University of Alberta

Design Evaluation and Optimization of School Buildings Using Artificial Intelligent Approaches

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Construction Engineering and Management

Department of Civil and Environmental Engineering

Spring 2013
Edmonton, Alberta

ABSTRACT

School buildings are one of the most important educational and learning environments and the appropriate design of these spaces has a significant impact in enhancing both students’ and teachers’ performance, comfort and satisfaction. As a result, the preliminary design evaluation and optimization of school buildings should be given a significant consideration. The key factor in design optimization of a school building is defining the users' expectations, which is qualitative and subjective in nature. To capture these qualitative and imprecise aspects of the problem, and optimize school building design parameters a multi-criteria fuzzy expert system is employed and the design evaluation and optimization model is developed. Different school building design parameters such as; building orientation and layout, envelope features, indoor air quality as well as day-lighting systems are investigated as part of the design evaluation and optimization process. The fuzzy expert system is used to analyze the optimal values of a list of parameters associated with the building design process to enhance the learning environment for school buildings. This method employs both quantitative and qualitative design performance parameters and allows for comparison analysis between different design alternatives in order to achieve the objectives of the study.

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Chapter 1

Introduction

1.1 Summary

The design development phase of the project is a complex process in nature which deals with many qualitative and subjective factors. Through this process reaching an optimal design solution can be done by implementing decision making approaches in preliminary design phase of the projects. On the other hand, complexity of the design phase and diversity of the design parameters including aesthetics, performance, comfort, structure and many other aspects imposes the use of multiple-criteria design decision-making method. This method will assist architects and designers to come to a best design solution among the proposed alternatives.

For learning spaces like school buildings, parameters such as; color, light, views, size, circulation, acoustic, ventilation, thermal condition and day-lighting are crucial considerations since they can affect students' and teachers' outcomes (Tanner and Lackney, 2006).Thus, primary design decision-making on location, orientation, geometry, facade and materials of building is very important. In this study, an evaluation method for school buildings design at the preliminary phase is developed. The method analyzes comfort parameters such as; acoustic, thermal, lighting and physical comfort in school design. These parameters can be used as optimization criteria for a new school design or as assessment criteria for an existing school to support better decision-making and choose the optimal design among alternatives.

The expert system developed in this study is a decision-making tool, which uses the fuzzy rule-based system. The model has been developed to provide a range of initial design alternatives requiring designer interaction and inputs in order to evaluate the design. The database used for developing this model was a "Design Knowledgebase" generated based on data obtained from experts' knowledge and design specialists' interview and questionnaire results as well as design guides and standards related to educational buildings. Once all the parameters required for development of the model were identified (Such as; input and output variables, fuzzy sets and rules) and recorded in a database (knowledgebase) the development of building design and performance evaluation model was initiated using Matlab Fuzzy toolbox. The performance evaluation output of the model can be used in order to optimize the design variables and overall comfort of the educational buildings for improved user satisfaction and performance.

1.2 Research Motivation

In order to evaluate the physical aspects of a building design, Building Performance Evaluation was introduced. The key factor in building performance evaluation is "productivity of buildings", which explains how well a building design performs to meet the needs and expectations of its users and how well it performs in terms of environmental issues such as energy consumption.

According to recent studies on the performance of buildings (Leaman (2004)), modern buildings do not efficiently perform to satisfy their owners' need and they consume relatively high amounts of energy, which indicated the loss of productivity in newly designed buildings.

When it comes to the educational facilities, the performance of the buildings would be more emphasized as these buildings are designed to meet the needs of a more specific group of users including teachers and students. Educational settings demand buildings with well-functioning designs and satisfying teaching and learning environments that enable the transmission of knowledge from teachers and the promotion of students learning (Ojogwu and Alutu, 2009). A well-designed classroom maintains certain conditions in terms of thermal, visual, acoustic, and physical factors that will properly accommodate users' needs and comfort (OECD, 2003).

The performance evaluation of educational buildings helps to acquire users' feedbacks from existing designs and assess the impact of existing buildings' designs on occupants' comfort, well-being and performance. Thus, the result of evaluations can help designers to improve and optimize their future practices by minimizing the identified problem areas. There are several studies that investigated the relationship between different design factors and occupants' satisfaction as well as the impact of those factors on occupants' work performance, which have been conducted by prominent research centers such as; the Center for the Built Environment (CBE) at the University of California, Berkeley; the Center for Building Performance and Diagnostics (CBPD) at Carnegie Mellon University; and the Center for Sustainable Building Research at the University of Minnesota. However, none of those studies incorporated the knowledge of experts in an evaluation model (framework) in order to reduce the subjectivity of assessments and provide a standardized/normalized and more precise estimation of building performance with optimization purposes.

1.3 Significance of the Study

As mentioned before, inadequate design of educational buildings negatively affects the academic performance of student and efficiency of the instructors so that these buildings not only fail to meet their minimum academic standards they also are not able to provide enough value and satisfaction for their users. For these reasons, performance evaluation of educational settings requires a large amount of research and elaboration in order to provide objective assessments and use the results of assessments to improve the building performance and academic performance of users accordingly. These concerns provide the basis for the study and the results of this study can be used as a baseline to measure the relationships between educational buildings' design features and occupants' satisfaction of their environments as well as their performance. Moreover, the developed model can be used as a design guideline and a rating system in addition to their implications for building design practices in educational buildings.

1.4 Research Objectives

The main objective of this study is to develop an appropriate model for performance evaluation of educational buildings showing relationships among the key building's design criteria with occupants' satisfaction and comfort at educational settings and their overall work performance. The study also tests the developed model based on the real observations to suggest a good-fit model. The purpose of the developed model is to explore what the important factors in design evaluation and optimization of school buildings are in order to enhance the learning environment, and consider those factors in the future design of school buildings. The specific research questions to guide this study are:

- What design criteria of a school building impact learning and teaching performance?
- What is the relationship between the identified design criteria in the learning environment and users' satisfaction and their overall performance?

- What is the best model to improve users' satisfaction with those design criteria in the learning environment and their overall work performance?

Why Fuzzy Expert System?

The Preliminary Design stage deals with numerous qualitative, imprecise, not clearly defined variables and many decisions require experience rather than strict calculations, so that;

- Fuzzy set theory Is implemented as a well-suited approach for problem solving in design and construction industry,
- Qualitative and imprecise variables can be represented by fuzzy sets,
- Expert knowledge can be used in the place of established scientific theory,
- Qualitative variables can be used in the absence of crisp values,
- Fuzzy set provides the ability to capture qualitative design variables and incorporate them into an evaluation model using a series of heuristic rules generated based on experts' knowledge.

1.5 Key Assumptions

The following key assumptions have been recognized in relation to the research problems;

- The educational building design is considered as an important factor that has impact on teaching and learning performance of both teachers and students.
- The targeted group of respondents for the survey procedure have enough capacity and experience to provide accurate feedbacks on the quality of their work environment.

1.6 Limitations of the Study

Several limitations have been identified for this research study including;

- This study is just limited to the public schools located in the Edmonton area and conducted during the 2012 academic year. So the sample group may not be big enough to be representative of the entire schools' population. Having a larger data set would be valuable in refining the model to a state that could deliver consistently accurate results.

- The small number of the experts that were identified to consult with during the model development is another limitation of the study. Larger number of experts from more varied backgrounds would be ideal to conduct a more accurate study.
- Although, the school buildings' evaluation is conducted using the knowledge of design specialists and experts in school design area, but they may not have enough proficiency in specific elements of learning environments and psychology of learning procedure.
- There is a possibility of biased evaluation during the survey procedure, so the respondents are asked to perform the evaluation with integrity and contemplation.

1.7 Outline of the Research

To evaluate school buildings' design and answer the problem of design optimization, both qualitative and quantitative parameters are of particular importance. Development of an expert system is proposed to capture the subjectivity of the problem in order to create a school building design evaluation model. Different school building design parameters such as building orientation and layout, envelope, indoor air quality and lighting must be investigated as parts of design evaluation and optimization process. The Model also allows the designer to explore different design alternatives to choose the optimized solution.

The proposed methodology incorporates experts' knowledge and performance analysis of existing learning environments with focus on the users in order to ensure better quality of design and higher level of users' satisfaction and comfort to facilitate higher achievement rates. The model is intended for two purposes; first and foremost, the model can be used as an evaluation tool, in order to accurately assess the performance of the learning environments in the early designs phase. Additionally, it could be used to identify the factors that are having the largest impact on performance factor, so that novel design measures for new school buildings can be focused accordingly.

The main tools of data collection for this study are interviews, survey questionnaires as well as observations. The case study approach employed to perform the performance analysis of the excising educational buildings in Edmonton area in order to determine the extent to which the performance of these buildings meets the needs of the occupants (students and teachers).

Based on the findings of the study, a framework for the school buildings' design optimization will be proposed in order to guide designers, construction engineers and managers in taking decisions concerning the improvement of buildings performance in educational institutions. So that the outline of the study is summarized as follow;

- An elaborate study and discussion on the building performance evaluation and its implementation in educational settings;
- Identification of the key design factors to measure building performance based on literature and experts' knowledge;
- Identification of users' needs and comfort requirements within educational settings;
- Determine the extent to which the identified needs are satisfied in the case study institutions with respect to key design factors;
- Develop a building performance evaluation framework/model based on the identified design/comfort factors as well as experts' knowledge and opinion for future evaluations and design optimization;
- Test and validate developed model according to the real performance data obtained from case study schools.

Chapter 2

Literature Review

2.1 Design Evaluation of Educational Buildings

Several parameters that affect students' and teachers' performance in school buildings are investigated and analyzed in this study. A classroom's physical, thermal, acoustic and visual comforts are the main factors, which have been evaluated through technical measurements and expert questionnaires. In terms of physical comfort of the classrooms, the minimum area for each student is between 1.00-1.50m^2 according to the recommendation of technical references (Montello, 1988), (Lintona et al., 1994), (Panagiotopoulou et al., 2004). For thermal comfort a dry bulb room temperature of around 23$^{\circ c}$, with a 50% relative humidity and cross ventilation is recommended (Mendell et al., 2005), (Peretti et al., 2011).

Window location should be considered according to the building orientation and the predominant wind direction in order to avoid direct solar radiation and undesired wind and heat gain as well as visual discomfort due to blackboard and desk surface glare. Moreover, the recommended lighting level according to technical references is 500 lx (Heschong Mahone Group, 1999), (Boyce, 2004). While, the American Speech-Language-Hearing Association recommends a noise level of 35 dB for classrooms (ASHA, 2003), Mehta et al. recommends noise levels between 40 and 50 dB for classrooms. Standard reverberation time is also recommended between 0.4s and 0.6s (Mehta et al., 1999). Noise generating sources for the classrooms could be streets for schools located in urban areas with heavy traffic or recreational and physical activity areas due to their proximity to classrooms (Nelson, et al., 2002). To avoid discomfort for students and teachers and improve their performances in school buildings, preliminary design evaluation and optimization of school buildings' design should be given significant consideration.

Although there is a LEED rating system for majority of building types, there is no specific system to evaluate and rate educational buildings performance similarly as LEED system does.

However, it is essential to assess educational buildings' performance as a large number of populations such as students, teachers and other staff, spend their time and days in these buildings (Wilson, 2002). Performance evaluation of educational buildings and occupants of the buildings can provide a useful tool to assist architects and construction engineers in designing and constructing better quality buildings. Although several studies have investigated the impact of design factors of educational buildings on occupants' performance so far, there is no developed expert system model that can evaluate and rate these buildings' performance.

2.1.1 Occupants Performance in Educational Settings

The performance of school occupants is measured based on students' personal development, achievement and working output, teachers' productivity, students' self assessment of their performance and occupants' constructive feedbacks.

The quality of school buildings and classroom environment can impact the productivity and comfort of occupants; unfavourable environmental situations related to amount of light, or thermal and acoustic control can negatively affect these occupants' outcomes (Evans et al, 2004). Additionally, negative psychological and emotional conditions resulting from unfavorable quality of classroom design can consequently cause less motivation and reduced productivity (Wright et al, 2002). The factors that affect individuals' performance within the educational setting, including indoor air quality; ventilation; daylight; and thermal, acoustic, physical and psychological comfort, are referred to as "Ergonomic" according to Ergonomics Committee of the American Industrial Hygiene Association (AIHA).

Research indicates that the socio-economical status, which is often measured as a combination of education, income, and occupation, also need to be considered when assessing the performance of students. The socio-economical status of individuals affects their academic achievement and psychological health in a significant way (Morgan, Farkas, Hillemeier, & Maczuga, 2009). The socio-economical status of the participants of this research study was verified and the sample group of the study was selected from similar social and economical background in order to reduce any discrepancies in measuring their performance (academic achievement) and maintain the consistency of analysis. Further explanation concerning performance/productivity measurement of school occupants is presented in section 2.6.3

2.2 Design Factors Affecting Student Learning performance and well-being

Many factors can impact learning and productivity in educational buildings. According to Hattie (1999) physical attributes of the school buildings and classroom environment, which include areas such as architecture and working and learning conditions, have an influence on students' learning. Hattie has been synthesizing a large number of related studies over the period of ten years on approximately 50 million students and these studies are very significant in regard to factors impacting learning (Hattie, 1999).

According to the United States Green Building Council (USGBC), poor environmental conditions affect a large number of educational buildings, which can deteriorate the health, well-being, and learning of their occupants. The class environment should provide a comfortable condition for occupants' working and learning (Hattie, 2009). It is difficult to analyse just a single factor to calculate the magnitude of the impact on learning; thus, all different influencing factors have to be considered in the analysis. Some of the factors that can enhance the classroom environment by providing a comfortable condition include classroom indoor air quality and thermal, lighting and acoustic conditions.

Studies by Ihab M.K. Elzeyadi show that within a learning environment, a better quality of temperature condition positively impacts occupants' performance by 3-10%, increased use of day-light improves performance by 5-20%, and an enhanced indoor air quality positively impacts occupants' performance by 5-20% (Elzeyadi, 2009).

The following factors contribute to a comfortable classroom environment and have an impact on learning and teaching outcomes according to several studies.

2.2.1 Physical Environment

The impact of physical environment on performance of the occupants within an educational setting has been examined in several studies. For example, Earthman (1996) claims that the effect of physical environment on occupants will be transferred to their behavioural responses, and thus, their achievement rates. In his study, the relationship between the physical environments of educational buildings, occupants' behavior, and their achievement was examined and a strong link between these factors was identified (Earthman, 1996). According to Earthman's study, a number of identified specific factors that can improve students' and teachers' performance include: control of the thermal condition, illumination, adequate space and high-quality furniture for students and teachers.

Banning and Canard (1996) also emphasized the existence of a strong relationship between the features of physical environment and students' development and performance, and they noticed that this relationship has been overlooked in numerous performance evaluation processes. The significance of the link between the students' achievement and their physical environment had not yet been identified for many designers and decision makers. Additionally, in another study by Veltrie et al. (2006), a link between physical environment of an educational setting and attendance rate of the students has been recognized.

All these studies urge the consideration and improvement of those various aspects that are connected to the physical environment of educational buildings. This enhances students' positive behavioural responses to the improved factors and, consequently, their motivations, participations, developments and achievements.

2.2.2 Indoor Environmental Quality

Indoor environmental quality is critical as people spend about 90 percent of their time indoors. Indoor environmental quality comprises many factors that have an effect on the occupants such as ventilation condition, thermal comfort, daylight and views, acoustic condition, colors etc. (EPA & the U. S. Consumer Product Safety Commission, 1995). It is found from review of the literature that most studies just consider one to three design factors and aspects of indoor environmental quality, as it is so complex to study all different aspects/factors at the same time. However, most of the aspects are investigated in this study in order to find the relationship between different variables of the design and occupants' outcome. In the following sections, the parameters that have an essential effect on the indoor environmental quality will be discussed.

2.2.3 Indoor Air Quality and Ventilation

Ventilation is one of the essential parameters for the occupants' comfort and productivity improvement (Kibert, 2005). Standard ventilation for acceptable indoor air quality is proposed by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in their Standards 62.1 and 62.2. Following these standards will improve the air quality of the building and accordingly the productivity of the occupants by decreasing "sick building syndrome" (SBS) symptoms (Wargocki et al, 2000). In another study by Seppanen and Fisk (2002), it is concluded that the sick building syndrome symptoms is increased in mechanically ventilated buildings. Pollutant emissions caused by deficient HVAC system design, construction, operation or maintenance are the other factors affecting human health, comfort and productivity. Odor, which is another harmful factor that is not normally considered in many building assessments, can result from several construction activities in the building or gas producing materials (Kibert, 2005).

2.2.4 Acoustics

Acoustic comfort can be provided by appropriate design of HVAC system, lighting and other sources that can produce noise and discomfort (Kibert, 2005). Although, acoustic condition has not been adequately addressed by many building performance assessment studies, yet the acceptable standard noise level for a classroom is recommended not to exceed 35 dBA, according to American National Standards Institute Classroom Acoustics Standard. There have been many studies showing that exposure to annoying and inescapable noises can negatively impact learning and performance by reducing individuals' motivation to successfully perform a task (Evans & Stecker, 2004).

2.2.5 Thermal Comfort

According to studies, individuals' behaviour satisfaction and performance can be greatly affected by extreme hot or cold temperatures. Individuals performing in appropriate temperature and comfortable thermal condition have more satisfaction, increased productivity and enhanced learning level (Ramsey & Beshir, 1998). According to Maslow's (1943) study in order to enhance the quality of a learning environment and consequently work performance of its users, physiological needs such as air and temperature comfort must be met. To accommodate this matter, an operable window in a classroom is one solution that provides users with the ability to control their classroom temperature and ventilation condition as well (CAGBC, 2004).

2.2.6 Daylight and Views

Natural Daylight in school buildings is an essential factor that has significant effects on health, well-being and productivity of the occupants (Veitch, 2005), (Webb, 2006), (Cuttle, 2002), (Heschong-Mahone Group, Inc., 2003), (Kim, et al., 2005) and according to HeschongMahone Group (1999) natural light contributes to students' achievement. Studies prove that classrooms located on the south side of the school buildings are brighter since they allow more natural daylight inside (Alexander et al., 1977). Pathways and corridors are usually darker because of their position with regard to the sun.

Daylight has a great impact on occupants' comfort, and schools with natural daylight enhance learning of students and performance of teachers as well. Therefore, the standard amount of daylight needed in classrooms as well as materials falling under the recommended surface reflectance must be considered in school buildings' design, particularly windows design, in order to optimize comfort in classrooms (Selkowitz et al, 1997). Natural classroom daylight can enhance students' outcome by significant amount in courses such as mathematics by 20% and reading by 26% according to Heschong Mahone Group (1999) studies. The results of this research study by Heschong Mahone Group has been strongly referred to by several studies such as; Herzog, 2007; Kennedy, 2007; Plympton, Conway & Epstein, 2000; Tanner, 2008.

Hathaway et al. (1992) also found that the attendance rate in schools resourced with natural daylight is 3.2 days per year higher than the attendance rate in those with artificial lighting sources. Inefficient window design has effect on health and well-being of occupants in the classrooms and can cause feelings of discomfort, isolation, depression, and tension (Finnegan & Solomon, 1981). Kibert (2005) claims that glare produced by a poorly positioned light source and highly reflective materials can cause discomfort and negatively impact learning and performance. According to Tanner (2008), windows in a classroom are one of the essential items since lack of light in classrooms can cause students dullness and sleepiness. Artificial lighting sources also may have a negative effect on students and teachers.

The Heschong Mahone Group (1999) studied over 21,000 students to examine the impact of daylight on learning over a period of one year. The students having most day-lighting in their classrooms had enhanced academic performance in mathematics by 20 percent and in reading by 26 percent compared to students having less daylight in their classrooms. A similar study has been conducted by Tanner (2008) to support these facts. All of these quantitative studies have examined elementary and high school students.

The other important factor that has been analyzed in previous studies is view condition. Views can generate either positive or negative impact. A view of nature and greeneries contribute to higher comfort and satisfaction level by reducing stress and depression, and there is a direct relationship between pleasant view, well-being and performance level of occupants (Kaplan et al, 1988). According to Tanner (2008), not all views through windows are beneficial; for example, views of walls or parking lots are undesirable to students and teachers. Conversely, unrestricted view of nature is desirable and beneficial to the well-being of students and teachers. He also held that some distracting views (e.g. view to greeneries) can be valuable for the learning process as they can provide a mental break after long hours of study and work.

2.3 Design Principles of Educational Buildings

As the design principles specifically pertaining to the educational buildings had not yet been developed until the mid-twentieth century, the designers of these buildings simply adhered to general design standards for different building parameters (e.g. lighting, thermal, acoustic and physical factors) in order to design a productive environment for learning and teaching activities(Mutlaq, 2002).

Although the physical environment of educational buildings is a crucial factor, which has a great impact on teaching and learning performance, this factor and its relationship with educational buildings' performance were not given a significant consideration. (Sanoff, 2003). According to literature, physical environment of educational buildings have direct and indirect influence on health and well-being (Mutlaq, 2002; OECD, 2003; Sanoff, 2003; Robinson and Robinson, 2009). In this study, all needs of occupants/users of an educational setting such as physical comfort, indoor air quality, adequate lighting, temperature and noise, will be addressed in a well-designed educational building. The role of a specialized architect/designer is emphasised here in order to achieve this well-designed educational building (Robinson, 2009). The aspects that should be considered in a well-designed building include functionality, accessibility, productivity, adaptability, flexibility, and sustainability, which contribute to the building performance to enhance the educational environment.

According to the Commission for Architecture and the Built Environment (CABE) (2009), there are several assessment criteria for any educational building design in Great Britain that need to be considered including; 1- Building Context, 2- Site plan, 3- Outdoor spaces, 4- Building organization, 5- Building form, mass and appearance, 6- Interior learning and teaching spaces, 7- Safety and security, as well as 8- Successful entire design. However, CABE's assessment criteria are British-specific and capture most of the basic requirements of a building design in British environment. There is a need to define international design principles, which are practical for any kind of educational buildings' design, and identify the key factors to address the design quality (Heitor, 2005). The defined design principles should describe how the educational buildings' physical environment must be to support educational achievements and enhance academic performance.

The design principles for educational buildings have also been developed in the United States of America and the following factors are recommended to be considered in educational buildings according to Lackney (2000): 1- accommodate all users' needs related to teaching and learning, 2- serve as community centres, 3- provide users with health, safety and security, 4- make effective use of all available resources, 5- allow for flexibility and adaptability. The performance of the building and the effect of design on educational achievement can be determined as a result of evaluations according to above mentioned criteria.

2.4 Building Performance Evaluation

To evaluate the success of a building design regarding occupants' comfort, satisfaction, building performance evaluation or formally called post occupancy evaluation (POE), can be employed as a method of assessment (Kats, 2010).

Building performance evaluation or post occupancy evaluation is defined in several ways. For example, Preiser (2002) defined BPE as; "a process of evaluating the performance of buildings after they have been occupied" or according to Zimring & Reizenstein (1980) definition BPE is; "examinations of the effectiveness of occupied environments for their users". Performance evaluation of buildings has been performed informally in the last two decades. Buildings were planned, designed and constructed with no evaluation concerning uses'/occupants' needs and requirements as well as buildings' performance itself. Just a small portion of buildings was evaluated and lessons learned from evaluations were applied in the design of future buildings of a similar type (Lackney, 2001). However, Building performance evaluation has become more documented and formal recently (Douglas, 1996). This evaluation method can provide a valuable tool, which can not only be used for design enhancement of existing buildings but also supports better and more successful design of the future buildings of a same type (Abbaszadeh, Zagreus, Lehrer, & Huizenga, 2006; Zimmerman & Martin, 2001).

The main characteristic of a functional, well-designed building according to Knirk (1993) is defined as "a building that serves the main needs and requirements of its occupants in a comfortable physical environment by providing enough natural light, temperature, noise level, and other needs of users".

Building performance evaluation therefore will assist to determine the extent to which a building satisfies the needs of its occupants/users and meets its design goals after occupation. This evaluation process also contributes to identify the aspects of a well-designed or well-performed building in order to develop a design framework for future buildings (Preiser, 1995, and Obiegbu, 2005, Ornstein, 2009). Two groups of people will be involved to conduct the building evaluation process; 1- occupants/users and 2- experts (Barrett and Baldry, 2003). The first group of evaluators, building's occupants or users, assess the building design and performance regarding their needs and comfort. This evaluation system is called user-based evaluation system which is known as post occupancy evaluation (POE). The next group of evaluators, which are the design experts, conduct an expert-based evaluation system by executing building design and performance assessments process according to their knowledge area and specialty. Experts' knowledge and their assessments' results would provide a valuable evaluation and optimization tool for the future buildings' design.

For educational buildings, feedbacks obtained from performance evaluation process can serve as an optimization tool that gathers, analyzes and implements the results of analysis for future planning, design and construction of the buildings. This tool assists to enhance performance of the educational buildings with a purpose of making improvement in occupants' well-being, satisfaction, comfort and productivity accordingly (Cots, 1990, and Lackney, 2001).

2.4.1 Key Issues in the Performance Evaluation Process

Performance evaluation of buildings ensures decision makers and design organizations with the degree to which they have achieved their overall design objectives. This is done by inspecting the accuracy of the strategies their followed and the approaches they selected in the process of design development and facility provisions. This evaluation process helps designers with their decision making procedure and the selection of appropriate practices in order to achieve their ultimate design goals (Amaratunga, 2000).

According to previous studies, the comparative analysis of a developing design with existing successful practices can be used as a validation tool for those designs under development (Then and Tan, 2002). In order to improve the planning and design process for the future projects, Then and Tan (2002) also suggest to use the information and lessons learned from the past practices and combine them with the current needs, trends and requirements to develop better plans and designs for the future projects. Then and Tan (2002) also believe that the adopted evaluation methodology, the factors to be evaluated and the measurability of variables pertained to those factors are very important and key issues in the process of performance evaluation. Therefore, according to Szigeti and Davis (2005) there are several key issues need to be considered for a better building performance evaluation process including; the minimum subjectivity in the evaluations, the consistent reliability in the results of the evaluations, and the meaningful evaluation results for the building performance.

Barrett and Baldry (2003) also maintain that the decision making process and strategic planning that lead to the final goals of a building design will be improved by conducting building performance evaluation. From the review of literature the following issues can be considered in building performance evaluation process;

- Whether buildings suit for the purpose of their design and meet their planned objectives;
- Whether buildings provide a satisfactory environment for their users;
- Whether buildings perform as functional and operational resources, and
- Whether buildings perform in a way to minimize their operational and maintenance costs.

The abovementioned building performance issues must be well-adjusted in order to optimize the planning strategies and design development of a building.

2.4.2 Building performance indicators

Key indicators for performance of a building are employed to predict an expected outcome and future performance using standardized or benchmarked data. If the benchmarked data is not available, it can be developed based on experience or intuition as what the construction industry practiced in the United Kingdom (UK) according to Egan (1998). Similarly, many construction industries have developed their own schema for key performance indicators.

As discussed in the UK construction industry, key performance indicators, those measure the future performance need to be distinguished and considered while conducting the performance evaluation process in order to reach the final evaluation goals (Beatham, 2003). This will facilitate the implementation of required adjustments or improvements when the performance outcomes necessitate changes.

According to Alexander (2002) different building types with varying functional goals and operational environments will call for different performance indicators. For example, the performance indicators for an educational building having learning environment and educational objectives differ from those of a commercial building having industrial environment and business goals. Key performance indicators must have a direction, benchmark, target and a time frame and they involve both quantitative and qualitative measurements accompanied together to interpret the indicators in the right context (Then, 2004).

According to Preiser (2002), depending on the aspects of a building that is being evaluated, several sources for the performance indicators can be identified. Generally, the most important indicators related to a building design include; appearance, accessibility, functionality, quality, energy efficiency, safety and security. These design criteria/indicators have also been referred as the indicators of a high-quality building in most design guides and standards. These indicators can be either qualitative, subjective aspects that are hard to be quantified or numerical quantitative aspects that can be numerically measured (Okolie, 2006).

In the following sections, five groups of performance indicators including; economic, functional, physical, service and environmental measures and their associated objectives are discussed (Then and Tan, 2002; Obiegbu, 2005).

- **Economic indicators**; these indicators contribute mainly to productivity, profitability and efficiency in terms of financial values with purpose of ensuring cost-effective reasonable resource allocation and provisions based upon what the market offers.

- **Functional indicators;** the purpose of the functional indicators is to ensure the suitability of a design product and how it functionally serves to the users' expectation from a facility service in terms of location, typology, form and size of a facility/building. This fact is also known as 'fitness for the purpose'. Therefore, the main role of the functional indicators is to assess what a building space present for its users to provide a pleasant environment to work, live or learn based on the function of that space. As mentioned before aspects such as; quality and size of a building space, layout of the space, space appearance, ergonomics, and environment as well as circulation and movement requirements, flexibility and adaptability of the space are all the key factors to be considered.

- **Physical indicators:** These indicators are representative of a building performance in terms of its physical appearance, envelope as well as other physical properties of a building such as maintainability and durability. The objective of the physical indicators is to ensure the efficiency of facilities' operation and buildings' condition to prevent any operational risks and to minimize the occupancy costs.

- **Service indicators:** Service indicators are related to the quality of services that a building provides for its users and they facilitate measuring those services. Therefore, the key purpose of the service indicators is to ensure the satisfactory and appropriate delivery of the service requirements. As these indicators deal with users' opinion and judgment of a building facilities and services, they are mostly subjective and qualitative measures in nature. A number of these subjective and qualitative measures related to building services include; air quality and temperature, lighting quality, comfort and etc.

- **Environmental indicators;** Environmental indicators include issues such as; environmental impact, sustainability goals, health, and safety, which are related to the impact of a building on the users, the community and the ecological environment.

Although each of these indicators is measured differently, they are linked and integrally contributed to the building performance evaluation process.

2.5 Methods of Building Performance Evaluation

In order to conduct building performance evaluation, various methodologies can be employed such as; 1- walk-through observations of indoor and outdoor spaces to explore buildings' design quality and occupants' condition in a space, 2- physical and environmental measurements, and 3- user survey using questionnaires to assess design parameters of a building (Meir, et al., 2009, Leaman & Bordass, 2001). Among these methods, user survey is more systematic and structured tool which captures the opinion of buildings' users regarding the performance of the building they occupy, and provides the designer of those buildings with the required information about the efficiency and deficiency of their designs (Zimmerman & Martin, 2001). (RIBA, 1991).

There are several occupants' survey questionnaires have been already developed, such as Post-occupancy Review of Buildings and their Engineering (PROBE), which is developed by Building Use Studies Ltd. (BUS) in the United Kingdom (Bordass & Leaman, 2004). This survey include items such as users' personal judgment (self-judgment) of; 1) thermal (heating and cooling) condition, 2) lighting condition, 3) ventilation condition, 4) Indoor air quality, 5) acoustic condition, 6) overall comfort and satisfaction, 9) health and safety provisions , and 10) their own productivity and performance (Cohen et al., 2001).

The other survey-based method has been developed by the Center for the Built Environment (CBE) at the University of California, Berkeley, which is a popular web-based questionnaire related to indoor environmental quality of buildings (Meir et al., 2009). This questionnaire includes both subjective and objective measures to assess different components of a building; several design aspects, and the performance of a facility (Meir et al., 2009). Seven indoor environmental quality parameters/criteria representing subjective assessment measures are considered in the survey including; layout, furnishings, thermal comfort, air quality, lighting, acoustics, and cleanliness (CBE, 2009). The scale used to rank these assessment criteria ranges from (-3) “very dissatisfied” to (+3) “very satisfied” for the satisfaction related questions, and (-3) “interferes” to (+3) “enhances” for productivity related questions.

Carnegie Mellon University’s Center for Building Performance and Diagnostics (CBPD) has also developed the assessment tool called National Environmental Assessment Toolkit (NEAT) to study the performance and productivity of buildings by combining both user-based and expert-based questionnaire systems (CBPD, 2010; Lahlou, 2009; Loftness et al., 2009). Similar to CBE’s method this toolkit is composed of both subjective measurements provided by occupants, as well as objective physical measurements provided by experts. The user-based questionnaire includes occupants’ satisfaction with their environment in terms of thermal, lighting, visual and acoustic comfort, air quality as well as physical condition. While the expert-based questionnaire includes continuous measurements of existing physical environments by assessing their thermal, air quality, lighting, visual, and acoustic condition during a specific period of time to monitor changeability of environmental conditions according to varied occupancy conditions and the technical characteristic of building systems (CBPD, 2010).

University of Minnesota's Center for Sustainable Building Research (CSBR) also has developed a web-based survey method for building performance evaluation called the B3-Sustainable Post-Occupancy Evaluation Survey to measure the impact of a building design on occupants' performance, well-being and satisfaction. Similar to previously mentioned methods, this survey also includes questions related to; 1- occupants environmental factors such as thermal condition, lighting and view condition, acoustic condition, etc., which are each composed of several sub-categories such as temperature, humidity, air velocity, indoor air quality, etc., 2- occupants behavioral parameters include satisfaction, comfort, performance, well-being and health, etc., as well as a number of other factors such as; furnishings, functionality, aesthetics, technology, etc. (Guerin, Brigham, Kim, Choi, & Scott, 2011).

The ultimate goal of performance evaluation is to collect occupants' responses with regard to the environmental and physical design quality of their learning environments, which helps to identify their level of satisfaction and performance. On the other hand, BPE assists to obtain experts' knowledge and opinion to develop a framework that enables designers and construction engineers to provide a better quality designs and avoid problems that can cause dissatisfaction and hinder the productivity and ideal performance (Meir et al., 2009).

In the next sections, the relationship between the educational buildings' design and the environmental quality in both classroom level and the overall facility level with the performance and satisfaction of their occupants are discussed.

2.6 General Aspects of Performance Evaluation

The essential characteristics that need to be reflected in process of building performance evaluation are mainly consist of functionality, accessibility, productivity, aesthetics, adaptability, flexibility, safety and security as they are all significant and crucial for success of building performance (Zimring, 2001).

2.6.1 Functionality

Functionality describes the extent to which a building fits for the activities of its occupants and supports its main design purposes. Poor functionality of a building causes reduced productivity of its occupants' activities and unfulfilled design objectives. As a result, improvement of a building's functionality is very crucial to improve the productivity (Kathrine and Svein, 2004). In terms of educational buildings, needs and design of a space, performance of a facility as well as durability of a facility's elements/components all are referred to as functionality.

2.6.2 Accessibility

National Institute of Building Science (NIBS) (2009) has defined accessibility as the "effortless and convenience access to all buildings and facilities, services, transportation, and technologies by all individuals with no excessive barriers".

The accessibility is one of the critical aspects of a facility design and its elimination from educational facilities causes exclusion of a certain population from the services provided by those facilities (Ormerod and Newton, 2005). In order to avoid the exclusion of people with disabilities, to provide the opportunity of using services offered by a facility for every individual, and to answer the needs of all groups of people within a facility, equal access to the facility need to be provided for all kind of population (Prideaux and Roulstone ,2009). The accessibility concerns should be considered in early phases of a project and be integrated in the design process (Prideaux and Roulstone, 2009).

A number of design features that need to be considered toward a better accessible facility for people with disabilities include; sanitary features, level approach, suitable parking, and horizontal and vertical circulation services as path finding devices. To ensure the inclusion of these accessibility provisions and their proper design, the role of a designer is more emphasized and is turned out to be more critical (Ormerod and Newton, 2005).

2.6.3 Productivity

According to 'National Institute of Building Science', productivity is connected to occupants' physical, environmental and psychological comfort and well-being with respect to the elements such as; temperature, indoor air quality, ventilation, and lighting (NIBS, 2009). The following principles in order to design a productive facility are also recommended by NIBS (2009);

- Enhance the health and well-being of occupants by effective design of workplaces and indoor environments;
- Provide a comfortable environment for the occupants in terms of thermal, lighting, visual, and acoustic condition to motivate efficiency and productivity of them accordingly;
- Ensure the properly and effectively integration of technological tools for designed pathways and spaces;
- Provide reliable, safe and secure spaces for buildings' occupants.

Providing adequate comfort in an educational facility related to thermal, lighting, visual, physical, psychological and acoustic conditions can render a facility as an encouraging environment to teach, learn, concentrate, communicate and interact. The improved comfort and satisfaction in an educational context will lead to the improved productivity and efficiency of its occupants (Mayaki, 2005).

2.7 Measuring Occupants Productivity

Quantifying students and teachers productivity based on the quality of their work is difficult procedure as it deals with the intangible and qualitative performance data. According to the available measures presented in the previous studies, a number of parameters including; reduced absenteeism rate (Hameed 2009), reduced sick period as it normally is the result of unhealthy air quality of the indoor environments (Dorgan 2006), enhanced accuracy and efficiency of learning, increased speed of learning, improved innovation and creativity, developed team work and communication skills, better commitment and liability(Clements-Croome 2006), and enhanced overall work performance and satisfaction (Morgan 2008; Martin 2006) can be applied to calculate the productivity of occupants. These parameters are more tangible to be quantified, and they can be measured in a quantitative/numerical manner.

Among these methods, the subjective work performance and satisfaction measurement performed by the occupants has been selected for the purpose of this study as the more recognized productivity assessment technique.

2.7.1 Aesthetic

Aesthetic, which refers to the physical appearance of a building and its components, is one of the evaluation factors of an educational building performance in the United Kingdom (CABE, 2009). In development of a building physical appearance, an integrated collaborative approach is recommended in order to achieve an aesthetically inspiring design. This approach gathers the ideas of buildings' occupants and the design team, as well as the other parties including landscape designers, interior designers, professional engineers, facility managers, project planners and constructors (Heitor, 2005, CABE, 2009; Robinson, 2009).

2.7.2 Health, Safety, and Security

According to NIBS (2009), health and safety in buildings are involved with the physical protection of the occupants against hazardous conditions. Safety measures have to be anticipated and implemented in a building design in order to physically protect the occupants against risky and unsafe conditions. The measurements need to be considered to design a safe building, electrical safety, fall protection, ergonomics and accidents prevention (NIBS, 2009). These safety measures would be more emphasized if they are addressed at early design stage of a project. The safety measures for educational buildings according to OECD (2006) are listed as following;

- availability of drinkable water sources in numerous areas;
- availability of enough sanitary spaces in a number of locations;

- availability of functioning fire alarms and emergency exits in several places;
- availability of appropriate spaces for emergency lighting system;
- availability of security systems to protect occupants' physical security and belongings

2.7.3 Flexibility and Adaptability

Flexible design refers to a design that can freely be revised or changed serving for diversity of users or for multiple functions and have the potential of accommodating future technologies within its physical context (Kathrine et al., 2004, and Robinson, 2009).

Flexibility or adaptability is an essential parameter in design of the educational buildings according to Robinson (2009). Extension, change or conversion in function of the educational/learning spaces and adjusting those spaces for diversity of educational activities with a varying size of users are also referred as flexibility and adaptability in space use and function (Heitor, 2005). As an instance, the flow of spaces into each other by installing portable dry-walls or doors helps to serve a variety of functions in the spaces and accommodate diversity of the users in different group sizes.

2.7.4 Environmental Sustainability

The environmental performance of buildings and the design of buildings with respect to sustainability principles is an imperative matter in a world concerned by energy related issues. According to Robinson (2009), in order to design a sustainable building, utilizing passive and renewable energy resources and recycled materials as well as reducing any environmental foot prints are number of the essential principles need to be followed.

In case of educational buildings' design, a sustainable solution would be a design with reduced energy consumption through increased awareness of energy savings, managed water usage through water preservation plans, and enhanced indoor environmental quality through contemplation of ecological/green design policies and practices. The Organisation for Economic Co-operation and Development (OECD, 2006) has also outlined the ecological/sustainable design factors as follow;

- Maximizing the site potential to ensure an environmentally responsible site development;
- Ensuring an efficient use of sustainable systems such as; energy and water, day light, recycling and waste management;
- Involving an efficient use of sustainable construction technologies and building materials.

