of a minimum of 3,500 cubic feet of outdoor air per square foot of floor area. Once the space is occupied, it must be ventilated at a minimum rate of 0.30 cubic feet per minute (cfm) per square foot of outside air or the design minimum outside air rate determined in IEQ Prerequisite 1: Minimum Indoor Air Quality Performance, whichever is greater. During each day of the flush-out period, ventilation must begin a minimum of 3 hours prior to occupancy and continue during occupancy. These conditions must be maintained until a total of 14,000 cubic feet per square foot of outside air has been delivered to the space.

OPTION 2: Air Testing

Conduct baseline IAQ testing, after construction ends and prior to occupancy, using testing protocols consistent with the EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air and as additionally detailed in the LEED NC Reference Guide 2009. Table 2 lists the maximum concentrations of the contaminants that cannot be exceeded if the credit has to be achieved.

Contaminant	Maximum Concentration
Formaldehyde	27 parts per billion
Particulates (PM10)	50 micrograms per cubic meter
Total volatile organic compounds (TVOCs)	500 micrograms per cubic meter
4-Phenylcyclohexene (4-PCH)*	6.5 micrograms per cubic meter
Carbon monoxide (CO)	9 part per million and no greater than 2 parts per million above outdoor levels
*This test is required only if carpets and fabrics with styrene butadiene rubber (SBR) latex backing are installed as part of the base building systems.	

Table 2: List of Air Pollutants (Source: LEED NC Reference Guide 2009)

Analysis: The Hess IAQ Management Plan for Credit 3.2 has been divided into two separate documents for either of the two options required by the credit. Option 1, attached as Appendix E, uses calculations to show that the required 14,000 cu.ft of outdoor air would be supplied per square foot of the floor area. The preparatory and the pre-flush out activities are also defined keeping in mind the temperature and the humidity readings. The Appendix F shows the phased flush out of the building, where 3,500 cu.ft would be flushed out in the first phase and the remaining 10,500 cu.ft in 45 days time. The calculations also reflect the days taken and the air flow rate if the flush out is performed after the building is occupied. The two appendices present the owners' condition to Hess which required them to show both methods with the calculations. In the end, Option 1 was chosen which required a complete flush-out of the building prior to occupancy.

3.3.2 SMACNA Standards

Sheet Metal and Air Conditioning National Contractors Association (SMACNA) is an international organization that developed guidelines for maintaining healthful indoor air quality during demolitions, renovations, and construction. The full document covers air pollutant sources, control measures, IAQ process management, quality control and documentation, interpersonal communication, sample projects, tables, references, resources, and checklists (LEED NC Reference Guide 2009).

According to the SMACNA standards, in order to complete the credits, the construction IAQ management plan should be complete before construction begins. The plan should include agenda items to be discussed regularly at preconstruction and construction meetings (SMACNA IAQ Guidelines 2nd Edition 2008). Continually educating subcontractors and field personnel and giving them the proper resources (e.g., collection bins, cleaning tools and materials) reinforce the importance of following the plan's procedures and encourage their compliance (SMACNA IAQ Guidelines 2nd Edition 2008).When possible, the design team should select a member of the contractor's team to serve as the indoor air quality manager and take responsibility for identifying problems and implementing solutions (SMACNA IAQ Guidelines 2nd Edition 2008). As discussed previously, the SMACNA standards recommend control measures in 5 areas:

- HVAC protection
- Source control
- Pathway interruption
- Housekeeping, and

- Scheduling.

The Appendix D discusses these with respect to the concerned project, along with Baseline Indoor Air Quality Testing.

3.3.3 IFC Data Structures

After discussing the Construction IAQ Management plans in detail, the next step of the analysis was to investigate how technology, or BIM tools to be more specific, are able to aid in order to accomplish these credits. More background research was done to find out the various techniques by which the technology would be beneficent to this specific case.

According to Loh et al. (2007), different BIM software have been analyzed and linked with IEQ in the past. The major software which come closest to environmental and building life cycle simulation have been reviewed and compared in Table 3. The table below shows the software description, their feature, and gaps among all the software.

BIM Software	Developer	Feature
DesignBuilder (www.designbuilder.co.uk)	DesignBuilder Software LTD	Feature: • Integrated with Energy plus • detail simulation for energy consumption, heating, cooling • 3D modelling tools • Customise product data
D-Profiler (www.dpearth.com/)	Beck Technology (US)	Feature: • Integrated with RSMeans cost data • Export to Google earth • 3D modelling tools • Starting templates for 46 types of building • Reports • Output model views
Solibri Model Checker (www.solibri.com)	Solibri (Finland)	Feature: • Proposed design alternative by looking at potential flaws in the design, clashing components. • Costing and energy budget • Model comparison analysis • Report layout in RTF and PDF • Multi selection to view several issues at the same time • Walk-through • Model checked to comply with the building codes.
Riuska (http://www.dds-bsp.co.uk/PDF/RIUSKA_english.pdf)	Granlund (Finland)	Feature: • Simulation of energy con-sumption for building services. • temperature simulation • heat loss calculation

Table 3: Comparison of BIM Software (Source: Loh et al 2007)

However, these software also fall short of complete IEQ analysis, mostly because of the loss of information and inaccuracy of data across the lifecycle of the building. According to Loh at al., a complete Environmental Impact Assessment (EIA) result has seen a potential to link the building IEQ data to the Industry Foundation Classes (IFC) 3D model. The idea of using the IFC 3D model in 3D-EIA is to share the IFC standard in the CAD platform with other design and construction team members, also fast track the environmental impact from a project in an easier way by adding attributes in the building components to enable design and analysis of the project in one shot (Loh et al. 2007). For instance, an IFC wall and IFC door with attribute input of CO2 emission can calculate easily without doing a separate set of material input for CO2 emission as in usual 3D system.

Similarly, IFC data structures can be used for the purpose of achieving credits IEQ 3.1 & 3.2, discussed in the previous section. As mentioned in Appendix D, one of the requirements of SMACNA standards is to achieve Source Control of the products employed in the building. With the use of a 3D model built in Revit and proper material attributes attached to it, the model can then be taken into Solibri Model Checker to check for the VOC contents of those elements. In the same way, another SMACNA requirement for the credit, Scheduling, can be obtained easily from the model as we can schedule high pollution activities that utilize high VOC level products to take place prior to installing highly absorbent materials.