The evaluation of studied building performance aspects is very critical issue, which can provide useful feedbacks for building designers, construction engineers and specialist in order to improve their future practices.

2.8 Evaluation of Building Design According to Occupants Needs

Occupants' needs, requirements and expectations of a building that they occupy, determine the intention of that building's design and the way it needs to function. Many designers have maintained that there is no single method which can contain all needs of a user in the design process (Cotts and Lee, 1992). According to Elsevier (2008) actual needs of buildings' users need to be captured in the design of buildings.

Although experts' opinion in building performance evaluation is always considered as more reliable solution, but the "users" of a building are the people who know more about many aspects of the building and its environment. Therefore, users are the actual experts whose opinions need to be regarded more effectively (Sanoff, 2003; Okolie and Shakantu, 2009).

In the educational building context, the actual users of the facility take in a diversity of people ranging from staffs, students, teachers to board and administrator of the school. These various users have different needs and expectations, so it could be complex and difficult to perform the evaluation of user needs and incorporate them into a single design (Lomash, 1997).

To avoid this complexity of evaluations, five fundamental questions are introduced by Lomash (1997) that need to be answered while assessing the performance of a building;

- Identify the people who are going to use the building (Occupants);
- Recognise the needs of those occupants,
- Determine the areas those needs exist;
- Determine when the needs will be fulfilled;
- Determine how long the needs will exist;

Many researchers state that, the success of a building design can be assured by the degree to which the building delivers the needs of its users (Barrett et al., 2003, NAO, 2003, Kathrine et al., 2004, Zimring, 2008, and Joe, 2009).

2.9 Relationship between Design Factors and Occupant's Comfort

Earlier studies suggest an existing relationship between key comfort factors in an educational building (e.g. temperature, ventilation, lighting and acoustic) with occupants' satisfaction with their learning environment. This satisfaction affects the level of attendance and the work performance of occupants subsequently. There is a proven drop in the attendance rate and the performance level of occupants resulted from their decreased satisfaction and comfort in a learning environment. A number of potential triggers for a discomfort condition in a learning environment are identified to be as; 1- unfavourable acoustic condition and noisy environment, 2- cooling and heating problems, 3- glare or inadequately designed lighting condition, and 4- unpleasant indoor air quality resulted from pollutants and odors that can cause sick building symptom (Fisk, 2002, Loftness et al., 2010) (Heerwagen, 2003).

According to previously developed survey questionnaires by research centers at universities of United States, the most commonly evaluated design factors by occupants include; thermal condition, indoor air quality, lighting and visual condition, acoustic and physical condition, which also are incorporated in the evaluation process of this study. A brief review of each influencing design parameter and its relationships with occupants' satisfaction and work performance is provided in the following sections.

2.9.1 Thermal Condition and Occupants' Comfort and Performance

According to studies, one of the most significant environmental factor that influence satisfaction, comfort and accordingly the performance of the occupants of an educational building is proven to be the thermal condition factor, and improvement of this factor is essential for occupants' performance improvement (Clements-Croome & Baizhan, 2000; Nasrollahi, Knight, & Jones, 2008). Occupants' thermal comfort is a measure to determine the thermal condition of a building's indoor environment. According to standard-55(Thermal Environmental Conditions for Human Occupancy) published by American Society of Heating, Refrigerating and Air-Conditioning (ASHARE), an internationally recognized definition for thermal comfort is "the state of mind that expresses satisfaction with the thermal environment" (ASHRAE, 2004). This standard approves the thermal comfort of an environment, if 80% of its occupants are satisfied with the thermal condition of that environment. In determination of users' thermal comfort and satisfaction, occupants' personal factors also need to be considered along with indoor environmental factors of a building (ASHRAE, 2004).

Frontczak (2011) also emphasized the significant contribution of thermal satisfaction to the overall environmental satisfaction and the adverse effect of dissatisfaction with temperature on occupants' physical and mental performance like learning and reading speed (Fisk, 2000; Wyon, 1996). According to Seppanen and Fisk (2005) for enhanced work performance, the ideal room temperature needs to be within the 20.0–23.0°C range. As proved in prior studies, occupants' satisfaction with the thermal conditions at the classroom level can impact their overall satisfaction within the whole facility.

2.9.2 Lighting Condition and Occupants' Comfort and Performance

The quality of lighting condition, which is a combination of artificial and natural lighting conditions, must be in acceptable level for buildings' occupants in order to; 1- accommodate enough visibility for their varying activities and communications, 2- enhance their moods, 3- provide comfort, health and safety, and 4- respond to their aesthetic requirements (NRCC, 2009). According to Boyce (1998), poor lighting quality like too much or too little light level in a learning environment causes lighting and visual discomfort, lack of visibility, reduced accuracy and delay in performance and consequently increased dissatisfaction of the users (NRCC, 2009). According to Veltri et al., (2006) the poor day-light condition in a classroom can cause tiredness and sleepiness, which hinders occupants' performance consequently (Veltri et al., 2006, p. 521). While, the physical and psychological comfort and satisfaction of occupants ,provided by a high-quality lighting condition, eliminates users' distraction and offers an appropriate learning and teaching environment. Lighting factors such as luminance and amount of glare also have a considerable influence on occupants' motivation and their outcomes (NEMA, 1989). Using natural day-light instead of artificial/electric lighting not only improves visual comfort of the users, but also results in energy savings in buildings (Jones, 2008).

According to Jones (2008), the amount of energy savings by making the better use of natural lighting instead of electric lighting is estimated to be 20 to 60 percent of overall building energy use. Several studies and surveys of occupants regarding lighting condition, show that the highest rate of complaints are related to inadequate day-light and light reflection problems in learning spaces (Abbaszabeh et al., 2006). According to studies of the Heschong Mahone Group (1999) students with the most day lighting in their classrooms having larger window areas progressed faster on mathematics and reading tests than students having less daylight in their classrooms with smaller windows. Natural light sources (windows) on both sides of the classrooms are recommended for students learning and comfort.

The National Research Council of Canada (NRCC) also suggests that the most important lighting condition factors that influence occupants' satisfaction with indoor environment include total luminance, uniformity of light, glare, and access to natural daylight. Prior studies conclude that, the ultimate satisfaction with the overall facility and the enhanced performance in educational buildings can be reached by improving the daylight condition and accordingly the daylight comfort of users in the classroom level.

2.9.3 IAQ Condition and Occupants' Comfort and Performance

According to the Indoor Air Quality - Scientific Finding Resource Bank (IAQ-SFRB, 2010), indoor air quality of a building is referred as an environmental characteristic that may impact occupants' health, comfort and performance. Contaminants and chemicals in the interior spaces resulted from pollutant sources negatively impact the Indoor air quality of the spaces. As previously mentioned, ASHRAE 62.1 Standard (2010) defined the acceptable Indoor Air Quality as an "air in which there are no known contaminants at harmful concentrations and a majority (80% or more) of the people do not express dissatisfaction".

According to the studies of Indoor Environment Department (IED) of Lawrence Berkeley National Laboratory (LBNL), improvement in occupants' performance would be reached by improved satisfaction with the indoor air quality of learning environments. Fisk and Seppanen (2007) also suggest that certain tasks related to accuracy and speed of reading and writing can be affected by poor indoor air quality resulted from pollutants such as; toxins from surface materials, equipment and furnishings.

Prior studies concluded that, the ultimate satisfaction with the overall facility and enhanced performance in educational buildings can be partially reached by improving the indoor air quality and occupants' satisfaction with environmental quality in the classroom level.

2.9.4 Acoustic Condition and Occupants' Comfort and Performance

According to several studies uncontrollable and distracting background noises disturb concentration and affect occupants' comfort and productivity (American Society of Interior Designers, 2005), (Steelcase, 2000). Armstrong studies also indicate that, when noise distractions are reduced by using absorbent materials, 25% improvement in occupants' satisfaction and 20% improvement in productivity rate are reached consequently. Earlier occupants' surveys indicate that; the greatest complaints regarding acoustic condition are related to the internal and external disturbing noises from HVAC systems and equipment as well as noise from open windows in naturally ventilation buildings (Field, 2008).

Prior studies concluded that, the ultimate satisfaction with overall facilities and enhanced performance in educational buildings is in part reachable by improving the acoustic condition and occupants' satisfaction with the noise level in classrooms and other learning spaces.

2.9.5 Physical Condition and Occupants' Comfort and Performance

According to a number of studies, physical condition of educational buildings directly affects occupants' performance by 6% to 11%, which means students in schools having satisfactory physical conditions scored 6% to 11% higher than those in schools with poor physical conditions. According to the studies of Alexander (1977), areas such as; public spaces (auditorium and lunges), pathways, outside walkways, and outdoor spaces are important for circulation and travel considerations within school buildings. It is also recommends to locate the major activity centers at the extremes and design comfortable passages for a better circulation. Dr. Breitbecker studies on the 'Development of Posture and Exercise' also referred to the furniture in a classroom level as one of the important physical factors that affects concentration and interaction of students by facilitating their circulation and movements.

The density is also an important factor in students' learning as a crowded school with a little space has negative impact on the performance of its users. The recommended maximum space for each seating student to avoid overcrowding is about 20 square feet (Sommer , 1969). In order to provide a quicker travel of students, the distance between spaces should be given a particular consideration (Tanner and Lackney, 2006).

The proper design of the furniture configuration and arrangement, their quality, their spacing with respect to each other and the front of the classroom are some of the essential factors to measure the physical condition of the classrooms. The interior design of a learning space in a way that it allows the free movement of students inside the classrooms and movements from inside to outside has a positive effect as it creates more involvement in classroom activities.

2.9.6 Visual Condition and Occupants' Comfort and Performance

Connection to nature through windows providing visual well-being for occupants and reducing their level of stress promotes physiological satisfaction and productivity/efficiency level of buildings' occupants (Heerwagen et al., 1986, Kaplan, 1992, Ulrich, 1992). This improvement in productivity level and work performance is a result of the enhanced quality of working environments and the improved psychological factors (Kroner, et al., 1992).

Prior studies conclude that, the ultimate satisfaction with the overall facility and enhanced performance in educational buildings can partially be reached by improving the visual condition and occupants' satisfaction with the views in the classroom level.

2.9.7 Furnishing Condition and Occupants' Comfort and Performance

The amount of space considered for each individual, the comfort of this space, the ability to adjust chairs and other furniture, etc. are all indicators of furnishing condition. Improvement of the furnishing can result in improved occupants' comfort and their better performance and satisfaction with overall working environments (Brill et al., 1984, O'Neil, 1994, Frontczak et al. 2011). In educational buildings context, furnishing comfort needs to be considered as one of the most important assessment factors for the indoor environment of a facility, which ultimately affects the physical comfort of the occupants and their overall satisfaction and performance (Lee & Guerin, 2009). Prior studies concluded that, the overall satisfaction with the entire facility and enhanced performance in educational buildings can in part be reached at by improving the furnishings condition and occupants' satisfaction with them in the classroom level.

In summary, review of literature about building comfort conditions and their impact on occupants' satisfaction and performance have found that, factors including thermal, lighting, physical and acoustic condition along with views and furnishing of a facility are closely related to occupants' satisfaction with their overall facility, which is associated with their learning/teaching performance.

2.10 Tools and Methods for Performance Evaluation of Educational Buildings

There are several studies conducted the performance evaluation of buildings and effectiveness of their environmental aspects in a systematic way using different methodologies and tools such as; survey questionnaires, walkthroughs, observations and focus group discussions. These various tools and methodologies were developed or adopted based upon different types of variables that influence the performance of educational buildings. A number of studies that are prominently cited due to their developed assessment strategies, methods and instruments are performed by Alexander (2008); Andersen (1999); Ayers (1999); Cash (1993); Kaplan et al. (1996); Kathrine et al. (2004); Lackney (2001); Ornstein (1997); Preiser (1988); Sanoff (2001); Tanner (2000, 2006); Yarborough (2001); and Zimring et al. (2005). These building performance evaluation methodologies might be employed to evaluate the existing educational buildings (POE) and their design improvements or they can be used to influence the design development and planning of future practices.

For the purpose of this study, three types of the previously developed instruments including survey questionnaires, observation walkthroughs and informal interviews are refined and employed to provide a basis for design evaluation process of educational buildings during the data collection stage.

2.11 Artificial Intelligent Approaches/ Fuzzy Expert System

The fuzzy set was first introduced in 1965 by Zadeh as a mathematical way to represent linguistic vagueness. It can be considered as a generalization of classical set theory. In a classical set, an element belongs to or does not belong to a set. That is, the membership of an element is crisp (0, 1), and an ‘‘A’’ crisp set of real objects are described by a unique membership function. Contrary, a fuzzy set is a generalization of an ordinary set which assign the degree of membership for each element to range over the unit interval between 0 and 1. That is, the transition from ‘‘belong to a set’’ to ‘‘not belong to a set’’ is gradual, and this smooth transition is characterized by the membership function that give fuzzy sets flexibility in modeling commonly used linguistic expressions (Zadeh, 1965).

In addition, fuzzy set theory can be used for developing rule-based models which combine physical insights, expert knowledge and numerical data in a transparent way that closely resembles the real world. Fuzzy set theory provides a systematic calculus to deal with linguistic information, and it performs numerical computation by using linguistic labels stipulated by membership functions. Moreover, fuzzy ‘if–then’’ rules form the key component of a FIS that can effectively model human expertise in a specific application (Perfilieva et al.2007).

To inference in a rule based fuzzy model, the fuzzy proposition needs to be represented by an implication function. The implication function is called fuzzy ‘‘if–then’’ rule. A fuzzy if–then rule, also known as the fuzzy rule, assumes the form ‘‘if x is A then y is B’’ where ‘A’ and ‘B’ are linguistic values defined by fuzzy sets on universes of discourse ‘X’ and ‘Y’, respectively. Often ‘‘x is A’’ is called the antecedent or premise, while ‘y’ is ‘B’ is called the consequence or conclusion. Examples of fuzzy if–then rules are widespread in daily linguistic expressions such as ‘‘If pressure is high, then volume is small’’ (Perfilieva et al.2007). The process of obtaining the overall consequent (conclusion) from the individual consequents contributed by each rule in the rule base is known as aggregation of rules. In determining an aggregation strategy two simple extreme cases exist, namely; conjunctive system of rules and disjunctive system of rules (J.Ross, 2004).

Generally speaking, fuzzy set theory lends itself nicely to many problems in design and construction of buildings. Preliminary Design stage of buildings is oftentimes impacted by a number of factors that are difficult to quantify to any extent. Furthermore, many decisions that are being made in design stage are the result of experience and instinct, rather than strict calculations. For these reasons, fuzzy set theory is generally a well-suited approach for problem solving in design and construction industry.

With regards to the problem of estimating the design performance of educational buildings, fuzzy set theory may provide an appropriate framework from which the problem may be approached. Fuzzy set theory provides the ability to capture qualitative observations of different design variables of existing school buildings that impact their performance, and incorporate them into an evaluation model using a series of heuristic rules generated based on experts' knowledge.

The benefits of using fuzzy set theory in this instance are obvious; expert knowledge can form the basis of the model in the place of established scientific theory, and qualitative observations can be input into the model in the absence of crisp values. Fuzzy set theory will form the basis of the model developed here, with a focus on incorporating qualitative assessments of actual comfort conditions into the problem of estimating the performance of educational facilities, such that the predicted performance output of the model will be reflective of the conditions under which the facility is functioning.

Chapter 3

Research Methodology

3.1 Introduction

The purpose of this study is to investigate the impact of building design and environmental conditions on occupants' performance with the intention of developing an evaluation model for performance assessment of educational institutions including; schools, colleges and universities. In order to develop the evaluation model, public schools of Edmonton were analysed as a basis for evaluations considering the aspects of environmental comfort. This method should be accompanied by occupants' opinions to improve the design quality of learning environments, ensure occupants' satisfaction and ultimately enhance students' achievement rates. In depth design analysis should be conducted considering different elements including; the plan type and layout of a school building, furniture and utilized equipment , the area available per activity and the configuration of spaces like classrooms, library, workshop, laboratory, auditorium, and lounge/dining area, etc. in a school complex. These elements can influence the quality of the learning environment and students' achievements.

Total of 10 school buildings have been selected to be analysed based on their design features and the characteristics of their several elements. The typology or outline of these selected schools are simplified and categorized into four different design groups. As the main school activities (teaching and learning) take place in classrooms for the most part, the proposed methodology mainly concentrated on evaluation and optimization of those areas. The proposed methodology incorporates experts' opinion and the design analysis of existing learning environments in order to ensure the better quality of designs, higher students' comfort level and higher achievement rates. The model is intended to be used for two purposes; 1- First and foremost, the model can be used as an estimation tool to accurately assess the performance of the existing school designs considering their present comfort conditions, 2- Additionally, the model could be used to identify the factors that have the largest impact on schools' performance, so that novel design measures for the future school buildings can be focused accordingly.

This chapter explains the methodology used to conduct the study including the research design, data collections strategies, sampling methods, instruments used for data collection and the research procedure. The key factors that influence the quality of the learning environments also will be discussed in this chapter.

3.2 Research Methodology

The mixed or multi-method approach combining both quantitative and qualitative approaches is adopted for this study, which takes both numerical data and descriptive data into account during the data collection and analysis processes.

The research can be considered as a quantitative study as quantitatively ranking of the building performance and comfort variables in educational buildings will be conducted by occupants of these buildings. The research also can be considered as a qualitative study as it gathers subjective data concerning opinions and explanations on different aspects of educational buildings' performance. For this type of data collection, qualitative tools such as interviews need to be employed. The mixed or multi-method approach must be employed with extra care in order not to let one method (e.g. qualitative) to affect the outcomes of the other one (e.g. quantitative). In summery application of this methodology allows;

- Using both numerical and descriptive data during data collection and analysis process,
- Implementing quantitative ranking of the design performance by users,
- Collecting qualitative and subjective data related to opinions and explanations on different aspects of educational buildings' performance,
- Conducting qualitative interviews related to experts' experiences and knowledge.

3.3 Research Design

The proposed methodology is mainly based upon the experts' opinions as well as the occupants' opinions through their participation in the interview and survey procedures as the main evaluation instruments of this study. First, the general information on the diverse parameters and design variables having the largest impact on a school performance were determined through casual discussions with professionals/experts. These experts were experienced in several design areas through high performance design practices. Afterwards, several sub-factors that were important to be considered in optimization and analysis of design performance were identified. These sub-factors were then categorized according to the main comfort parameters that they fall under. After all the main impacting factors and sub-factors were identified and categorized, a survey was given to the experts in order to develop the standard definitions for each input factor and measure the relative importance of the factors using a semantic scale on level of 'one-five'. Values of the semantic scale range from 'poor' to 'excellent' similar to the linear function of ''fuzzy set'' theory. The results of this survey were then used as a basis in creating the fuzzy membership functions and defining the membership degrees of the comfort variables, which were utilized in development of the expert system for design evaluation model. Thus, the comfort variables (parameters) were assigned values between zero (0) and one (1) and the membership degrees (MD) were calculated accordingly. The average of the experts' evaluations on the comfort variables was calculated to assign the membership degrees.

Using the expert's interviews and surveys, total of twenty six different variables under the main four categories of environmental comfort factors were identified. The identified twenty six variables were qualitatively assessed by specialist/experts. The evaluation model developed based on experts' qualitative assessments attempting to incorporate all those variables as the representative of occupants' satisfaction criteria. These variables will be thoroughly discussed in the following chapter.

For the purpose of school design optimization at the preliminary design stage, several alternatives will be analysed and those with the greatest membership degree of comfort variables will be considered as the optimal alternatives.

3.4 Post Occupancy Evaluation Method

In order to conduct the performance and quality assessment of educational facilities, the researcher of this study developed an online survey. This survey served as a valuable tool to get the required information about occupants' comfort and satisfaction level and to identify the specific problem areas within the facility according to the evaluation results.

3.5 Data Collection (Sampling or Participant Selection)

The main participants of this study were the occupants of public school buildings in Edmonton, Alberta, including; the students, teachers, administrators and other educated school boards who gained the capacity to participate in this research study. Thirty school facilities, falling under almost the same building age, were selected and contacted for this study ranging from preliminary to high school. Among all selected schools only eleven of them accepted to participate in the study. Finally, the total of eighty participants including all students, teacher and administrators were contributed to this research study. To avoid capacity concerns for student' participation in the study, an age limit was considered during the selection of participants and only those students between sixteen to eighteen years old were contacted. However, for the other groups of participants (teachers and principals) there was no age limit to participate in the study.

3.5.1 Data Resources

The data was collected from the case-studies, and previously conducted studies found in the documents like literature, book publications, journal articles and reports. As already mentioned the chosen methodology for this research study was based on the multi-layer or mixed method, combining qualitative and quantitative data collection instruments. Experts' interviews were fallen under qualitative instruments and were related to the experience and knowledge of professionals in the area of educational buildings design. Survey questionnaire was considered as quantitative instrument that measures the performance indicators of educational buildings that were identified from literature and extracted from experts' knowledge and experience.

3.5.2 Data Collection Instruments

3.5.2.1 Survey Questionnaire

In order to allow the easy access to questionnaires for all the participants from several educational buildings, to maintain the anonymity of participants, to get the responds within a reasonable period of time, and to easily transferring and analysing the data an e-survey (online questionnaire) data collection instrument was employed. This post occupancy evaluation tool obtained the required data regarding occupants comfort and satisfaction with their learning and working environments, and the impact of these environments on their performance and achievement level. The comfort factors that were reflected in the e-survey questions were determined based on specialists' knowledge using interviews that will be explained in the following sections. To develop the survey questions, beside experts' knowledge in the fields of educational facility design, similar studies on post occupancy evaluation of buildings, educational buildings' assessments, published school surveys as well as school design guidelines were deliberated and relevant studies were used as a prototype for this research study.

The questionnaires were designed to include both close-ended (multiple choice) questions and few open-ended questions. Close-ended questions were related to the aspects concerned with functionality, productivity, accessibility, health, and safety, etc. along with environmental aspects of a building design such as; temperature, ventilation, lighting and acoustics. While open-ended questions asked for participants' opinions and suggestions on how to improve the facility design and performance.

An email containing; the initial invitation to participate in the study, informed consent letter, and the survey questionnaire along with the approval letters obtained from Human Research Ethics Review Process (HERO) and Cooperative Activities Program (CAP), was sent to the principal of each selected school requesting to contact the researcher if they wished to participate. The principals that replied to this email with their consent asked to invite their administrative members and teachers to participate in the study. An invitation email to schools boards and staffs was provided by the researcher to the school principal, containing the study description, letter of informed consent and the survey questionnaire. To assure the anonymity, no identification information was requested from the participants anywhere in the survey and the confidentiality agreements were also signed prior to the commencement of the study.

The total of 80 people showed interest to participate in the survey procedure, including 10 students, 40 teachers and 30 administrators by contacting the researcher via email and sending back the signed informed consent letter. The survey was designed to take no more than 30 minutes, and the questions mainly focused on the characteristics of an ideal learning environment in terms of several parameters that affect the comfort and satisfaction as discussed earlier.

The data collection procedure provided a foundation for development of research database for the later data analysis process. Most of the architects or design/construction firms for the studied schools were identified by the principal of each school and then contacted by email or phone initially. Upon their consent, the casual interview sessions were arranged afterwards.

3.5.2.2 Observations/walkthrough

The observations of a number of studied schools were also conducted in company with survey questionnaire. The observation procedure provided the chance to physically explore the learning facilities and measure several spaces in relation to the identified comfort factors. These observations were documented using a number of captured photographs and free-hand drawings.

There are also some other data obtained from the school tours for this study such as; 1- school achievement reports representing students achievements basically in mathematics, science and language proficiencies, and 2- reports on attendance and absenteeism rates of students and teachers. This information could also be found at online school report system for each selected school during a specific period of time. A number of online resources that have also been used for obtaining this information for each studied school are listed below:

- http://alberta.compareschoolrankings.org/elementary/SchoolsByRankLocationName.aspx
- http://www.edmontonsun.com/2012/06/12/education-pullout
- http://education.alberta.ca/admin/resources/gla.aspx

Obtained data used to calculate the percentage of students, who achieved high grades in courses like science, language, and mathematics, etc., as well as the attendance and absenteeism rates of the students in the schools under examination in this research study.

3.5.2.3 Experts' Interviews

The informal interviews were conducted with the experts and design specialist who were specifically experienced in the field of educational facility design. These interviews provided the necessary information regarding:

- The potential impact of a building design on teaching and learning performance in the educational facilities;
- Essential requirements for the building performance evaluation;
- Key factors and elements that need to be evaluated; and
- Main limitations and obstacles of performance evaluation of educational buildings.

The informal semi-structured interviews facilitated creating a standard meaning for building performance features and for subjectively collected survey data in the study context. The interviews adopted a conversational style starting with general questions to proceed to further more elaborated questions. Main questions were on key performance issues related to the elements of educational buildings' design and particularly the performance assessment of case study buildings. This was followed by more detailed questions related to environmental comfort factors. The interviews were concluded by asking the experts' suggestions about any issues that might not have been considered in the research questionnaire. The interviews lasted between thirty to forty five minutes with each participant.

3.5.2.4 School Performance Reports

After obtaining all required data from school occupants' questionnaires, experts' interviews and school physical observations along with online data sources, and before moving to the data analysis stage, an excel datasheet including students' performance records in several courses obtained from the school score cards was created. This database included the following parts: School name/ID, and score rate in Science, Language, Mathematics and Social Studies as well as Daily attendance rate, School Performance rate, and School Performance factor. An example of the developed datasheet for some of the studied schools is presented in Table 3-1.

Table 3-1 Recorded Performance for Sample of Studied Schools Obtained from Score Cards

School ID	Science %	Language %	Math %	Social Studies %	Attendance %	Overall Performance Rating/10	Performance Factor
1	88.9	57.1	59.3	71.4	92	7.38	satisfactory
2	93.2	69.5	79.7	72.4	98	8.26	excellent
3	91.2	58.8	76.5	70.5	89	7.72	satisfactory

- As shown in the table 3-1, the science, language, mathematics and social science proficiency rates along with the percentage of students attendance for each of the studied schools (derived from the score cards) was recorded in the excel datasheet under science %, language %, math %, social science % and attendance % columns respectively.
- For each of the case study schools, the overall school performance rates (derived from the school performance reports) were calculated as the mean values of students' performance in the abovementioned courses and their attendance rates. The calculated mean values were than plotted on 1-10 scale and obtained values were recorded under "overall performance" column. For example for the first school in table 3-1, the mean value of students' performance was calculate as '73.74', and the plotted value on the 1-10 scale (7.374) was rounded to the nearest two decimal place resulting in '7.38'.
- The "school performance factor" was also derived from the same performance reports of each investigated school and recorded under the "Performance factor" column ranging from poor, unsatisfactory, satisfactory to excellent.

The accuracy of the information in the developed excel sheet was double-checked by comparing it to the online school performance records and then verified.

3.6 Research Procedures

The research procedure was initiated by receiving all required approval letters from the University of Alberta Institutional Review Board as well as the school district. The accuracy of selected instruments for data collection stage of the study was confirmed by Cooperative Activities Program of University of Alberta and the required changes and modifications on occupants' questionnaire implemented prior to the commencement of the survey procedure. In the interim, the clarity and appropriateness of survey questionnaire was also verified by designers and experts before starting the survey procedure. The questionnaire was revised again based on the verification results, and then was sent to all occupants of targeted school buildings via email notice requesting their participation. The study objective, informed consent forms, and confidentiality agreements were also contained in the email notice. Those occupants agreed to participate in the study completed the questionnaire and sent it back to the researcher.

Meanwhile, the principals contacted to obtain permission for walkthrough observation phase. All selected school buildings were observed and the developed checklist of their design variables and building condition were filled out. The results of observations were transferred to a questionnaire format including series of tabulated matrices for experts' paired comparison analysis. The experts were contacted again and survey questionnaires were sent to them in order to obtain the analysis results on the school designs, which were then used to develop the evaluation model in MATLAB. All obtained data from experts were analyzed and employed in order to develop the Expert System Model and to determine its several components such as; input variable, membership functions and rule-bases. The model was developed and verified using data obtained from occupants' survey procedure along with schools performance data.

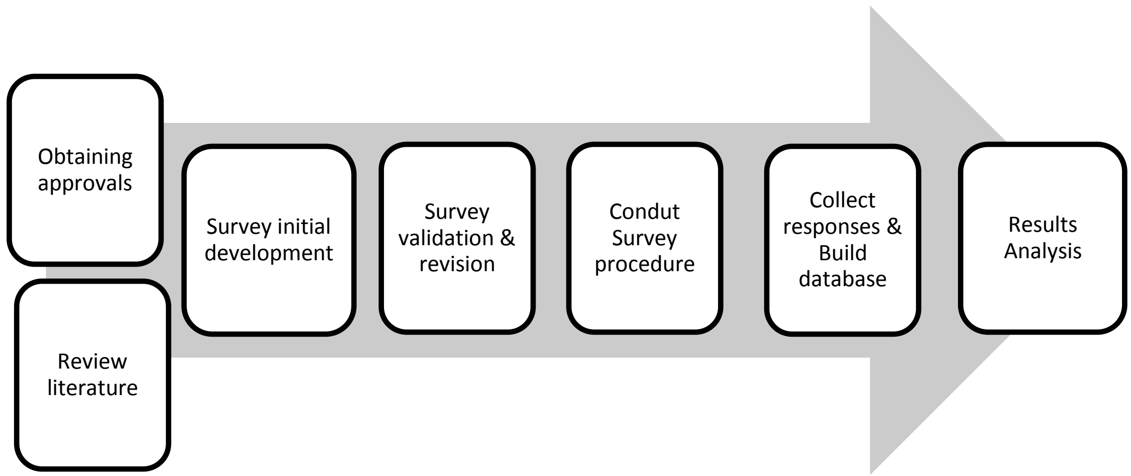


Figure 3-2 Process Diagram for Occupants Survey and Design Evaluation Procedure

The comprehensive description of each step of the research procedure and the associated data analysis procedure are all presented in the following chapters of this dissertation. The research process diagrams including; 1- the school occupants' evaluation procedure and 2- the experts' knowledge-based analysis procedure are shown in Figures 3-2 and 3-3 respectively.

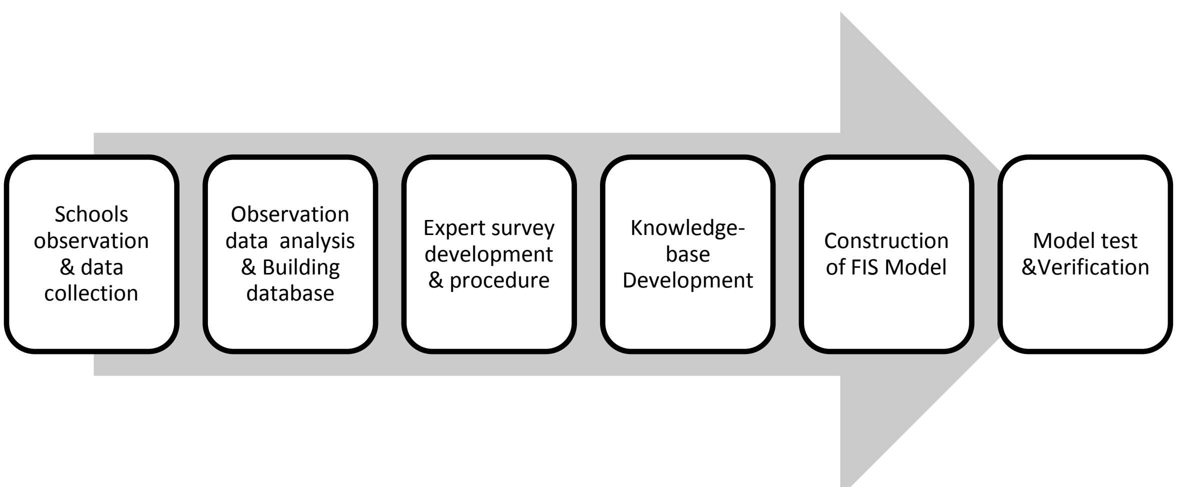


Figure 3-3 Process Diagram for Experts Evaluation Procedure and Development of FES Model

The details regarding each phase of the research study, shown on the process diagrams above, are described in the following chapters. To conclude the study, the comparison of the outputs obtained from school occupants' survey with those of the developed model based on experts' survey is conducted and the results of the comparison are discussed and analyzed in chapter 6.

3.7 Ethical Issues

- **Human Subjects and Ethical Issues Considerations**

Professional ethics were maintained throughout the data collection process of this research study. Prior to commencing the data collection phase of the research study, the study was reviewed by the Human Research Ethics Review Boards (HERO) as well as Corporative Activities Program (CAP) at University of Alberta and the required approvals were obtained. There were also no identified potential risks associated with this study. The data obtained and analyzed will be kept for five years and then discarded. The REB and CAP documents can be found in Appendix A-G.

- **Credibility, Validity and Reliability**

Before the survey questions were finalized, they were tested to verify that they could be easily understood and answered. Their objectivity was also ensured by avoiding either leading or biased questions and attempting to just include questions related to the research problem. Therefore, some questions were eliminated from the initial sets of questions and some were modified or simplified and then re-tested. To insure the reliability, a number of accredited design professionals were asked to review the instrumentation through this research and provide their comments and recommendations. They also double-checked the final survey questionnaire regarding their comprehensibility and clearness. The survey questions followed a similar pattern for all participating schools.

To ensure validity, data was obtained using multiple perspectives such as; teachers', students', and administrators' viewpoints. Several patterns of questions including open-ended questions and Likert scales along with multiple sources such as; online data, school design standards, design handbooks, etc. all helped to validate the findings. All documentations regarding survey questionnaire, interview questions, informed consent forms and confidentiality agreements can be found in Appendix A-G.

Chapter 4

Data Collection and Analysis

In this chapter, the data obtained using several data collection instruments, described in chapter three, are studied and analyzed under four main categories including; 1.experts initial interview and questionnaire results analysis, 2.School walkthrough and observation results analysis, 3. School post occupancy survey results analysis, and 4. Experts' evaluation analysis regarding design variables of observed sample schools.

4.1 Analysis of Data Obtained From Experts (Questionnaire/Interviews)

As mentioned before, the research study was initiated by casual interviews with a number of experts conducted by the researcher. The target of these interviews and questionnaire was the experts and designers specialized in educational buildings design. The aim of these interviews was to obtain information on attitude towards the evaluation of buildings by the experts and professionals, and develop an idea of research methodology and data analysis approach as well as building evaluation methods on those schools under investigation. From selected design experts and professionals, four of them responded to the researcher's invitation for interview and participated in the survey procedure by completing the questionnaire that was designed and distributed by the researcher. The questions included in this initial survey questionnaire are listed and the analysis of the responses is explained in this section.

4.1.1 Building Performance Evaluation Types Conducted by Experts

A question concerning the types of common evaluation types, asked experts to rank different evaluation methods on 1-5 scale and the responses were converted to 1-100 scale in order to calculate the percentage of responses. The resulted values are summarized in table 4-1.

Table 4-1 Building Performance Evaluation Methods and Their Frequency of Use by Experts

Evaluation category	Never (1)	Not common (2)	Sometimes (3)	Common (4)	Very frequent (5)	Mean (1-5)
Observations/ Walkthrough	20	10	10	35	25	3.35
Inspections	25	15	5	5	50	3.4
Measurements	30	25	15	20	10	2.55
Users Questionnaire	5	25	5	25	40	3.7
Performance indicators	85	10	5	0	0	1.2

According to the responses, inspections are the most frequent used building performance evaluation method which is used by 50% of professionals in their assessment cases. It also can be noted from table 4-1 that observation or walkthrough and user questionnaire are the methods that are commonly applied by 35% and 25% of professionals respectively. However, considering the mean values of responses calculated based on the following formula, user questionnaire is the most common method of building performance evaluation.

Mean value on (1-5) scale; ((5*1) +(25*2)+(5*3)+(25*4)+(40*5))/100= 3.7.

4.1.2 Techniques/Instruments Used in Evaluation of Buildings

The question of techniques or instruments mostly used by design experts for evaluation of educational buildings was also enquired and the converted responses of experts on 1-100 scale as well as the mean value of responses are presented in Table 4-2.

Table 4-2 Typical Building Performance Evaluation Instruments and Their Frequency of Usage

Instruments	Never (1)	Not common (2)	Sometimes (3)	Common (4)	Very frequent (5)	Mean (1-5)
Surveys	20	10	10	50	10	3.2
Focus group meetings	50	30	10	5	5	1.85
Measurements	60	35	5	0	0	1.45
Occupants satisfaction	20	10	20	35	15	3.15

As shown in table 4-2 the instruments often used for the evaluations by the specialist are survey and occupants satisfaction. However, focus group meetings and measurements are rarely used and not given enough consideration in building evaluation according to the experts' responses.

4.1.3 Most Critical Aspects of Educational Buildings Evaluation

The key aspects of a building performance are identified and then asked to be weighed by experts on a likert scale of 1-4, according to their level of importance to an educational building. The percentages of experts' responses as well as the calculated mean values of responses, the standard deviations and ranking of the factors are summarized in table 4-3. In order to calculate the mean values the percentage of responses (or number of respondents) on 1-4 scale is considered. For example the mean value for functionality is calculated using either; [((0*1)+(14*2)+(29*3)+(57*4))/100] or [((0*1)+(1*2)+(2*3)+(4*4))/7] formula.

Table 4-3 Critical Aspects of Educational Buildings Performance

Performance aspect	Not Important (1)	Somewhat important (2)	Important (3)	Very Important (4)	Mean	SD
Environmental concerns	0	14	43	43	3.29	0.76
Functionality	0	14	29	57	3.43	0.79

Productivity	0	29	43	29	3.00	0.82
Accessibility	0	43	43	14	2.71	0.76
Security	0	29	57	14	2.86	0.69
Safety	0	14	57	29	3.14	0.69
Aesthetics	14	29	43	14	2.43	0.98

According to experts rankings, functionality and environmental concerns are the most important aspects of performance evaluation in an educational building and attained the highest ranks by them. Safety, productivity and security are ranked after respectively as indicated in table 4-3.

4.1.4 Value of Building Performance Evaluation

Values and advantages associated with performance evaluation of educational buildings are discussed and analyzed by the experts and the percentages of their responses are presented in Table 4-4. The mean value and standard deviation of responses are calculated in a similar manner as presented in section 4.1.3.

Table 4-4 Advantages of Building Performance Evaluation According to Experts

Benefits of Performance Evaluation	Not Important (1)	Somewhat important (2)	Important (3)	Very Important (4)	Mean Value	SD
Increased productivity	0	14	43	43	3.29	0.76
Feedback to design and construction process	0	14	14	72	3.58	0.79
Increased user efficiency	0	14	29	57	3.43	0.79
User satisfaction	0	14	43	43	3.29	0.76

The most important benefit of the building performance evaluation is stated to be “Feedback to design and construction process”, followed by increased user efficiency, user satisfaction, and increased productivity respectively, which are notable from summarized results in table 4-4.

4.2 Creating Standard Definitions for Design Variables

The identified factors that need to be considered and investigated throughout different phases of the study including; development of occupants survey questionnaire, school observation checklist and experts evaluation survey as well as the standard definition and associated parameters of each factor is presented in this sections.

4.2.1 ***Thermal Comfort Factor***

Thermal comfort of the buildings is evaluated according to solar penetration to the spaces and ventilation conditions of the learning spaces. To evaluate these two parameters respectively, building orientation in relation to sun direction and openings position in relation to predominant wind direction are considered in this section. The values that experts associated with each of the provided linguistic terms are indicated in the following sections.

- ***Ventilation***

1. Opening position according to each other

Single *openings just on one facade*
Adjacent; *windows positioned on perpendicular walls concerning to each other with a degree of 90*
Parallel/opposite; *window located on opposite walls, with 180 degrees in relation to each other*

2. Building orientation

Northward; *building oriented toward North with a degree between 315-45*
North-Eastward; *building oriented toward North East with a degree between 0-90*
Eastward; *building oriented toward East with a degree between 45-135*
South-Eastward; *building oriented toward South East with a degree between 90-180*
Southward; *building oriented toward South with a degree between135-225*
South-Westward; *building oriented toward South West with a degree between 180-270*
Westward; *building oriented toward West with a degree between 225-315*
North-Westward; *building oriented toward North West with a degree between270-360*

3. Opening location according to wind direction

Perpendicular; *winds with a degree of 90±10 to the façade with located openings on*
Parallel to ; *winds with a degree of (0 or 180) ±10 to the façade with located openings on*
Diagonal; *winds with a degree of (30-60) ±10 to the façade with located openings on*

4. Prevailing wind direction

from North; *prevailing winds with a degree of 0/360*
from North East ; *prevailing winds with a degree between 0-90*
from East; *prevailing winds with a degree of 90*
from South East ; *prevailing winds with a degree between 90-180*
from South ; *prevailing winds with a degree of 180*
from South West ; *prevailing winds with a degree between180-270*
from West; *prevailing winds with a degree of 270*
from North West ; *prevailing winds with a degree between 270-360*

- ***Temperature***

1. Solar Penetration/ Heat gain

Space layout

Deep plan; *plans with shorter side toward sun, Depth of plan is longer than plan Length (D>L)*
Square plan; *classrooms with the same sides dimensions, plan depth and length are equal, (D=L)*
Extended plan; *plans with longer side toward sun, Depth of plan is shorter than its Length (D<L)*

Opening location according to sun

Northern facade*; receive sun-light radiation from North facade (degree of 0/360±45)*
Southern facade; *receive sun-light radiance from south facade (degree of 180±45*
Easters facade*; receive sun-light radiance from East facade (degree of 90±45)*
Western facade*; receive sun-light radiance from West facade (degree of 270±45)*

2. Air movement/ Circulation

Opening location and position

Windows location is defined in a similar manner as previously explained in the ventilation section.

Prevailing/ Predominant wind direction

Predominant wind direction is defined in a similar manner as previously explained in the ventilation section.

- ***Humidity/Indoor Air Quality***

Low/dry; *0 to 30% relative humidity inside a room is considered low/dry,*
Normal; *30% to 45% relative humidity inside a room is considered as normal,*
High; *45% to 100% relative humidity inside a room is considered a fairly high humidity level.*

4.2.2 *Lighting Comfort Factor*

- ***Natural Day-light Illumination Level***

1. **Classroom Orientation according to sun-path**

Classroom orientation is similarly defined in a same manner as building orientation definition in ventilation section, under thermal comfort factor. Eight geographical orientations as described in thermal comfort section (N, NE, E, SE, S, SW, W, NW) ranging from 0 to 36o degrees are studied.

2. **Classroom Geometry (defined by Length to width ratio)**

Elevated Rectangle shape; *classrooms with smaller length than the width dimension, L/W<1 (between 0-1) have elevated rectangular shapes.*

Elongated Rectangle shape, *classrooms with bigger length than the width dimension, L/W>1 (between 1-2) have elongated rectangular shapes.*

Square-shaped, *classrooms with equal dimensions of length and width, L=W or L/W=1 have square shapes.*

3. **Opening location**

Openings location/position was defined using the same approach applied for thermal condition.

Northern facade*; receive sun-light radiation from North facade (degree of 0/360±45)*
Southern facade; *receive sun-light radiance from south facade (degree of 180±45*
Easters facade*; receive sun-light radiance from East facade (degree of 90±45)*
Western facade*; receive sun-light radiance from West facade (degree of 270±45)*

- ***Glare of Natural Daylight***

1. **Opening distribution** (measured by center-to-center spacing between openings);

Touching or close, regular spacing and far apart are the linguistic terms assigned to openings distribution according to information obtained from experts and literature. A range of one to ten (0-10) is assumed for these distribution terms, where one is indicator of touching (very close) openings and ten is indicator of very far apart openings.

> ***Close/Touching;*** *windows are located very close to each other with* center-to-center spacing *of 0.3-3 meters*
> ***Regular;*** *windows are placed on a regular basis with center-to-center spacing of 2.7-5 meters*
> ***Far apart;*** *windows are placed very far apart with* center-to-center spacing *of 4.5-10 meters*

2. **Number of Openings**

The minimum number of openings is assumed to be just one opening, while the maximum number of is eight openings (generally ranged from 1-8).

> ***Few,*** *one to four (1-3) amount of openings is considered to be as a few numbers of openings for a classroom.*
> ***Satisfactory;*** *three to six (3-5) is satisfactory amount of openings*
> ***Many;*** *five to eight (5-8) amount is described as many for number of openings*

- ***View Condition***

1. **Opening size (defined by window to wall ratio)**

In general, 10% to 80% of total wall area is considered to be taken by openings area, which means window to wall ratio of 0.1 to 0.8.

> ***Small openings;*** *range considered for ratio of small size window to wall area is 0.1-0.4*
> ***Average openings;*** *range considered for ratio of average size window to wall area is 0.3- 0.6*
> ***Large openings;*** *range considered for ratio of large size window to wall area is 0.5-0.8.*

2. **Shape of openings (defined by window height to width)**

According to literature, opening shape is determined by calculating its height to width ratio. The range for this ratio, recommended by design specialists, is assumed from 1/1.5 to 1.5/1.

Horizontal; *If height to width ratio (H/W) is 1/1.5, it means the height of the opening is smaller than its width, and it is a horizontal (elongated rectangular) window.*

Square shape; *If height to width ratio (H/W) is 1, it means the height of the opening is equal to its width, thus it is a square-shaped window.*

Vertical; *If height to width ratio (H/W) is 1.5/1, it means opening has the larger height than the width, then it is a vertical (elevated rectangular) window.*

- ***Glass transmissivity***

From literature and specialists knowledge glass transmissivity is considered to be between 0.1-0.85, which means a glass can be 10% to 85% translucent.

Regular glass; *a glass with 0.1 to 0.30 transmissivity*
Semi-tint glass; *a glass with 0.25 to 0.50 transmissivity*
Semi-transparent glass; *a glass with 0.45 to 0.65 transmissivity*
Translucent glass; *a glass with 0.60 to 0.85 transmissivity*

4.2.3 *Acoustic Comfort Factor*

For acoustic condition evaluation, variables such as 1- School geometry (defines classrooms configuration), 2- Distance from noise generating sources, 3- Existence of noise barriers 4- Material quality as well as 5- reverberation time are important. The same procedure as of thermal comfort and lighting comfort factors are applied for assessment of acoustic comfort variables by experts.

- ***Background Noise Level***

1. **School geometry and classrooms configuration**

Geometry of the school building defines the classrooms arrangement inside the school layout. In this case different classrooms configurations within the school settings were determined using walkthrough observations of case study schools. These configurations are listed as following.

- ***square shape (Typology; A)***
- ***elevated rectangular (Typology; B)***
- ***elongated rectangular (Typology; B)***
- ***L-shaped (Typology; C)***
- ***U-shaped (Typology; D)***
- ***H-shaped (Typology; E)***
-

2. **Distance from noise generating sources**

The location of Noise generation sources in relation to the learning spaces is very important factor in evaluating the users' acoustic comfort. Linguistically this can range from very close to very far distance, which is translated to numerical range from 1 to10 for the purpose of this study.

Close; *a range of 1-4 is used as an indicator for close distance.*

Average; *a range of 4-7 is used as an indicator for close distance.*

Far; *a range of 7-10 is used as an indicator for close distance.*

3. **Existence of noise barriers**

As discussed before, the existence of the noise barriers, such as open areas, corridors or greeneries can help in reducing the noise disturbance in learning environments and enhances the performance and satisfaction of the users accordingly.

None-to-Few; *none-few existence of noise barrier; range of (0-0.5) is used as an indicator of few noise barrier within a school setting,*
Some-to-Enough; *some to enough existence of noise barrier; (0.5-1) range is used as an indicator of existence of noise barrier.*

- ***Classroom Noise Level***

1. **Space layout**

Deep plan; *Spaces with longer width or depth of the plan compare to the length (D>L)*
Square plan; *Spaces with the same sides dimensions, plan depth and length are equal, (L=D)*
Extended plan; *Spaces with shorter width/depth of the plan than its Length (D<L)*

2. **material quality**

Material quality is measured based on degree of absorbance and is ranged from none sound-absorbent to sound-absorbent material.

Sound-absorbent; *sound absorbing materials are specified by assigning range between 1-4*
Semi-sound absorbent; *a range of 4-7 is used for semi-sound absorbing materials.*
None-sound absorbent; *to identify non-sound absorbents a range of 7-10 is assigned.*

3. reverberation time

According to literature, experts and school buildings design specifications; the ideal reverberation time is stated to be between 0.4-0.6 sec. Therefore, whatever under 0.4 is assumed to be normal or acceptable, and poor or unfavourable.

Unfavourable/poor reverberation time; *a range of 0-0.2 sec is assumed as unfavourable for reverberation time.*
Acceptable/normal reverberation time; *a range of 0.2-0.4 sec is normal or acceptable.*
Ideal reverberation time; *the range of 0.4 -0.6 sec is ideal for reverberation.*

4.2.4 *Physical Comfort Factor*

In this section, the factors need to be considered in order to improve the physical comfort of the school buildings and occupants satisfaction are analyzed using experts' knowledge.

- ***Space Functionality and Movement Comfort***

a. Classroom size (number of seats)

The classroom size is referred to as the number of seats placed in the classroom, which according to experts and school design manuals ranges from 0 -140 seats.

Small; *for a small classroom 0-50 seats are considered.*
Regular; *50-100 seats refers to a regular-sized classroom.*
Large; *a large classroom typically contains 100 -140 seats.*

b. Classroom Outline

The proper outline of the classroom takes into consideration many factors. This include; 1- the alignment and arrangement of students' seats according to the openings (views and lighting) and to the front of the classroom (view to white-board), 2- appropriate circulation design within the classroom area, from outside to the inside of the classroom and between the seats, and 3- enough available spacing between seats and for each individual.

Poor defined; *poorly designed classrooms with inappropriate or compact arrangement of seats and inconvenient circulation system.*
Well defined; *classrooms with well-arranged seats with enough spacing and convenient circulation.*

- ***Building Accessibility and Outside Circulation***

c. Circulation facility(pathways, ramps, signage)

Circulation facilities are evaluated based on their unambiguousness and clearness within a school setting. The range of 0 to 1 is assumed for the evaluations.

Ambiguous; *pathways with ambiguity or without enough signage and directions*
Clear; *clear designed pathways, with adequate signs, maps or direction facilities*

d. Travel distance (distance between spaces)

According to school design manuals and design experts, in order to reduce travel time and provide the convenient circulation, the recommended range for travel distance need to be between 50 to 500 meters, and this range is categorized from close to far distance.

Close distance; *50- 200 meters is assumed to be proximate and thus quite convenient travel distance.*
Reasonable distance; *200-350 meters is as convenient but it is reasonable distance for circulation.*
Far distance; *350-500 meters is considered as far travel distance and is unfavourable for the school occupants.*

- ***Facilities and Services***

1. Public spaces

Absence or presence of public spaces in a school building is an indicator of well-designed or poor-designed school in terms of its physical condition.

Poor; *a poor-designed school building does not have enough public spaces.*
Satisfying; *a satisfying design encompass reasonable amount of public areas.*
Excellent; *an excellent school design has variety of useful and convenient public spaces.*

2. Outdoor Spaces

Similar to public spaces, existence of outdoor spaces in a school building is deemed as an important factor that influence occupants satisfaction and performance, thus has an impact on school evaluation results.

Absent; *no outdoor space is considered for school design.*
Enough; *reasonable amount of outdoor areas are considered.*
Abundant; *plentiful amount of outdoor spaces exist in a school setting.*

4.2.5 Relative Importance of Factors

Each evaluated design parameters were ranked by the experts in terms of the magnitude of impact that they have on productivity, comfort and satisfaction of the school occupants, which consequently define the overall school performance. The importance rankings of the design factors later were used to weigh the rule-bases in developed expert system model. The average results of rankings, conducted by four design specialists, are presented as followings;

Thermal Condition Factor:

- Opening position……………………………………………………………….……3
- Opening location……………………………………………………….………1
- Building orientation………………………………..………………………...2
- Predominant wind direction…………………………..……………………..…1

Lighting Condition Factor:

- Classrooms Orientation……..…………………..……..………………………...1
- Classrooms Geometry………………………………………………………..……2
- Opening position and location………………………….…..……………...……1
- Opening Size……………………………………………….….…...……………..3
- Opening Distribution ……………………………….…….……...…...….……5
- Number of Openings…………………………………………….………..…....……….3
- Shape of Opening……………………………………….…….…....…………6
- Glass Transmissivity……………………………………………...………………4

Acoustic Condition Factor:

- School geometry /classrooms configuration …………………………..…………….2
- Distance from noise generating sources……………………………..………………1
- Existence of noise barriers……………………………………...………………3
- Material quality……………………………………….…………..…………3
- Reverberation time ……………………………………………….………………4

Physical Condition Factor:

- Travel distance ……………………………………………………………..……..4
- Classroom size……………………………………..………..……..……..2
- Classroom outline……………………………………………………..……...…….1
- Circulation facilities……………………………..………………..……….3
- Public spaces…………………………………………….…………..………5
- Outdoor spaces……………………………………..…………..……………6

4.3 Observations and Analysis of Case Study Schools

The observations and walkthrough evaluations of all the case study schools were carried out by the researcher, which include the investigation of design, building outline and configuration, and space requirements of studied buildings.

4.3.1 Identified School Plans Typologies

From walkthrough and observations phase of the study, several typologies for configuration of the case study schools were identifies and presented in table 4-5.

Table 4-5 School Buildings Typologies Identified from Observations

Typology	Configuration	Number of identified schools
A	Square shaped	4
B	Rectangular(elevated, elongated)	5
C	L-shaped	1
D	U-shaped	1

4.3.2 Observed and Investigated Spaces

The spaces that studied and investigated in each school building include; office areas, classrooms and other learning spaces, as well as public, social and service buildings. Then, the design characteristics of each studied space were observed, categorized into environmental and physical characteristics and recorded in order to conduct the in-depth analysis using knowledge of experts and specialist in building design area, in addition to comparing those recorded characteristics with the minimum requirements derived from school design standards and principles.

Office Areas

The office spaces that were investigated during the walkthrough observations include teachers/instructors office, school principle/head office and technical staff office. The environmental and physical characteristics off each observed space for the case study schools are presented in table 4-6.

Table 4-6 Observed Office Areas within Studied School Buildings

<table>
<tr><th rowspan="2">Spaces</th><th colspan="3">Environmental Characteristics</th><th rowspan="2">Physical characteristics</th></tr>
<tr><th>Thermal characteristics</th><th>Lighting characteristics</th><th>Acoustic characteristics</th></tr>
<tr><td>Teachers’ office</td><td rowspan="3">Temperature/Ventilation;
(Space and Openings features)
-Indoor air quality;
(Space Outline,
Orientation,
openings features)</td><td rowspan="3">- Daylight & View;
(Space Outline,
Space Orientation,
Windows Features)
- Glare;
- Glass Type</td><td rowspan="3">- Background noise;
Noise source,
Noise Barriers,
Material Types</td><td rowspan="3">- Physical Comfort;
Space Size,
Space Outline,
-Flexibility,
-Furniture condition</td></tr>
<tr><td>Principal’s office</td></tr>
<tr><td>Staff’s office</td></tr>
</table>

Classrooms and Learning Spaces

The classrooms and learning spaces were also observed and investigated during the walkthroughs and the spatial and design characteristics, layouts and average estimated sizes of these spaces based on the number of seats for each space were observed and the overview of observations’ results is presented in table 4-7.

Table 4-7 Observed Classrooms and Other Learning Spaces in Studied School Buildings

<table>
<tr><th rowspan="2">Spaces</th><th colspan="3">Environmental Characteristics</th><th rowspan="2">Physical characteristics</th></tr>
<tr><th>Thermal characteristics</th><th>Lighting characteristics</th><th>Acoustic characteristics</th></tr>
<tr><td>Classrooms (under 60)</td><td rowspan="5">- Temperature,
-Ventilation,
-IAQ,
-Solar Penetration
(Space and Openings features)</td><td rowspan="5">-Natural & Artificial lighting
-Glare
-Views
(Space Outline,
Space Orientation,
Windows Features)</td><td rowspan="5">-Inside noise level
Reverberation,
Space outline
-Background noise
Noise Source,
Noise Barries,
Material Types</td><td rowspan="5">- Functionality,
Operate for defined functions
- Physical Comfort,
Space Size,
Space Outline,
- Flexibility,
- Furniture</td></tr>
<tr><td>Lecture halls (over 60)</td></tr>
<tr><td>Laboratories/ workshops</td></tr>
<tr><td>Computer labs</td></tr>
<tr><td>Media rooms</td></tr>
</table>

Public, Social and Service buildings

The spaces including lounge area, community rooms, dining area, library and entertainment rooms were observed as the key public/social spaces within a school building and their environmental and physical characteristics were investigated. The result of this analysis for one of the case study schools is presented in table 4-8.

Table 4-8 Observed Public and Social Areas within Studied School Buildings

Spaces	**Environmental Characteristics**			**Physical characteristics**
	Thermal characteristics	**Lighting characteristics**	**Acoustic characteristics**	
Community rooms	-**Temperature/Ventilation**; (Openings position and location) -**Indoor air quality**; (Space Outline, Space Orientation, openings features)	-**Daylight**; (Space orientation, Space outline, Openings features) -**View** Outside view	**N/A**	**- Functionality,** Operate for defined functions **- Accessibility;** Pathways and signs **- Physical Comfort,** Space Size, Outline, and Circulation **- Flexibility,** **- Furniture**
Entertainment area				
Lounge area				
Food court				
Library	-**Temperature/Ventilation**, -**Indoor air quality**, **-solar penetration**	**-Daylight & View;** (Space orientation, Space outline, Openings features) **-Glare,** **-Glass Type**	**- Background noise;** Noise Source, Noise Barries, Material Types	**- Functionality,** **- Accessibility;** **- Physical Comfort,** **- Furniture**

4.3.3 Overall Observation Analysis and Inspected Design Features

Thermal Condition

Thermal Condition of the buildings is analyzed based on the parameters affecting the temperature of several spaces, solar penetration and natural ventilation condition inside the learning spaces. To investigate these parameters respectively, building orientation in relation to sun direction and prevailing wind direction as well as openings location on the façade and position according to each other were all observed and the observation results were recorded in the prepared checklist and finally in the developed database of observations. An example of the checklist is presented at the end of this section (Figure 4.2). According to observation results, in some cases either the openings location or their position with respect to each other or building orientation regarding to the wind direction were overlooked and poorly designed, which caused in poor ventilation condition of some case study schools consequently.

Lighting Condition

For the lighting condition features related to classrooms and other areas spatial aspects including; space orientation and geometry (depth of plan) as well as several characteristics of their openings were inspected. The inspected key aspects pertaining to the opening are; openings position and location on the envelope, their shape and size, the number of openings in each space and finally their distribution pattern on the envelope. A checklist of observed parameters were filled and recorded in the observation database. According to observations in selected sample schools, the average opening size, indicated by window-to-floor area ratio, fluctuates between 5 - 10 m^2.

According to information obtained from literature and experts, the depth of plan for the learning spaces such as the classrooms need to be considered no more than six meter (6m) in order to benefit from enough natural day-lighting in the spaces (Hausladen 2005, p. 46). The depth of the plan is measured as the distance between the farthest points in the classroom from its nearest/adjacent window. So that, in the observed school buildings for those classroom configurations that have a long deep plan (beyond 6m) with just one-sided openings, the amount of natural lighting and the distribution of the light over the classroom area are poor and unsatisfactory, therefore the need for artificial lighting is identified.

Visual Condition and Glare

As there are no surrounding buildings around almost all studied schools, shadow or light reflection is not present in most of their classroom and other areas. Moreover, those schools having East or West orientation according to sun provide more visually comfortable classrooms and satisfactory learning environment than those with South and North orientation However, those schools with south orientation directly face towards the sun- path and make the best use of sunlight for most of the daytime, and, those schools with East or West orientation are more vulnerable to adverse low-altitude sun-light during the day.

Acoustics Condition

For acoustic condition evaluation, variables such as; School geometry and configuration classrooms and other spaces, distance of those spaces from noise generating sources, existence of noise barriers between spaces and noisy sources, as well as wall and openings material quality are observed and the results of investigation were recorded in the prepared checklist in Figure 4.2. As most of the classroom areas in the studied school buildings are rectangular, there is a constant distribution of the sound throughout the entire classroom and other learning environment, and the teachers' voice can be easily heard by all the students mostly.

Functionality and Physical Condition

To analyze the physical parameters of the case study schools, features related to functionality, accessibility and flexibility of the several spaces within an educational setting are rendered to be as the key elements for observation and analysis. The parameters that are associated with these three key elements include; outline and size of several spaces and whether those spaces fit to their functional purposes, the distance to be traveled between and inside several spaces, circulation and movement facilities to the educational buildings as well as inside the buildings, the existence of outdoor and public services and finally the furniture and technical facilities considered for each space.

Functionality: From the observations and analysis of the case study schools, there are three typologies of space layout (outline) identified for classroom and other learning environments. These typical layouts as shown in Figure 4-1 contain; square-shape elongated or elevated rectangular-shape and L-shape layouts. The number of seats is considered as an indicator of learning space size. For the inspected schools, this number typically varies between 30-60 seats. Lecture halls are normally allocated for those learning spaces with larger than 60 seats.

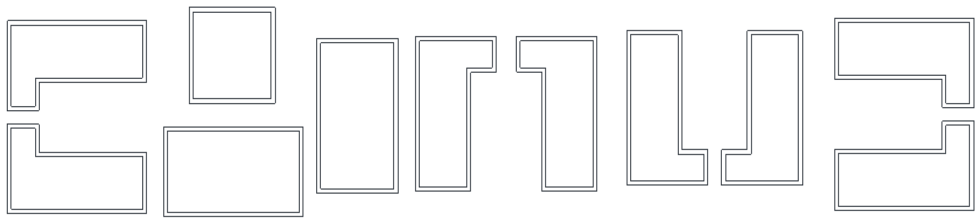


Figure 4-1 Identified Layout Typologies for Classrooms and other Learning Spaces

Typical travel distance between several spaces for the case study schools is measured between almost 10 meters to 100 meters.

Accessibility: is evaluated based on existence and condition of several circulation facilities around and inside educational buildings such as; passages, pathways and ramps their signage. Most of the observed schools have clear pathways with enough signage toward and inside them. The contemplations for cold weather condition, such as allocation of covered paths and pedways are also observed in most of the cases.

Flexibility: One exercised method observed in some of the case study schools is the use of furniture and equipment to make a classroom flexible place for integrated teaching and learning activities. However, because of the small size of some classrooms, or their inappropriate layouts that limit the actual available space for those areas, this method is not adoptable in all cases. However, in the old school buildings no particular strategies related to the flexibility of the spaces and classrooms were considered.

4.3.4 Schools' Observation Checklist

A checklist to record the observation data of several spaces in the studied school settings is developed and an example of the recorded data for one of the cases is presented in figure 4-2.

General Information		
School Geometry	School 1	*Square* *Elevated-rectangle* *Elongated-rectangle* ***L-shaped*** *U-shaped* *H-shaped*
School Building Orientation	School 1	***North*** *South* *North-East* *North-West* *South-East* *South-West* *East* *West*
Thermal Comfort factor		
Opening position	Classrooms	***Single*** ***Adjacent*** *Parallel*
	Labs	***Single*** *Adjacent* *Parallel*
	Library	*Single* ***Adjacent*** *Parallel*
	Offices	***Single*** *Adjacent* *Parallel*
	Public areas	***Single*** ***Adjacent*** *Parallel*
Opening location	Classrooms	*North* ***South*** *North-East* *North-West* ***South-East*** *South-West* *East* *West*
	Labs	*North* *South* *North-East* *North-West* *South-East* *South-West* *East* ***West***
	Library	*North* *South* *North-East* ***North-West*** *South-East* *South-West* *East* *West*
	Offices	*North* *South* *North-East* *North-West* *South-East* *South-West* *East* ***West***
	Public areas	*North* *South* *North-East* *North-West* *South-East* ***South-West*** *East* ***West***
Predominant wind direction	Building	*North* *North-East* *East* *South-East* *South* *South-West* *West* *North-West*
Space configuration	Classrooms	*Deep plan* ***Square plan*** ***Extended plan***
	Labs	***Deep plan*** *Square plan* *Extended plan*
	Library	*Deep plan* *Square plan* ***Extended plan***
	Offices	*Deep plan* ***Square plan*** *Extended plan*
	Public areas	*Deep plan* *Square plan* ***Extended plan***
Lighting Comfort factor		
Space Orientation	Classrooms	***North*** *South* *North-East* *North-West* *South-East* *South-West* ***East*** *West*
	Labs	*North* *South* *North-East* *North-West* *South-East* *South-West* ***East*** *West*
	Library	***North*** *South* *North-East* *North-West* *South-East* *South-West* *East* *West*
	Offices	*North* *South* *North-East* *North-West* *South-East* *South-West* ***East*** *West*
	Public areas	***North*** *South* *North-East* *North-West* *South-East* *South-West* ***East*** *West*
Space Geometry	Classrooms	***Elevated Rectangle shape*** ***Square-shaped*** *Elongated Rectangle shape*
	Labs	*Elevated Rectangle shape* *Square-shaped* ***Elongated Rectangle shape***
	Library	***Elevated Rectangle shape*** *Square-shaped* *Elongated Rectangle shape*
	Offices	*Elevated Rectangle shape* ***Square-shaped*** *Elongated Rectangle shape*
	Public areas	***Elevated Rectangle shape*** *Square-shaped* *Elongated Rectangle shape*
Opening position	Classrooms	***Single*** ***Adjacent*** *Parallel*
	Labs	***Single*** *Adjacent* *Parallel*
	Library	*Single* ***Adjacent*** *Parallel*

	Offices	***Single***				*Adjacent*					*Parallel*
	Public areas	***Single***				***Adjacent***					*Parallel*
Opening size		*Small*				*Average*					*Large*
	Classrooms	*1*	*2*	*3*	*4*	*5*	*6*	***7***	***8***	*9*	*10*
	Labs	*1*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*10*
	Library	*1*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*10*
	Offices	*1*	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*
	Public areas	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	***9***	*10*
Opening distribution		*Touching*				*Regular*					*Far apart*
	Classrooms	*1*	*2*	***3***	***4***	*5*	*6*	*7*	*8*	*9*	*10*
	Labs	*1*	*2*	*3*	***4***	*5*	*6*	*7*	*8*	*9*	*10*
	Library	*1*	*2*	***3***	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Offices	*1*	*2*	*3*	*4*	*5*	***6***	*7*	*8*	*9*	*10*
	Public areas	*1*	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Number of Openings		*Few*				*Satisfactory*					*Many*
	Classrooms	*1*	***2***	***3***	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Labs	*1*	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Library	*1*	*2*	*3*	***4***	*5*	*6*	*7*	*8*	*9*	*10*
	Offices	***1***	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Public areas	*1*	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*
Shape of opening	Classrooms	*Elevated Rectangle*				*Square*					***Elongated Rectangle***
	Labs	*Elevated Rectangle*				*Square*					***Elongated Rectangle***
	Library	*Elevated Rectangle*				*Square*					***Elongated Rectangle***
	Offices	*Elevated Rectangle*				*Square*					***Elongated Rectangle***
	Public areas	*Elevated Rectangle*				*Square*					***Elongated Rectangle***
Glass transmissivity		*Regular*		*Semi-tint*			*Semi-translucent*				*Translucent*
	Classrooms	*1*	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Library	*1*	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Offices	*1*	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Public areas	*1*	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Acoustic Comfort factor											
Distance from noisy sources		*Close*				*Average*					*Far*
	Classrooms	*1*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*10*
	Labs	*1*	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*
	Library	*1*	*2*	*3*	***4***	*5*	*6*	*7*	*8*	*9*	*10*
	Offices	*1*	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*
existence of barriers	Classrooms	*None*	*2*	***3***	*4*	*5*	*6*	*7*	*8*	*9*	*Enough*
	Labs	***None***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Enough*
	Library	***None***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Enough*
	Offices	***None***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Enough*
Material Quality		*Sound absorbent*				*Semi-sound absorbent*					*None-sound absorbent*
	Classrooms	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	***10***
	Labs	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	***10***
	Library	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	***10***
	Offices	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	***10***

Physical Comfort factor											
Travel distance between …		*Close*				*Reasonable*					*Far*
	Learning spaces	***1***	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Class-services	*1*	*2*	***3***	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Class-Library	*1*	*2*	*3*	***4***	*5*	*6*	*7*	*8*	*9*	*10*
	Class-Offices	*1*	***2***	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
	Class- Publics	*1*	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*
Space size		*Small*				*Regular*					*Large*
	Classrooms	*1*	*2*	*3*	*4*	*5*	*6*	*7*	***8***	*9*	*10*
	Labs	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	***9***	*10*
	Library	*1*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*10*
	Offices	*1*	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*
	Public areas	*1*	*2*	*3*	*4*	*5*	*6*	*7*	***8***	*9*	*10*
Space layout	Classrooms	*Poor-defined*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	***9***	*Well-defined*
	Labs	*Poor-defined*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	***9***	*Well-defined*
	Library	*Poor-defined*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*Well-defined*
	Offices	*Poor-defined*	*2*	*3*	*4*	*5*	***6***	*7*	*8*	*9*	*Well-defined*
	Public areas	*Poor-defined*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*Well-defined*
Circulation facilities	Inside school	*Ambiguous*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*Clear*
	From Outside	*Ambiguous*	*2*	*3*	*4*	*5*	*6*	*7*	***8***	*9*	*Clear*
Public spaces		*Poor*				*Satisfying*					*Excellent*
	Community area	*1*	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*
	Food court	*1*	*2*	*3*	*4*	*5*	***6***	*7*	*8*	*9*	*10*
	Lounge area	*1*	*2*	*3*	*4*	*5*	*6*	***7***	*8*	*9*	*10*
	Entertainment	*1*	*2*	*3*	***4***	*5*	*6*	*7*	*8*	*9*	*10*
Outdoor spaces		*Absent*				*Enough*					*Abundant*
		1	*2*	*3*	*4*	***5***	*6*	*7*	*8*	*9*	*10*

Figure 4-2 Developed Checklist and Recorded Results of Observations for Five Sample Schools

This checklist was filled for all observed case study schools and a database of design variables associated with those schools were developed accordingly. The database was than utilize for development of evaluation survey in order to collect experts' assessment results regarding observed design parameters of each building and measure their overall performance.

4.4 School Occupants Survey Procedure and Analysis of Results

As mentioned in previous chapters, occupants' questionnaire through survey procedure applied as one of the most appropriate methodologies to obtain performance data from educational buildings. This methodology was also recognized as the mostly practiced method according to building design experts in order to obtain the view and opinion of school occupants regarding the comfort and performance of their learning environment.

The survey questionnaire was designed by the researcher using the evaluation parameters acquired from review of the literature as well as experts knowledge. Thus, the level of satisfaction, comfort, and achievement of the school occupants associated with several parameters of building performance were measured on a scale of (1-10) accordingly. Designed questionnaires were distributed between 30 schools through online survey procedure and finally a total of 11 schools containing 80 individuals consented to participate in the survey.

This section will present the analysis and results of the questions included in the online survey of school occupants, which were basically related to environmental comfort and functionality of learning spaces since they were identified as the most important factors of building performance. The statistical analysis of the responses were simply done by calculating an average of responses provided by several occupants at each school, because of the small size of participating schools that contributed in this research study. The main survey questions, the responses to the questions, and the analysis of the responses are presents in the following sections.

4.4.1 Comfort and Environmental Quality of Learning Spaces

Thermal, lighting/visual, and acoustic comforts together with indoor air quality are the fundamental aspects of environmental condition that have great impact on occupants comfort and satisfaction in educational buildings. Questions related to the aforementioned aspects of indoor environmental quality of the selected case study schools were designed and distributed between the occupants. The intention of such survey was to prepare a buildings assessment tool in terms of such environmental issues as temperature, ventilation, lighting, acoustics and air quality. To do so, each of these factors needs to be evaluated and rated on a scale of 1-10 by the school occupants.

Thermal comfort evaluation

The climate in the state of Alberta, Canada, is dry and continental with warm summers and cold winters, which often produce extremely cold conditions in winter. The important variables related to thermal condition and comfort evaluation of school buildings, which are included in the questionnaire, are discussed in this section:

a. Temperature

According to the responses, the thermal condition of the targeted classrooms was evaluated as satisfactory in average, but there can be seen some discrepancies as follow. In winter season, the thermal condition of some case study schools is poor. On a winter sunny day, a large area of solar penetration in classrooms can be occurred as a result of the low-attitude of sun path. Thus according to the occupants' responses, overheating is a more common problem than cold temperature in winter season within the studied schools. In summer the overheating on sunny days is still noticed as a problem in some classrooms.

The percentage of users' responses on 1-10 scale and the calculated mean value of responses are shown in table 4-9. In order to calculate mean values for each of the schools under study the following approach has been employed;

As an instance for School # 1;

Mean= [(0*1)+(0*2)+(0*3)+(
(12.5*4)+(37.5*5)+(25*6)+(25*7)+(0*8)+(0*9)+(0*10)//100] or
[(0*1)+(0*2)+(0*3)+(1*4)+(3*5)+(2*6)+(2*7)+(0*8)+(0*9)+(0*10)/8] = 5.8

The same approach has been utilized in order to calculate the mean values for all other investigated environmental and physical parameters of ten case study school buildings.

Table 4-9 Occupants Evaluation Results on Temperature Condition in Studied School Buildings

Temperature	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean Result**	**Comments**
	Response rate (%)											
School 1	0	0	0	12.5	37.5	25	25	0	0	0	**5.8**	satisfactory
School 2	0	0	0	62.5	25	12.5	0	0	0	0	**4.5**	unsatisfactory
School 3	0	0	12.5	25	25	37.5	0	0	0	0	**5**	acceptable
School 4	0	0	0	0	0	25	50	25	0	0	**7**	satisfactory
School 5	0	0	0	0	0	11	44.4	22.2	22.2	0	**7.5**	satisfactory
School 6	0	0	12.5	0	0	12.5	25	37.5	12.5	0	**7**	satisfactory
School 7	0	28.6	14.3	28.6	28.6	0	0	0.0	0.0	0	**3.6**	unsatisfactory
School 8	0	0	0	0	0	12.5	25	25	37.5	0	**7.9**	satisfactory
School 9	0	0	0	0	12.5	12.5	25	37.5	12.5	0	**7**	satisfactory
School 10	0	12.5	25	25	25	12.5	0	0	0	0	**4**	unsatisfactory

b. Ventilation

Regarding the ventilation condition in the case study schools, the highest degree of dissatisfaction occurs in summer. This also causes overheating resulted from poor air circulation pattern and inappropriate placement of openings in most classrooms design. Thus as it can be noticed from evaluation results, survey participants reflected dissatisfaction state with ventilation condition of their learning environments on average.

Table 4-10 Occupants Evaluation Results on Ventilation Condition in Studied School Buildings

Ventilati on	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean result**	**Comments**
	Response rate (%)											
School 1	12.5	25.0	37.5	12.5	0.0	12.5	0.0	0.0	0.0	0.0	**3.0**	unsatisfactory
School 2	37.5	25.0	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	**2.1**	unsatisfactory
School 3	12.5	37.5	25.0	12.5	12.5	0.0	0.0	0.0	0.0	0.0	**2.8**	unsatisfactory
School 4	0	37.5	25	25	12.5	0	0	0	0	0	**3.1**	unsatisfactory
School 5	0	0	0	22.2	33.3	22.2	22.2	0	0	0	**5.4**	acceptable

School 6	0	0.0	25.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	**3.9**	unsatisfactory
School 7	0	0	14.3	14.3	28.6	14.3	28.6	0	0	0	**5.3**	acceptable
School 8	0	0	37.5	37.5	12.5	12.5	0	0	0	0	**4.0**	unsatisfactory
School 9	0	0	0	12.5	25	25	25	12.5	0	0	**6.0**	acceptable
School 10	0	25	37.5	25	0	12.5	0	0	0	0	**3.4**	unsatisfactory

c. Indoor Air Quality and Humidity

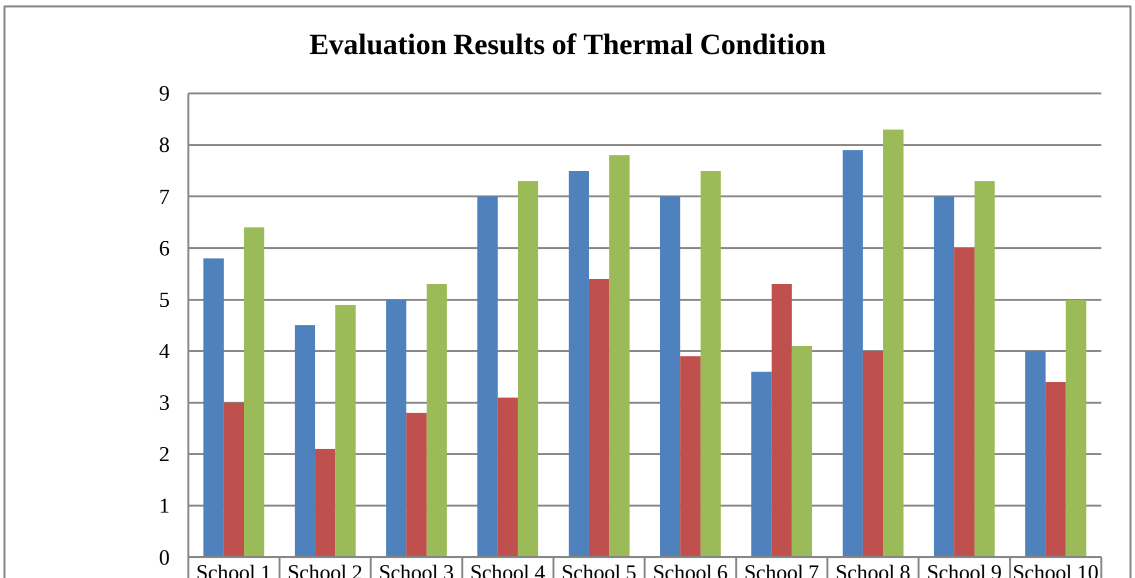
In general, the result of analysis does not show any serious discomfort situation produced by the poor indoor air quality, and just a small number of survey participants are not satisfied with the indoor air quality of their teaching and learning environments. The cause of this dissatisfaction, which was identified through school and classrooms observation, was the poor ventilation and air circulation resulted from inefficient design, size and location of the openings that serve as the ventilation gaps in the indoor spaces.

Table 4-11 Occupants Evaluation of Indoor Air Quality Condition in Studied School Buildings

IAQ	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean result**	**Comment**
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	25.0	37.5	12.5	25.0	0.0	0	**6.4**	acceptable
School 2	0.0	0.0	25.0	12.5	25.0	25.0	12.5	0.0	0.0	0	**4.9**	acceptable
School 3	0.0	0.0	0.0	25.0	37.5	25.0	12.5	0.0	0.0	0	**5.3**	acceptable
School 4	0.0	0.0	0.0	0.0	12.5	25.0	12.5	25.0	25.0	0	**7.3**	satisfactory
School 5	0.0	0.0	0.0	0.0	0.0	11.1	33.3	33.3	11	11	**7.8**	satisfactory
School 6	0.0	0.0	0.0	0.0	0.0	25.0	25.0	25.0	25.0	0	**7.5**	satisfactory
School 7	0.0	14.3	14.3	28.6	28.6	14.3	0.0	0.0	0.0	0	**4.1**	unsatisfactory
School 8	0.0	0.0	0.0	0.0	0.0	12.5	12.5	37.5	12.5	25.0	**8.3**	satisfactory
School 9	0.0	0.0	0.0	0.0	12.5	12.5	25.0	37.5	12.5	0	**7.3**	satisfactory
School 10	0.0	0.0	12.5	25.0	25.0	25.0	12.5	0.0	0.0	0	**5.0**	acceptable

The overall result of occupants evaluation regarding the ‘Thermal Condition and Performance’ of the ten studied cases is summarized in Figure 4-3. Figure 4-3 shows how occupants of studied schools were less satisfied with ventilation condition of their learning environments than the other factor of thermal comfort including temperature and indoor air quality.