Also, the volume of air required to be utilized during the Building Flush-out to achieve credit 3.2(mentioned in Appendices D & E), can be obtained easily from the 3D model. A complete Revit model would be linked to the monitoring sensors which would be used for transferring the information to the model, which then keeps track of the volume of air flushed. Also, building area calculations can be performed faster and more accurately with the help of a BIM model.

One other characteristic, not mentioned in the Construction IAQ plans, is the Option 2 in Credit 3.2. The Table 2 on Page 27 shows the maximum concentrations of the contaminants that cannot be exceeded if the credit has to be achieved. While the credit 3.2 requires that the contaminants need to be checked for a specified sample period, it is here the BIM model can be efficient over the lifecycle of the building, as the quantity of the materials can be fed into the system and the model will be able to extract the information of VOC content emitted by the materials, which in turn would determine the overall performance of the building.

3.4 FINDINGS

It has been reflected from the background study, the formation of the matrix and the detailed analysis that BIM, both as a technology and a methodology, can be immensely useful while being utilized for the maintenance of the building over its entire lifecycle. BIM tools with the ability of information management and intelligent modeling capacity can help manage indoor air quality better than it is right now.

One example could be that the air contaminants in the building from the materials and people alike, which are mitigated by the correct use of software technology and a complete BIM model. We know that CO2 sensors are currently used to monitor temperature and humidity apart from air quality and the use of CFDs could be better managed by linking the model to the information derived out of it. The impact of this would be that the BIM model would act as a database of information and it could be easily accessible to the facility managers of the building. In many new buildings, the emissions of volatile organic compounds (VOCs) from building materials, furniture and equipment may impact indoor air quality, which tends to cause general symptoms, such as headache; eye, nose, or throat irritations; dry cough and tiredness. Since VOCs emitted by building materials are recognized as major problems affecting human comfort, health and productivity (Hongyu and Fariborz 2002), it is necessary to know their emission characteristics.

When testing materials for emission of chemicals, VOCs may be used for categorizing or screening the materials. No health or comfort evaluation can be made based on emission rates. Rather, health and comfort evaluations must be based on exposure to concentrations in a given space. In order to calculate the steady-state concentrations in a given space, the amount of the source (material) and the quantity and quality of the supply air to the space (ventilation) must be known in addition to the emission rate or factor[3]. For the simplification of understanding, the author has assumed a steady emission rate. It is here the BIM model can be efficient as the quantity of the materials can be fed into the system and the model will be able to extract the information of VOC content emitted by the materials over the lifecycle of the building, which in turn would determine the overall performance of the building.

Referring to the IAQ management plans, BIM authoring software such as Revit in conjunction with validation tools like Solibri Model Checker can improve the efficiency of the process and the building in the long run. It is important to mention here that the use of the software can have a more direct impact on the other LEED IEQ criteria. An example of this is credit 6.1: Controllability of Systems, Lighting where the use of simulation software can help achieve the credit easily.

CREDITS	CREDIT REQUIREMENTS	SPECIFIC BIM SOLUTION
Cr 3.1	Source Control of the products employed	Material attributes attached to Revit Model & checked in Solibri Model Checker
Cr 3.1	Scheduling	With the help of a complete 3D model, schedule high pollution activities with materials with high VOC content prior to absorbent materials
Cr 3.2	Building Flush-Out	Building Area calculations obtained from Revit Model for the volume of air flushed out
Cr 3.2	Air Testing for Contaminants	A complete Revit Model determines the quantity of materials whose VOC content can be found out from applications such as the Model Checker

Table 4: BIM Solutions to Construction IAQ Plan Requirements

[3] Emission rates are affected by a variety of factors such as humidity, temperature and nature of ventilations among other things. Different materials respond differently to these factors and therefore, have different emission rates. Also, a steady emission rate has been assumed in this study while emission rates can vary with time. Usually, Emission rates are inversely proportional to the passage of time.

Table 4 shows how some of the requirements of credits 3.1 & 3.2: Construction IAQ plans can be satisfied using specific BIM solutions. For example, one of the key SMACNA conditions for the satisfaction of credit 3.1, 'Source control' can be checked for in a better manner by attaching material attributes to the products employed in a Revit model and further checked for VOC content in Solibri Model Checker. This table gives us an understanding of how different types of BIM tools can satisfy different nature of requirements of the above mentioned credits.

Also, prior research show that the concentration of any pollutant in a space is a balance between the net emission in the space and what is removed and supplied by the ventilation (Berglund et al. 1997). If high VOC concentrations occur in a building, this may either indicate that there are strong indoor or outdoor sources or, if this is not the case, that general or local ventilation is inadequate. In the first case, source control measures should be taken. In the second case or if source control cannot be applied, ventilation has to be improved. With the help of the BIM model, the designer would be able to check for the ventilation requirements in the building. Hence, the utilities of BIM cannot be underestimated when taking into account the Indoor Environmental Quality management of the building or a facility.

CHAPTER 4: FINAL RESULTS

4.1 CONCLUSIONS

The literature review and the formation of matrix reflect that there are gaps in the current BIM technology that need to be addressed in order to successfully implement IEQ performance measures across the lifecycle of the building. Efforts such as compatibility of different BIM tools with IEQ analysis methods (such as better management of CFDs by storing the information derived from it in a 3D environment) and organization of IFC data structures are being done these days to incorporate these measures in the BIM tools but certain areas like tracking VOC content in the building materials and hazardous gaseous substances are still to be integrated in the tools.

Through the course of this study, the author has answered the research questions formulated at the start of the research. In the matrix, author has listed how the specified IEQ performance measures can be monitored using different BIM platforms. The second research question was answered through the detailed investigation, where the tools were mentioned and how they aid in the achievement of the credit was explained. It needs to noted, however, that a detailed analysis of more number of credits would have given the author a further understanding of the applicability of BIM tools.

The long term benefits of incorporation of these tools would affect all the stakeholders associated with the facility. It would provide an easy way for the architects and the engineers to examine alternative design strategies as they would be able to compare the efficiency of design solutions on the basis of the satisfaction of IEQ performance measures. This would also result in the architects and engineers to achieve higher operational efficiency in terms of building performance and reduced cost of maintenance over the lifecycle of the building.

As far as the other stakeholders are concerned, the owners and the eventual occupants of the building would benefit financially because of the lower design intrusions and lesser number of change orders during the construction of the project. Also, it would achieve a major milestone of increasing awareness amongst major stakeholders for potential use of BIM on a Project to enhance the IEQ management.

Both the hypothesis formed at the end of the literature review was supported by the detailed investigation later in the study as the creation of the matrix showed that some of the IEQ Performance criteria are not applicable to BIM tools while the second hypothesis was examined and supported when the utility of specific BIM tools was found for the requirements of IEQ credits 3.1 & 3.2.

In the end, this research hopes to have accomplished the task of assessing the need of BIM tools to improve IEQ management of the building. The author hopes that this research can be taken forward and utilized to help the current BIM technology improve in terms of incorporating IEQ tools and making the building more sustainable over its lifecycle.

4.2 LIMITATIONS

The main limitation of this research was that a software review was not done specifically for the purpose of this research. The analysis was based on the author's prior experience with the software and literature review. Also, since an in-depth analysis was carried out for only two of the IEQ credits, it did not present as accurate an analysis as a complete detailed analysis would have provided. This analysis would have given the reader a complete understanding of the exact requirements of each credit and a potential BIM solution for it.

4.3 SUGGESTIONS FOR FUTURE RESEARCH

The integration of the BIM and IEQ design solutions will provide an easy way for architects and engineers to examine the implications of alternative design strategies, helping them achieve higher operational efficiency and building performance.

As per Krygiel and Nies, successful building is a logical outcome of an integrated process, requiring a connection between the design and construction processes, as well as an understanding of that design, which can be used throughout a building's lifecycle. The author would concur with the statement as this research can be carried forward by conducting research on the similar lines from the perspective of the owners, constructors, facility managers and occupants. It is important to note here that this research was conducted from the point of views of the designers as he is the one making use of the BIM tools during the design phase and usually leads the team when incorporating the BIM methodology.

Also, the detailed analysis carried out was done only for two credits (LEED IEQ Credits 3.1 & 3.2) from the LEED 3.0 IEQ Credits. Future research could take forward this study and explore other credits with the help of a case study. This would help in examining the exact nature of the requirements of each credit and how specific BIM tools can help achieve those credits.

Furthermore, the relationship between IEQ and BIM will continually improve and expand beyond the automation of simple processes and documentation. As this relationship matures, industry focus on facility performance will shift beyond minimizing negative impacts to reaching net-zero impact and ultimately to creating facilities that contribute to regeneration. This can be done by recommending the software developers to enhance the current tools to measure the IEQ of the project during the design, construction and the facility management of the building.

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APPENDICES

Appendix A: BIM Tools Experience

Software	Project Name	Description
Revit Architecture	• SUB 1, George Mason University, VA. • Wheatley High School, Washington DC. • Malibu Villas, CA.	Involved in 3D modeling and coordination of 3D models in the mentioned projects using Revit. Different elements of Revit have been used in different phases of construction
Ecotect	• SUB 1, George Mason University, VA. • IMT, Manesar, India	Ecotect has been utilized by the author for energy simulation of two different projects. Evaluation reports were also prepared based on the simulations
Solibri Model Checker	NA	Do not have a field experience of the software. However, extensive research has been done on it by learning all the characteristics of the software.

Appendix B: IEQ Performance Criteria Mapping

	Credits	Evaluation Process	Potential Sustainable Solution	Criteria For Certification	Utility Of BIM Tools
Prereq.1	Minimum Indoor Air Quality Performance	Establish minimum indoor air quality (IAQ) performance	Design ventilation systems to meet the minimum outdoor air ventilation rates; Balance the impacts of ventilation rates on energy use and indoor air quality to optimize for energy efficiency and occupant health	Meet min req's of Sections 4-7 of ASHRAE 62.1-2004 ventilation for acceptable IAQ, design mech ventilation systems using Ventilation Rate Procedure or applicable local code (whichever is more stringent); Naturally ventilated bldgs comply with ASHRAE	Optimizing the use of natural light and minimizing the use of artificial illumination in the early design phase through a Revit model helps to achieve the minimum IAQ requirements.
Prereq.2	Environmental Tobacco Smoke(ETS) Control	To prevent or minimize exposure of building occupants, indoor surfaces and ventilation air distribution systems to environmental tobacco smoke (ETS).	Prohibit smoking in commercial buildings or effectively control the ventilation air in smoking rooms. For residential buildings, prohibit smoking in common areas, design building envelope and systems to minimize ETS transfer among dwelling units.	Prevent or minimize exposure of bldg occupants, indoor surfaces, & systems to ETS	NA
Credit 1	Outdoor Air Delivery Monitoring	Provide capacity for ventilation system monitoring to help sustain occupant comfort and wellbeing	Install carbon dioxide and airflow measurement equipment and feed the information to the HVAC system	Install permanent monitoring systems that provide feedback on ventilation system performance - include an alarm for 10% deviations	Feedback such as how much energy the building will use and the anticipated CO2 emissions can be obtained from a BIM model.

	Credits	Evaluation Process	Potential Sustainable Solution	Criteria For Certification	Utility Of BIM Tools
Credit 2	Increased Ventilation	Provide additional outdoor air ventilation to improve indoor air quality for improved occupant comfort..	Use heat recovery to minimize the additional energy consumption associated with higher ventilation rates.	Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above min rate req'd by ASHRAE Std. 62.1-2004, Design natural ventilation systems to meet Carbon Trust Good Practice Guide 237	With the help of BIM model, IAQ and energy consumption can be assessed.
Credit 3.1	Construction IAQ Management Plan, During Construction	Reduce indoor air quality problems during the construction/renovation process in order to help sustain the comfort of construction workers and building occupants.	Adopt an IAQ management plan to protect the HVAC system during construction, control pollutant sources and interrupt contamination pathways.	During Construction: Verify compliance with SMCNA IAQ guidelines, protect absorptive materials from moisture damage, use filtration media with MERV of 8 at each return air grille if use permanently installed AHU's	BIM tools such as Revit and Solibri Model Checker can be used to satisfy the SMACNA requirements in order to achieve the credit.
Credit 3.2	Construction IAQ Management Plan, Before Occupancy	Reduce indoor air quality problems during the construction/renovation process in order to help sustain the comfort of construction workers and building occupants.	Prior to occupancy, perform a building flush-out or test the air contaminant levels in the building.	Before Occupancy: Bldg flushout supplying req'd vol of outdoor air per SF of floor area & maintain req'd min internal temp & relative humidity OR conduct IAQ baseline test & verify compliance with max contaminant concentration	Building Area Calculations with the help of a Revit Model and monitoring the volume of air flushed out can be performed with the help of BIM tools.