The reason for this dissatisfaction was further investigated through the school observation phase. Poor design of openings size and location as well as their position with respect to each other in some cases besides the overlooked importance of building orientation regarding to the wind direction were identified as the key impacting parameters in resulted poor ventilation condition of some case study schools.



	School 1	School 2	School 3	School 4	School 5	School 6	School 7	School 8	School 9	School 10
Temperature	5.8	4.5	5	7	7.5	7	3.6	7.9	7	4
Ventilation	3	2.1	2.8	3.1	5.4	3.9	5.3	4	6	3.4
IAQ	6.4	4.9	5.3	7.3	7.8	7.5	4.1	8.3	7.3	5

Figure 4-3 Overall ‘Thermal Condition and Performance’ Evaluation According to Schools Occupants

Lighting/Visual Comfort Evaluation

Although, Natural lighting has been proven as the main desired source of light by the occupants that increase their satisfaction and performance, but the use of artificial lighting also needs be considered as a complementary resource to the natural light. Both of these lighting sources need to be appropriately integrated into the designs of school buildings. Design variables that define satisfaction of the users with the lighting condition within the studied schools are investigated through the developed survey and the responses are analyzed in this section.

a. Natural Lighting

As natural lighting attains the higher desirability over artificial lighting by the occupants according to the survey result, the consideration of large openings appear to be a key factor in the school designs. As mentioned in previous section, the average opening area for the observed sample schools fluctuates between 5 - 10 m². Other than the openings size (indicated by ratio of window-to-wall area), there are some other important factors like classrooms configuration, that impacts the sufficiency of natural lighting in the classroom area, and lighting comfort and satisfaction of the occupants accordingly.

As mentioned in previous section, wherever the classroom outline goes beyond the standard six meters (6m) limitation in depth of plan the need to artificial lighting is necessary. Having discussed that all, both natural and artificial lighting conditions of the studied learning spaces were evaluated by their occupants and the results of evaluations are presented in table 4-12.

Table 4-12 Occupants Evaluation of Natural Lighting Condition in Studied School Buildings

Natural light level	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean result**	**Comment**
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	25.0	37.5	12.5	25.0	0.0	0.0	**6.4**	Acceptable
School 2	0.0	0.0	0.0	0.0	0.0	25.0	25.0	25.0	12.5	12.5	**7.6**	Satisfactory
School 3	0.0	0.0	0.0	0.0	12.5	25.0	25.0	25.0	12.5	0.0	**7.0**	Satisfactory
School 4	0.0	0.0	0.0	0.0	12.5	12.5	25.0	25.0	25.0	0.0	**7.4**	Satisfactory
School 5	0.0	0.0	0.0	0.0	0.0	11.1	22.2	44.4	22.2	0.0	**7.8**	Satisfactory
School 6	0.0	0.0	0.0	0.0	0.0	37.5	12.5	12.5	0.0	0.0	**5.9**	Acceptable
School 7	0.0	0.0	0.0	0.0	0.0	14.3	0.0	42.9	14.3	28.6	**8.4**	very satisfactory
School 8	0.0	0.0	0.0	0.0	0.0	12.5	12.5	25.0	37.5	12.5	**8.3**	very satisfactory
School 9	0.0	0.0	0.0	0.0	25.0	25.0	25.0	12.5	12.5	0.0	**6.6**	Acceptable
School 10	0.0	0.0	0.0	12.5	25.0	12.5	25.0	25.0	0.0	0.0	**6.3**	Acceptable

Regarding the sufficiency of natural lighting for the studied schools, the survey results indicate the satisfaction rate, which falls between ‘acceptable’ to ‘very satisfied’ as presented in 4-12.

Table 4-13 Occupants Evaluation of Artificial Lighting Condition in Studied School Buildings

Artificial lighting	Very dissatisfied	2	3	4	5	6	7	8	9	Very satisfied	Mean result	Comment
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	0.0	25.0	12.5	25.0	25.0	12.5	**7.9**	satisfactory
School 2	0.0	0.0	0.0	0.0	0.0	12.5	12.5	37.5	12.5	25.0	**8.3**	satisfactory
School 3	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	0.0	0.0	**6.8**	acceptable
School 4	0.0	0.0	0.0	0.0	12.5	12.5	25.0	37.5	12.5	0.0	**7.3**	satisfactory
School 5	0.0	0.0	0.0	22.2	22.2	33.3	22.2	0.0	0.0	0.0	**5.6**	acceptable
School 6	0.0	0.0	0.0	0.0	0.0	0.0	12.5	37.5	37.5	12.5	**8.5**	satisfactory
School 7	0.0	0.0	0.0	0.0	0.0	14.3	0.0	42.9	14.3	28.6	**8.4**	satisfactory
School 8	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25.0	25.0	12.5	**8.0**	satisfactory
School 9	0.0	0.0	0.0	0.0	0.0	25.0	12.5	37.5	25.0	0.0	**7.6**	satisfactory
School 10	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25.0	37.5	**8.9**	very satisfactory

b. Glare

The glare is another important factor impacting the occupants’ visual comfort and satisfaction. As mentioned before, typically there are no surrounding buildings around almost all studied schools, so that shadow or light reflection is not expected to be a problem in the classrooms of those schools. From results of survey questionnaire together with observation analysis, the spaces with East or West orientation toward sun-path were evaluated more visually comfortable and have less glare problem than those with South and North orientation.

One identified solution for the glare problem of the observed classroom spaces is the use of blinds, which can regulate the intensity of the direct sun-light in those classrooms with visual discomfort. The results of visual comfort evaluation of case study schools from occupants' point of view are summarized in table 4-14.

Table 4-14 Occupants Evaluation Results of Glare Condition in Studied School Buildings

Glare	Very dissatisfied	2	3	4	5	6	7	8	9	Very satisfied	Mean result	Comment
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	0.0	12.5	12.5	25.0	25.0	25.0	**8.4**	very satisfactory
School 2	0.0	0.0	0.0	0.0	25.0	12.5	25.0	37.5	0.0	0.0	**6.8**	Acceptable
School 3	0.0	0.0	0.0	0.0	12.5	37.5	25.0	25.0	0.0	0.0	**6.6**	Acceptable
School 4	0.0	0.0	0.0	0.0	12.5	0.0	25.0	37.5	25.0	0.0	**7.6**	Satisfactory
School 5	0.0	0.0	0.0	0.0	11.1	33.3	33.3	11.1	11.1	0.0	**6.8**	Acceptable
School 6	0.0	0.0	0.0	0.0	0.0	12.5	12.5	25.0	25.0	25.0	**8.4**	very satisfactory
School 7	0.0	0.0	0.0	0.0	14.3	14.3	14.3	28.6	28.6	0.0	**7.4**	Satisfactory
School 8	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	0.0	**7.8**	Satisfactory
School 9	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25.0	25.0	12.5	**8.0**	Satisfactory
School 10	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	**8.8**	very satisfactory

c. Views

Views and visual satisfaction are proven to have significant impact on school occupants' physiological state, thus, their attitude and work performance consequently. There are two parameters considered for evaluation in this study regarding the visual condition and views in investigated school buildings which are the level of outside or external views from the classrooms and availability of view to green spaces such as; gardens, parks, mountains, etc. The summery of responses to these questions are provided in below tables.

Table 4-15 Occupants Evaluation Results of Visual Condition (outside views) of Studied Schools

Outside view	Very dissatisfied	2	3	4	5	6	7	8	9	Very satisfied	Mean result	Comment
	Response rate (%)											
School 1	25.0	25.0	12.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	**2.8**	very unsatisfactory
School 2	0.0	0.0	0.0	25.0	37.5	25.0	12.5	0.0	0.0	0.0	**5.3**	Acceptable

School 3	0.0	0.0	0.0	37.5	12.5	25.0	25.0	0.0	0.0	0.0	**5.4**	acceptable
School 4	0.0	12.5	25.0	37.5	12.5	12.5	0.0	0.0	0.0	0.0	**3.9**	Unsatisfactory
School 5	0.0	0.0	0.0	0.0	22.2	22.2	33.3	22.2	0.0	0.0	**6.6**	Acceptable
School 6	25.0	0.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.4**	very unsatisfactory
School 7	0.0	14.3	28.6	28.6	28.6	0.0	0.0	0.0	0.0	0.0	**3.7**	Unsatisfactory
School 8	0.0	25.0	0.0	25.0	37.5	12.5	0.0	0.0	0.0	0.0	**4.1**	Unsatisfactory
School 9	0.0	0.0	25	12.5	25.0	25.0	12.5	0.0	0.0	0.0	**4.9**	Unsatisfactory
School 10	12.5	25.0	50.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	**2.6**	very unsatisfactory

Table 4-16 Occupants Evaluation Results of Visual Condition (greenery views) in Studied Schools

View to greeneries	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean result**	**Comment**
	Response rate (%)											
School 1	12.5	25.0	25.0	12.5	25.0	0.0	0.0	0.0	0.0	0.0	**3.1**	Unsatisfactory
School 2	0.0	0.0	37.5	25.0	12.5	25.0	0.0	0.0	0.0	0.0	**4.3**	Unsatisfactory
School 3	0.0	0.0	12.5	25.0	25.0	25.0	12.5	0.0	0.0	0.0	**5.0**	Acceptable
School 4	0.0	0.0	25.0	50.0	25.0	0.0	0.0	0.0	0.0	0.0	**4.0**	Unsatisfactory
School 5	0.0	0.0	0.0	11.1	33.3	22.2	11.1	22.2	0.0	0.0	**6.0**	Acceptable
School 6	0.0	0.0	12.5	0.0	0.0	12.5	0.0	0.0	0.0	0.0	**3.5**	Unsatisfactory
School 7	0.0	0.0	14.3	14.3	14.3	28.6	28.6	0.0	0.0	0.0	**5.4**	Acceptable
School 8	0.0	25.0	25.0	37.5	0.0	12.5	0.0	0.0	0.0	0.0	**3.5**	Unsatisfactory
School 9	0.0	0.0	12.5	25.0	12.5	25.0	25.0	0.0	0.0	0.0	**5.3**	Acceptable
School 10	37.5	25.0	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	**2.1**	very unsatisfactory

As can be seen from the results of responses, the overall visual condition of the studied schools indicate the dissatisfaction rate falling between ‘very dissatisfied’ to ‘almost satisfied’ according to the occupants. The evaluation results of overall lighting condition for the case study schools are presented in Figure 4-4.

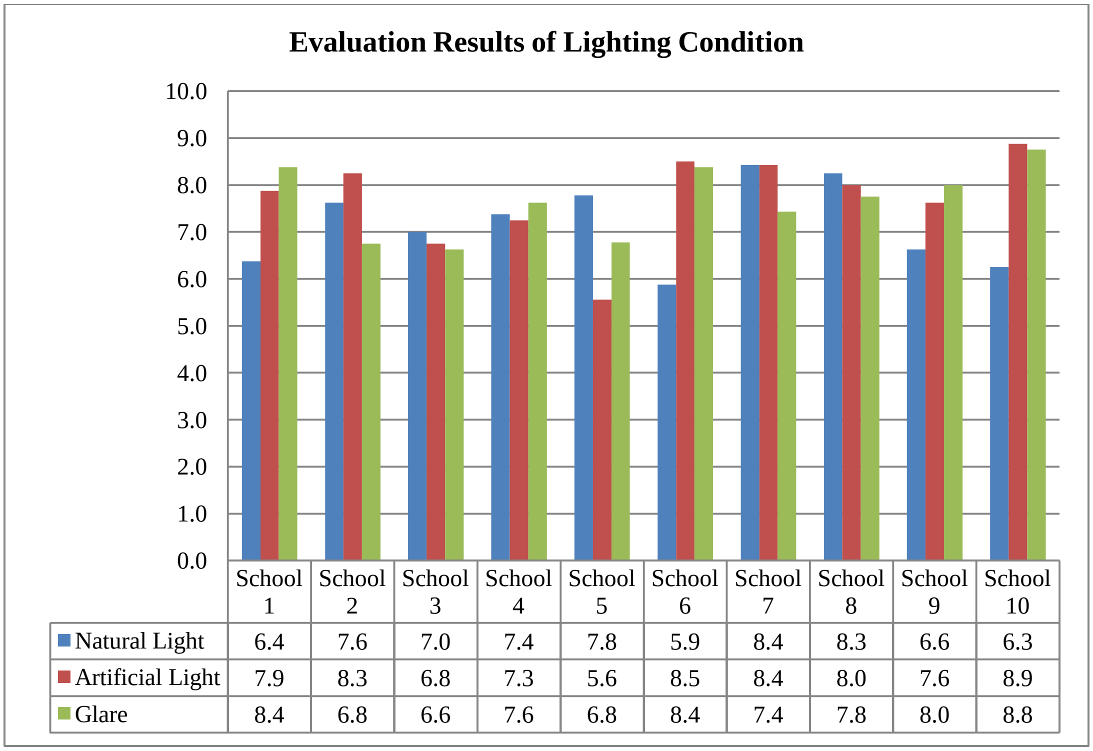


Figure 4-4 Overall 'Lighting Condition and Performance' Evaluation According to Occupants

Acoustics Comfort Evaluation

The parameters related to acoustic comfort that are considered in this research study are comprised of the quality of acoustic condition defined by classroom and background noise levels, and the ability to control the noises. As most of the observed classroom areas in the studied schools are rectangular, there is a constant distribution of the sound throughout the entire classroom environment, and the teachers' voice can be easily heard by all the students. As a result, occupants of these investigated classrooms responded positively to the acoustic condition and comfort of their communications.

Table 4-17 Occupants Evaluation Results of Acoustic Condition (classroom noise)

Classroom noise level	Very dissatisfied	2	3	4	5	6	7	8	9	Very satisfied	Mean Value	Comment
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	0.0	37.5	25.0	25.0	12.5	0.0	**7.1**	Satisfactory
School 2	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25.0	25.0	12.5	**8.0**	Satisfactory
School 3	0.0	0.0	0.0	0.0	12.5	25.0	25.0	25.0	12.5	0.0	**7.0**	Satisfactory

School 4	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	12.5	12.5	**7.9**	Satisfactory
School 5	0.0	0.0	0.0	0.0	0.0	11.1	11.1	22.2	33.3	22.2	**8.4**	Satisfactory
School 6	0.0	0.0	0.0	0.0	0.0	0.0	37.5	37.5	25.0	0.0	**7.9**	Satisfactory
School 7	0.0	0.0	0.0	0.0	14.3	0	42.9	28.6	14.3	0.0	**7.3**	Satisfactory
School 8	0.0	0.0	0.0	0.0	25.0	37.5	12.5	12.5	12.5	0.0	**6.5**	Acceptable
School 9	0.0	0.0	0.0	0.0	25.0	12.5	25.0	12.5	25.0	0.0	**7.0**	Satisfactory
School 10	0.0	0.0	0.0	0.0	25.0	25.0	25.0	25.0	0.0	0.0	**6.5**	Acceptable

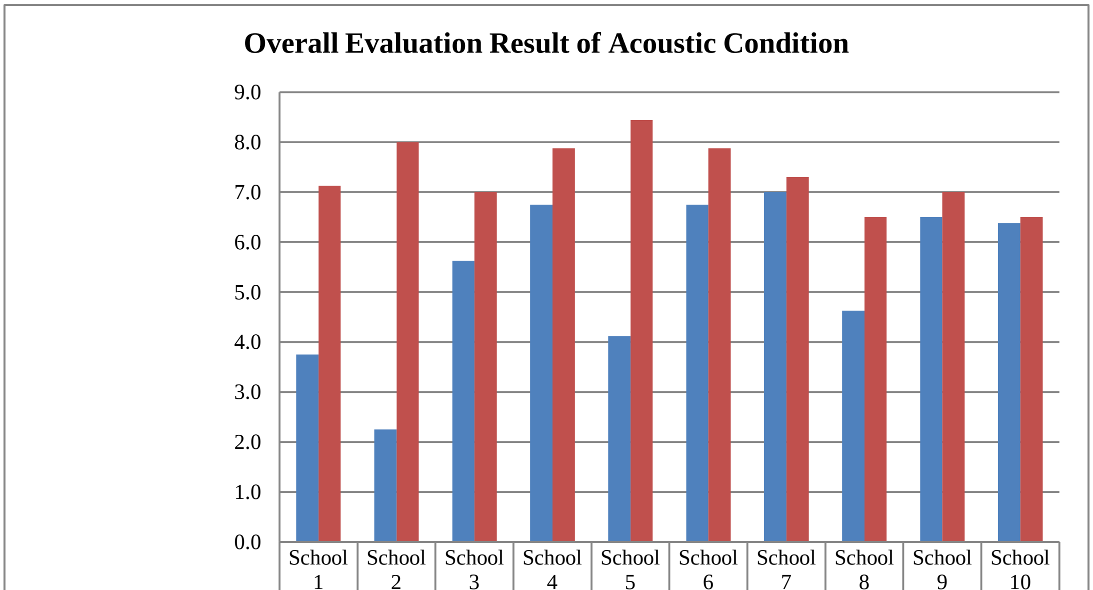
According to the surveys responses, those schools located on open sites are rated higher regarding the acoustic condition and satisfaction than those located on dense sites. The reason for this higher satisfaction is the existence of noise barriers such as; a school yard or green areas against the traffic noises created in the buildings stand back space from roads.

Table 4-18 Occupants Evaluation Results of Acoustic Condition (background noise level)

Background noises	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean**	**Comment**
	Response rate (%)											
School 1	0.0	25	25	12.5	25	12.5	0.0	0.0	0.0	0.0	**3.8**	dissatisfactory
School 2	37.5	37.5	0.0	12.5	12.5	0.0	0.0	0.0	0.0	0.0	**2.3**	very dissatisfactory
School 3	0.0	0.0	0.0	12.5	37.5	25	25	0.0	0.0	0.0	**5.6**	acceptable
School 4	0.0	0.0	0.0	0.0	12.5	25	37.5	25	0.0	0.0	**6.8**	acceptable
School 5	0.0	0.0	33.3	33.3	22.2	1	0.0	0.0	0.0	0.0	**4.1**	dissatisfactory
School 6	0.0	0.0	0.0	0.0	0.0	25	37.5	25	0.0	0.0	**6.8**	acceptable
School 7	0.0	0.0	0.0	0.0	14.3	14.3	28.6	43	0.0	0.0	**7.0**	satisfactory
School 8	0.0	0.0	12.5	37.5	25	25	0.0	0.0	0.0	0.0	**4.6**	dissatisfactory
School 9	0.0	0.0	0.0	12.5	25	12.5	25	0.0	25	0.0	**6.5**	acceptable
School 10	0.0	0.0	0.0	0.0	25	37.5	12.5	25	0.0	0.0	**6.4**	acceptable

From results shown in tables 4-18 we can see that in most of the studied schools respondents feel that the annoying background noise condition is somewhere between ‘almost dissatisfactory’ to ‘acceptable’ level. This means that the noise level of the surrounding areas are distracting and annoying so as improvements are required.

The overall 'Acoustic Condition and Performance' evaluation of ten case study schools according to occupants' evaluation results is illustrated in Figure 4-5. From Figure 4-5, we can note that school occupants are generally satisfied with the noise level of their learning spaces. Conversely the background noise level is recognized as problematic area in some cases.



	School 1	School 2	School 3	School 4	School 5	School 6	School 7	School 8	School 9	School 10
Background Noise	3.8	2.3	5.6	6.8	4.1	6.8	7.0	4.6	6.5	6.4
Classroom Noise Level	7.1	8.0	7.0	7.9	8.4	7.9	7.3	6.5	7.0	6.5

Figure 4-5 Overall 'Acoustic Condition and Performance' Evaluation According to Occupants

Physical Comfort Evaluation

As determined earlier at the beginning of the study from experts' survey and interview results, the functionality is one of the most critical factors to be considered in building performance evaluation procedure together with environmental comfort factors. Thus, the focus moves from issues of environmental comfort to address the functional performance of learning spaces. In this section several aspects are addressed, such as classrooms design, size and outline, circulation patterns, and public and outdoor spaces. The following sections discuss each aspect, analyzing the physical and functional features and differences identified across the case study schools.

a. Functionality

A functional setting in this study is referred as a well-designed, efficient facility that suitably serves for the purpose of its design, which in this case is providing an ideal learning and teaching environment for its users. Variables such as building layout and geometry that affect the average travel distance between classrooms and other spaces are incorporated into the functionality aspect. From the observations and analysis result, presented in section 4.3, distances measured between several spaces of case study schools range from almost 10 to 100 meters.

A survey questionnaire containing aforementioned considerations was developed using the semantic scale measurement in order to evaluate users satisfaction with the distance and the time spent in walking from one space to reach another space. The plans of the investigated school buildings were evaluated, along with the survey of users regarding their satisfaction with each building layout and travel distances.

Table 4-19 Occupants Evaluation Results on Functionality of Studied School Buildings

Travel distance	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean result**	**Comment**
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25	37.5	25	**8.8**	very satisfactory
School 2	12.5	12.5	37.5	25	12.5	0.0	0.0	0.0	0.0	0.0	**3.1**	Dissatisfactory
School 3	0.0	0.0	0.0	0.0	12.5	12.5	37.5	25	12.5	0.0	**7.1**	Satisfactory
School 4	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25	25	12.5	**8.0**	Satisfactory
School 5	0.0	0.0	11.1	22.2	22.2	22.2	22.2	0.0	0.0	0.0	**5.2**	Acceptable
School 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	37.5	50	**9.4**	very satisfactory
School 7	0.0	0.0	0.0	0.0	0.0	0.0	14.3	28.6	28.6	28.6	**8.7**	very satisfactory
School 8	0.0	0.0	0.0	0.0	0.0	0.0	12.5	12.5	37.5	37.5	**9.0**	very satisfactory
School 9	0.0	0.0	0.0	0.0	25.0	37.5	12.5	12.5	12.5	0.0	**6.5**	Acceptable
School 10	0.0	0.0	12.5	37.5	37.5	12.5	0.0	0.0	0.0	0.0	**4.5**	Dissatisfactory

- **Classroom Size and Circulation**

Although, expansive classroom spaces are always desirable from occupants' perspective, but allowing for a space with useful and purposeful arrangement also need to be reflected in a classroom design. In his section questions like the amount of available space per individual in the classrooms, seating arrangement in the classrooms as well as the circulation and movement within the classroom space is studied and investigated through the survey questionnaire. Tables 4-20 and 4-21 show the overall responses from the occupants of all case study schools regarding the mentioned concerns.

Table 4-20 Occupants' Evaluations on Classrooms Sizes and Available Space per Individual

Class size & Available space	**Very Small**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very Large**	**Mean**	**Comments**
	Response rate (%)											
School 1	0	0	0	0	0	25	25	25	25	0	**7.5**	satisfactory
School 2	0	13	37.5	37.5	12.5	0	0	0	0	0	**3.5**	dissatisfactory
School 3	0	0	0	0	12.5	37.5	25	25	0	0	**6.6**	acceptable
School 4	0	0	0	0	0	25	25	25	25	0	**7.5**	satisfactory
School 5	0	0	0	11	33.3	22	22	11	0	0	**5.9**	acceptable
School 6	0.	0	0	0	0	12.5	12	25	37	12.5	**8.3**	satisfactory
School 7	0	0	0	0	14.3	28.6	29	29	0	0	**6.7**	acceptable
School 8	0	0	0	0	25	37.5	25	12.5	0	0	**6.3**	acceptable
School 9	0	0	0	0	0	25	0	37.5	25	12.5	**8.0**	satisfactory
School 10	0	0	37.5	12.5	25	25	0	0	0	0	**4.4**	dissatisfactory

Table 4-21 Occupants Evaluation on Classrooms Outlines and Circulation Condition in Schools

Class Outline	**poor**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**well**	**Mean**	**Comments**
	Response rate (%)											
School 1	0.0	0	0.0	0.0	0.0	12.5	25	37.5	12.5	12.5	**7.9**	satisfactory
School 2	0.0	0	37.5	50	12.5	0.0	0.0	0.0	0.0	0.0	**3.8**	dissatisfactory
School 3	0.0	0	0.0	0.0	0.0	25	25	37.5	12.5	0.0	**7.4**	satisfactory
School 4	0.0	0	0.0	0.0	0.0	12.5	25	25	25	12.5	**8.0**	satisfactory

School 5	0.0	11	0.0	44	22.2	22.2	0.0	0.0	0.0	0.0	**4.4**	dissatisfactory
School 6	0.0	0	0.0	0.0	0.0	12.5	12.5	25	25	25	**8.4**	satisfactory
School 7	0.0	0	0.0	0.0	0.0	0.0	14.3	28.6	28.6	28.6	**8.7**	satisfactory
School 8	0.0	0	0.0	0.0	12.5	25	25	25	12.5	0.0	**7.0**	satisfactory
School 9	0.0	0	0.0	0.0	0.0	25	25	25	0.0	25	**7.8**	satisfactory
School 10	0.0	0	0.0	0.0	12.5	25	12.5	25	25	0.0	**7.3**	satisfactory

b. Accessibility to the buildings

One of the most important building performance aspects is accessibility of the building to all users. The studied school buildings were also rated regarding their accessibility from users' viewpoints. Then occupants were asked to assess the pathways and walkways throughout the entire buildings on a scale of 1 to 10, from ambiguous to distinct/clear. The responses are presented and analysed in Tables 4-22 and 4-23 respectively.

Table 4-22 Occupants' Evaluation Results on Accessibility (pathways) of Studied Schools

Pathways	**Ambiguous**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Clear**	**Mean**	**Comment**
School 1	0.0	0.0	0.0	0.0	0.0	12.5	12.5	25.0	37.5	12.5	**8.3**	satisfactory
School 2	0.0	0.0	0.0	0.0	12.5	12.5	37.5	37.5	0.0	0.0	**7.0**	satisfactory
School 3	0.0	12.5	25.0	37.5	25.0	0.0	0.0	0.0	0.0	0.0	**3.8**	dissatisfactory
School 4	0.0	0.0	0.0	0.0	0.0	12.5	37.5	12.5	25.0	12.5	**7.9**	satisfactory
School 5	0.0	0.0	11.1	22.2	22.2	33.3	11.1	0.0	0.0	0.0	**5.1**	acceptable
School 6	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25.0	37.5	**8.9**	very satisfactory
School 7	0.0	0.0	0.0	0.0	0.0	0.0	28.6	28.6	28.6	14.3	**8.3**	satisfactory
School 8	0.0	0.0	0.0	0.0	0.0	12.5	0.0	25.0	37.5	25.0	**8.6**	very satisfactory
School 9	0.0	0.0	12.5	25.0	37.5	25.0	0.0	0.0	0.0	0.0	**4.8**	dissatisfactory
School 10	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	0.0	0.0	**6.8**	acceptable

From tables 4-22 and 4-23 it can be noticed that the users' assessment of the accessibility into and around their school buildings is overlay high, which indicates the clearness of the pathways and existence of enough signage around and inside these studied buildings.

Table 4-23 Occupants' Evaluation Results on Accessibility (signage) of Studied Schools

Signage	Ambiguous	2	3	4	5	6	7	8	9	Clear	Mean	Comment
School 1	0.0	0.0	0.0	0.0	0.0	12.5	25.0	37.5	25.0	0.0	**7.8**	satisfactory
School 2	0.0	0.0	0.0	0.0	12.5	12.5	37.5	25.0	12.5	0.0	**7.1**	satisfactory
School 3	0.0	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	**3.3**	dissatisfactory
School 4	0.0	0.0	0.0	0.0	0.0	25.0	37.5	12.5	12.5	12.5	**7.5**	satisfactory
School 5	0.0	0.0	22.2	22.2	22.2	22.2	11.1	0.0	0.0	0.0	**4.8**	dissatisfactory
School 6	0.0	0.0	0.0	0.0	0.0	12.5	12.5	25.0	25.0	25.0	**8.4**	satisfactory
School 7	0.0	0.0	0.0	0.0	14.3	0.0	28.6	28.6	14.3	14.3	**7.7**	satisfactory
School 8	0.0	0.0	0.0	0.0	0.0	0.0	25.0	25.0	37.5	12.5	**8.4**	satisfactory
School 9	0.0	0.0	25.0	37.5	12.5	25.0	0.0	0.0	0.0	0.0	**4.4**	dissatisfactory
School 10	0.0	0.0	0.0	0.0	12.5	37.5	37.5	12.5	0.0	0.0	**6.5**	acceptable

c. Flexibility

In order to create an adaptable learning environment, which can accommodate variety of teaching and learning related activities, flexibility appears to be an essential factor in design and planning of educational buildings.

From schools observations (section 4.3), utilizing movable furniture and portable equipment provides flexible spatial plans for many of the studied classrooms that can integrate teaching and learning activities. However, this strategy calls for large classroom areas an appropriate layouts to be adopted, which is absent in some cases particularly those in the old buildings. The average of occupants rating regarding the flexibility aspect of their learning environment is appeared to be between almost poor to acceptable in all studied schools, and the summery of the occupants responses is presented in Table 4-24.

Table 4-24 Occupants Evaluation Results on Flexibility of Studied School Buildings

Flexibility	Very poor	2	3	4	5	6	7	8	9	Very excellent	Mean Value	Comment
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	12.5	37.5	37.5	12.5	0.0	0.0	**6.5**	Acceptable
School 2	0.0	0.0	25.0	25.0	37.5	12.5	0.0	0.0	0.0	0.0	**4.4**	dissatisfactory

School 3	0.0	25.0	37.5	12.5	25.0	0.0	0.0	0.0	0.0	0.0	**3.4**	dissatisfactory
School 4	12.5	37.5	25.0	12.5	12.5	0.0	0.0	0.0	0.0	0.0	**2.8**	dissatisfactory
School 5	0.0	0.0	0.0	11.1	33.3	33.3	22.2	0.0	0.0	0.0	**5.7**	Acceptable
School 6	0.0	0.0	0.0	0.0	0.0	37.5	12.5	0.0	0.0	0.0	**5.4**	Acceptable
School 7	0.0	0.0	0.0	14.3	57.2	14.3	14.3	0.0	0.0	0.0	**5.3**	Acceptable
School 8	0.0	0.0	0.0	0.0	25.0	37.5	12.5	25.0	0.0	0.0	**6.4**	Acceptable
School 9	0.0	0.0	0.0	12.5	25.0	25.0	37.5	0.0	0.0	0.0	**5.9**	Acceptable
School 10	0.0	0.0	12.5	37.5	25.0	25.0	0.0	0.0	0.0	0.0	**4.6**	dissatisfactory

d. Facility/services and furniture

The facilities and furniture of the studied school buildings are investigated in terms of their appropriateness to satisfy occupants' needs and enhance their comfort and performance. The results of the investigations and survey responses indicate a high level of satisfaction with the furniture and facilities of the studied schools in average. The ergonomic design of the furniture like seats and desks is recognized as one of the main reasons for occupants' satisfaction with the facility and furniture condition of their educational settings. Furthermore the adjustable design of this furniture and the ability to move them easily, provide teachers and students with a multi-functional environment for diversity of activities. Table 4-25 shows the overall responses to the survey questions related to targeted schools facility and furniture conditions.

Table 4-25 Occupants Evaluation on Facility and Furniture Condition of Studied School Buildings

Facility & Furniture	**Very Poor**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very Excellent**	**Mean Value**	**Comments**
	Response rate (%)											
School 1	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25.0	12.5	25.0	**8.1**	Satisfactory
School 2	0.0	0.0	0.0	25.0	37.5	25.0	12.5	0.0	0.0	0.0	**5.3**	Acceptable
School 3	0.0	0.0	0.0	0.0	25.0	25.0	37.5	12.5	0.0	0.0	**6.4**	Acceptable
School 4	0.0	0.0	0.0	0.0	0.0	12.5	12.5	25.0	25.0	25.0	**8.4**	Satisfactory
School 5	0.0	0.0	0.0	0.0	22.2	33.3	22.2	22.2	0.0	0.0	**6.4**	Acceptable
School 6	0.0	0.0	0.0	0.0	0.0	12.5	12.5	12.5	25.0	37.5	**8.6**	Satisfactory
School 7	0.0	0.0	0.0	0.0	0.0	0.0	28.6	28.6	28.6	14.3	**8.3**	Satisfactory

School 8	0.0	0.0	0.0	0.0	0.0	25.0	37.5	12.5	12.5	12.5	**7.5**	Satisfactory
School 9	0.0	0.0	0.0	0.0	0.0	37.5	25.0	25.0	12.5	0.0	**7.1**	Satisfactory
School 10	0.0	0.0	0.0	0.0	12.5	37.5	37.5	12.5	0.0	0.0	**6.5**	Acceptable

- **Outdoor Spaces and Public Areas**

The prediction of an outdoor space for educational buildings can enhance the quality of users' life, their working performance and ultimately their achievements. According to the occupants survey, schools with considered outdoor spaces such as; outdoor public areas and lunges, greeneries and flower beds, small pools, sports fields, etc. obtained higher level of satisfaction than those without any of these outdoor spaces . The typical level of satisfaction with the outside environment of the studied schools falls below the average, which means the outdoor spaces are not well-planned in many of the studied schools.

Table 4-26 Occupants' Evaluation on Public Spaces of Studied School Buildings

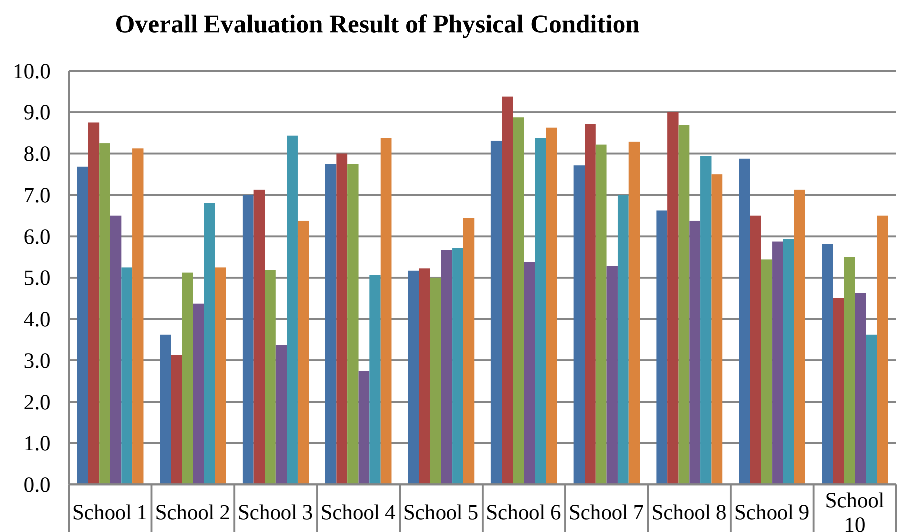
Public Spaces	**Poor**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Excellent**	**Mean value**	**Comments**
	Response rate (%)											
School 1	0.0	0.0	0.0	25	37.5	12.5	25.0	0.0	0.0	0.0	**5.4**	Acceptable
School 2	0.0	0.0	0.0	12.5	12.5	37.5	37.5	0.0	0.0	0.0	**6.0**	Acceptable
School 3	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25	37.5	25.0	**8.8**	very satisfactory
School 4	0.0	0.0	0.0	0.0	0.0	12.5	25.0	12.5	25	25.0	**8.3**	Satisfactory
School 5	0.0	11	0.0	11	22.2	22.2	22.2	11	0.0	0.0	**5.6**	Acceptable
School 6	0.0	0.0	0.0	0.0	0.0	12.5	12.5	25	37.5	12.5	**8.3**	Satisfactory
School 7	0.0	0.0	0.0	0.0	0.0	0.0	14.3	14.3	28.6	42.9	**9.0**	very satisfactory
School 8	0.0	0.0	0.0	0.0	12.5	25.0	25.0	25	12.5	0.0	**7.0**	Satisfactory
School 9	0.0	0.0	0.0	12.5	12.5	37.5	25.0	12.5	0.0	0.0	**6.1**	Acceptable
School 10	0.0	0.0	12.5	25	25	25.0	12.5	0.0	0.0	0.0	**5.0**	Acceptable

Table 4-27 Occupants' Evaluation on Outdoor Facilities of Studied School Buildings

Outdoor Facilities	**Non**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Plenty**	**Mean value**	**Comments**
	Response rate (%)											

School 1	0.0	0.0	0.0	25.0	37.5	37.5	0.0	0.0	0.0	0.0	**5.1**	acceptable
School 2	0.0	0.0	0.0	0.0	0.0	25.0	12.5	37.5	25.0	0.0	**7.6**	satisfactory
School 3	0.0	0.0	0.0	0.0	0.0	0.0	25.0	37.5	37.5	0.0	**8.1**	satisfactory
School 4	37.5	37.5	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1.9**	dissatisfactory
School 5	0.0	0.0	0.0	0.0	33.3	44.4	22.2	0.0	0.0	0.0	**5.9**	acceptable
School 6	0.0	0.0	0.0	0.0	0.0	0.0	25.0	25.0	25.0	25.0	**8.5**	very satisfactory
School 7	0.0	0.0	14.3	14.3	28.6	42.9	0.0	0.0	0.0	0.0	**5.0**	acceptable
School 8	0.0	0.0	0.0	0.0	0.0	0.0	12.5	25.0	25.0	37.5	**8.9**	satisfactory
School 9	0.0	0.0	0.0	12.5	25.0	37.5	25.0	0.0	0.0	0.0	**5.8**	acceptable
School 10	25.0	37.5	25.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	**2.3**	dissatisfactory

Figure 4-6 illustrates the overall ‘Physical Condition and Performance’ of the studied school buildings according to the assessment result of their users. It can be noticed from the chart that ‘Flexibility’ is the parameter that generates the less satisfaction in most cases. However, there is no consistency regarding the other parameters of physical performance and the results indicate the presence of compromise between several factors impacting the physical condition.



	School 1	School 2	School 3	School 4	School 5	School 6	School 7	School 8	School 9	School 10
Functionality	7.7	3.6	7.0	7.8	5.2	8.3	7.7	6.6	7.9	5.8
Circulation	8.8	3.1	7.1	8.0	5.2	9.4	8.7	9.0	6.5	4.5
Accessibility	8.3	5.1	5.2	7.8	5.0	8.9	8.2	8.7	5.4	5.5
Flexibility	6.5	4.4	3.4	2.8	5.7	5.4	5.3	6.4	5.9	4.6
Facility & Services	5.3	6.8	8.4	5.1	5.7	8.4	7.0	7.9	5.9	3.6
Furniture	8.1	5.3	6.4	8.4	6.4	8.6	8.3	7.5	7.1	6.5

Figure 4-6 Overall ‘Physical Condition and Performance’ Evaluation of Schools Occupants

4.4.2 Performance Measures and Overall Satisfaction Level

To measure the overall assessment/rating of the occupants on the performance of studied educational buildings, the earlier identified aspects of the building performance, which investigated and analyzed in this chapter of the research study, were considered as the basis for such assessments. The responses obtained from the occupants regarding each aspect of the performance assessment are presented in table 4-28. It can be seen from table 4-28 that the typical response to all performance aspects, which are the indicators of comfort and satisfaction in learning environments were rated poor to ordinary by the occupants. However, on the specific aspects of the performance few inconsistencies in occupants' responses are noticeable.

Table 4-28 Overall Satisfaction Results Regarding Performance Indicators of Studied Schools

Comfort & performance aspects	**Very Dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very Satisfied**	**Mean /10**	**Overall rank**
	Response rate (%)											
Temperature	0	3.75	6.25	15	15	16.25	20	15	8.75	0	**5.9**	acceptable
Ventilation	6.25	16.25	22.5	21.25	13.75	11.25	7.5	12.5	0	0	**3.9**	dissatisfactory
IAQ	0	1.25	5	8.75	16.25	21.25	16.25	18.75	8.75	3.75	**6.4**	acceptable
Natural light	0	0	0	2.5	12.5	21.3	18.8	26.3	13.8	5	**7.2**	satisfactory
Artificial light	0	0	0	2.5	5.0	16.3	17.5	28.8	17.5	12.5	**7.7**	satisfactory
Glare Condition	0	0	0	0	7.5	15	21.3	27.5	20	8.8	**7.6**	satisfactory
Outside view	6.3	13.8	15	22.5	18.8	12.5	8.8	2.5	0	0	**4.2**	dissatisfactory
Greenery View	5	11.3	18.8	23.8	16.3	15	7.5	2.5	0	0	**4.2**	dissatisfactory
Background noise	3.75	6.25	7.5	12.5	21.25	18.75	16.25	11.25	2.5	0	**5.4**	acceptable
Classroom noise	0	0	0	0	10	17.5	25	25	17.5	5	**7.4**	satisfactory
	Ambiguous	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Clear**		
	Response rate (%)											
Pathways	0	1.25	5	8.75	11.25	13.75	17.5	17.5	15	10	**6.9**	acceptable/ satisfactory
Signage	0	2.5	8.8	8.8	8.8	15	21.3	16.3	12.5	6.3	**6.6**	acceptable
	Very Uncomfort	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very Comfort**		
	Response rate (%)											
Public areas	0	1.25	1.25	8.75	12.5	18.75	21.25	12.5	13.75	10	**6.9**	acceptable/ satisfactory

Outdoor facility	6.25	7.5	6.25	6.25	12.5	18.75	12.5	12.5	11.25	6.25	**5.9**	acceptable
Facility & Furniture	0	0	0	2.5	10	22.5	25	17.5	11.25	11.25	**7.3**	satisfactory
Flexibility	1.25	6.25	10	15	27.5	22.5	13.75	3.75	0	0	**5.0**	acceptable
Classroom size-space/individual	0	12.5	7.5	6.25	12.5	23.75	16.25	18.75	11.25	2.5	**6.5**	acceptable
Circulation & Space outline	0	1.25	3.75	10	6.25	16.25	16.25	22.5	13.75	10	**7.1**	satisfactory

From Table 4-28, it can be concluded that ventilation condition is the most uncomfortable aspect of the building performance in the studied school buildings considering the 39 percent of response rates. Visual comfort (views to outside and greenery) and flexibility of learning spaces followed after respectively with 42 and 50 percent. Moreover, the analysis shows aspects including acoustic comfort (background noise), temperature and outdoor facilities were measured almost poor with 54, 59 and 59 response rate respectively, which indicate overall dissatisfaction to nearly satisfaction of the users with those factors. Natural and artificial lighting conditions, glare, classroom noise level and classroom outline as well as facility and furniture conditions are the factors that were rated the highest by school occupants with 72, 77, 76, 74 , 71 and 73 percent respectively , thus they were considered as the most "satisfactory" aspects of the studied school buildings. The overall assessment result substantiates the need of improvement in the planning and design of educational facilities, which ultimately results in enhancement of building performance and level of users' satisfaction and comfort. Table 4-29 shows the general level of occupants' satisfaction with their teaching and learning environments in the studied educational buildings.

Table 4-29 General Occupants Satisfaction with Their Learning Environments in Studied Schools

Overall Satisfaction	**Very dissatisfied**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Very satisfied**	**Mean value**	**Comments**
	Response rate (%)											
School 1	0	0.0	37.5	25.0	25.0	12.5	0.0	0	0	0	**4.1**	dissatisfactory
School 2	0	12.5	12.5	25.0	25.0	25.0	0.0	0	0	0	**4.4**	dissatisfactory
School 3	0	0.0	12.5	37.5	37.5	12.5	0.0	0	0	0	**4.5**	dissatisfactory
School 4	0	0.0	25.0	25.0	12.5	25.0	12.5	0	0	0	**4.8**	acceptable

School 5	0	0.0	33.3	22.2	22.2	22.2	0.0	0	0	0	**4.3**	dissatisfactory
School 6	0	0.0	0.0	0.0	0.0	37.5	12.5	0	0	0	**5.4**	acceptable
School 7	0	0.0	0.0	14.3	14.3	42.9	28.6	0	0	0	**5.9**	acceptable
School 8	0	0.0	25.0	50.0	25.0	0.0	0.0	0	0	0	**4.0**	dissatisfactory
School 9	0	12.5	25.0	25.0	25.0	12.5	0.0	0	0	0	**4.0**	dissatisfactory
School 10	0	0.0	37.5	12.5	37.5	12.5	0.0	0	0	0	**4.3**	dissatisfactory

As can be noticed from Figure 4-7, the occupants of studied schools are overally dissatisfied with their learning environments and their assessment ratings are mainly beween 4 to 5 on the 1-10 rating scale. Only the occupants of schoold 6 and 7 have scored their schools over average of 5 and the most satissfaction and comforet condition is identified in those two school buildings.

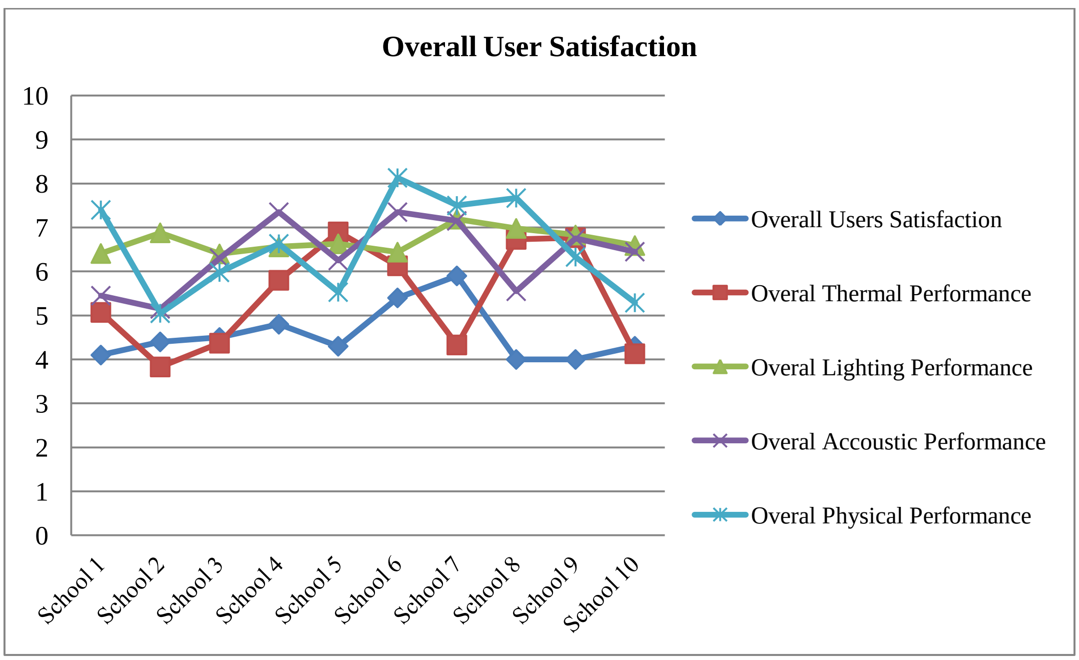


Figure 4-7 Overall Occupants' Satisfaction Results Regarding their Learning Environments

4.5 Experts Survey Procedure and Data Analysis

After conducting observations and school surveys to investigate and discover the expectations and needs of the users' in educational settings, which is qualitative and subjective in nature, along with precise analysis of design parameters of observed educational buildings, it is time to develop a design evaluation survey in order to collect the knowledge and qualification result of experts on several identified design variables. Professionals'/experts' knowledge is important and need to be employed in order to capture the qualitative, subjective and imprecise aspects of the problem. The collected experts' knowledge and analysis results were later contributed in creation of the database (knowledgebase) that was required for development of the "Design Evaluation Model" throughout this research study.

Since the layout and configuration of buildings have direct impact on environmental comfort factors such as, thermal, lighting and acoustic conditions as well as physical comfort, the layout and configuration of each observed case study school were first analysed. All 10 school plans were then categorized based on their configurations or shapes as presented in Table 4-5 in section 4.3.1 of this chapter, and performance evaluation of those school buildings conducted based on these defined categories later on in this section of the chapter.

In general the four primary factors that considered to be evaluated for school buildings design using experts' knowledge are thermal, lighting, acoustic and physical factors, from which several sub-factors are branch out and evaluated. For example; for thermal comfort factor, presence of ventilation condition, indoor temperature and air quality and exposure to the sun and wind need to be considered for evaluations. For lighting comfort factor, orientation of the classrooms and the whole building according to sun direction and the potential generated glare on work surfaces are important. Locations of noise producing activities inside and outside the educational facilities regarding the learning spaces and consideration of sound barriers (such as open spaces or corridors) against internal and external disturbing noises are the factors required to be investigated and analysed for assessment of acoustic comfort factor. Finally for the physical comfort assessment, parameters like the distance between several spaces inside a school building, the functionality, quality and outline of these spaces as well as the area considered for them all along with the accessibility of the overall facility are a number of considerable factors.

The purpose of the survey was to collect information based on the knowledge and experience of the design experts and specialist on how different identified design variables are perceived as impacting on the overall performance of the school buildings and their occupants' productivity accordingly and how those variables interact with each other in creating a well-designed educational facility. The survey was developed in 1-5 likert scale format representing poor to excellent qualitative terms for experts' evaluation of each design variable (Figure 4-8).

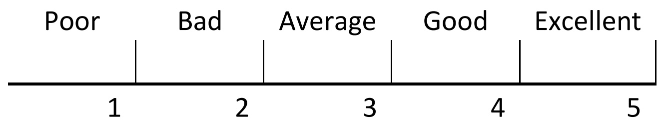


Figure 4-8 Developed 1-5 Likert Scale used for Experts Qualitative Assessment of Several Comfort Factors

It is important to mention that beside those parameters and design alternatives that identified and collected through the case study observation process, for the purpose of model development, all feasible and potential design alternatives covering the entire universe of discourse were investigated and identified to be considered in the analysis throughout experts' survey procedure. Thus, the results of the analysis can be incorporated in construction of the model that is capable of measuring various building typologies located in diverse geographical regions.

4.5.1 Quantitative Interpretation of Collected Qualitative Data

The obtained qualitative data from surveys transformed to numerical quantitative values using the following diagram similar to linear function of "fuzzy set". The average of respondents' evaluation is mapped on the diagram and transformed to numerical value between 0 and 1, which defines the membership degrees of the associated design factor according to "fuzzy set theory".

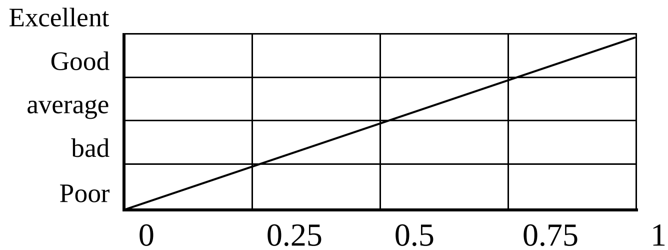


Figure 4-9 Conversion of Qualitative Performance Measures to Quantitative Values Using "Fuzzy" Linear Function

4.5.2 Assessment of Thermal Comfort Parameters by Experts

As mentioned in previous sections, for thermal comfort factor parameters like solar orientation, location of openings as well as ventilation conditions of classrooms need to be considered. Ventilation condition was measured based on predominant winds direction in relation to classrooms orientation as well as openings location in the classrooms.

To obtain experts evaluation on thermal condition of the sample schools, first the classrooms configurations divided to three categories based on their opening positions, which could be parallel, single or adjacent. Then eight solar orientations and eight predominant wind directions (N,S,E,W,NW.SW,NE,SE) were peered with each other making thirty two (4*8) combinations and analysed under those three categories. This finally created three combinations of 4*8 matrices (3*(4*8)= 96). These combinations are referred as the design variables of the thermal comfort factor. Afterwards, four design experts specialized in buildings thermal design area evaluated these design variables, on a 1-5 likert scale indicating (poor to excellent condition of each variable) as shown in Figure 4-9, and then their qualitative evaluation results were converted to numerical values using the linear function presented in Figure 3-1. The experts' evaluation results were later used to create fuzzy rule-base for each developed comfort module and the overall performance evaluation model (FIS model).

Experts' Qualifications Results on Schools Thermal Condition Variables

a- Evaluation of Ventilation Condition

Openings location paired with predominant wind direction and evaluated by four building thermal design specialists on the aforementioned scale (shown in Figure 4-9), and the qualitative evaluation were converted to membership degree (MD) values. The analyses were performed for three states of opening positions including, single façade, parallel façade and adjacent façade positions. Experts' qualitative analysis results for openings positioned on a single façade were collected and their representative numerical values are presented in table 4-30. As can be seen from Figure 4-9, numerical values for poor, bad, average, good, and excellent evaluation terms are represented by figures 1, 2, 3, 4, and 5 respectively.

Table 4-30 Experts' paired Comparison Analysis on Ventilation Condition of Spaces with a Single Opening

Single façade	Predominant Winds Direction							
Opening location	**North**	**South**	**East**	**West**	**Northeast**	**Northwest**	**Southeast**	**Southwest**
N	1,3,2,3	1,2,3,2	1,2,2,2	2,1,3,1	1,2,2,2	2,2,2,2	2,2,2,3	1,2,3,1
S	1,2,3,4	1,2,2,2	1,2,3,2	2,1,2,2	1,1,2,1	1,2,2,2	2,1,2,2	1,1,1,1
E	2,1,2,2	1,2,3,3	3,3,2,1	2,2,3,1	1.5,1,1,1	1.5,2, 1,1	1,1,1,1	2,1,1,1
W	2,3,1,1	1,2,2,2	3,2,1,4	2,2,1,2	1,2,1,1	1,1,0.5,1.5	2,1,1,1	0.5,1,1,1

The average of the values presented in each cell of the Table 4-30 was then calculated and the resulted value was mapped on the fuzzy linear function diagram and converted to MD value as shown in table 4-33. As an instance; the average value of cell (1*1) on table 4-30 containing figures 1,3,2,3 (poor, average, bad, average) is calculated as 2.25 and after conversion to MD the produced value is 0.45 as can be seen on table 4-33. The same procedure is applied for all the cells in all evaluation matrices.

In a similar manner, the analysis results of four specialists on ventilation condition represented by opening location and predominant wind direction in respect to each other, for learning spaces with openings positioned on the adjacent façades are presented in table 4-31.

Table 4-31 Experts' paired Comparison Analysis on Ventilation Condition of Spaces with Adjacent Openings

Adjacent Opening Location	Predominant Winds Direction							
	North	South	East	West	Northeast	Northwest	Southeast	Southwest
N& W	1,2,2,2	2,2,3.3	2,2,3,3	1,2,2,2	1,2,3,3	1,1,2,2	2,2,3,2	1,2,2,2
N& E	2,2,3,4	1,3,3,2	1,2,2,4	2,3,2,4	1,1,2,3	2,3,3,2	1,2,2,2	1,2,3,3
S& E	2,2,4,3	1,1,2,1	1,1,1,1	2,2,3,3	1,2,3,2	2,2,3,2	1,1,1,1	1,2,2,2
S& W	2,3,2,2	1.5,1,1,1	3,2,2,2	1,1,1,2	2.5,2,2,2	2,3,3,2.5	1.5,2,2.5,2	1.5,1,1,0.5

Again the average values and converted MD values are calculated for all ventilation variables (indicated by the ventilation matrix cells) and presented in Table 4-33. Once more, qualitative analysis of four experts on ventilation condition of spaces and classrooms with openings positioned on their parallel façades was performed and the numerical indicators of the assessments are presented in table 4-32.

Table 4-32 Experts' Paired Comparison Analysis on Ventilation Condition of Spaces with Parallel Openings

Parallel Opening location	Predominant Winds Direction							
	North	South	East	West	Northeast	Northwest	Southeast	Southwest
N & S	5,4,4,4	4,4.5,4,4	1,2,2,3	2,1.5,2,2	2,3,3,3	2.5,3,3,3	2,3,3,4	2.5,2,3,2.5
E & W	2,1,1,2	1.5,2,1,2	4,4,3,4	3,3,4,5	3,2,4,3	2,2.5,2,3	3,2,3,2	3,2,3,3

The averages of all assessments obtained from four design experts' qualifications on the studied design variables were calculated and the outcomes of calculations were then converted to membership degree values and those MD values were finally recorded in table 4-33.

Table 4-33 Average of Experts' Analysis Results Converted to MD Values

Opening Position & location	Predominant Winds Direction							
	North	South	East	West	Northeast	Northwest	Southeast	Southwest
Single								
North	0.45	0.40	0.35	0.35	0.35	0.40	0.45	0.35
South	0.50	0.35	0.40	0.35	0.25	0.35	0.35	0.20
East	0.35	0.45	0.45	0.40	0.22	0.28	0.20	0.25
West	0.35	0.35	0.50	0.35	0.25	0.20	0.24	0.18
Adjacent								
N& W	0.35	0.50	0.50	0.35	0.45	0.30	0.45	0.35
N& E	0.55	0.45	0.45	0.55	0.35	0.50	0.35	0.45
S& E	0.55	0.25	0.20	0.50	0.45	0.35	0.20	0.35
S& W	0.45	0.23	0.45	0.25	0.43	0.53	0.40	0.20
Paralleled								
N&S	0.85	0.83	0.40	0.35	0.55	0.58	0.60	0.50
E&W	0.30	0.33	0.75	0.75	0.60	0.48	0.50	0.55

As can be noticed from table 4-33 the best design variables are those obtained 0.85 and 0.83 average scores (MDs) of experts, which are related to schools having openings in opposite position to each other and classrooms oriented toward wind direction in which the possibility of natural cross ventilation through two openings is provided.

b. Temperature

Solar penetration and air movement inside spaces are the most important factors that define the temperature condition of a learning space in school building during the cold and warm seasons throughout the year. For warm seasons, the presence of the air flow inside the interior spaces like classrooms provides a pleasant temperature condition and allows concentration and better performance. Evaluation of the air movement condition in the learning spaces requires investigation of openings location and position on the building envelope and the prevailing wind direction, which is similar to the approach practiced for evaluation of ventilation condition. Allowing the circulation of the air inside the spaces not only ventilates the environment but also regulate the air temperature during the warm seasons.

For cold season period that is also more extensive according to Edmonton weather condition, assessment of solar penetration condition inside the learning environments is a key factor. For this purpose, first different space outlines as studied in section 1.5 of this chapter, were categorized in three classifications including deep, square and extensive plans, then these classified space configurations studied regarding to different locations of openings on the facade in order to determine the existence of solar penetration and its extend. The pair comparison analysis was conducted by four design experts in a similar way to the previous sections and the results are shown in table 4-34.

For simplicity purposes, the numerical indicators of the collected qualitative assessments of the experts in addition to the average values of them were calculated by the researcher and only the finally obtained membership degree (MD) values are presented in the following sections.

Table 4-34 Experts' Evaluation Result on Temperature Condition in Cold Season Calculated as MD Values

Space Configuration	Opening Location			
	North	South	East	West
Deep plan	0.25	0.77	0.75	0.72
Square plan	0.42	0.87	0.8	0.75
Extended plan	0.45	0.9	0.82	0.82

As can be seen from table 4-34, those spaces having space configuration of square and extended plan and openings located on their south façade provide larger area of solar penetration and heat gain and accordingly they provide warmer temperature condition in winter compared to the other alternatives. However, this can be a negative factor if overheating occurs according to the experts, and the corrective solutions such as implementation of adjustable blinds or shielding windows need to be considered.

Table 4-35 Experts' Evaluation Result on Temperature Condition in Warm Season Calculated as MD Values

Space Configuration	Opening Location			
	North	South	East	West
Deep plan	0.85	0.75	035	0.37
Square plan	0.82	0.72	0.25	0.3
Extended plan	0.80	0.72	0.22	0.27

In summer season, buildings with east and west exposure to sun will experience over heating periods during the warm season so the combination of these variables with any kind of space configuration obtained the lowest ranking of the experts related to the comfort level that they provide and their desirability for the building users accordingly as presented in table 4-35. According to experts the southern façade is always the most optimal option for opening location, and using overhang/window shields can help to minimize overheating problem in the summer while harvesting the best natural day-light as well.

4.5.3 Assessment of Lighting Comfort Parameters by Experts

The combination of several parameters defined the lighting design variables. As can be seen in the following tables (tables 4-36 to 4-40), these combinations were tabulated for qualitative assessment of design specialist. For each of the lighting design variables, the qualitative results of experts' assessment were then converted to the numerical values, which are the representative of their membership degrees (MDs) in a way similar to the fuzzy set theory.

Experts Qualifications Results on Schools' Lighting Comfort variables

As can be seen, there are too many factors to be evaluated for the lighting condition of educational spaces, and the combination of these factors will make numerous situation to be considered. To make the assessments more realistic feasible and effective in terms of lighting comfort of the school occupants, the results of the walkthrough observations on the case study schools are implemented in the evaluation procedure. To do so, first the typology of the spaces regarding the orientation and geometry of the classes, location of the windows in each space and their position in relation to each other, typical number of openings used for each space, and their distribution on the walls, as well as common size and shape considered for the openings, are carefully analyzed and categorized for the observed schools in the Edmonton area.

After finalizing analysis, the identified categories of the studied space topologies were formulized and prepared for experts' evaluations. For example in terms of schools geometry the most used shapes are square and rectangular with seats alignment alongside the length of the classrooms that is defined as elongated rectangular shape. This process is applied for all the lighting comfort factors in order to drive the final lighting design variables to be evaluated by the design specialists in this area.

The first combination of the factors is opening position and location in relation to each other. As there are three positions of openings including, single, parallel and adjacent windows, and four locations of them on envelope including north façade, south façade, east and finally west facade, the combinations would be;

Table 4-36 Ten Combinations of Opening Position and Opening Location

Opening Position	**Combinations with the Opening location**			
Single	North	South	East	West
Adjacent	N & E	S & E	N & W	S & W
Parallel	N & S	E & W		

As can be seen from table 4-36 we have ten combinations for openings position-location variables. These ten variables were then paired with two geometry variables, which are square and rectangular shapes, creating twenty variables as a result (table 4-37), and then analyzed in combination with eight different space orientation by experts as shown in table 4-38.

Table 4-37 Combinations of Opening Position-Location Variables with Space Geometry

Space Geometry	**Combination with 10 predefined opening position-location variables**									
Square	Single -N	Single -S	Single -E	Single -W	Adjacent - N & E	Adjacent - S & E	Adjacent - N & W	Adjacent - S & W	Parallel - N & S	Parallel- E & W
Rectangular	Single -N	Single -S	Single -E	Single -W	Adjacent - N & E	Adjacent - S & E	Adjacent - N & W	Adjacent - S & W	Parallel - N & S	Parallel- E & W

From table 4-37, it can be noted that there are twenty different variables created in total that need to paired with classroom orientation factor constructing 20*8 combinations representing 160 different design variables related to natural lighting. These variables then qualified using experts' knowledge and the average results were converted to MD values and recorded in Table 4-38.

Table 4-38 Experts' Analysis Results of Natural Lighting Variables of Case Study Schools

Geometry & Opening Position		**Opening Location**	**Space Orientation According to Sun**							
			N	**S**	**E**	**W**	**N.E**	**S.E**	**N.W**	**S.W**
Square	**Single**	**N**	0.67	0.42	0.29	0.42	0.46	0.42	0.46	0.50
		S	0.54	0.25	0.17	0.00	0.25	0.33	0.13	0.17
		E	0.33	0.35	0.40	0.42	0.42	0.22	0.20	0.25

		W	0.23	0.25	0.35	0.38	0.40	0.20	0.18	0.23
	Adjacent	**N&E**	0.38	0.13	0.29	0.50	0.34	0.38	0.42	0.71
		S&E	0.89	0.85	0.92	0.90	0.80	0.83	0.83	0.85
		N&W	0.17	0.29	0.46	0.34	0.38	0.25	0.63	0.29
		S&W	0.08	0.25	0.21	0.00	0.21	0.13	0.33	0.17
	Par allel	**N&S**	0.69	0.58	0.55	0.40	0.42	0.27	0.29	0.27
		E&W	0.60	0.55	0.55	0.35	0.38	0.40	0.35	0.33
Rectangular	**Single**	**N**	0.67	0.50	0.38	0.54	0.46	0.46	0.42	0.50
		S	0.58	0.42	0.21	0.00	0.21	0.13	0.33	0.25
		E	0.25	0.08	0.33	0.42	0.29	0.29	0.21	0.21
		W	0.17	0.29	0.42	0.50	0.29	0,29	0.38	0.38
	Adjacent	**N&E**	0.25	0.13	0.34	0.46	0.34	0.38	0.33	0.38
		S&E	0.08	0.25	0.25	0.08	0.29	0.04	0.25	0.17
		N&W	0.29	0.63	0.08	0.17	0.29	0.21	0.33	0.59
		S&W	0.46	0.17	0.21	0.13	0.54	0.25	0.34	0.29
	Par allel	**N&S**	0.63	0.38	0.13	0.08	0.25	0.13	0.25	0.17
		E&W	0.08	0.08	0.29	0.58	0.13	0.38	0.21	0.25

As can be noticed from table above, those variables with evaluation score above 0.6 provide the highest comfort in terms of natural lighting condition within the learning spaces. One example of these variables can be found on 10*3 cell of the table scored 0.92 and indicated with "Square-shaped" classrooms with "adjacent" openings that are located on 'South' and 'East' facades of the classrooms having "Eastward" orientation according to sun direction. The other successful combination can also be found in a similar manner. It is noticeable from experts analysis that the most successful alternative in terms of natural lighting condition are those having the east-west orientation according to the sun direction and openings on either south or east faced rather than the other facades, which allows the better utilization of the natural day light inside the classrooms during the day time. Furthermore, those classrooms with square or elongated-rectangular layouts are more favorable in terms of lighting comfort as they provide more uniform distribution of sun-light rather than those with deep, elevated-rectangular space layouts with an uneven lighting distribution.

Table 4-38 is considered all possible combinations along with those observed during the schools observation process. These combinations were later utilized in determining and developing the “rule-base” for FIS lighting evaluation model.

Glare and Views are the other important factors need to be considered for lighting comfort evaluation of the educational spaces in addition to the natural lighting condition. These factors are being affected by parameters including; amount and distribution of openings on the building envelope, along with the glass types used for these openings for glare condition evaluation as well as openings sizes and shapes for view/visual condition. As previously described in section 4.2, the standard definition and several states/sub factors of each of abovementioned (glare, view) factors was analyzed and categories base on experts knowledge and review of literature and the paired comparison matrix is developed for experts' assessment. Number of openings and their distribution are paired to represent glare condition on working surfaces considering glass transparency level as well. Nine variables associated with “glare condition” were constructed from the combination of openings amount and distribution (3*3) for each type of glass (transparent and tint), which makes 18 (2*(3*3)) combinations totality. These combinations have been qualified then by design experts. Table 4-39 and 4-40 show the average score of experts evaluations converted to MD values.

- ***<u>For Transparent Glass Type:</u>***

Table 4-39 Experts’ Analysis Results of Glare Condition of Studied Schools Considering Transparent Glass Type

Number of Openings	**Openings Distribution**		
	Close	**Regular**	**Far apart**
Few (1-3)	0.25	0.55	0.45
Enough (3-5)	0.30	0.75	0.55
Many (5-8)	0.35	0.70	0.55

It can be noticed from 4-39 that those variables having MD value of 0.75 and 0.70 created from the combination of three to eight (enough to many) number of openings with regular distribution on the façade provide the highest comfort condition with regard to glare.

- ***For Tint Glass Type:***

Table 4-40 Experts' Analysis Results of Glare Condition of Studied Schools Considering Tint Glass Type

Number of Openings	Openings Distribution		
	Close	**Regular**	**Far apart**
Few (1-3)	0.35	0.63	0.50
Enough (3-5)	0.42	0.82	0.63
Many (5-8)	0.45	0.80	0.60

Table 4-40 shows the experts' assessment results of glare condition considering tinted glass types. It is noticeable from table that the results are slightly improved using this type of glass. To evaluate "view condition" of the learning space, openings size and shapes are also paired making another 3*3 combination of view related variables and each of those variables were qualified by design specialists and the average score of evaluations representing the membership degrees (MDs) associated with each variable were recorder in Table 4-41 .

Table 4-41 Experts' Analysis Results of View Condition of Studied Schools (3*3 Combinations)

Opening shape (H/W)	Openings size (window/wall ratio)		
	Small (0-0.4)	**Average (0.3-0.6)**	**Large (0.5-0.8)**
Square (1)	0.25	0.50	0.52
Horizontal (2/3)	0.15	0.23	0.45
Vertical (3/2)	0.22	0.60	0.62

As can be seen from table 4-41, those variables with average score (MD) of 0.6 and 0.62 provide the best view conditions within the learning spaces. These variables are created from the combination of vertical-shaped openings with relatively average to large sizes on to the facade.

4.5.4 Assessment of Acoustic Comfort Parameters by Experts

Regarding the acoustic comfort in classrooms, school outline and classrooms configurations still play important roles and need to be considered as influencing parameters. The typology of school outline can determine the location of noise-generating spaces in relation to the classrooms locations and their distances from the classrooms, which need to be minimised to reach the optimal acoustic design.

Similar to evaluation process of thermal and lighting design variables, acoustic design variables were also analysed and evaluated by qualification of three experts specialized in building acoustic design. To do so, a group of acoustic design variable were defined and listed for experts evaluations based on the relationship between the location of noise generating sources and classrooms, as well as the existence of noise barriers or distance between the noisy area and classrooms. The qualitative evaluations of specialist were converted to the numerical values and the average of these numerical values was calculated and recorded for each acoustic design variable as presented in following sections.

Experts Qualifications Results on Schools' Acoustic Comfort Variables

As mentioned above, design layout of each case study schools and the way it defines several spaces arrangements inside school buildings with regard to the distance of the noisy activities from learning spaces either with consideration of the noise barrier (to seal the disturbing noises) or without any barriers are all potential factors that impact the background noise level of the educational settings. These factors were paired to construct two (3*6) matrix of acoustic design variables representing several alternatives to be evaluated by acoustic design specialists. The results of qualitative analysis performed by four experts in acoustics area were converted to MD values and outcomes are presented in Table 4-42 and 4-43. Table 4-42 shows the evaluation results with consideration of the sound hindering areas or noise barriers between learning spaces and the noise generating sources.

- *Existence of Noise Barrier between Learning Spaces and Noise Generating Sources;*

Table 4-42 Evaluation Results of Experts on Acoustic Condition based on Background Noise Level Variables with Consideration of Noise Barrie

Distance from Noise	**School Geometry**					
	Square	**Rectangle (elongated)**	**Rectangle (elevated)**	**L-shape**	**U-shape**	**H-shape**
Close	0.35	0.33	0.45	0.30	0.20	0.25

Average	0.60	0.55	0.70	0.50	0.40	0.45
Far	0.75	0.65	0.85	0.60	0.50	0.55

As can be noticed from table 4-42, those schools with either square or rectangular geometry allowing for average to far distance between noise generating areas and learning spaces provide better acoustic condition by transferring the lowest amount of background noises to the learning areas that permits better concentration. Table 4-43 shows the analysis results without allowing for sound hindering areas/barriers between learning spaces and the noise generating sources.

- *No existence of Noise Barrier between Learning Spaces and Noise Generating Sources;*

Table 4-43 Evaluation Results of Experts on Acoustic Condition based on Background Noise Level Variables without Consideration of Noise Barrie

Distance from noise generating sources	**School Geometry**					
	Square	**Rectangle (elongated)**	**Rectangle (elevated)**	**L-shape**	**U-shape**	**H-shape**
Close	0.25	0.20	0.35	0.17	0.10	0.15
Average	0.42	0.35	0.63	0.33	0.25	0.30
Far	0.65	0.50	0.75	0.45	0.35	0.42

Table 4-43 also shows that the best alternatives are those schools having square or rectangular shaped layout with average to far distance between noise generating areas and learning spaces since they transfer the lowest amount of background noises to the learning areas and offer better learning and teaching environments for their users.

Because of lack of information about factors such as material type and reverberation time, those factors were not evaluated associated with the case study school buildings; however they were generally analyzed and evaluated disregarding any specific case based merely on the knowledge acquired from literature, acoustic design guides, as well as experts' interviews. The results of analysis were implemented in the developed FIS model. In general, sound absorbing materials have higher qualification rank and were given higher value of MD in experts' evaluations that non-sound absorbing ones that were evaluated as poor material regarding acoustic condition. These ranking were implemented in the model using MD values obtained from the analysis. The same procedure was applied for reverberation time. Finally the two factors were paired and their combination generated six variables (2*3 matrixes) under three categories of classroom configurations. These variables were qualitatively analyzed and evaluated by experts and the results of analysis were converted to numerical values of membership degrees (MD) and presented in following tables (Table 4-44, 4-45, 4-46).

- Classrooms with Deep Plan Configuration;

Table 4-44 Experts' Analysis Results of Classroom Noise Level Variables

Material Quality	**Reverberation Time**		
	Unfavourable	**Acceptable**	**Ideal**
Sound- absorbing,	0.35	0.55	0.75
None-sound absorbing	0.10	0.25	0.50

- Classrooms with Square Plan Configuration;

Table 4-445Experts' Analysis Results of Classroom Noise Level Variables

Material Quality	**Reverberation Time**		
	Unfavourable	**Acceptable**	**Ideal**
Sound- absorbing,	0.50	0.75	0.95
None-sound absorbing	0.22	0.45	0.65

- Classrooms with Extended Plan Configuration;

Table 4-46 Experts' Analysis Results of Classroom Noise Level Variables

Material Quality	**Reverberation Time**		
	Unfavourable	**Acceptable**	**Ideal**
Sound- absorbing,	0.55	0.80	0.97
None-sound absorbing	0.25	0.50	0.70

As can be seen from results of evaluations shown in tables above, the best alternatives can be found on cell (1*3) of each evaluation matrix, which is the representative of a classroom with sound-absorbing material type and ideal reverberation time inside the space.

4.5.5 Experts Assessments of Schools' Physical Comfort Variables

To evaluate the physical condition of the school facilities, the previously identified factors that have impact on physical condition of the learning spaces (section 4-2) were investigated during observation stage of the study and then evaluated by design specialist in this area. Three experts were asked to answer the evaluation questionnaire regarding space functionality, flexibility, accessibility and circulation facilities, as well as condition of other services and facilities such as outdoor and public areas. For this reason, the data obtained from observation of the case study schools were analyzed and three matrices each representing six (2*3) physical design variable/alternatives were developed and the pair comparison analysis were performed by experts using the similar approach as previous sections.

The first part of the evaluation is related to classrooms functional/physical condition and comfort. For this part of the assessment classrooms size and outline are considered as follow.

Table 4-47 Experts' Qualification Results on Space Functionality Variables

Classroom outline	**Classroom size**		
	Small	Regular	Large
Poor designed	0.05	0.25	0.50
Well designed	0.55	0.75	0.90

It is noticeable from the average of experts' responses as presented in Table 4-47, those classrooms with larger area and well-designed space outline provide better physical and functional condition for their users.

To evaluate accessibility condition and circulation facilities within a school setting, pathways, signage and travel distance between several functional spaces were evaluated and the resulted MD values are shown in table 4-48.

Table 4-48 Experts' Qualification Results on Accessibility and Movement Variables

Circulation facilities	**Travel distance**		
	Close	Reasonable	Far
Ambiguous	0.50	0.25	0.10
Clear	0.95	0.75	0.55

According to evaluation results presented in Table 4-48, the best alternative is the one achieved the MD value of 0.95, which indicates a school with clear circulation facilities such as pathways and signs and providing lowest travel distance between spaces.

In order to assess the condition of overall facilities and services in learning environment, public spaces and outdoor areas have taken into consideration and the generated alternatives from their combination were analyzed and evaluated as shown in Table 4-49.

Table 4-49 Experts' Qualification Results on Building Facility & Services

Public Facility and Services	**Outdoor Facility and Services**		
	Absent	Enough	Abundant
Poor	0.15	0.45	0.55
Satisfying	0.45	0.65	0.75
Excellent	0.50	0.90	0.95

It is apparent from the results, summarized in Table 4-49, that the best design alternatives are those which consider satisfactory well-designed public spaces as well as enough outdoor facilities and services for their users.

4.5.6 Summary of Survey Responses

To conclude the experts survey procedure, previously developed database of observations including a summary of environmental and physical characteristics of ten observed schools was distributed between four design experts for their review and analysis. The developed database of ten case study schools is shown in table 4-50.

Table 4-50 the List of Environmental and Physical Characteristics of ten Sample Schools

	School ID									
Detailed Sub-factors	**# 1**	**# 2**	**# 3**	**# 4**	**# 5**	**# 6**	**# 7**	**# 8**	**# 9**	**# 10**
Plan Type	L	Rect.	H	Square	Rect.	Square	Rect.	Rect.	L	U
Thermal Factor										
Opening position	S & A	S & A	P & A	S & A	S & A	S & A	S & A	P & A	S & A	S&P&A
Opening location	W- S- N&W- S&W- S&E	W- N&W- S&W	E&W- N&E- N&W- S&E- S&W	E-W- N&E- S&E- N&W S&W	E-N&E- S&E	N-S- N&E- N&W- S&E- S&W	W- N&W- S&W	N&S- S&E	E- N- N&W- N&E- S&E	N- E- S- N&S- N&E- N&W- S&E- S&W
Building orientation	W=>E	S=>N	S=>N	S=>N	S=>N	W=>E	N=>S	S	E=>W	E=>W
Lighting Factor										
Class Orientation	N- E	N-E	N-S-E	N- W	W	N	E-N	S	S- W	W-N
Class Geometry	S & R	R & S	S	S & R	S & R	S & R	S & R	R	R	R & S
Opening position	S & A	S & A	P & A	S & A	S & A	S & A	S & A	P & A	S & A	S&P&A
Opening size	Large	Average	Small	Average	Average	Average	Small	Average	Large	Small
Opening distribution	Close	Regular	Far	Regular	Regular	Far	Far	Regular	Close	Far
# of Openings/class	2-3	2- 3	3-4	2-3	2-3	3-4	2-3	3-4	3-4	2-3-4
Shape of opening	Elong.R	Elong.R	R	Elong.R	Elong.R	R	Elong.R	Elong.R	Elong.R	R, S
Acoustic Factor										
School Geometry	C	B	E	A	B	A	B	B	C	D
Distance from noise	Ave.	Close	Close	Far	Ave.	Ave.	Far	Close	Ave.	Close
barriers existence	No	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes
Material Quality	None	None	Semi	Absorb	None	Semi	Semi	None	Absorb.	Absorb
Physical Factor										
Travel distance	Close	Far	Ok	Close	Ok	Close	Close	Close	Ok	Far
Classroom size	Large	Small	Reg.	Large	Reg.	Large	Reg.	Reg.	Large	Small
Classroom outline	Well	Poor	Well	Well	Poor	Well	Well	Well	Well	Well
Circulation facilities	Clear	Clear	Unclear	Clear	Clear	Clear	Clear	Clear	Unclear	Clear
Public spaces	Ok	Ok	Excel.	Excel.	Ok	Excel.	Excel.	Excel.	Ok	Ok
Outdoor spaces	Enough	Ample	Ample	Absent	Enough	Ample	Enough	Ample	Enough	Absent

An example of each expert's evaluation result on one of the case study schools as well as a list of overall experts' evaluation of all case study schools based on the main comfort factors are presented in Tables 4-51 and 4-52 respectively.