	Credits	Evaluation Process	Potential Sustainable Solution	Criteria For Certification	Utility Of BIM Tools
Credit 4.1	Low Emitting Materials - Adhesives & Sealants	To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.	Specify low-VOC materials in construction documents. Ensure that VOC limits are clearly stated in each section of the specifications where adhesives and sealants are addressed.	Adhesives & Sealants: Comply with VOC limits for South Coast Air Quality Mgmt District (SCAQMD) Rule #1168 or the Green Seal Std. for Commercial Adhesives GS-36	The credit could be achieved by checking the VOC contents of the adhesives & sealants used with the help of a BIM analysis tool such as Solibri Model Checker
Credit 4.2	Low Emitting Materials - Paints & Coatings	To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.	Specify low-VOC paints and coatings in construction documents. Ensure that VOC limits are clearly stated in each section of the specifications where paints and coatings are addressed. Track the VOC content of all interior paints and coatings during construction.	Paints & Coatings: Comply with VOC content limits established in Green Seal Std. GS-11	Same as Above
Credit 4.3	Low Emitting Materials - Flooring Systems	To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.	Specify requirements for product testing and/or certification in the documents. Select products that are either certified under the Green Label Plus program or for which testing is done by qualified laboratories according to appropriate requirements.	Carpet and Carpet Cusion - meet req's of Carpet and Rug Institute's Green Label Plus program, Carpet adhesive - meet req's of EQ Credit 4.1: VOC limit of 50g/L	The material attributes can be applied to the flooring systems in a Revit Model and then checked for the quantity of indoor air contaminants

	Credits	Evaluation Process	Potential Sustainable Solution	Criteria For Certification	Utility Of BIM Tools
Credit 4.4	Low Emitting Materials - Composite Wood & Agrifiber Products	To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.	Specify wood and agrifiber products that contain no added urea-formaldehyde resins. Specify laminating adhesives for field and shop applied assemblies that contain no added ureaformaldehyde resins.	No added urea-formaldehyde resins in interior composite wood, agrifiber products, or laminating adhesives	Same as Above
Credit 5	Indoor Chemical & Pollutant Source Control	To minimize building occupant exposure to potentially hazardous particulates and chemical pollutants.	Design facility cleaning and maintenance areas with isolated exhaust systems for contaminants. Install high-level filtration systems in air handling units processing both return air and outside supply air. Ensure that air handling units can accommodate required filter sizes and pressure drops.	Install entryway systems min 6' long in main travel direction, Create negative pressure w/ exhaust in areas of hazardous gases or chemicals, Provide MERV of 13 or better for mechanically ventilated bldgs	NA
Credit 6.1	Controllability of Systems, Lighting	Provide a high level of lighting system control by individual occupants or by specific groups in multi-occupant spaces	Design the building with occupant controls for lighting. Integrate lighting systems controllability into the overall lighting design, providing ambient and task lighting.	Lighting - provide lighting controls for min 90% of bldg occupants AND provide lighting system controllability for all shared multi-occupant spaces	Simulation of Daylighting in a BIM analysis tool such as Ecotect results in the output of quality lighting systems

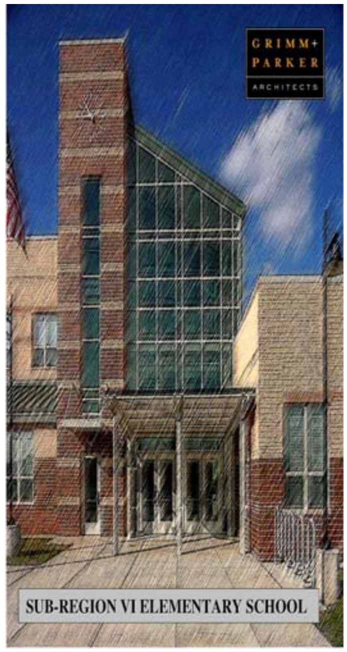
	Credits	Evaluation Process	Potential Sustainable Solution	Criteria For Certification	Utility Of BIM Tools
Credit 6.2	Controllability of Systems, Thermal Comfort	Provide a high level of thermal comfort system control by individual occupants or by specific groups in multi-occupant spaces	Design the building and systems with comfort controls to allow adjustments to suit individual needs or those of groups in shared spaces. Design system incorporating operable windows, hybrid systems integrating operable windows and mechanical systems, or mechanical systems alone	Thermal Comfort - provide individual comfort controls for min 50% of bldg occupants AND provide comfort system controls for all shared multi-occupant spaces	The ability to conduct a thermal analysis through Ecotect or EQuest makes it easier for the BIM model to get this credit.
Credit 7.1	Thermal Comfort, Design	Provide a comfortable thermal environment that supports the productivity and well-being of building occupants.	Design building envelope& systems in order to deliver performance to the comfort criteria. Evaluate air & radiant temperature, air speed, and relative humidity in an integrated fashion	Design HVAC systems and the bldg envelope to meet the req's of ASHRAE Std 55-2004,	The exhaustive variety of analyses: ASHRAE load calculations and dynamic thermal analysis produce a LEED thermal credit report from the BIM model.
Credit 7.2	Thermal Comfort, Verification	Provide for the assessment of building thermal comfort over time.	Establish thermal comfort and the documentation & validation of building performance according to the AHRAE criteria.	Verification - issue a thermal comfort survey to occupants w/in 6-18 months of occupancy and take action if > 20% of occupants are dissatisfied	Same As Above

	Credits	Evaluation Process	Potential Sustainable Solution	Criteria For Certification	Utility Of BIM Tools
Credit 8.1	Daylight & Views - Daylight	Provide for the building occupants a connection between indoors and outdoors through the introduction of daylight and views	Design the building to maximize interior daylighting. Consider building orientation, shallow floor plates, shading devices, glazing and photocell-based controls.	Daylight 75% of Spaces: achieve min glazing factor of 2% OR min daylight illumination level of 25 foot candles in min 75% of all regularly occupied areas	Through a BIM Model, Visualization of daylighting lead to better design decisions regarding orientation, location of windows or the use of natural lighting, which in turn helps the project achieve goals for natural illumination.
Credit 8.2	Daylight & Views - Views	Provide for the building occupants a connection between indoors and outdoors through the introduction of daylight and views	Design the space to maximize daylighting. Consider lower partition heights, interior shading devices, interior glazing, and photocell-based controls.	Views for 90% of Spaces: achieve direct line of site to outdoors via vision glazing between 2'6" and 7'6" AFF for bldg occupants in 90% of all regularly occupied areas	Same As Above