Table 4-51 Evaluation Results on Comfort Conditions of an Example School by Each Experts

School 1	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1	1.5	1	1.5	1.25	0.25
Lighting Condition	0.5	1.5	1	1	1	0.2
Acoustic Condition	1	2	2	2	1.75	0.35
Physical Condition	4	4.5	4.5	5	4.5	0.9
Overall Performance	1.63	2.38	2.13	2.38	2.13	0.43

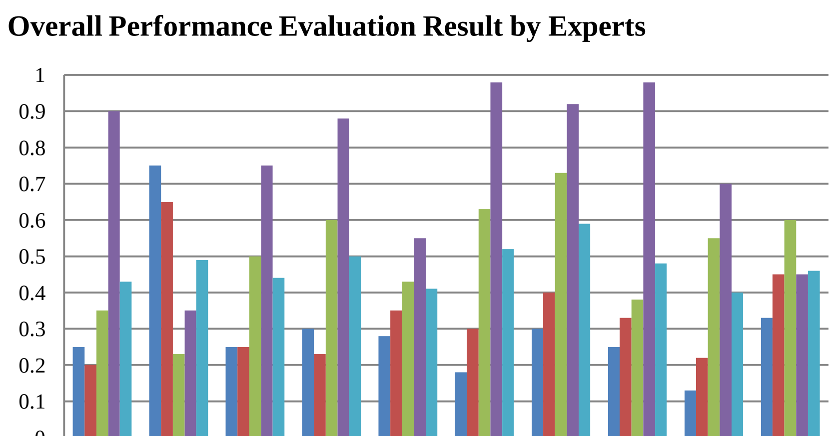
From Table 4.51, we can see that physical condition of school#1 has obtained the highest overall score of all experts (4.5), which falls between good and excellent on the 1-5 likert scale and translated to the numerical MD value of 0.9 on fuzzy 0-1 scale. The other comfort conditions are ranked almost poorly by the experts and the overall performance of the school is fallen below the average and close to "Bad" value on the 1-5 likert scale. This procedure is completed in order to evaluate the comfort conditions and overall performance of all studied schools and the final results are presented in Table 4-52.

Table 4-52 Average Assessment Score of Experts on all Comfort Conditions and Overall Performance of Ten Studied Schools all Converted to MD values

School ID	School Category/ Typology	Overall Experts' Qualification of Comfort Factors				Overall Performance MD	Overall Rank
		Thermal Condition	Lighting Condition	Acoustic Condition	Physical Condition		
School 1	C	0.25	0.20	0.35	0.90	**0.43**	**8**
School 2	B	0.75	0.65	0.23	0.35	**0.49**	**4**
School 3	B	0.25	0.25	0.50	0.75	**0.44**	**7**
School 4	A	0.30	0.23	0.60	0.88	**0.50**	**3**
School 5	B	0.28	0.35	0.43	0.55	**0.41**	**9**
School 6	A	0.18	0.30	0.63	0.98	**0.52**	**2**
School 7	B	0.30	0.40	0.73	0.92	**0.59**	**1**
School 8	B	0.25	0.33	0.38	0.98	**0.48**	**5**
School 9	C	0.13	0.22	0.55	0.70	**0.40**	**10**
School 10	D	0.33	0.45	0.60	0.45	**0.46**	**6**

From Table 4-52, the best school design according to experts' evaluation is the one identified as school 7, which achieved the overall rank of 1 out of 10 schools.

The overall performance of this school is measured as 0.59 on 0-1 MD scale. Although, this school facility provides the highest 'Physical' and 'Acoustic' comfort condition for its occupants, but we can see from the results that the 'Lighting' and 'Thermal' comforts of this school fall too far behind those of School 2, which provides the most comfortable 'Lighting' and 'Thermal' conditions but achieves 4th rank because of its poor 'Acoustic' and 'Physical' design. This example indicates that; there is always compromises between buildings design comfort factors in choosing the most successful and optimized alternative. To address this issue a weighing system of the variables was developed and distributed between experts asking them to determine the relative importance of those variables and their associated comfort conditions as presented in section 4.2.5. Assigned rates were later implemented in determining the weights during generation of FIS Model rule-base.



	School 1	School 2	School 3	School 4	School 5	School 6	School 7	School 8	School 9	School 10
Thermal Performance	0.25	0.75	0.25	0.3	0.28	0.18	0.3	0.25	0.13	0.33
Lighting Performance	0.2	0.65	0.25	0.23	0.35	0.3	0.4	0.33	0.22	0.45
Acoustic Performance	0.35	0.23	0.5	0.6	0.43	0.63	0.73	0.38	0.55	0.6
Physical Performance	0.9	0.35	0.75	0.88	0.55	0.98	0.92	0.98	0.7	0.45
Overall Performance	0.43	0.49	0.44	0.5	0.41	0.52	0.59	0.48	0.4	0.46

Table 4-10 Overall 'Performance Evaluation' of the Comfort Factors by Four Design Specialists

Figure 4-10 shows the overall performance of four comfort factors as well as overall school design performance according to the evaluation results obtained from four design specialists in educational facility design area. Overall

“Performance Factor” of the case study schools evaluated on one by one basis by all the experts’ are also listed as presented in table 4-53.

Table 4-53 Overall Performance Ranking of the Sample Schools by Four Design Specialists

School ID	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
School 1	1.63	2.38	2.13	2.38	2.13	0.43
School 2	2.25	2.25	2.75	2.63	2.47	0.49
School 3	2.25	2.38	2.25	1.88	2.19	0.44
School 4	2.25	2.75	2.50	2.50	2.50	0.50
School 5	1.88	2.38	1.88	2.00	2.03	0.41
School 6	2.38	2.63	3.00	2.38	2.59	0.52
School 7	3.00	3.00	3.13	2.63	2.94	0.59
School 8	2.25	2.63	2.25	2.50	2.41	0.48
School 9	2.00	1.75	2.25	2.00	2.00	0.40
School 10	2.63	2.25	2.25	2.00	2.28	0.46

As mentioned earlier in this chapter, the final evaluation and qualification results of the experts’ on several design aspects of the educational buildings and the database developed accordingly by the researcher based upon the experts knowledge were then used to develop the Fuzzy Expert System (FIS) model and construct the rule-base of the model for the purpose of this study, which is the establishment of a proper school design evaluation system. The comprehensive procedure of FIS model development using the data collected and analyzed in this chapter is presented in chapter five of the research study.

Chapter 5

Development of Performance Evaluation Model Using Fuzzy Expert System (FES)

5.1 Introduction

Now that the qualitative and subjective aspects of the design is studied and analyzed using experts knowledge and the analysis results are collected and recorded as a database (knowledgebase) of educational buildings design it is the time to develop a performance and design evaluation model with optimisation of environmental and physical comfort parameters. The collected experts' knowledge must be employed in development of the model in order to avoid the potential subjectivity of the data collected during the occupants' survey, observation procedure and the analysis performed by the researcher.

To reach the optimal design of the parameters in order to enhance the learning environments for occupants, the investigated and collected data from e-surveys and observations is analyzed and the evaluation Model/Framework is developed using expert knowledge. The developed model can be used as an evaluation tool, in order to accurately assess the performance of the learning environments in the early designs phase. Additionally, it could be used to identify the factors that are having the largest impact on performance factor, so that novel design measures for new school buildings can be focused accordingly.

5.2 Identification of Input Factors for Development of FES Model in MATLAB

Among questions from different developed questionnaire sets, common items related to satisfaction with comfort aspects at the both classroom level and overall school facility level were selected for this study. These selected comfort aspect, which were considered as the independent variables of the study defined the dependent variables including; occupants' satisfaction with the comfort variables of the facility, and their overall work performance. The variables for this study will be discussed in this section. General ideas of the different factors that have an impact on performance were determined through casual discussions with professionals that are experienced through high performance design practices. A number of different factors that are important to consider in optimizing performance were identified and categorized according to the parameters of the comfort that they fall under. After the main factors that are perceived as having an impact on performance were identified and categorized, a survey was given to experts to measure the relative importance of each factor and develop standard definitions for each input factor in the model as presented in section 4.2 of Chapter 4. The results of these analyses were used as a basis in developing the fuzzy membership functions in the expert system, as well as developing the rule base.

Using the interviews and surveys, twenty three different input factors under four main categories of comfort factors were identified as having an impact on the performance of the school design, which are summarized in Table 5-1.

Table 5-1 Identified Input Factors for the Building Performance Evaluation Model

Input Category	Input Factor
Thermal Comfort	Building Orientation
Thermal Comfort	Predominant wind direction
Thermal Comfort	Opening Location
Thermal Comfort	Opening Position
Lighting Comfort	Classroom Orientation
Lighting Comfort	Classroom Geometry(L/W)
Lighting Comfort	Opening Location
Lighting Comfort	Opening Position
Lighting Comfort	Opening Size(window/wall)
Lighting Comfort	Opening Distribution
Lighting Comfort	Glass Transmissivity
Lighting Comfort	Number of Openings
Lighting Comfort	Opening Shape(Height/Width)
Acoustic Comfort	School Geometry(L/W)
Acoustic Comfort	Distance from Noise G.S
Acoustic Comfort	Material Quality
Acoustic Comfort	Reverberation Time
Physical Comfort	Distance between spaces(travel distance)
Physical Comfort	Classroom size(# of seats)
Physical Comfort	circulation facility(pathways, ramps)
Physical Comfort	Public spaces
Physical Comfort	Outdoor Spaces
Physical Comfort	Classroom Outline

Developed model attempted to incorporate these factors into the evaluation of design performance, such that to be representative of occupants comfort condition and efficiency.

As mentioned in previous chapter, beside those parameters and design alternatives that identified and collected through the case study observation process, for the purpose of FES model development, all feasible and potential design alternatives covering the entire universe of discourse were investigated, identified and considered in the analysis throughout experts' survey procedure. Therefore, the results of the analysis are incorporated in construction of the model that is capable of measuring various building typologies located in diverse geographical regions.

5.2.1 Comfort Condition Categories

As previously studied in literature review chapter, several factors contribute to occupant satisfaction with an educational building's environmental condition including; daylight, visual, thermal, acoustics, and physical comfort.

Thermal Comfort Parameter

The orientation of the school buildings according to the solar orientation and wind direction, building shape or geometry as well as the openings locations and sizes are the essential variables which can define the natural ventilation and the temperature condition of the interior spaces.

Lighting Comfort Parameter

The parameters uses for lighting comfort evaluation of the schools are including the geometry/ outline of classrooms and other learning spaces and their orientation in relation with the sun direction in addition to location and size of the openings on the wall surfaces.

Acoustic Comfort parameter

To evaluate the acoustic comfort in classrooms, school plan geometry, which defines the arrangement of the classrooms and other learning spaces as well the location and distance of noise generating spaces in relation to the learning spaces are the key factors. These factors create the design decision-making variables for school design problem which should be assessed and ranked by specialized experts in this area.

Physical Comfort Parameter

The main parameters for physical comfort evaluation are including distance between different functional spaces, size of classrooms and other spaces, and density of spaces. These factors along with pathways and outside walkways conditions within school buildings have a great impact on circulation and movement inside the spaces and also travel comfort between the spaces. Areas such as public spaces and outdoor spaces should also be considered in the evaluations. The layout design of spaces is also an important factor in assessing the space density and overcrowding possibility inside those spaces.

5.3 Knowledgebase (Database) for Development of FES Model

As explained earlier in previous chapter, to obtain the data required for development of the Fuzzy Expert System (FES) model, the experts' survey procedure was employed. The important factors which constructed the primary modules of the FES model (thermal, lighting, acoustic, and physical modules) and their input variables were identified based on review of the literature accompanied by the results obtained from experts' survey and interview procedure.

After determination of the input variables for the FES model, these variables investigated and examined in several existing school buildings and the results of observations analyzed and then assessed by experts knowledge through the second set of survey questionnaire procedure. These questionnaires were acted as an evaluation tool for the purpose of building design qualification by design specialists and experts. The assessment of the key design variables of school buildings were accomplished in either individual or paired comparison manner, in other word some design variables evaluated individually such as those related to physical comfort, and some evaluated with respect to each other such as those falling under lighting and thermal comfort categories.

The results of these qualifications along with observation and survey data analysis provided the basis for knowledgebase and construction of FES model ultimately. As these evaluations were performed qualitatively based on experts' opinion and knowledge, the quantification of the assessment results in order to produce numerical values of them was required.

Initially, a rating system similar to those of "fuzzy set theory" was employed for the questionnaires incorporating 1-5 likert scale, where the imperfection of a design variable quality or absence of some variables is indicated by point "1", while the excellent quality or full presence of a variable is indicated by point "5". This 1-5 scale is then mapped and translated to 0-1 rating scale of the "fuzzy set theory" using the linear function graph shown in Figure 5-1.

In order to determine the membership degree for state of each design/input variables within each created FES module, the qualitative evaluation of each individual expert mapped and quantified in a numerical value, and then average of experts' rates (membership degrees) is calculated.

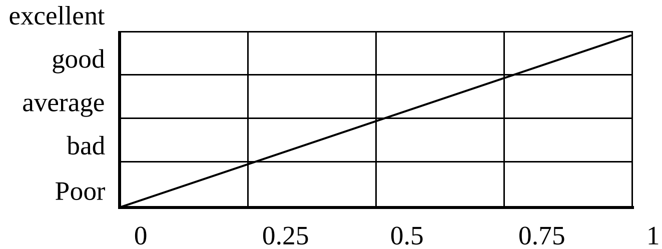


Figure 5-1 Translation of Qualitative Performance Measures to Quantitative Values Using "Fuzzy" Linear Function

The knowledgebase required to develop the FIS performance model includes input category representing the modules, input variables representing module associated inputs, input states representing fuzzy sets or the membership functions(MF) and finally the range of each input variable in order to map the membership degrees(MD) using the fuzzy sets. The input variables under each input category as well as the associated states of each input variable and the range pertaining to each variable are presented in Table 5-2.

Table 5-2 Developed Database (Knowledgebase) required for of FIS Model Construction

Input Category	**Input Variables**	**Range (x-axis)**	**Input States(Fuzzy Sets)**
Thermal Comfort	Building Orientation	0-360	N-S, S-N, E-W, W-E
Thermal Comfort	Predominant wind direction	0-360	N, NE, E, SE, S, SW, W, NW
Thermal Comfort	Opening Location	0-360	N-S -E- W
Thermal Comfort	Opening Position	1-10	Single, Adjacent, Parallel(opposite)
Lighting Comfort	Classroom Orientation	0-360	N-S, S-N, E-W, W-E
Lighting Comfort	Classroom Geometry (L/W)	0-2	Elevated Rectangle, Square, Elongated Rectangle
Lighting Comfort	Opening Location	0-360	N-S -E- W
Lighting Comfort	Opening Position	1-10	Single, Adjacent, Parallel
Lighting Comfort	Opening Size(window/wall)	0.1-0.8	Small, Average, large
Lighting Comfort	Opening Distribution	1-10	Touching, Close, Normal, Far apart
Lighting Comfort	Glass Transmissivity	0.1-0.85	Regular, Translucent
Lighting Comfort	Number of Openings	1-8	Few, satisfactory, Many
Lighting Comfort	Opening Shape (Height/Width)	0.5-1.5	Elongated Rectangle, Square, Elevated Rectangle
Acoustic Comfort	School Geometry (L/W)	1.0-2.0	Rect., L-shape, U-shape, H-shape, T-shape
Acoustic Comfort	Distance from Noise G.S	1-10	Close, Average, Far
Acoustic Comfort	Material Quality	1-10	Sound- absorbent, None-absorbent

Acoustic Comfort	Reverberation Time	0-1	Unfavourable, Acceptable, Favourable, Ideal
Physical Comfort	Distance between spaces (travel distance)	50-500	Close, Reasonable, Far
Physical Comfort	Classroom size(# of seats)	0-140	large, regular, small
Physical Comfort	circulation facility (pathways, ramps)	0-1	ambiguous, acceptable, clear
Physical Comfort	Public spaces	0-1	Poor, satisfying, excellent
Physical Comfort	Outdoor Spaces	1-10	Absent, enough, Plentiful
Physical Comfort	Classroom Outline	0-1	Poor defined, Well defined

5.4 Design and Implementation of the Model

Implementation of the model is carried out using MATLAB Fuzzy Logic Toolbox. Four major modules including; Thermal Comfort, Lighting Comfort, Acoustic Comfort, and Physical Comfort Modules are created to handle the inputs to the final performance evaluation model. Each of these four modules contains several sub-modules representing different design variables that impact each of the four identified comfort condition. These modules and their sub-modules are studied in the following sections of this chapter. The developed modules process the inputs related to their respective areas of function and output the respective "Comfort Indices" which are required to develop the performance evaluation module in order to measure the overall 'Design Performance Index' consequently.

At first, the input factors are fuzzified through the membership functions that were defined using the survey results applying "direct method with multiple experts". After fuzzification, the inputs are implicated using a rule-base consisting of a set of if-then rules, such that the combined impact of all input factors can be accounted for. The results of the system are then aggregated and defuzzified, outputting the comfort factor/index, which is a crisp number ranging from 0 to 1.00. If the resulted comfort factors are closer to 1.00, which means a higher comfort condition of a building, then it will impact the overall school performance and the school rating would be higher as well. The school performance can then be optimized by improving each and overall comfort condition. This procedure is adopted for all comfort modules. The overall structure of the developed performance evaluation model is presented in Figure 5-2.

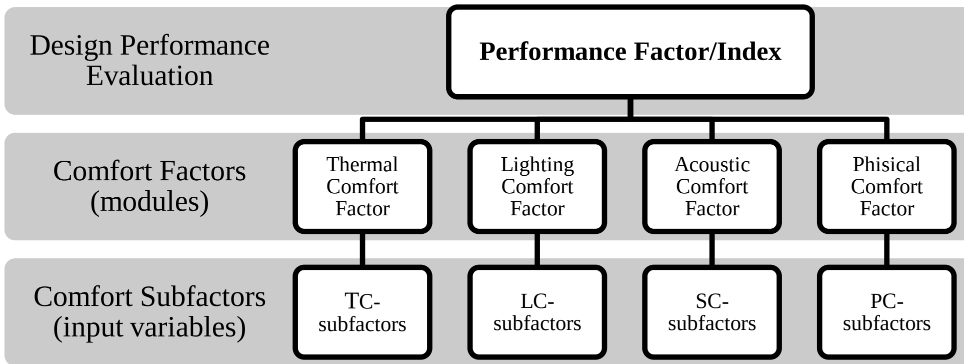


Figure 5-2 General Structure of the Model

5.4.1 Creation of Thermal Comfort Evaluation Module

The thermal comfort factor is calculated using a fuzzy inference system; the basic architecture of the inference system is illustrated in Figure 5-3.

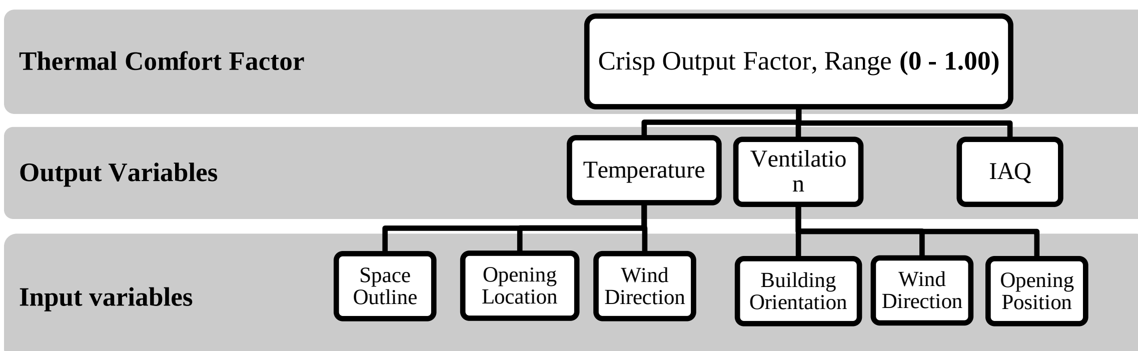


Figure 5-3 Architecture of Thermal Comfort Evaluation Module

To develop the fuzzy inference module for "Thermal Comfort" factor, first, the two key output variables including; temperature and ventilation were developed and then the input variables associated with each of those outputs were defined and created. These input variables were considered to be; 1- predominant wind direction, 2- building orientation, 3-opening location, and 4- openings position. The inputs were then fuzzified using membership functions that were defined according to experts’ survey result as well as literature review. After fuzzification of input variables, the inputs were then associated using FIS rule-base section consisting of a set of heuristic if-then rules. The rules were also developed using the same experts' surveys as a guideline, such that the combined impact of all factors associated with Thermal Condition can be accounted for. The results of the system are then aggregated and defuzzified, outputting the 'Temperature Index' and 'ventilation Index' together resulted in prediction of 'Thermal Comfort Factor'. These outputs are all crisp numbers ranging from 0 to 1.00. School performance rating can be improved if the predicted thermal comfort is favourable, or conversely decreased if it is unfavourable. The developed evaluation module for "Thermal Comfort Factor" using Matlab Fuzzy Logic Toolbox is illustrated as Figure 5-4.

Determining Fuzzy Sets for Thermal Comfort Module

To obtain the output of 'Ventilation Index' three input variables including building orientation, openings position and predominant wind direction were created. For 'predominant wind direction' input variable the fuzzy sets were determined based on the 0 to 360 degree of radius,

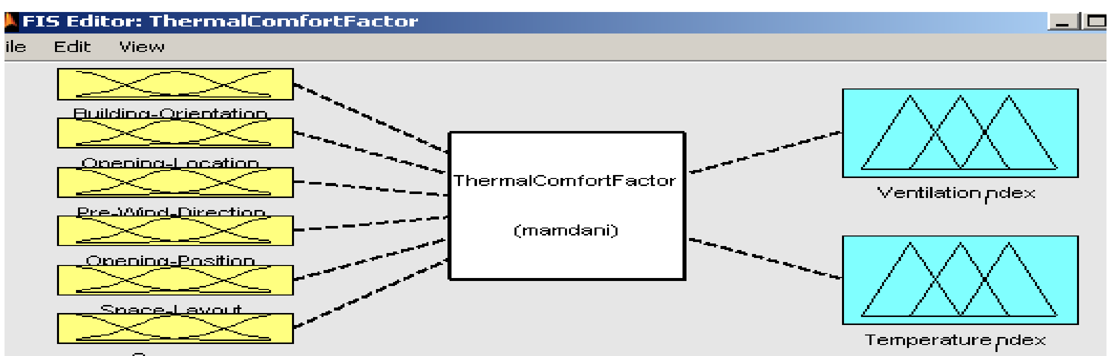


Figure 5-4 Developed 'Thermal Comfort Factor' Evaluation Module in Matlab

which was used to define 8 geographic directions (N, S, E, W, NE, NW, SE, and SW) as shown in Table 5-3.

Table 5-3: Created Fuzzy Sets and Their Ranges for 'Predominant Wind direction'

N to NE	NE to E	E to SE	SE to S	S to SW	SW to W	W to NW	NW to N
0-45	45-90	90-135	135-180	180-225	225-270	270-315	315-360

The geographical orientations were used to define the four different orientations of a building including; 1- East-West (westward), 2- West-East (Eastward), 3- North-South (Southward), and 4- South-North (Northward), orientations. The fuzzy sets were ranged from 0-360 degree as shown in Table 5-4.

Table 5-4: Created Fuzzy Sets and Their Associated Ranges for 'Building Orientation'

Northward	Eastward	Southward	Westward
-90-90	0-180	90-270	180-360

For opening position three fuzzy sets including; single, adjacent or opposite positions were developed. The range was defined based on the measured angles between openings located on different facades. For example for adjacent openings the created angle between windows could range between 20-160 degrees. Table 5-4 shows the defined fuzzy sets and their associated ranges for input variable of 'opening position'.

Table 5-4: Created Fuzzy Sets and Their Associated Ranges for 'Opening Position'

Single	Adjacent	Opposite
0-20	20-160	160-180

An Example of developed fuzzy sets and their defined ranges for 'building orientation' variable is illustrated in Figure 5-5.

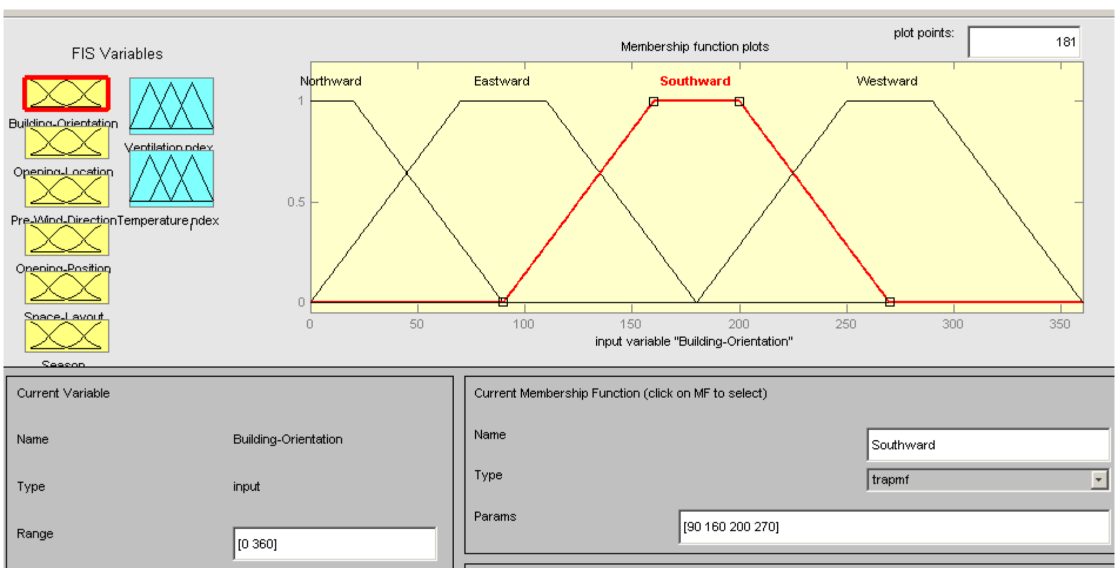


Figure 5-5 Developed Fuzzy Sets and Defined Ranges for 'Building Orientation' Variable

To obtain the output of 'Temperature Index' four considered input variables included; Space orientation according to sun, Openings location on the façade, Space layout and the Season in which the evaluation is conducted. Space orientation and opening location were created and their ranges were defined in a similar manner as explained in ventilation section.

For the space layout three important plan types including deep plan, square plan and extended plan were created and the ranges were defined according to their length width ratios. For example for extended rectangular plan, as the length is bigger than width, the defined ratio using fuzzy set theory can cover any value between 1.1 to 2 on the defined [0-2] range and for the deep plan types the range was considered between 0-0.9. The created Fuzzy sets and their defined ranges are shown in Table 5-5 and Figure 5-6. For 'Season' variable, two fuzzy sets of 'Warm' and 'Cold' on the range of [0-1] were created.

Table 5-5: Created Fuzzy Sets and Their Associated Ranges for 'Space Layout'

Deep plan	Square plan	Extended plan
0-0.9	0.8-1.2	1.1-2

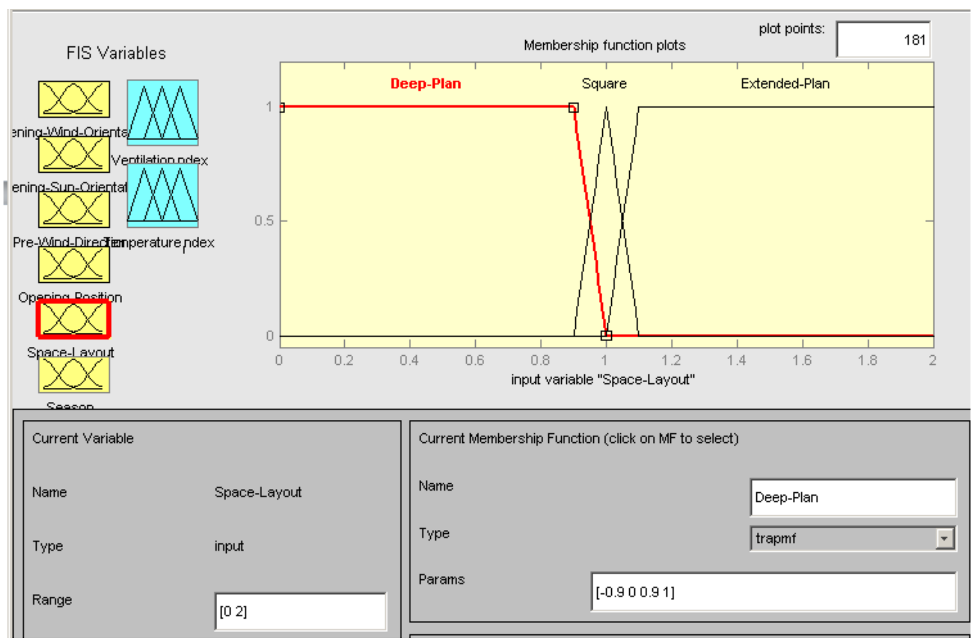


Figure 5-6 Developed Fuzzy Sets and Defined Ranges for 'Space Orientation' Variable

Finally, for ‘Ventilation Index’ and ‘Temperature Index’ variables, five fuzzy sets similar to the previously designed (1-5) scale, for experts survey, were created. These sets were consisting of ‘Poor’, ‘Bad’, ‘Satisfying’, ‘Good’, and ‘Excellent’. Figure 5-7 shows these created fuzzy sets for ‘Ventilation index’ variable.

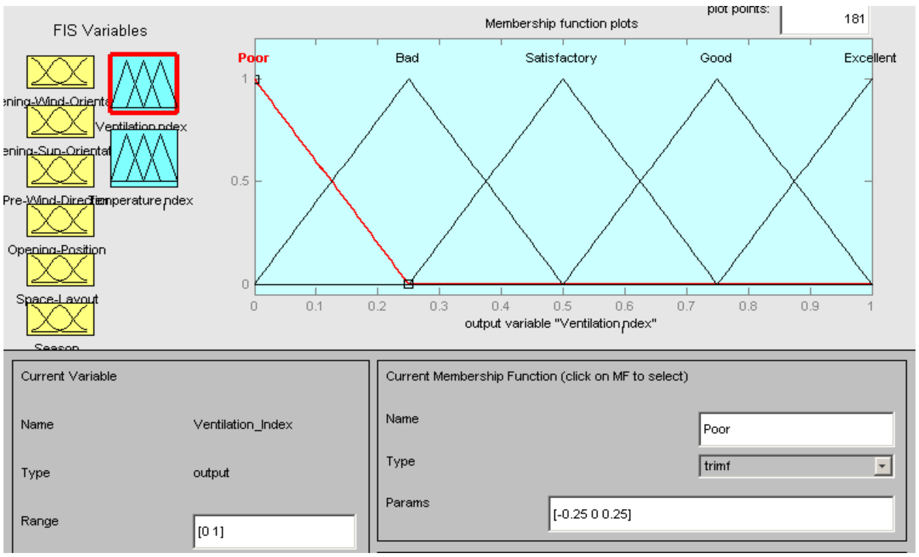


Figure 5-7 Developed Fuzzy Sets for ‘Ventilation Index’ Variable

5.4.2 Creation of Lighting Comfort Evaluation Module

The lighting comfort evaluation module is calculated using the fuzzy inference system; the basic architecture of the inference system is illustrated in Figure 5-8.

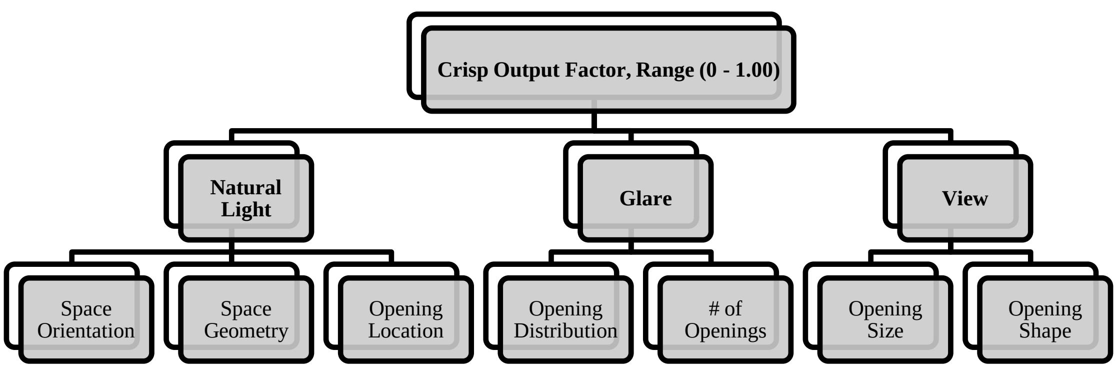


Figure 5-8 Architecture of Lighting Comfort Evaluation Module

In the developed fuzzy inference evaluation module for 'Lighting Comfort Factor', three output variables and eight input variable were created. The input variables consist of 'Space orientation', 'Space geometry', and 'Opening location' resulted in the 'Natural Light Index' variable of the module, 'Number of openings' and 'Openings distribution' produced the output variable of 'Glare Index', and finally 'Opening shape' and 'Opening size' produced View or 'Visual Index' output of the module. 'Glass transmissivity' is an input variable that considered for both natural lighting and glare evaluations.

Similar to the creation of thermal comfort module, these eight input variables were fuzzified using created membership functions of each fuzzy set of the module and then were implicated using a set of heuristic if-then rules developed using the knowledgebase developed based on experts surveys. The results of the system were then aggregated and defuzzified, outputting the 'Natural-Light Index', 'Glare Index' and 'Visual Index' all incorporated in calculation of 'Lighting Comfort Factor' accordingly. The Lighting comfort Factor is a crisp number ranging from 0.0 to 1.00. Estimated school performance rating can then be increased if lighting comforts is favorable, or conversely, de-rated if lighting comfort is unfavourable.

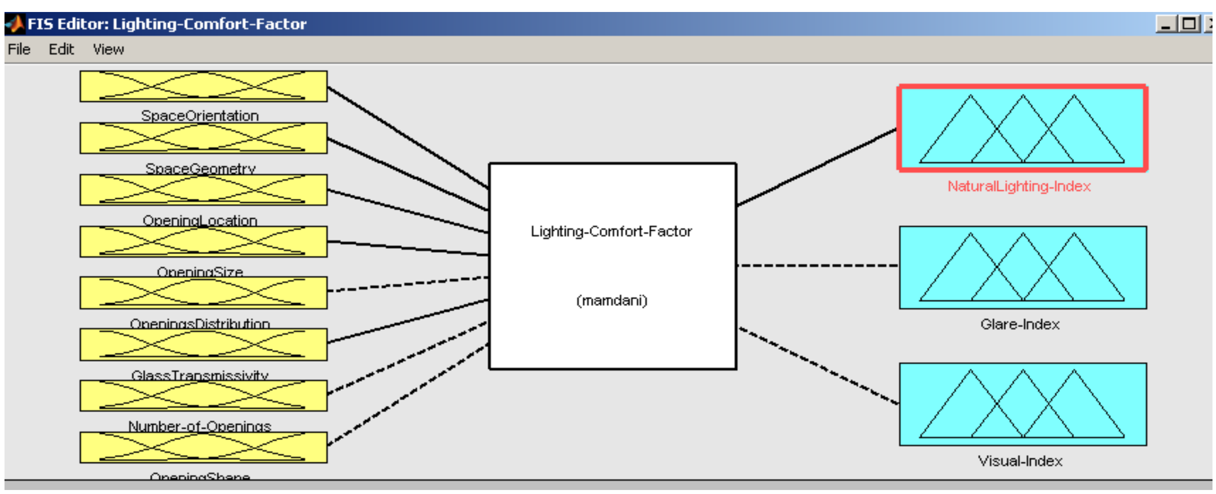


Figure 5-9 Developed 'Lighting Comfort Factor' Evaluation Module in MATLAB

Determining Fuzzy Sets for Lighting Comfort Module

Fuzzy sets for space orientation and opening location were defined using the same approach applied for thermal comfort module. For space geometry length to width ration is used to determine either rectangular or square shape of a classroom. If the ration is equal to 1 it is called square shaped room otherwise it is either elevated or elongated rectangle.

If	L/W <1	so L < w	then	it is elevated rectangular classroom.
If	L/W =1	so L = w	then	it is square-shaped classroom.
If	L/W >1	so L > w	then	it is elongated rectangular classroom.

To determine the opening size, window to wall ratio is assumed to be an indicator of different sizes. The range allocated for window to wall ratio is 0.1 to 0.8 which means 10% to 80% of wall area is considered to be opening (window) area.

For openings distribution 1 to 10 ranges is assumed in which, 1 is an indicator of touching or close openings and 10 is an indicator for far apart openings, and whatever in between is assumed to be regular or average distanced openings. The illustration of fuzzy sets and their associated membership functions is presented in Figure 5-10.

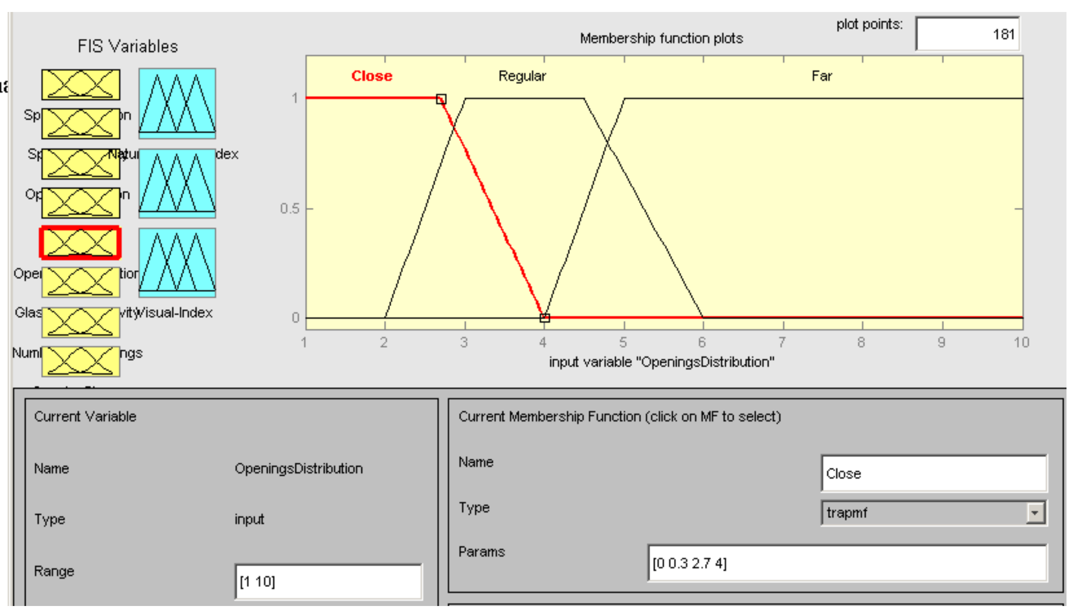


Figure 5-10 Created Fuzzy Sets for ‘Opening Distribution’ Variable

For number of openings the range is defined between [1,8] representing the minimum amount of one and the maximum of eight openings considered for a learning space as shown in Figure 5-11.

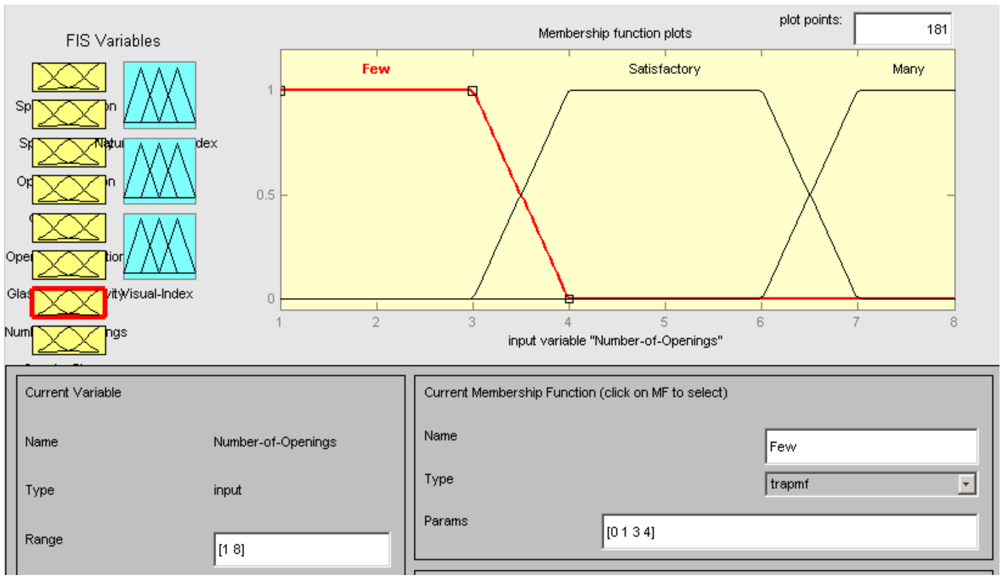


Figure 5-11 Created Fuzzy Sets for 'Number of Openings' Variable

Openings shape is determined by calculating height to width ratio. The range is assumed between 1/1.5 to 1.5/1 (Gange et al. 2010 and 2011).

If	H/W= 1/1.5	so	H<W	then	we have elongated rectangle window.
If	H/W= 1/1	so	H=W	then	we have square-shaped window.
If	H/W= 1.5/1	so	H>W	then	we have elevated rectangle window.

From literature and specialists knowledge glass transmissivity is considered between 0.1 to 0.85 or 10% to 85% translucent. 0.1 is for regular (tint) glass, 0.85 is for transparent glass and whatever in between is categorized as semi-tint, and semi-transparent glass (Flager et al. 2009).

5.4.3 Creation of 'Acoustic Comfort' Evaluation Module

For acoustic comfort evaluation module two output variables and six input variables were considered. The input variables that produce the output of 'Background Noise Level' include 'School Geometry' 'Distance from Noise', and

'Existence of Sound Barrier', while input variables including 'Material quality', 'Space Outline' and Reverberation/echo time produce the 'Classroom Noise Level' output variable. The architecture of the acoustic comfort module is shown in Figure 5-12.

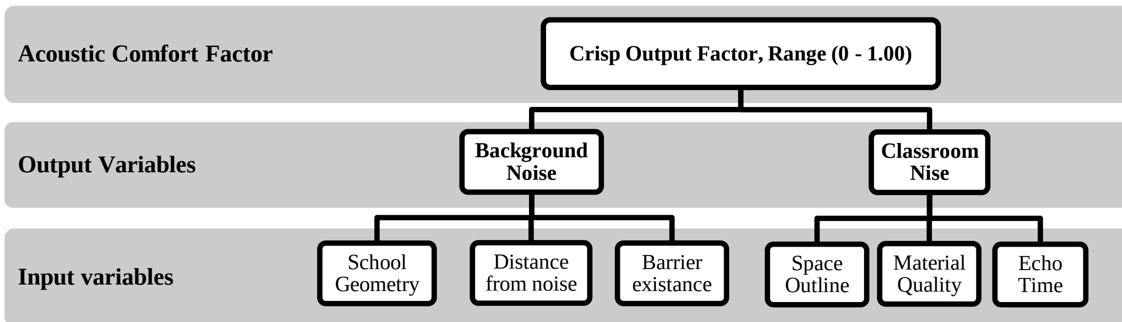


Figure 5-12 Architecture of 'Acoustic Comfort' Evaluation Module

The same procedure as of thermal comfort and lighting comfort factors are applied for acoustic comfort factors module development, and he developed evaluation module for 'Acoustic Comfort Factor' is demonstrated in Figure 5-13.

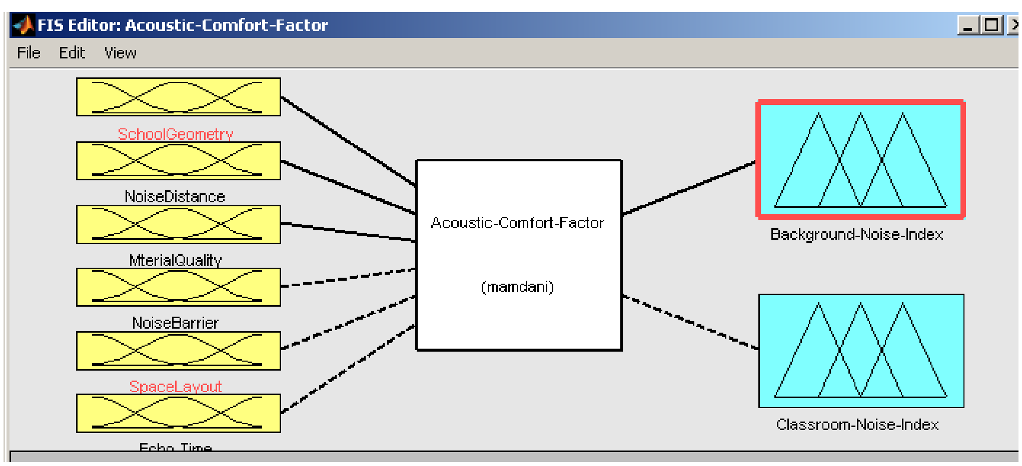


Figure 5-13 Developed 'Acoustic Comfort Factor' Evaluation Module in MATLAB

Determining Fuzzy Sets for Acoustic Comfort Module

Geometry of school is an important input factor for determination of acoustic comfort as it defines the arrangement of classrooms and other spaces inside the school layout. This factor itself is determined by using the aspect ratio. Aspect ratio is a parameter that helps to define the shape of a desired area (school geometry in this case) and calculated through dividing width by depth of the bounding rectangle of that area (da Garca et al. 2007). For development of ‘School Geometry’ variable five typical shapes identified through review of literature, observations procedure and experts survey were used. These include square-shaped, horizontal and vertical rectangular shapes, L-shaped and U-shaped school plans.

For ‘Distance from Noise’ variable three fuzzy sets of ‘Close’, ‘Average’ and ‘Far’ are created and the ranges is defined between 1-10 which is indicator of very close to very far location as shown in Figure 5-14.

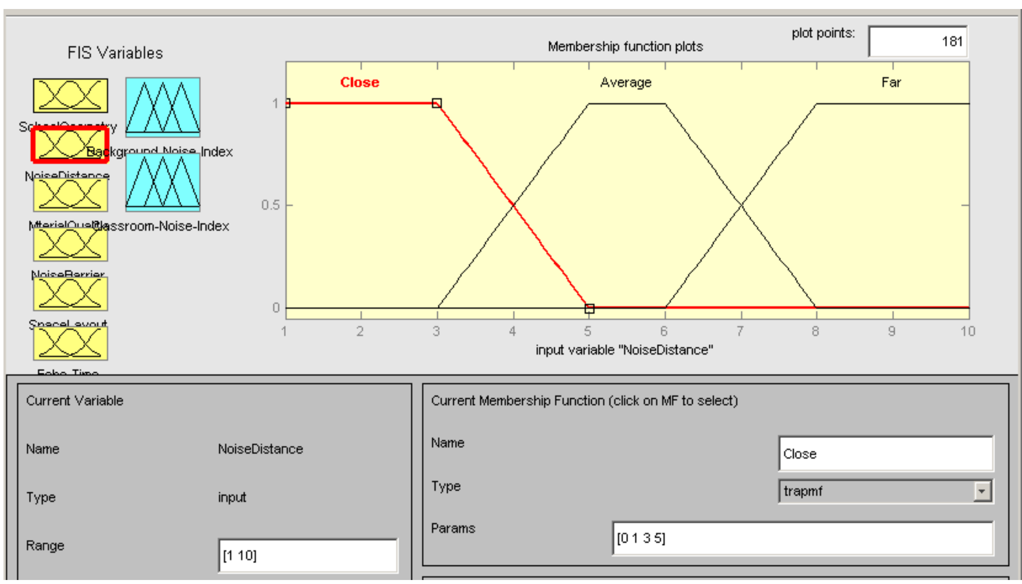


Figure 5-14 Developed Fuzzy Sets for ‘Distance from Noise’ Variable and their Defined Ranges

‘Material Quality’ variable is measured based on degree of absorbance and ranged from none sound-absorbent to sound-absorbent materials on 1-10 scale as illustrated in Figure 5-15. The states for ‘Existence of noise barrier’ were considered to be between 0 and 1, where 0 is an indicator of none- existence and 1 is an indicator of enough existence of noise barriers in the building, whatever in between falls in the range of 0-1 based on the extent of considered barriers.

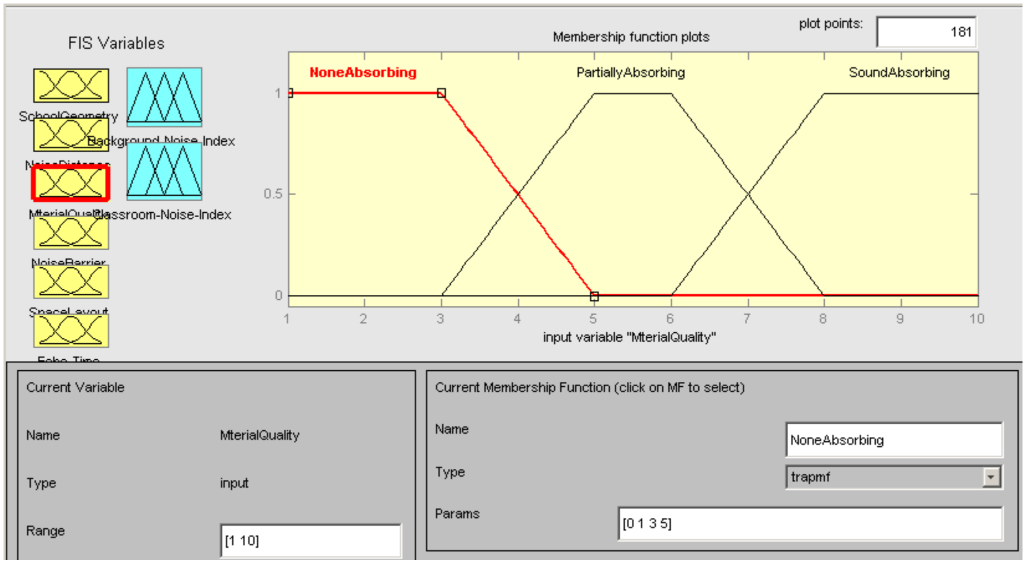


Figure 5-15 Developed Fuzzy Sets for ‘Material Quality’ Variable and their Defined Ranges

According to school buildings design standards, the ideal reverberation (echo) time is stated to be 0.4-0.6 (Brubaker, 1998). Therefore the fuzzy sets for ‘Echo Time’ are determined as poor to ideal range of reverberation time and the range for echo time is assumed between 0 to 0.6, where the range of [0-0.2] is an indicator of unfavourable echo time, [0.2-0.4] stands for normal and [0.4-0.6] for ideal echo time. These created fuzzy sets are demonstrated in Figure 5-16.

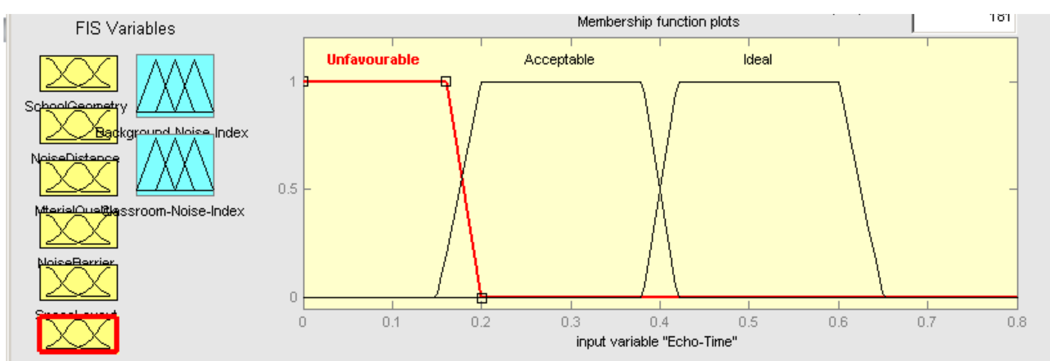


Figure 5-16 Developed Fuzzy Sets for ‘Echo Time’ Variable and their Defined Ranges

5.4.4 Creation of Physical Comfort Evaluation Module

The input variables for physical comfort module are identified as; ‘Space size’ and ‘Space outline’ resulting in ‘Functionality Index’ output variable, ‘Travel distance’ and ‘Circulation facilities’ outputting ‘Accessibility Index’ variable, ‘Public spaces’, and ‘ Outdoor spaces’ outputting ‘Facility Index’ variable. The module development procedure was conducted in a similar manner as the previous modules’ development. The overall structure of the model and the developed evaluation model for ‘Physical Comfort Factor’ are presented in Figure 5-17, and Figure 5-18 respectively.

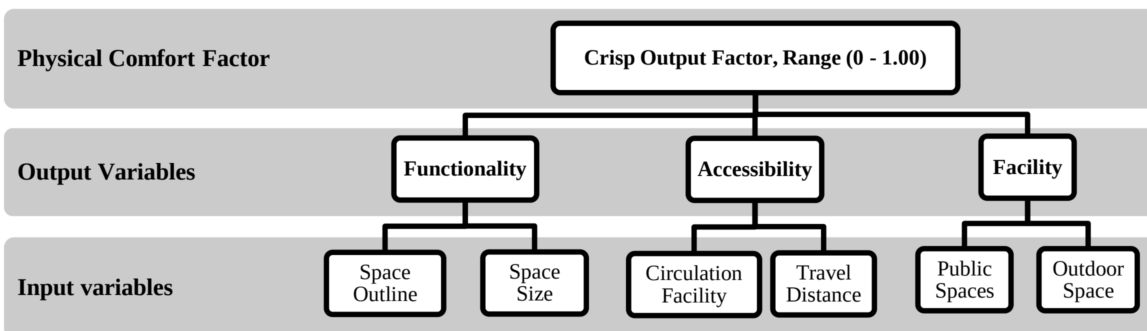


Figure 5-17 Architecture of ‘Physical Comfort Evaluation ‘Module

Determining Fuzzy Sets for Physical Comfort Module

The fuzzy sets for ‘Space Outline’ variable were defined as poor-designed to well-designed spaces ranging from 0-1. For ‘Space Size’ variable, the classroom size could range from 0 to 140 seats according to school design manual and standards. The fuzzy sets to represent this range were defined as ‘small’,’ regular’ and ‘large’ as shown in Figure 5-19.

To improve the physical comfort of the schools through providing the convenient circulation inside school buildings, travel distance and accordingly travel time between different spaces need to be reduced. For this purpose, the range of ‘Travel Distance’ according to design manuals is recommended to be between 50 to 500 meters, which indicates close to far classification of distance. The fuzzy sets and their assigned ranges for associated with the 'Travel Distance' variable are demonstrated in Figure 5-20.

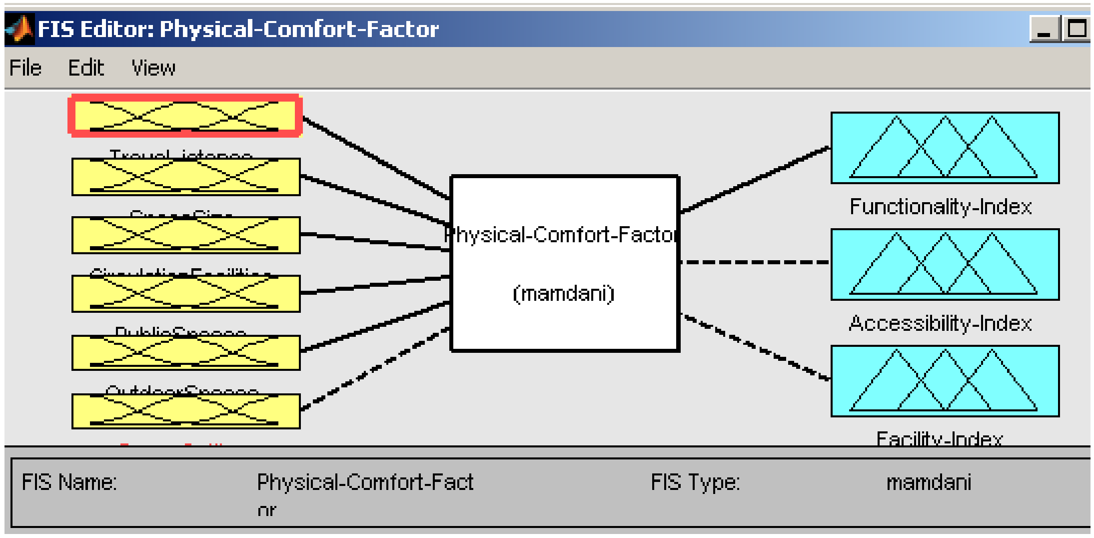


Figure 5-18 Developed 'Physical Comfort factor' Evaluation Module in MATLAB

Circulation facilities including pathways and signage inside and outside of the building is defined by two fuzzy sets 'Clear' and 'Ambiguous' in the range of [0-1], indicating clearly to vaguely designed circulation provision.

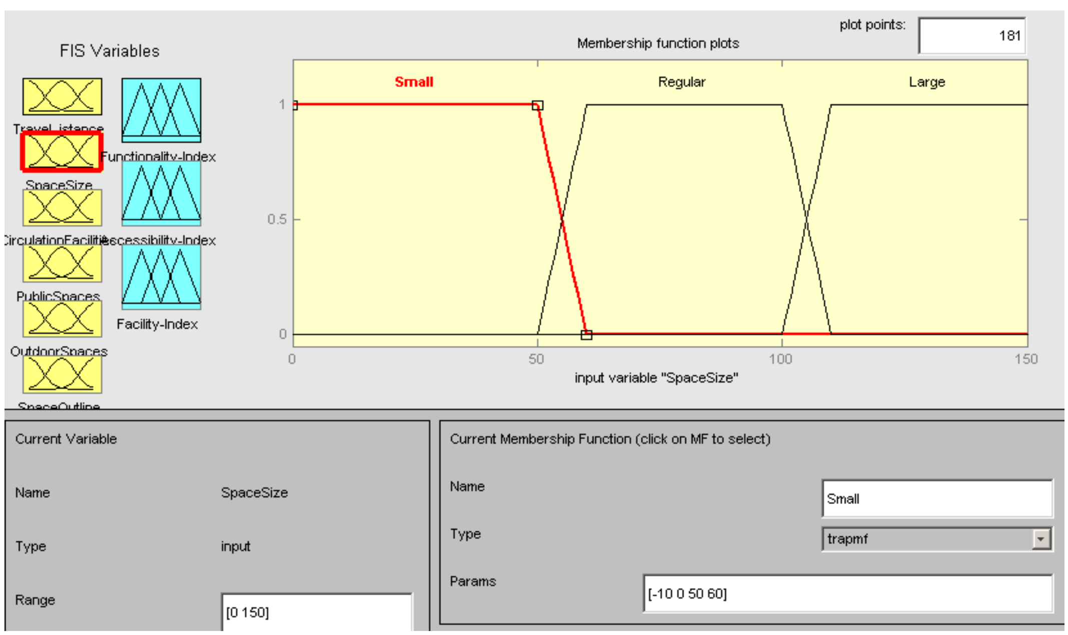


Figure 5-19 Developed Fuzzy Sets for 'Space Size' Variable and their Defined Ranges

Public spaces and outdoor spaces in a school building are classified based on their absence or presence within a school building (Tanner, 2008 and 2009). The range of 1 to 10 is assumed to be the indicator of this classification.

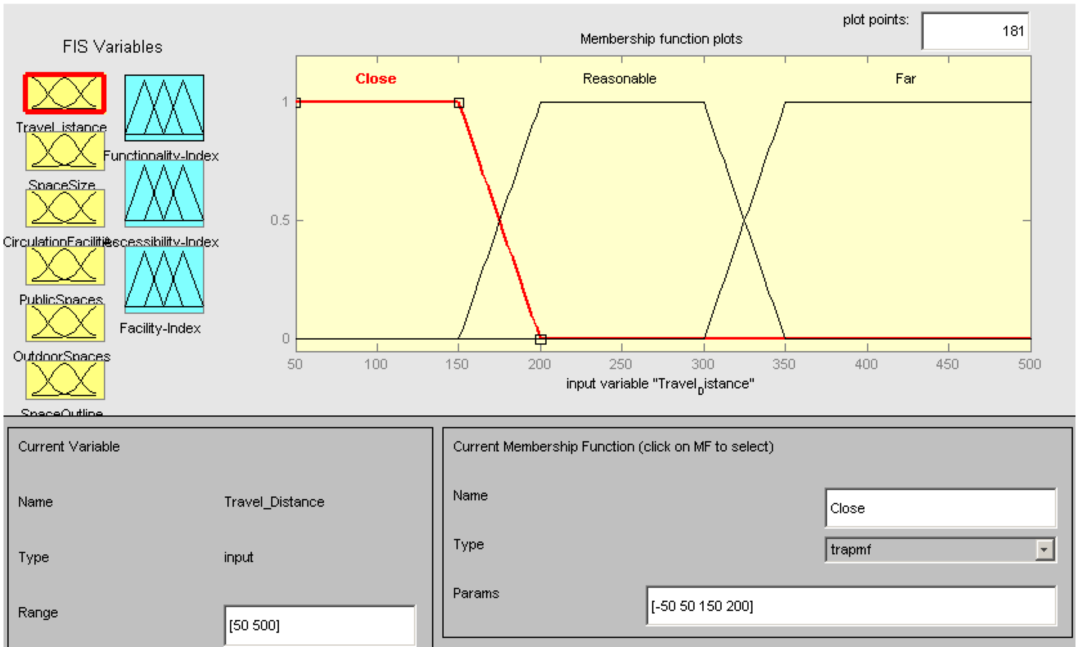


Figure 5-20 Developed Fuzzy Sets for 'Travel Distance' Variable and their Defined Ranges

5.4.5 Development of Performance Evaluation Module

School design and overall performance evaluation is carried out through development of 'Performance Evaluation Model, which captures the ten outputs (indices) resulted from the four developed comfort modules as its input variables, and produces the school performance factors as its four output variables (illustrated in Figure 5-21).

The result of the evaluation will provide the design performance factor which will be used to rate the design and performance of school buildings. Ideally the optimized solution is the school design, which obtains the highest rank of membership degrees from design variables; however, as there are always compromises between several variables of a multi-criteria problem, the best solution can be selected as the one with the most reasonable combination of rating values (MD).

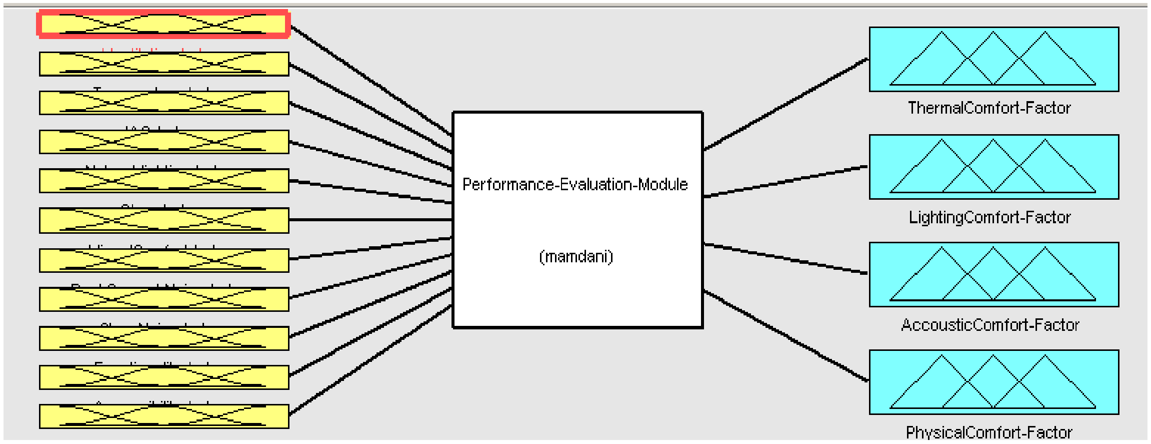


Figure 5-21 School Design & Performance Evaluation Model

After evaluating all design variables of several alternative school buildings using the developed model, total score of the school building performance is calculated and the rating for each design alternative is determined based on the total score. Total score of the design is obtained and associated rating is determined based on proposed rating scheme illustrated in Table 5-6. The rating method chosen for school design evaluation is similar to LEED rating system developed by the 'United States Green Buildings Council'. For total scores between 90-100 percent the design rating is considered to be "Platinum", for 80-89 percent score the rating is "Gold", for 70-79 percent it is "Silver", for 60-69 percent the rating is Bronze, for 50-59 percent it is "Certified", and for less than 50 percent the design rating is equal to "Basic".

Table 5-6 Rating Scheme for School Performance Evaluation

Total Evaluated Score	**School Design Rating**
<50	Basic
50-59	Certified
60-69	Bronze
70-79	Silver
80-89	Gold
90-100	Platinum

5.5 Summary of Model Inputs and Outputs

In summary, the model consists of overall twenty six input factors and four output factors resulted in one main output indicating the measured building performance factor by the model. These factors are listed and demonstrated in Table 5-7.

Table 5-7 List of Incorporated Inputs to and Resulted Outputs of Performance Evaluation Model

Input Category	Sub-category	Input Factor	Output Factor	Ultimate Output
Thermal Comfort Condition	Ventilation Condition	Building Orientation	**Thermal Comfort Index**	**Building Performance Factor/ Index**
		Opening Location		
		Opening Position		
		Predominant wind direction		
	Temperature Condition	Space Outline		
		Opening Location		
		Predominant wind direction		
	Indoor Air Quality	Odors, Contaminants, Humidity		
Lighting Comfort Condition	Natural Lighting Level	Space Orientation	**Lighting Comfort Index**	
		Space Geometry(L/W)		
		Opening Position& Location		
	Glare Condition	Number of Openings		
		Opening Distribution		
	View Condition	Opening Size(window/wall)		
		Opening Shape(Height/Width)		
	Glass Transparency	Glass Type		
	Artificial Lighting	Ability to Control		
Acoustic Comfort Condition	Background Noise Level	School Geometry(L/W)	**Acoustic Comfort Index**	
		Distance from Noise G.S		
		barriers existence		
	Classroom Noise Level	Space Outline		
		Material Quality		
		Reverberation Time		
Physical Comfort Condition	Functionality & Flow Condition	Classroom Outline	**Physical Comfort Index**	
		Classroom size(# of seats)		
	Accessibility & Circulation	Circulation facility (pathways, ramps)		
		Travel distance		
	Facilities & Savvies	Public Spaces		
		Outdoor Spaces		

5.6 Construction of Membership Functions

Membership functions and degrees of overlap were defined for each of the input variables in the modules, using information collected through the survey process, review of literature as well as the specifications and design guide books as an instruction. The results of the survey demonstrate that many of the parameters affecting the comfort factors in school building and subsequently performance of the design are subjective and qualitative in nature and are described in linguistic terms. In order to capture this subjectivity and represent the qualitative data membership functions provided by fuzzy logic theory are generated.

Several methods of creating membership functions have been proposed in the literature such as horizontal method, vertical method, parametric optimization, direct methodology with multiple experts, and exemplification (Pedrycz et al.1998). The method applied here to construct the membership functions is direct methodology with multiple experts. The complexity of generating the membership functions is laid under the x-axis scale definition in an universal manner, which can be accomplish on objective data basis (Fayek et al. 2001).

In this study, as an instance, the geometry of the classroom or openings shape, which are descriptive/ linguistic terms in nature can be defined on the basis of the objective or numerical data specified with a number to assign the x-axis values related to their membership functions. For opening shape the indicators like height and width of the windows and the ratio of window height to width is used to define the x-axis numerically. For geometry of the classroom the ratio of the length to width is chosen to be used as a numerical value for objective definition of the x-axis of membership functions. For physical factors such as circulation between spaces, the travel time or the travel distance can be considered.

After defining the x-axis scale for each of the membership functions, appropriate terms to describe each input factor and the optimal number of membership functions to describe each of those factors is identified. Finally, the appropriate shape and range of each membership function is determined. The triangular, trapezoidal, and bell-shaped membership function shapes are used in this study. An example of created membership functions for performance evaluation module is shown in Figure 5-22. The membership functions allow the inputs of the model to be fuzzified and processed through fuzzy inference system in order to determine the net impact of the combination of factors present.

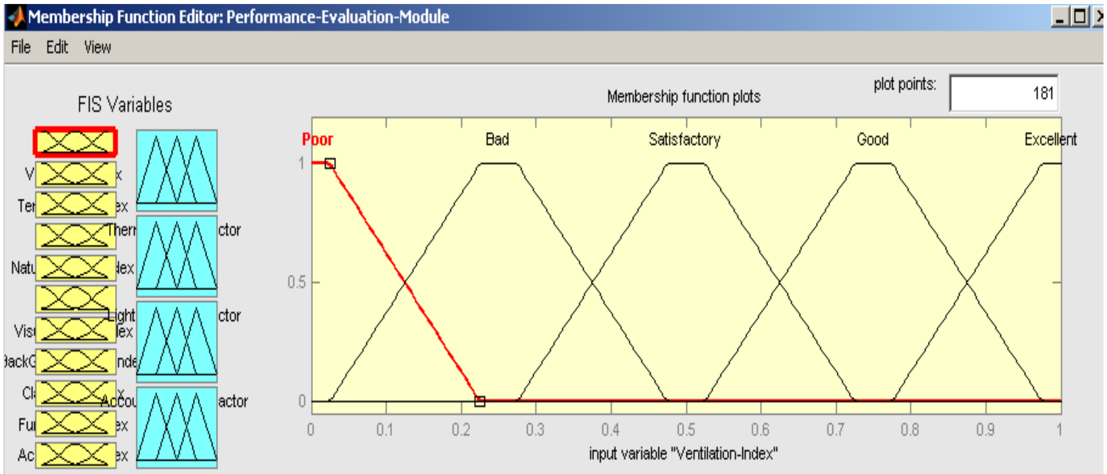


Figure 5-22 Generated Membership Functions for Performance Evaluation Module

5.7 Construction of FES Rule-base based on the Experts' Assessment Results

The experts' qualification results on the identified design variables presented in chapter four of this study were used to construct the rule-base for each developed module in the Fuzzy Inference System. The relative importance of different factors were determined using experts' knowledge as presented in section 4.2.5 of chapter four, and employed to weigh the net impact of the presence of certain combinations of input factors. The number of generated rules in developed Fuzzy Expert System model depends on number of input factors and number of MFs assigned to each input factor. Calculations to determine the number of rules and examples of generated rules are listed in Tables 5-8 to 5-12 respectively.

Table 5-8 Computation of amount of Required Rules for Model Rule-bases Development

Module	Outputs	Number of Inputs	Number of MF	Number of rules
Thermal Comfort	Temperature Condition	3	3-4-8	3*4*8= 96
	Ventilation Condition	3	3-4-8	3*4*8= 96
	Indoor Air Quality	1	3^1	3
Lighting & Visual Comfort	Natural Lighting	4	8-2-4-3	8*2*4*3= 192
	Artificial Lighting	1	3^1	3
	Glare Condition	2	3-3	3*3=9
	Views	2	3-3	3*3=9
Acoustic Comfort	Class Noise Level	3	3-3-3	3*3*3=27
	Background Noise	3	2-6-3	2*6*3= 36

Physical Comfort	Functionality	2	3-2	3*2=6
	Accessibility	2	2-3	2*3=6
	Flexibility	1	3^1	3
	Facility/Services	2	3-3	3*3=9
Overall Performance	Thermal Index	3	5-5-5	(5^3)= 125
	Lighting Index	4	5-5-5-5	(5^4)= 625
	Acoustic Index	2	5-5	(5^2)= 25
	Physical Index	4	5-5-5-5	(5^4)= 625

Table 5-9 Examples of developed rules for "Temperature Index”

If	Building Orientation	and	Opening Position	and	Opening Location	and	Prevailing Wind	then	Ventilation Index
	East-West		*Parallel*		*S&N*		*Northward*		*Excellent*
	East-West		*Single*		*S*		*Southward*		*Poor*
	North-South		*Adjacent*		*N&E*		*East*		*Satisfactory*
	South-North		*Parallel*		*E&W*		*Northeast*		*Good*

Table 5-10 Examples of Developed Rules for "Overall Lighting Performance" Module

If	Natural Lighting Index	and	Artificial Lighting Index	and	Glare Index	and	Visual Index	then	Lighting Comfort Factor
	Excellent		*Excellent*		*Poor*		*Satisfying*		*Gold*
	Poor		*Poor*		*Poor*		*Excellent*		*Bronze*
	Excellent		*Good*		*Poor*		*Poor*		*Silver*
	Excellent		*Good*		*Good*		*atisfying*		*Platinum*

Table 5-11 Examples of Developed Rules for "Acoustic Comfort" Module

If	Building Geometry	and	Distance from Noise	and	Noise Barrier	then	Background Noise Level
	L-shaped		*Far*		*None*		*Satisfying*
	Square		*Average*		*Existent*		*Good*
	H-Rectangle		*Close*		*None*		*Poor*
	V-Rectangle		*Far*		*Existent*		*Excellent*

Table 5-12 Examples of Developed Rules for "Physical Comfort" Module

If	Functionality Index	and	Accessibility Index	and	Flexibility Index	and	Facility Index	then	Physical Comfort Factor
	Good		*Good*		*Poor*		*Good*		*Gold*
	Poor		*Poor*		*Poor*		*Excellent*		*Bronze*
	Excellent		*Excellent*		*Poor*		*Poor*		*Silver*
	Excellent		*Good*		*Good*		*Very Good*		*Platinum*

An example of generated rule-base for thermal comfort module is illustrated in Figure 5-23.

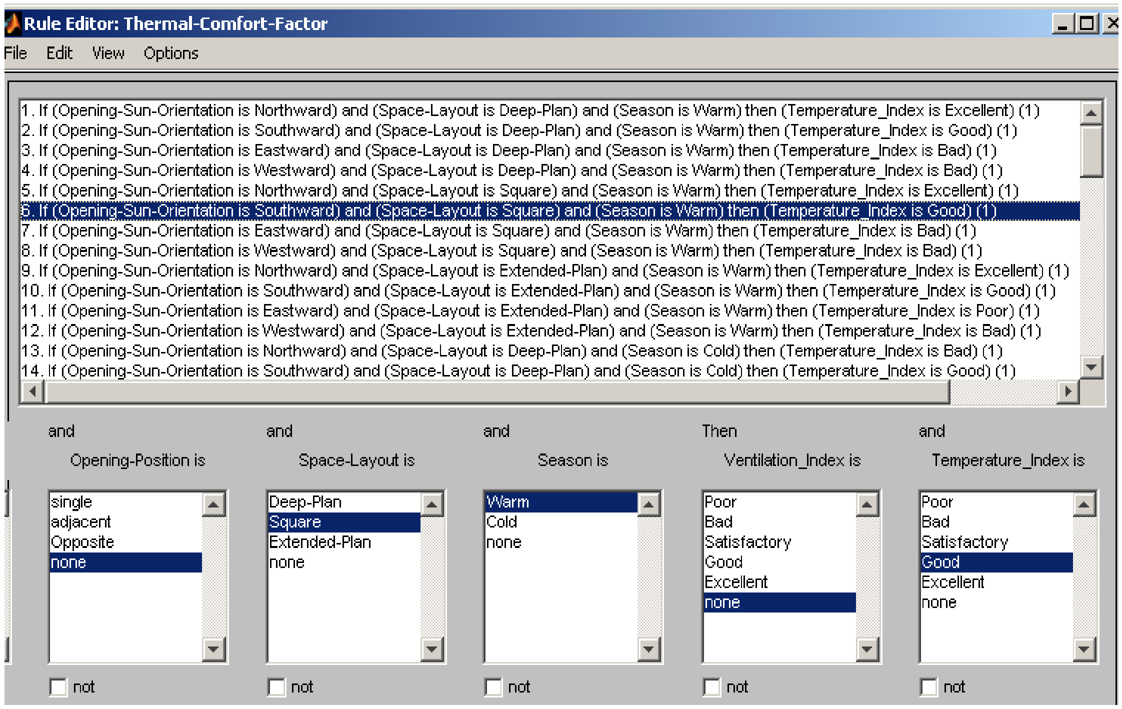


Figure 5-23 Illustration of Developed Fuzzy Rules-bases for "Thermal Comfort" Module

The Rule-viewer associated with developed rule-base of the model is illustrated in Figure 5-24. User of the model can obtain the measured output of the model, in this case ‘ventilation index’ and ‘temperature index’ by defining the desired input variables in rule-viewer section.

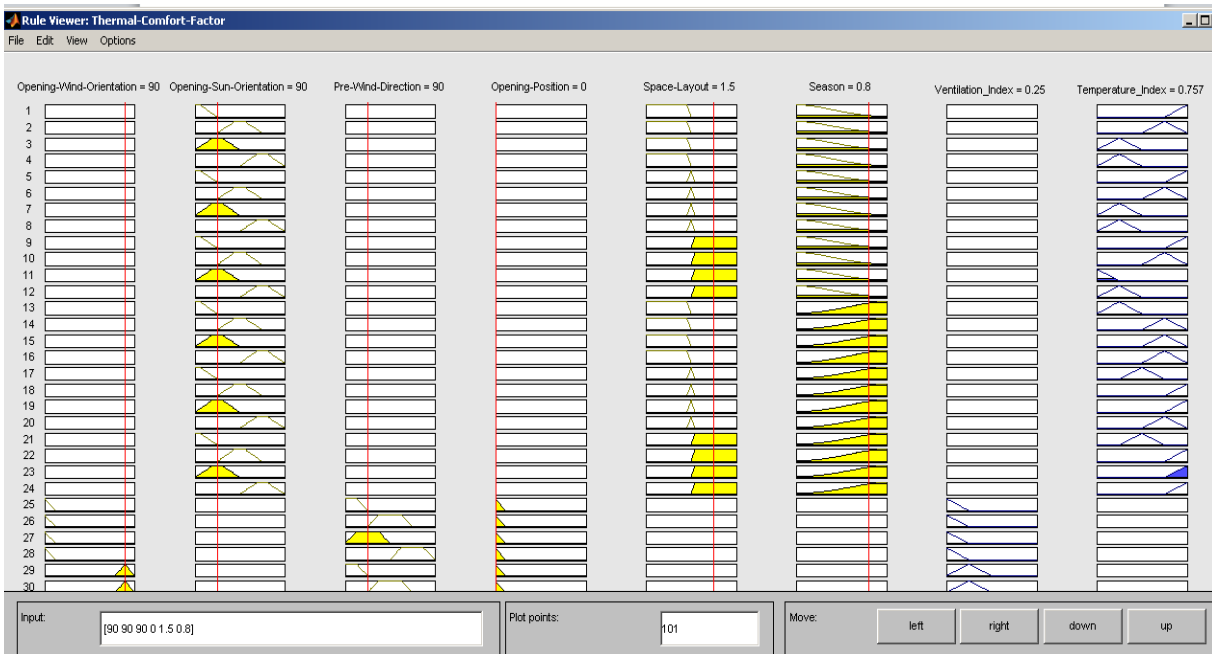


Figure 5-24 Illustration of Rule-viewer in Fuzzy Inference System of Thermal Comfort Module

5.8 Testing and Verification of Developed Fuzzy Expert System Model

The collected data from the e-survey process and observations is divided into two parts;1- training data set and 2- testing data set. The training data set is employed to develop the model along with data obtained from experts' interview and questionnaire and the testing data set is used to validate the accuracy of the model. The data set consist of ten sets of qualitative observations collected over a period of three months from August to October 2012. Each set of observations is accompanied by the corresponding occupants' productivity in each school building from which the data was collected. The standardized definitions of input factors that were determined through the expert survey process were used as a guideline in rating each of the input factors.