Appendix C: IEQ Phase Wise Distribution

	Credits	Design Phase	Construction Phase	Facilities Management
Prereq.1	Minimum Indoor Air Quality Performance			
Prereq.2	Environmental Tobacco Smoke(ETS) Control			
Credit 1	Outdoor Air Delivery Monitoring			
Credit 2	Increased Ventilation			
Credit 3.1	Construction IAQ Management Plan, During Construction			
Credit 3.2	Construction IAQ Management Plan, Before Occupancy			
Credit 4.1	Low Emitting Materials - Adhesives & Sealants			
Credit 4.2	Low Emitting Materials - Paints & Coatings			
Credit 4.3	Low Emitting Materials - Flooring Systems			
Credit 4.4	Low Emitting Materials - Composite Wood & Agrifiber Products			
Credit 5	Indoor Chemical & Pollutant Source Control			
Credit 6.1	Controllability of Systems, Lighting			
Credit 6.2	Controllability of Systems, Thermal Comfort			
Credit 7.1	Thermal Comfort, Design			
Credit 7.2	Thermal Comfort, Verification			
Credit 8.1	Daylight & Views - Daylight			
Credit 8.2	Daylight & Views - Views			

Construction Indoor Air Quality Plan



Barack Obama Elementary School

(a.k.a. Sub-Region VI Elementary School)
12700 Brooke Lane
Upper Marlboro, Maryland 20772

Submitted by:

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Construction Indoor Air Quality Plan

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Construction Indoor Air Quality Plan

APPROVED RECORD COPY

Project
Barack Obama Elementary School
(a.k.a. Sub-Region VI Elementary School)
12700 Brooke Lane
Upper Marlboro, Maryland 20772

Owner
Prince George's County Public Schools
13300 Old Marlboro Pike
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SECTION I. INTRODUCTION

This plan, in association with Specification Sections 01150 and 01450 of the Contract Documents and the LEED^{TM}-NC v2.2 Reference Guide, constitutes as the Construction Indoor Air Quality Plan for the Sub-Region VI Elementary School project. This plan describes the measures to be taken to provide good indoor air quality during construction and after construction is complete.

It is not the intent of this plan to replace or supersede any OSHA regulations as to safe construction workplace practices. It remains the responsibility of the General Contractor and the individual Contractors to maintain safe building and site operations. Additional precautions may be necessary when hazardous materials are present.

This plan will address construction indoor air quality by recommending procedures in six areas of concern, which in turn will allow the building to achieve the appropriate LEED^{TM} program credits:

- HVAC Protection
- Source Control
- Pathway Interruption
- Housekeeping
- Scheduling
- Baseline Indoor Air Quality Testing

SECTION II. CONCERNS AND CONTROLS

Outlined below is a detailed review of the five areas of concern and control measures to be performed in each area of concern.

A. HVAC System Protection

All HVAC equipment must be protected from collecting not only dust, but odors which can embed within the porous materials in the system and later be released.

1. During construction, filters (minimum of MERV 8) are to be installed for supply air intake and return air system openings when the HVAC system is in use. Frequent maintenance and filter replacement is to be performed. Filters are to be replaced as they become loaded, maximum every two weeks, prior to building flush-out, and prior to occupancy.

2. When performing construction activities that produce dust such as drywall sanding, concrete cutting, masonry work, wood sawing, or insulating, seal off the supply diffusers and return air system openings completely for the duration of the task.

3. Shut down and seal off the supply diffusers and return air ducts during any demolition operations.

4. Whenever the HVAC system is not used during construction, seal off the supply diffusers and return air system openings to prevent the accumulation of dust and debris in the duct system.

5. Provide periodic duct inspections during construction. If the ducts become contaminated due to inadequate protection, clean the ducts professionally in accordance with the SMACNA (Sheet Metal and Air Conditioning Contractors National Association) standards.

B. Source Control

The most effective type of pollution control is generally at the source. Products specified for this project will take this into consideration thereby minimizing any threat to the air quality of the completed building.

1. Use low VOC products as indicated by the specifications to reduce potential problems.

2. Exhaust pollution sources to the outside with portable fan systems. Prevent exhaust from re-circulating back into the building.

3. Keep containers of wet products closed as much as possible. Cover or seal containers of waste materials that can release odor or dust.

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4. No smoking activities are allowed on PGCPS property.

5. Avoid cutting block, brick, and concrete inside the building. If this is not practical, then tent off the area and exhaust the dust to the exterior where practical. Cutting in finished areas should be avoided at all costs.

6. Prohibit “Bake-out” of spaces to accelerate the release of VOC’s.

C. <u>Pathway Interruption</u>

Control is the effort to prevent VOC’s and other contaminants from spreading to other areas of the building which are occupied or where Type B finishes could absorb them for later release.

1. Provide dust curtains or temporary enclosures to prevent dust from migrating to other areas when applicable.

2. Locate pollutant sources as far away as possible from supply ducts and areas occupied by workers when feasible. Supply and exhaust systems may have to be shut down or isolated during such activity.

3. During construction, isolate areas of work to prevent contamination of clean or occupied areas. Pressure differentials may need to be utilized to prevent contaminated air from entering clean areas if practical.

4. Depending on weather, ventilation using 100% outside air will be used to exhaust contaminated air directly to the outside during installation of VOC emitting materials.

5. Take photographs showing the above and other activities to document compliance.

D. <u>Housekeeping</u>

As dust and other contaminants accumulate during the construction phase, they will become airborne when disturbed by nearby activity. Also, spills or excess application of products containing solvents will increase odors on site. Finally, leaving the jobsite wet or damp for extended periods could result in the growth of mold and bacteria.

1. Provide regular cleaning concentrating on HVAC equipment and building spaces to remove contaminants from the building prior to occupancy.

2. All coils, air filters, fans, and ductwork shall remain clean.

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3. Suppress and minimize dust with wetting agents or sweeping compounds. Utilize efficient and effective dust collecting methods such as a damp cloth, wet mop, or vacuum with particulate filters.

4. Remove accumulations of water inside the building. Protect porous materials such as insulation and ceiling tile from exposure to moisture.

5. Thoroughly clean all interior surfaces prior to replacing filters and running the HVAC system for system balancing, commissioning, and building flush-out.

6. Take photographs showing the above and other activities to document compliance.

E. Scheduling

These measures include careful scheduling to logically sequence the application of Type A and Type B finishes; minimizing the chances for absorption of VOC's and other contaminants released during construction.

1. Schedule high pollution activities that utilize high VOC level products to take place prior to installing highly absorbent materials. Examples of high VOC level products include paints, sealers, insulation, adhesives, caulking, and cleaners. Examples of highly absorbent materials include ceiling tiles, gypsum wall board, fabric furnishings, carpet, and insulation. These materials will act as "sponges" for VOC's, odors, and other contaminants and release them later after occupancy.

2. Protect highly absorbent materials from being exposed to dust, debris, demolition, and contamination by moisture during delivery, storage, and installation.

3. Continuously ventilate areas where high VOC level products have been installed for at least forty-eight (48) hours after installation, and prior to occupancy.

4. Avoid storing highly absorbent materials on site if they cannot be protected.

5. The approved project schedule generally allows for off-gassing to occur before installing absorptive materials, but there may be some minor coordination required during installation. The main area of conflict will be final or touch-up painting the walls in the corridors where there is acoustical ceiling tile, but the paint products required in these areas are low-VOC paint products. Based on this, virtually no off-gassing will occur in these areas.

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F. <u>Baseline Indoor Air Quality Testing</u>

This measure is necessary to ensure the HVAC system is performing to standard and is maintaining the proper temperature, humidity, outside air quality, filter installation, drain pan operation and to ensure compliance with ASHRAE Standard 62.

1. An independent contractor shall test the indoor air quality for contaminants upon completion of construction and prior to occupancy to demonstrate that the maximum contaminant concentrations listed in specification section 01450, page 7 are not exceeded. Should any of the concentrations be exceeded, additional flush outs will be conducted until the concentrations have been lowered to within the allowable standards.

2. <u>As required by LEED, the baseline indoor air quality testing will occur following completion of punchlist activities but before Owner occupancy. All areas of the building will be tested simultaneously so separation of building by testing areas will not be required. The exact start date of testing will be determined per the updated project schedule. Per the project baseline schedule, the anticipated testing date is February 1st, 2010.</u>

SECTION III. PLANNING, DOCUMENTING, AND ENFORCING

A. Distribution

Upon approval by the Owner and Architect, this Indoor Air Quality Plan will be distributed to the management personnel (project manager, superintendents, and foreman) of all Contractors. Additionally, a copy of this plan will be posted in the General Contractor's trailer. Each Contractor Foreman and/or Project Manager will read this plan and sign a statement that they have read the plan.

B. Instruction

The General Contractor will provide on-site instruction to all crews on the job site. A copy of the plan will be provided and the plan will be discussed to ensure all personnel understand the intent and procedures indicated herein. A copy of the plan and/or personal instruction will be provided in Spanish as required.

C. Meetings

The General Contractor shall incorporate discussion of indoor air quality at all meetings for all trade contractors involved with this project. At a minimum, indoor air quality goals and issues will be discussed at the following meetings:

1. Construction kick-off meetings

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2. Trade pre-construction meetings

3. Weekly foreman's meetings

4. Bi-weekly progress meetings

D. Signage

At all project entrances and within the General Contractor's Trailer, "No Smoking" signs will be posted in English and Spanish stating that smoking is not permitted on PGCPS property. This established perimeter will protect against tobacco smoke from entering into the building through fresh air intakes or windows. "No Smoking" signs will also be placed throughout the building as a reminder to all trade contractor employees working inside the building. Additional signs will be developed and implemented as required as the project progresses.

E. Enforcement

The General Contractor shall act as the Indoor Air Quality Manager and will inspect for indoor air quality problems on a regular basis, inform the trade contractor's foreman of these problems, and direct mitigation as required. All trade contractors are bound by the guidance contained within this plan and within the Specifications. Failure to follow the procedures spelled out in this plan will result in:

1. The on-site foreman for the responsible party will be notified of the problem/deficiency and immediate correction is to occur based on the direction of the General Contractor.

2. The trade contractor's Project Manager will be formally notified in writing of the problem/deficiency indicating repeat failure to correct the problem/deficiency. Immediate corrective action will be required for the problem/deficiency and to prevent further occurrences.

3. If the previous steps fail to correct the problem, the General Contractor will take the necessary corrective action and back-charge the responsible trade contractor for all costs associated with the corrective effort.

4. Continual non-compliance by individuals will result in their being permanently removed from the job site by the General Contractor.

F. Documentation

At a minimum, the following documentation shall be gathered to ensure compliance with this plan:

1. Maintain photographs of construction indoor air quality management measures.

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2. Submit product data on filtration media used during construction and installed prior to occupancy.

3. Maintain meeting minutes, checklists, worksheets, notifications, and deficiency / resolution logs.

4. Statement of Receipt and Understanding of Plan (see Attachment A)

5. Instruction Course Sign In Sheet (see Attachment B)

SECTION IV. SUMMARY

The Indoor Air Quality Plan contained herein and in conjunction with the Specifications is the complete, coordinated plan. Its goal is to assure the highest possible air quality at building occupancy and for years to come. When all members of the project team give their full commitment to this effort, we will achieve Indoor Air Quality success.

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SECTION V. REFERENCES

1. Sheet Metal and Air Conditioning Contractors National Association (SMACNA) IAQ Guidelines for Occupied Buildings under Construction, 1995, Chapter 3 "Control Measures."

2. Sheet Metal and Air Conditioning Contractors National Association (SMACNA) Duct Cleanliness for New Construction Guidelines.

3. ASHRAE Standard 52.2-1999": "Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size."

4. BIFMA M7.1-2005 and X7.1-2005 Standard for Formaldehyde and TVOC Emissions of Low-emitting Office Furniture Systems and Seating.

5. FloorScore by Resilient Floor Covering Institute.

6. US Green Building Council (USGBC) LEED™-NC v2.2 Green Building Rating System Reference Guide

7. California Department of Health Services Standard Practice for The Testing of Volatile Organic Emissions from Various Sources Using Small-Scale Environmental Chambers, including 2004 Addenda.

8. Greenguard Environmental Institute, Greenguard Children and Schools Certification Program.

9. Green Label Plus Carpet Testing Program by Carpet and Rug Institute for Carpet, Cushion and Adhesives.

10. SCS Indoor Advantage Gold – certification program for indoor finishes other than floor coverings.

11. US EPA "Compendium of Methods for the Determination of Air Pollutants in Indoor Air."

12. US EPA "Environmental Technology Verification (ETV) Large Chamber Test Protocol for Measuring Emissions of VOCs and Aldehydes."

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Construction Indoor Air Quality Plan

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Statement of Receipt and Understanding of Plan

This is to confirm that I have received, read, understand and will assist in enforcing the Construction Indoor Air Quality Plan for the Sub-Region VI Elementary School Project located in Upper Marlboro, Maryland.

I understand that it is the goal of all individuals working on this project to commit to any measures that need to be taken in order to provide good indoor air quality during construction and after construction is complete.

______________________	______________________
Printed Name	**Company**
______________________	______________________
Signature	**Date**

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Construction Indoor Air Quality Plan

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Instruction Course Sign In Sheet

Date	Printed Name	Signature

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Intent

Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupancy.

Requirement

OPTION 1- FLUSH-OUT

After construction ends, prior to occupancy and with all interior finishes installed, perform a building flush-out by supplying a total of 14,000 cu.ft. of outdoor air per sq.ft. of floor area while maintaining an internal temperature of at least 60°F and a relative humidity no higher than 60%. If occupancy is desired prior to completion of the flush-out, the space may be occupied following the delivery of a minimum of 3,500 cu.ft. of outdoor air per sq.ft. of floor area to the space. Once occupied, the building shall be ventilated at a minimum rate of 0.30 cfm/sq.ft. of outside air or the design minimum until a total of 14,000 cu.ft./sq.ft. of outside air has been delivered.

System Analysis

The construction activities, as further defined below, in all areas of the building will be completed entirely before commencement of the flush-out thus not requiring segregation by HVAC zone. The building utilizes five (5) 100% outside air Energy Recovery Units to provide outside air to the building and one (1) Hood Vent/Supply Fan to provide outside air to the kitchen. The system is designed to be run at 100% outside air while maintaining design humidity levels. The ground source heat pump units will be used to maintain temperature in the spaces. Additional means of air circulation, such as stand-alone fans, will be used as necessary to circulate air in potential dead air zones.

Option #1A: Compliance before Owner Occupancy

- The total combined min. OA output: 26,450cfm
- The total building square footage: 82,659sf
- The total OA required before Owner occupancy: 1,157,226,000cf
- Duration required before Owner occupancy: 56.09 days* *(at min. OA)*

**NOTE: Date based upon 13hr/day occupancy schedule seven (7) days per week.*

Schedule of Activities

- Construction complete: January 20, 2010
- Commence Flush-out: March 19, 2010
- Total Flush-out Complete: May 21, 2010* (scheduled date)
- Owner Occupancy- Full staff: August 15, 2010

Preparatory activities: Complete Construction

- All interior painting completed
- All interior furnishing and cabinet work installation completed
- All flooring materials installed including any adhesives used for carpeting, VCT, Linoleum and paneling
- All ceiling tile installed
- Site work complete around the building perimeter
- Final cleaning completed
- Final TAB completed
- Punchlist completed
- Initial Cx checkout of units

Pre-Flush-out Activities: Prepare for Flush-out using building HVAC System

- Remove any temporary filters and duct coverings from Construction IAQP
- Replace ERU filtration media with new MERV-8 filters
- Replace all heat pump filtration media with new filters
  NOTE: Per LEED-NCv2.2 Reference Guide, if the system is configured such that only outside air is filtered, these outside air filters do not need to be replaced. Actual conditions must be verified.
- As required, open interior doors and provide mechanical means of air flow as required ensuring all areas of the building are properly ventilated and prevent dead air zones in the building.
- Verify BAS is properly programmed for building flush-out and trending reports (running time, OA output, temperature, humidity)
- Establish testing parameters (system run time, trending increments, etc.)
- Confirm design 26,450cfm OA output with actual from TAB report
- Confirm space temperatures and humidity can be maintained
- Establish and verify exhaust fan needs to allow air transfer with positive pressure but avoid over-pressurizing the building
- Run pre-test

Flush-out using building HVAC System

- Verify pre-flush-out activities are complete
- Commence flush-out when all ERU's are operating within the required parameters
- Confirm settings and trending has started
- As the building will remain unoccupied, the system will be run 13 hours a day for a minimum of 56.09 days to achieve the full 14,000cu. ft./sq.ft. of OA required. Following the flush, the units will be run at the normal occupied OA rate and schedule.

Issue Resolution Protocol during Flush-out

- Should the humidity or temperature exceed the limits, the BAS system will automatically take steps to correct.
- All responsible parties will notified at time of issue
- Impact to flush-out duration will be evaluated and adjustments made accordingly.

Final Reporting

- After Completion of the flush-out, trending logs will be provided indicating duration, OA supply, temperature, and humidity readings

HESS CONSTRUCTION + ENGINEERING SERVICES

Barack Obama ES
EQcr3.2 Calculations

BUILDING INFORMATION: REF. M-3.1

ERU	UNIT CFM	OUTSIDE AIR CFM		EXHAUST
		MIN	MAX	CFM
1	9,935		9,935	9,390
2	11,015		11,015	10,225
3	3,010		3,010	2,685
4	7,000	1,500	7,000	5,500
5	990		990	885
MAU-1	3,300		3,300	

26,450	**TOTAL SYSTEM MIN. OA CFM**
35,250	TOTAL SYSTEM MAX. OA CFM
28,685	TOTAL SYSTEM EXHAUST CFM

82,659 **SF FLOOR AREA**

OPTION 1A: COMPLIANCE BEFORE OWNER OCCUPANCY

REQUIRED		***ACTUAL***
14,000	CFM/SF OA	20,956
1,157,226,000	TOTAL CF OA	1,732,185,000
DURATION AT MAX OA, 24 HOURS/DAY		
43,751.46	MINUTES	49,140.00
729.19	HOURS	819.00
56.09	***DAYS****	***63.00***

****NOTE: 1 day = 13hr/day system run time***

EQcr3.2: Constuction IAQ Management Plan: Before Occupancy
Barack Obama Elementary School (LEED-NCv2.2)

Intent

Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupancy.

Requirement

OPTION 1- FLUSH-OUT

After construction ends, prior to occupancy and with all interior finishes installed, perform a building flush-out by supplying a total of 14,000 cu.ft. of outdoor air per sq.ft. of floor area while maintaining an internal temperature of at least 60°F and a relative humidity no higher than 60%. If occupancy is desired prior to completion of the flush-out, the space may be occupied following the delivery of a minimum of 3,500 cu.ft. of outdoor air per sq.ft. of floor area to the space. Once occupied, the building shall be ventilated at a minimum rate of 0.30 cfm/sq.ft. of outside air or the design minimum until a total of 14,000 cu.ft./sq.ft. of outside air has been delivered.

System Analysis

The construction activities, as further defined below, in all areas of the building will be completed entirely before commencement of the flush-out thus not requiring segregation by HVAC zone. The The building utilizes five (5) 100% outside air Energy Recovery Units to provide outside air to the building and one (1) Hood Vent/Supply Fan to provide outside air to the kitchen. The ground source heat pump units will be used to maintain temperature in the spaces. Additional means of air circulation, such as stand-alone fans, will be used as necessary to circulate air in potential dead air zones.

- The total combined min. OA output: 26,450cfm
- The total building square footage: 82,659sf
- The total OA required at 14,000cu.ft./sq.ft: 1,157,226,000cf

Option #1B: Alternate Compliance with Owner Occupancy

Initial 3,500cu.ft./sq.ft.

- Total OA required before Owner occupancy: 289,306,500cf
- Duration required before Owner occupancy (13hr/day*): 14.02 days (*at design min. OA rate 0.32cfm/sf)*

**NOTE: 13hr/day = occupancy schedule of 10 hours + 3 hours startup prior to occupancy required by LEED*

Remaining 10,500cu.ft./sq.ft.

- Total OA required after Owner occupancy: 867,919,500cf
- Duration required after Owner occupancy (13hr/day*): 42.07 days *(at design min. OA rate 0.32cfm/sf)*

**NOTE: 13hr/day = occupancy schedule of 10 hours + 3 hours startup prior to occupancy required by LEED*

Schedule of Activities

- Construction complete: January 20, 2010
- Commence Flush-out: March 19, 2010
- Initial Flush-out Complete: April 3, 2010
- Commence Remaining Flush-out: April 3, 2010
- Total Flush-out Complete : May 21, 2010* (scheduled date)
- Owner Furniture Move-in: April 12, 2010
- Owner Occupancy- Admin. Staff: April 12, 2010
- Owner Occupancy- Full staff: August 2010

**NOTE: Date based upon 13hr/day occupancy schedule seven (7) days per week.*

Preparatory activities: Complete Construction

- All interior painting completed
- All interior furnishing and cabinet work installation completed
- All flooring materials installed including any adhesives used for carpeting, VCT, Linoleum and paneling
- All ceiling tile installed
- Site work complete around the building perimeter
- Final cleaning completed
- Final TAB completed
- Punchlist completed
- Initial Cx checkout of units

Pre-Flush-out Activities: Prepare for Flush-out using building HVAC System

- Remove any temporary filters and duct coverings from Construction IAQP
- Replace ERU filtration media with new MERV-8 filters
- Replace all heat pump filtration media with new filters
  NOTE: Per LEED-NCv2.2 Reference Guide, if the system is configured such that only outside air is filtered, these outside air filters do not need to be replaced. Actual conditions must be verified.
- As required, open interior doors and provide mechanical means of air flow as required ensuring all areas of the building are properly ventilated and prevent dead air zones in the building.
- Verify BAS is properly programmed for building flush-out and trending reports (running time, OA output, temperature, humidity)
- Establish testing parameters (system run time, trending increments, etc.)
- Confirm design 81,100cfm OA output with actual from TAB report
- Confirm space temperatures and humidity can be maintained
- Establish and verify exhaust fan needs to allow air transfer with positive pressure but avoid over-pressurizing the building
- Run pre-test

Flush-out using building HVAC System

- Verify pre-flush-out activities are complete
- Commence flush-out when all ERU's are operating within the required parameters
- Confirm settings and trending has started
- As the building will remain unoccupied, the system will be run 13 hours a day for the first 11 days to achieve the minimum 3,500cu. ft./sq. ft. for Owner occupancy. Following the initial 11 days, the units will be run at the normal occupancy OA rate and schedule until the full 14,000cu. ft./sq. ft. is achieved.

Issue Resolution Protocol during Flush-out

- Should the humidity or temperature exceed the limits, the BAS system will automatically take steps to correct.
- All responsible parties will notified at time of issue
- Impact to flush-out duration will be evaluated and adjustments made accordingly.

Final Reporting

- After Completion of the flush-out, trending logs will be provided indicating duration, OA supply, temperature, and humidity readings

HESS CONSTRUCTION + ENGINEERING SERVICES

BUILDING INFORMATION: REF. M-3.1

ERU	UNIT CFM	OUTSIDE AIR CFM MIN	OUTSIDE AIR CFM MAX	EXHAUST CFM
1	9,935		9,935	9,390
2	11,015		11,015	10,225
3	3,010		3,010	2,685
4	7,000	1,500	7,000	5,500
5	990		990	885
MAU-1	3,300		3,300	

26,450 **TOTAL SYSTEM MIN. OA CFM**

35,250 TOTAL SYSTEM MAX. OA CFM

28,685 TOTAL SYSTEM EXHAUST CFM

82,659 **SF FLOOR AREA**

OPTION 1B: ALTERNATE COMPLIANCE WITH OWNER OCCUPANCY

BEFORE OCCUPANCY

3,500 CF/SF OUTSIDE AIR

289,306,500 CF REQUIRED

DURATION AT MIN OA BEFORE OCCUPANCY

10,937.86 MINUTES

182.30 HOURS

14.02 DAYS REQ. (13 HRS/DAY)

15.00 DAYS ACT. (13 HRS/DAY)

AFTER OCCUPANCY

0.30 CFM/SF LEED MINIMUM REQ.

0.32 CFM/SF ACTUAL MINIMUM

0.43 CFM/SF ACTUAL MAXIMUM

10,500 CF/SF OUTSIDE AIR

867,919,500 CF REQUIRED

DURATION OF OA AFTER OCCUPANCY

	RATE (CFM/SF)	0.30	0.32	0.43
	MINUTES	35,000.00	32,813.59	24,621.83
	HOURS	583.33	546.89	410.36
REQUIRED:	***DAYS (13 HR)***	***44.87***	***42.07***	***31.57***
ACTUAL:	***DAYS (13 HR)***		***48.00***	