5.8.1 Numerical Example of Model Implementation for a Case Study School

In this section the input data that was collected from observation of one of the case study school is used to illustrate the operation of the developed model.

Data was collected through joint assessments between the researcher and school administrators at the collaborating process. A summary of the qualitative assessments of school conditions during inspection is provided in Table 5-13.

Table 5-13 Data Collected for a Case Study School (School#7) on October 15th, 2012

Lighting Comfort Factors								
Classroom Orientation	Classroom Geometry	Opening Location	Opening Position	Opening Size (window/wall)	Opening Distribution	Glass Transmissivity	# of Openings	Opening Shape
E-W	Square	N&S	Parallel	Average	Far	Translucent	4	Elev.rect.

Acoustic Comfort Factors				
School Geometry	Noise Distance	Material Quality	Echo-Time	Class Outline
Elongated Rectangle	Far no-barrier	None absorbent	favorable	Square

Thermal Comfort Factors			
Opening Location	Classroom Orientation	Predominant wind direction	Opening position
S N&S	E-W	Northward	Single Parallel

Physical Comfort Factors					
Travel Distance	Classroom Size	Circulation Facility	Public Spaces	Outdoor Spaces	Classroom Outline
Close	Regular	Acceptable	Poor	Enough	Well-defined

These crisp input data is then entered into the four comfort factors modules developed in MATLAB in order to assess the combined impact of these parameters on the comfort conditions of the school users. Initially, the membership degree of each input factor is obtained referring to the developed modules for the linguistic data, and then these membership grades for each of the influencing parameters are imported into the "rule viewer" of the modules in order to calculate a numerical value for thermal, lighting, acoustic and physical conditions. In other word the fuzzy input data are given to the model and the defuzzified output value is calculated using the membership grades and developed functions. Then the numerical output values of these modules will be used as input variables of the developed performance module and will provide a defuzzified value called "School Performance Factor" which is an indicator of the school design quality and performance. The output values obtained from the model using the abovementioned input data are shown in Table 5-14.

Table 5-14 Summary of Defuzzified Outputs

Model Output				
Thermal Comfort Factor	Lighting Comfort Factor	Acoustic Comfort Factor	Physical Comfort Factor	School Performance
0.58	**0.59**	**0.48**	**0.80**	**0.61**

The outputs obtained from four comfort factor modules and the performance evaluation module on ten case study schools as well as the overall school design ratings are presented in Table 5-15 and Figure 5-25 accordingly.

Table 5-15 Performance Evaluation Outputs of 10 Case-study Schools Obtained from FIS Model

School ID	**Thermal Factor**	**Lighting Factor**	**Acoustic Factor**	**Physical Factor**	**Overall Performance**	**Rating**
1	**0.20**	**0.26**	0.52	0.86	**0.46**	Basic
2	0.33	0.50	0.64	0.52	0.50	Certified
3	0.26	0.54	0.71	**0.42**	**0. 48**	Basic
4	**0.20**	0.38	0.64	0.95	0.54	Certified
5	0.26	0.50	0.45	0.48	**0.42**	Basic
6	0.62	0.29	0.62	0.72	0.56	**Certified**
7	0.58	0.59	0.48	0.80	0.61	**Bronze**
8	**0.18**	**0.26**	0.70	0.92	0.52	Certified
9	0.44	0.42	**0.29**	0.72	**0.47**	Basic
10	0.70	0.65	**0.23**	**0.38**	**0.49**	Basic

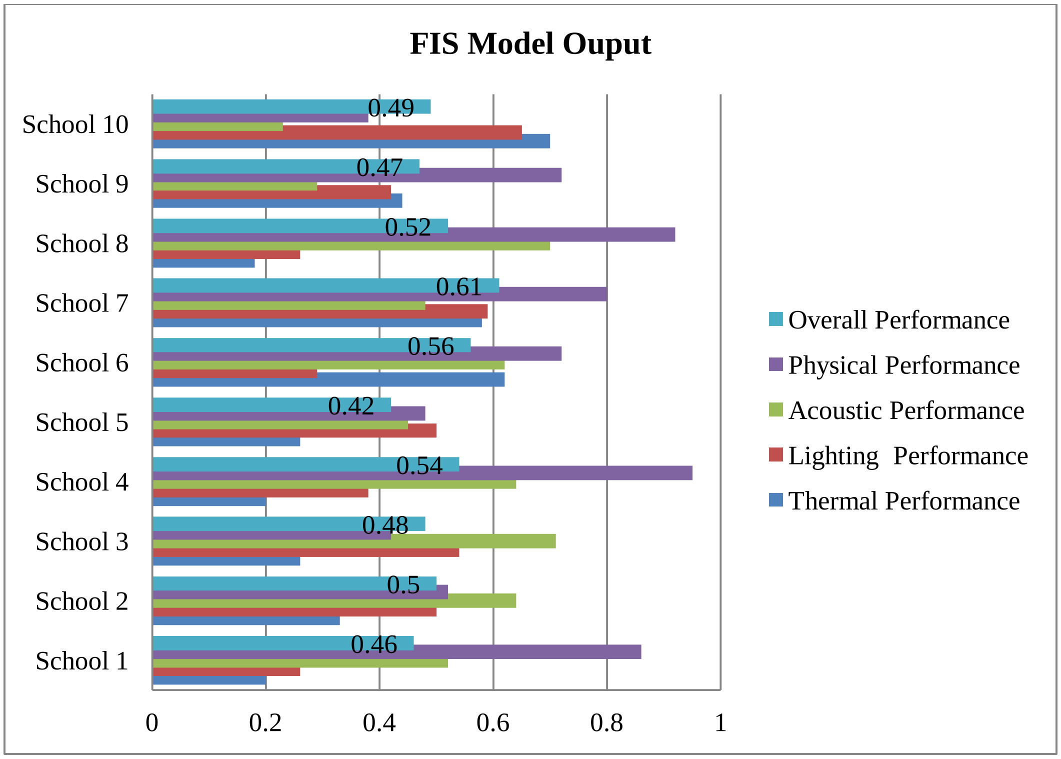


Figure 5-25 Illustration of 'Performance Evaluation' Outputs of FIS Model for 10 Case-study School Buildings

5.9 Conclusion

The goal of this study was to evaluate several design alternatives and make optimised decisions, with regard to comfort parameters, manipulated at a preliminary design phase. The analysis data for each of the ten sample schools design are expressed in MDs as represented in Table 5-15. Design variables are qualified according to each comfort parameter, as thoroughly explained in the previous sections.

In order to reach an optimal design solution among a group of school building designs, all alternatives can be compared and substandard alternatives can be eliminated from the list of solutions. In the case of performance evaluation of ten studied schools, it is noticeable from Table 5-15 and Figure 5-25, that schools with IDs of 1, 5, and 9 have obtained the lowest scores of overall performance evaluations and many of the variables scored under acceptable level. These alternatives can be considered as deficient solutions and eliminated from the list of optimal solution accordingly.

Results of evaluations show that, there is no solution with a maximisation of all aspects of comfort and even if a design alternative achieves the highest of overall score, some of its comfort aspects may be deficient. For this reason, multi-criteria decision making method (AHP approach) is implemented to include the impacting weights of several design criteria in order to compare available design alternatives/solutions and identify feasible alternatives according to those weighted criteria. In this case, the sub-standard evaluation scores obtained for each comfort criteria in relation to those of other design alternatives are identified and these deficient design alternatives are eliminated. Using this method, a group of feasible design solutions are identified and presented in Table 5-16. The sub-standard scores of each comfort criteria associated with each of the ten design alternatives are also highlighted in Table 5-15.

Table 5-16 a List of Optimum/feasible Design Solutions

School ID	Thermal Factor	Lighting Factor	Acoustic Factor	Physical Factor	Overall Performance	Rating
6	0.62	0.29	0.62	0.72	0.56	**Certified**
7	0.58	0.59	0.48	0.80	0.61	**Bronze**

As can be seen from table 5-16, by exclusion of the deficient alternatives from a group of ten school building designs, two feasible alternatives are selected as the optimum design solutions.

Chapter 6

CONCLUSION

6.1 Summary of the Research Study

A preliminary design evaluation and optimization of school buildings must be given a significant consideration as these educational buildings are of a great importance in providing a satisfactory environment for both students and teachers in order to enhance learning and performance. The key factor in design evaluation and optimization of a school building is defining the users' expectations, which is qualitative and subjective in nature. To capture these qualitative and imprecise aspects of the problem, and optimize school building design parameters, professionals/expert knowledge needed to be employed to develop the design evaluation and optimization model accordingly.

To evaluate school building design and answer the problem of school design optimization, both qualitative and quantitative parameters were significant. Development of an expert system was proposed to capture the subjectivity of the problem, in order to create a school building design evaluation model. Different school building design parameters related to building orientation and layout, envelope, indoor air quality, as well as day-lighting systems were investigated as part of the design evaluation and optimization process. Then, investigated data were analyzed to reach the optimal design of the parameters associated with the building design process to enhance the learning environments. A series of interviews and survey questionnaires were employed in order to collect this data.

The proposed methodology incorporated experts' opinion and design analysis of existing learning environments in order to ensure better quality of design, and higher comfort level, to facilitate higher achievement rates. The purpose of developed model was two-fold; first and foremost, the model was developed to be used as an evaluation tool, in order to accurately assess the performance of the learning environments in the early designs phase. Additionally, it could be used to identify the factors that are having the largest impact on performance factor, so that novel design measures for new school buildings can be focused accordingly. The Model also allows the designer to explore different design alternatives to choose the optimized solution.

The methodology is structured around the performance evaluation of buildings with a focus on the user. The study therefore attempts to determine the extent to which user needs were met with respect to some identified design /performance measures within the target institutions. The research adopts the mixed method of data collection, which employed both qualitative and quantitative data sets. The main tools of data collection were interviews, questionnaires/surveys, and observations. The case studies involved the analysis of building performance evaluation of public schools in Edmonton to determine the extent to which the performance of the school buildings meets the needs of their occupants.

Based on the findings of the study, a framework for the school buildings' design optimization were proposed in order to guide designer/architects and construction managers in taking decisions concerning the improvement of building performance in educational institutions. Ideally the optimized solution was the alternatives that obtained the highest rank of membership degrees from design variables; however, as there is always conflict between several variables of a multi criteria problem, the best solution can be the one with the most reasonable combination of rating values (MDs).

6.2 Discussion of the Results

Two main factors were used to assess the accuracy of the model, the total percentage error between the models predicted performance factor and the actual performance factor, and whether or not the model predicted performance factor was close enough to evaluation based strictly on the experts' estimated average and users assessment. The percentage error of the model is calculated in accordance with Equation [1], the accuracy of the model as assessed based on percentage error is given in Table 6-1.

$$E\% = [MP-AP] / AP * 100\% \qquad [1]$$

Where **E%** is Percent error, **MP** is Model Measured Performance, and **AP** is Actual Performance estimate obtained from surveys.

Table 6-1 Model Performance Based on % Error

Developed Model Assessment		
Measured Performance	Absolute Error	% Error
0.46	0.06	12%
0.50	0.00	1%
0.48	0.04	7%
0.54	0.04	7%
0.42	0.12	22%
0.56	0.04	7%
0.61	0.02	3%
0.52	0.03	5%
0.47	0.07	13%
0.49	0.01	2%

The performance of the model versus estimation based on the experts' and users' average is assessed by using the straight users and experts average performance evaluation as the actual estimate, and assessing whether the modeled estimated performance is close to this actual estimate. The initial result of the model is quite promising and the model correctly predicts the performance of the design close to those of the estimate. In testing the ten sets of observation data, the model performance was promising. For 70% of tested cases, the model was able to provide a close prediction to the actual output with an error of less than 10%. However, there was one case in which the model failed to predict the output with high degree of accuracy close to the actual evaluation results and produced the percentage error of 22%.

6.3 General Conclusion

To evaluate the school building design and solve the design optimization problem, both qualitative and quantitative parameters were given a particular importance. To solve the subjectivity of the problem, a multi-criteria fuzzy expert system was proposed and the design evaluation model was developed. Different parameters of school buildings design such as; building orientation and layout, envelope, indoor air quality as well as day-lighting were investigated as part of the design evaluation and optimization process. Beside evaluation purpose, the Model allows the design and construction team to explore different design alternatives to choose the optimized solution. In order to compare model performance with actual data obtained from users' survey procedure, first, the relative importance of each design variable associated with four comfort conditions were reflected on the initial assessment results of school occupants. These relative importance of factors were reflected by applying the weights obtained from experts' questionnaire results as presented in Table 6-2.

Table 6-2 Relative Importance Weight Applied on each Evaluated Variable by Users

	Thermal Condition			**Lighting Condition**			
Variables	**Ventilation**	**Temperature**	**IAQ**	**Natural Lighting**	**Artificial Lighting**	**Glare**	**Views**
Importance Weight	*2	*2	*1	*3	*2	*2	*1

	Acoustic Condition	
Variables	**Background Noise**	**Class Noise**
Importance Weight	*1	*2

	Physical Condition					
Variables	**Functionality**	**Accessibility**	**Circulation**	**Flexibility**	**Facility & service**	**Furniture**
Importance Weight	*4	*3	*3	*1	*2	*2

The measured performance evaluations of ten case study schools obtained from developed FES model were compared with those collected from both users and experts perspectives and the results of comparisons are illustrated in table 6-3 and figure 6-1 accordingly.

Table 6-3 Comparison of Overall Performance Evaluation Results Obtained from Model with those Collected from Users and Experts

	Users Evaluation	**Experts Evaluation**	**Model Outputs**	**Error %**
School 1	0.52	0.43	0.46	12%
School 2	0.49	0.49	0.50	1%
School 3	0.52	0.44	0.48	7%
School 4	0.58	0.5	0.54	7%
School 5	0.54	0.41	0.42	22%
School 6	0.61	0.52	0.56	7%
School 7	0.63	0.59	0.61	3%
School 8	0.54	0.48	0.52	5%
School 9	0.54	0.4	0.47	13%
School 10	0.50	0.46	0.49	2%

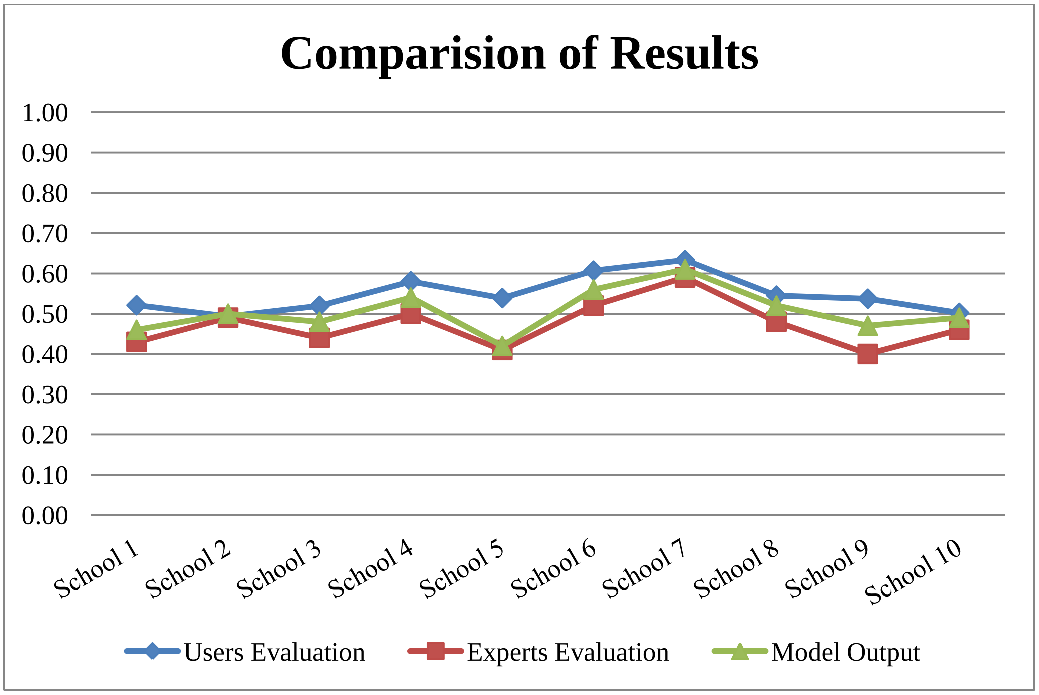


Figure 6-1 Comparison of Model Overall 'Performance Evaluation' Output with Evaluation Results Obtained from Users and Experts

As can be seen from Figure 6-1 the performance of case study school buildings are estimated approximately close to evaluation results of both users and experts and follow equal trend for majority of the samples. The discrepancy can be seen only in the evaluations results of schools 1, 5 and 9, where the building performance have been measured inferior by FES model compare with the actual assessment of the users. It is also notable in all cases that users' plotted evaluation results are located above the model outputs in the comparison graph, which shows higher satisfaction of the users with their learning environments compare to the evaluation results of the model developed based upon experts knowledge. According to the experts, this divergence might arise due to the effect of psychological or socio-economic factors at the time of user survey. Also, the biased and subjective judgment of users on their learning environment during the survey procedure could be an affecting factor, although they were asked to maintain integrity.

6.4 Contribution to the Construction Industry

The contribution of the research study to the construction industry is identified as followings;

- The construction professionals and managers have been urged to adopt the building performance evaluation model as a tool to address the functional failures of building facilities in the educational systems.
- Building performance evaluation could be part of the procurement process. This would enable the design and construction teams to evaluate the extent to which completed buildings meet the performance objectives.
- Proper implementation of feedback mechanism from the user to the design and building team
- The research has generated a qualitative and quantitative assessment of building performance within the learning environments of Edmonton
- research on building performance evaluation can open a window for achieving higher efficiency and effectiveness in the management of educational building facilities

6.5 Limitations of the Model

- Several limitations can be identified in the survey procedure used in identifying factors that affect the performance of the school building design, ranking the relative importance of these factors and establishing standardized definitions of each factor. The largest such limitation is the small number of experts that were consulted with in developing the model. Ideally, in order to develop this model further and increase the range of application of the model, a larger pool of expert knowledge would be required, not only more experts, but experts from more varied backgrounds.

- Due to the small number of schools accepted to participate in the study, it was only possible to collect a small sample data set for testing and verification of the model. In total, only 10 schools including 80 participants were participated in survey procedure. However, collection of this limited data set was useful for illustrating the functionality of the model and analysis of the collected data set showed promising initial results. However, more data is needed in order to verify the membership functions and rule base coded into the model. In the current state, the validity of the model is verified. Having a larger data set to draw from would be invaluable in refining the model to a state in which it could deliver consistently accurate results.

- Qualitative data is collected and entered in the model in three main forms of inputs as listed in table 6-2. For all model inputs, standard definitions for each state of the input variables were developed in an effort to remove some subjectivity in user evaluation.

Table 6-2 Forms of Input Data

Method of Input	**Example Input Factor**	**Example Input**
Crisp Number	Travel Distance	150 m
Defined Category	Opening Distribution	Close
1 - 10 Rating Scale	Outdoor Spaces	Abundant

In the case of crisp number and defined category inputs, the subjectivity in user evaluation is removed. However, for the model inputs that are assessed on a 1-10 or 0-1 rating scale, there still exists a moderate degree of subjectivity in user inputs, which means two different evaluators could give the same set of conditions different ratings on the scale. Further refining and verifying the standard definitions of input variables could help to more reduce this subjectivity to higher acceptable degree.

6.6 Generalization of the Study

- Beside parameters and design variables that identified through the case study observation process, all feasible and potential design alternatives (scenarios) covering the entire universe of discourse were considered in this research study.

- The model is capable of measuring various building typologies located in diverse geographical regions.

6.7 Future Work

It is recommended that the future development of the model be focused on the following areas, with the ultimate goal of developing this model to an acceptable performance estimation tool;

- Expanding the expert knowledge base through a survey program that targets experts with a more diverse range of experience
- Collecting additional data for testing and validating the model
- Refining the standard definitions for input factors in order to further reduce the subjectivity that is to some extent inevitable during user input
- Better defining and applying the relative importance of each weighting factor for performance evaluation

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APPENDIX A

Initial Contact

Dear Sir/Madam,

Study Title: Design Evaluation and Optimization of School Buildings Using Artificial Intelligent Approaches

Research Investigator:
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780 492 8096

My name is Eilnaz Alyari Tabrizi, a Graduate research student in Construction Management Program at University of Alberta, Edmonton Canada. As a part of my thesis research, I am conducting a survey on "Design Evaluation and Optimization of School Buildings to Enhance Students Performance" The aim of the survey is to determine the extent to which educational buildings satisfy the needs of occupants.

You are invited to participate in a research study which seeks to gather information about your school building design and the impact of school building design on the productivity of students and teachers. In this research, the intention is to discover the value of design parameters in a classroom and in what way these parameters have an impact on learning.

A letter explaining this research study and the terms of consent to take part in this study is attached to this email. If you have any questions please do not hesitate to contact me, at alyarita@ualberta.ca or 780-298-7791.

If you are willing to volunteer to participate in this research study please send an email to alyarita@ualberta.ca, and I will contact you to set up a time and place to conduct the interview.
Your participation would be very much appreciated.

Sincerely,
Eilnaz A.Tabrizi
(780) 298-7791
alyarita@ualberta.ca

APPENDIX B

SCHOOL PARTICIPANTS INFORMATION LETTER and CONSENT FORM

Study Title: Design Evaluation and Optimization of School Buildings Using Artificial Intelligent Approaches

Research Investigator:
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Background

My name is Eilnaz A.Tabrizi and I am a graduate student in the Construction Engineering and Management Program at the University of Alberta.
This research seeks to gather information about school building design and the impact of school building design on the productivity of students and teachers.
You are being invited to participate in this study as one of the main occupants of your school building, who is being impacted by the design and environmental of the building in everyday life.
I will be conducting survey in order to learn more about the design quality of your school buildings. The results of this study will be used in support of my thesis research.

Purpose

- The purpose of my research is to explore the impact of school building design, design components and more specifically, the value of design parameters in a classroom and in what way these parameters have an impact on learning and productivity of students and teachers. The intention is to explore whether or not design factors in a classroom have any impact on learning/performance; and are there factors necessary, desirable or perhaps an impediment to learning.

Study Procedures

- I will be conducting this research by inviting you to participate in an e-survey for this study.

- By completing the e-survey you are consenting to participate in the research study.
- As a participant, you may request to read the final report, upon approval of the University of Alberta.
- No names will be recorded during the survey procedure or used in the project.
- The type(s) of data need to be collected is;
    - The e-survey includes almost 30 questions. The completion of the questionnaire should take no longer than 15 minutes.
    - Observations include classroom and overall school building's indoor and outdoor environment exploration may be required, which should take no longer than 30 minutes, and there is no specific condition for observations.
    - Several photos of school building may be collected during the observations by permission of school board.

Benefits

- You will not benefit from being in this study.
- We hope that the information gained from the study provide insight that can be used in the design of better classroom spaces for learning.
- There are not any costs involved in being in the research.
- The participants will not receive any compensations (or reimbursements) for being a participant.

Risk

- There are no known risks to being in this study. If we learn anything during the research that may affect your willingness to continue being in the study, we will tell you right away.
- Participating in this study will not affect your status or standing at your school now or in the future.

Voluntary Participation

- You are under no obligation to participate in this study. The participation is completely voluntary, and you are not obliged to answer any specific questions even if participating in the study.
- Even if you agree to be in the study you can change your mind and withdraw at any time without explanation or consequences of any kind.
- If you withdraw, we will continue to use the data we have collected until your request for provided data removal from the study.
- It is recommended to withdraw data and information provided, no later than 14 days after the e-survey submission, which is just a day before data analysis commencement.
- In case you wish to withdraw your data, please contact the main research investigator at alyarita@ualberta.ca .

Confidentiality & Anonymity

- The study is intended to be used in support of my thesis/dissertation. The presentation of data in the thesis or any follow up papers will not allow for the identification of any individual.

- All information collected for this study will be keep strictly confidential and your identity will be protected at all times. The information that you provide will not be seen by anyone else, and only my Supervisor and I will have access to the information.
- Anonymity of participants can be guaranteed during the study and participants will not be identified and not in the dissemination of the research.
- All collected documents and data will be kept in a secure place during and after the completion of research project. Electronic data will be password protected and encrypted as well. All hard copies and electronic copies of data collected for the study will be destroyed immediately after the completion of the research study in order to ensure privacy and confidentiality.
- As a participant, you may request to read the final report or a copy of a report of the research findings, upon approval of the University of Alberta.
- If you wish to get the final copy of the report, please contact the main research investigator at alyarita@ualberta.ca .

Further Information

- If you have any further questions regarding this study, please do not hesitate to contact me, Eilnaz A.Tabrizi, as a main researcher at alyarita@alberta.ca, or Dr. Simaan Abourizk, the supervisor of the study, at abourizk@ualberta.ca).
- The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

__________________________ Signature

__________________ Date

APPENDIX C

EXPERTS INFORMATION LETTER and CONSENT FORM

Study Title: Design Evaluation and Optimization of School Buildings Using Artificial Intelligent Approaches

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780 492 8096

Background

My name is Eilnaz A.Tabrizi and I am a graduate student in the Construction Engineering and Management Program at the University of Alberta.
This research seeks to gather information about school building design and the impact of school building design on the productivity of students and teachers.
You are being invited to participate in this study as an expert in design area /specialist in school buildings design, who can provide valuable recommendations which will assist the conduct of this study. I will be conducting interviews in order to learn more about the design parameters of a educational/ school buildings. The results of this study will be used in support of my thesis research.

Purpose

- The purpose of my research is to explore the impact of school building design, design components and more specifically, the value of design parameters in a classroom and in what way these parameters have an impact on learning and productivity of students and teachers. The intention is to explore whether or not design factors in a classroom have any impact on learning/performance; are there factors necessary, desirable or perhaps an impediment to learning. This research will attempt to answer the following questions:
  - In what ways do the classroom design parameters of a school impact learning?
  - In what ways do these parameters impose their impacts?
  - In what ways would these parameters improve or detract from learning in a classroom?

Study Procedures

- I will be conducting this research by inviting you to participate in an interview for this study.
- If you consent to participate in this research study by relying back this email, we will arrange a time and the location for the upcoming interview.
- As a participant, you may request to read the final report, upon approval of the University of Alberta.
- No names will be recorded during the interview procedure or used in the project.
- The type(s) of data need to be collected is just an informal interview, which will take no longer than 30 minutes.

Benefits

- You will not benefit from being in this study.
- We hope that the information gained from the study provide insight that can be used in the design of better classroom spaces for learning.
- There are not any costs involved in being in the research.
- The participants in the interview will not receive any compensations (or reimbursements) for being a participant.

Risk

There are no known risks to being in this study. If we learn anything during the research that may affect your willingness to continue being in the study, we will tell you right away.

Voluntary Participation

- You are under no obligation to participate in this study. The participation is completely voluntary, and you are not obliged to answer any specific questions even if participating in the study.
- Even if you agree to be in the study you can change your mind and withdraw at any time without explanation or consequences of any kind.
- If you withdraw, we will continue to use the data we have collected until your request for provided data removal from the study.
- It is recommended to withdraw data and information provided, no later than 14 days after the survey day, which is just a day before data analysis commencement.
- In case you wish to withdraw your data, please contact the main research investigator at alyarita@ualberta.ca .

Confidentiality & Anonymity

- The study is intended to be used in support of my thesis/dissertation. The presentation of data in the thesis or any follow up papers will not allow for the identification of any individual.
- All information collected for this study will be keep strictly confidential and your identity will be protected at all times. The information that you provide will not be seen by anyone else, and only my Supervisor and I will have access to the information.
- Anonymity of participants can be guaranteed during the study and participants will not be identified and not in the dissemination of the research.

- All collected documents and data will be kept in a secure place during and after the completion of research project. Electronic data will be password protected and encrypted as well. All hard copies and electronic copies of data collected for the study will be destroyed immediately after the completion of the research study in order to ensure privacy and confidentiality.
- As a participant, you may request to read the final report or a copy of a report of the research findings, upon approval of the University of Alberta.
- If you wish to get the final copy of the report, please contact the main research investigator at alyarita@ualberta.ca .

Further Information

- List researcher contact information and third party contact information. (e.g. If you have any further questions regarding this study, please do not hesitate to contact LIST RESEARCHERS HERE).
- The following statement should also be included. ("The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615."

__________________________ ____________________

Signature Date

APPENDIX D

Confidentiality Agreement

Research Study- Design Evaluation and Optimization of School Buildings Using Artificial Intelligent Approaches

Researchers: Eilnaz A.Tabrizi (Graduate Student) and Dr. Simaan AbouRizk (Thesis Supervisor)

CONFIDENTIALITY AGREEMENT

As the main researcher of this study, I will maintain confidentiality of all information from interviews and surveys. The information from these surveys and interviews will be revealed by research participants who participated in this project on good faith that their interviews would remain strictly confidential. I understand that I have a responsibility to honor this confidentially agreement.

I hereby agree not to share any information with anyone except my thesis supervisor, Dr. Simaan AbouRizk. Any violation of this agreement would constitute a serious breach of ethical standards, and I therefore pledge not to do so.

________________________ Signature

_________________ Date

APPENDIX E

School Participants Survey Questionnaire

Dear Sir/madam

My name is Eilnaz Alyari Tabrizi, a Graduate research student in Construction Management Program at University of Alberta, Edmonton Canada. I am conducting a survey on “Design Evaluation and Optimization of School Buildings to Enhance Students Performance” The aim of the survey is to determine the extent to which educational buildings satisfy the needs of occupants.
The purpose of this survey is to obtain your opinion and experience on the performance of your educational building as well as how it can be improved. The survey is estimated to last no longer than 30 minutes.
The data obtained through this interview and any documentation from you will be treated confidentially and no records will bear your identity or your institution’s name.

QUESTIONS FOR THE STUDY

Please rank the following statements and factors, on scale of 1 to 10, regarding the school building and classrooms evaluation.

<u>Thermal Comfort Aspects</u>

1. **Temperature of the classroom**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

2. **Air velocity**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

3. **Humidity**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

4. **Indoor air Quality of the classroom**

Very Poor 2 3 4 5 6 7 8 9 Very Excellent

5. **Ventilation of the classroom**

Very Poor 2 3 4 5 6 7 8 9 Very Excellent

Acoustic Comfort Aspects

1. **Background noises level**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

2. **Ability to understand desired sounds**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

3. **Classroom noise level**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

Physical Comfort Aspects

1. **Walkways** (how distinct walkways are)

Amigos 2 3 4 5 6 7 8 9 Distinct

2. **Pathways** (if pathways are clear and comfortable allowing for movement)

Amigos 2 3 4 5 6 7 8 9 Clear

3. **Public Areas and lunges** (if Public Areas are inviting, comfortable, and include ample lighting.)

Uncomfortable 2 3 4 5 6 7 8 9 Comfortable

4. **Signage** (if all spaces and classrooms are obvious and signed inside the school)

Obscure 2 3 4 5 6 7 8 9 Obvious

5. **Existence of Outdoor Spaces**

None-existence 2 3 4 5 6 7 8 9 Plenty

6. **Comfort of classroom furniture**

Very uncomfortable 2 3 4 5 6 7 8 9 Very Comfortable

7. **Ability to adjust furniture**

Very Poor 2 3 4 5 6 7 8 9 Very Excellent

8. **Amount of space available for each individual**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

9. **Seating arrangement in the classroom**

Very Poor 2 3 4 5 6 7 8 9 Very Excellent

10. **Circulation in the classroom area**

Very Poor 2 3 4 5 6 7 8 9 Very Excellent

<u>Day-Light Comfort Aspects</u>

1. **Light Level in Classrooms (**from windows, skylights, and artificial light)

No Light 2 3 4 5 6 7 8 9 Ample Light

2. **Amount of electric lighting (artificial light)**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

3. **Amount/level of day-lighting (natural light)**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

4. **Visual comfort of the lighting**

Very uncomfortable 2 3 4 5 6 7 8 9 Very Comfortable

5. **Ability to control the natural light**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

6. **Ability to control artificial lighting level in presence of natural day-light**

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

<u>Visual Comfort Aspects</u>

1. **Level of outside/external views from classroom**

Restricted 2 3 4 5 6 7 8 9 Unrestricted

2. **View to green areas** (gardens, parks, fountains, mountains)

Non-existent 2 3 4 5 6 7 8 9 Plentiful

General

1. **The overall satisfaction with the facility** (site, building, classroom, other areas)

Very Dissatisfied 2 3 4 5 6 7 8 9 Very Satisfied

2. **The overall effect of the facility on your performance**

Hinders Performance 2 3 4 5 6 7 8 9 Enhances Performance

- If you have any further questions regarding this study, please do not hesitate to contact me, Eilnaz A.Tabrizi, as a main researcher at alyarita@alberta.ca, or Dr. Simaan Abourizk, the supervisor of the study, at abourizk@ualberta.ca).
- The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

Signature of Research Participant Date
(Printed Name)

APPENDIX F

Experts Initial Interview Questions

Dear Sir/madam

My name is Eilnaz Alyari Tabrizi, a Graduate research student in Construction Management Program at University of Alberta, Edmonton Canada. I am conducting a survey on "Design Evaluation and Optimization of School Buildings to Enhance Students Performance" The aim of the survey is to determine the extent to which educational buildings satisfy the needs of occupants.
The purpose of this interview is to obtain your opinion and experience on the performance of educational buildings as well as how they can be improved. The interview is estimated to last between 30 to 45 minutes.
The data obtained through this interview and any documentation from you will be treated confidentially and no records will bear your identity or your institution's name.
The questions are about your current practices and some key aspects of building performance evaluation.

1. Are you involved in the design, construction and management of buildings?

2. What are your key measures for judging the success of a new building design after a building is completed and occupied?

3. Do you conduct any form of building performance evaluation? If yes, please describe how.

4. Why building performance evaluation is helpful, and who should normally conduct it?

5. Are there features that have been included in your buildings to improve productivity of design, indoor environmental quality and occupant comfort and satisfaction?

6. What are your key indicators of how well a building is performing for occupants?

7. What assessment tools for evaluation of building performance and occupants' comfort/satisfaction are you aware of?

8. Do you use any benchmarks such as guides, standards, codes or regulations? If yes, what benefits do they provide for your design and construction practice?

9. Have you received occupants' complaints regarding your buildings? If yes, what are the most common areas of complaints? Are these complains common, rare or occasional? Please provide a brief description for each;

Thermal Condition.......................................

Lighting Condition.......................................

Acoustic Condition.......................................

Ventilation.......................................

Physical Condition.......................................

Aesthetics.......................................

Views.......................................

Air quality.......................................

Safety...

Others...

10. What suggestions do you have for improving the performance evaluation of buildings?

Thank you for spending your valuable time to make this meeting possible. I wish to also thank you for the insights I have gained from your rich experience which will help in compiling data for this research.

APPENDIX G

Letter of Approval from Cooperative Activities Program

UNIVERSITY OF ALBERTA
FACULTY OF EDUCATION

Cooperative Activities Program (CAP)
Research Project Application

School District (Please choose one school district, unless multiple districts are crucial to your research)

☐ Edmonton Catholic Schools
☐ Elk Island Public Schools (*Sherwood Park & Area*)
☒ Edmonton Public Schools
☐ St Albert Public Schools (*formerly St Albert Protestant*)

Title of Research

Design Evaluation and Optimization of School Buildings Using Artificial Intelligent Approaches

Date Submitted – MM 09 DD 14 YYYY 2012

Proposed Start Date – MM 10 DD 01 YYYY 2012

Proposed End Date (Final Report) – MM 10 DD 31 YYYY 2012

Applicant Information (University of Alberta, Faculty Member)

Name: Simaan AbouRizk Email: abourizk@ualberta.ca

Faculty/Department: Engineering / Civil - Env.

(*If applying on behalf of student, your signature indicates that you have read this application and approve its submission*)

Applicant Signature [signature] Date Sep. 13, 2012

**If this request is being made on behalf of a student, provide the following information:*

☒ Graduate Student ☐ Undergraduate Student

Student's Name: Elnaz Alyari Tabrizi Email: alyarita@ualberta.ca

Phone Number: 780- 298 7791

Faculty/Department: Civil and Environmental Engineering

For Office Use Only

University Review: ☑ *Approved* ☐ *Denied* *Date:* Sept. 18/2012

Associate Dean Research & Graduate Studies: [signature]
Dr Patricia Boechler

District Review: ☑ *Approved* ☐ *Denied* *Date:* Oct. 3/2012

District Representative: Sharon Gentilini [signature]
Printed Name *Signature*

The personal information requested on this form is collected under the authority of Section 33(c) of the Alberta Freedom of Information and Protection of Privacy Act for administrative purposes only.
Form revised July 17, 2012

APPENDIX H

Letter of Approval from School District

EDMONTON PUBLIC SCHOOLS

Superintendent of Schools
Edgar Schmidt

Centre for Education
One Kingsway
Edmonton, Alberta T5H 4G9
T 780-429-8000
F 780-429-8318
info@epsb.ca
www.epsb.ca

October 10, 2012

Dr. Patricia Boechler
Associate Dean, Research and Graduate Studies
845 Education South
University of Alberta
Edmonton, Alberta
T6G 2G5

770.12

Dear Dr. Boechler:

Re: *Design Evaluation and Optimization of School Buildings Using Artificial Intelligent Approaches—Tabrizi*

The aforementioned research request has been approved, subject to the following conditions:

1. Principal, teacher and school staff participation in the study shall be voluntary;
2. Participants are free to withdraw at any time;
3. Anonymity of the participants and confidentiality of information obtained is assured;
4. Personal information may only be used for the stated purpose for which the information was collected or compiled; and
5. The researcher conforms to the requirements of the Freedom of Information and Protection of Privacy Act and Regulation.

Eilnaz A. Tabrizi may now contact the undernoted principals to obtain approval and to make the necessary arrangements for conducting the study. It is the responsibility of the researcher to provide the principal with a copy of the proposal and all related documents, if requested. I wish Ms. Tabrizi success in this endeavour and anticipate reception of the results as they become available. If you require further information, please contact Shannon Gentilini at 780-903-8499.

Sincerely,

Shannon Gentilini
Research Liaison

SG/jf

Bright futures begin here

APPENDIX I

Screenshot of Developed Observation Database

School ID	Number of Spaces	Actual Observation Data																							
		Thermal Condition Factor					Lighting Condition Factor								Accoustic Condition Factor					Physical Condition Factor					
		Ventilation & Temprature					Natural Daylight			Glare Condition		View Condition		Glass Type	Background Noise			Class Noise Level		Functionality & movement		Accessibility		Facility & Service	
		Opening position	Opening location	Building orientation	wind direction	Space layout	Class Orientation	Class Geometry	Opening location	Opening distribution	Number of Openings	Opening size	Shape of opening	Glass transmissivity	School Geometry	Distance from noise	Existence of barriers	Space layout	Material quality	Space outline	Space size	Travel distance	Circulation facilities	Public spaces	Outdoor spaces
1	2	Single	W	West-East		Square	West-East	Square	W	Close	2	Large	Elongated Rectangle	Semi Tint	L-shaped	Average	None	Square	None Absorbant	Well defined	Large	Close	Clear	Satisfying	Enough
	3	Single	S			Square	South-North	Square	S		2							Square							
	1	Adjacent	N&W			Deep	West-East	Rectangle	N&W		3							Deep							
	1	Adjacent	S&W			Extended	South-North	Rectangle	S&W		3							Extended							
	1	Adjacent	S&E			Extended	South-North	Square	S&E		2							Extended							
2	4	Single	W	South-North		Square	West-East	Square	W	Regular	2	Average	Elongated Rectangle	Semi transparent	Rectangle	Close	None	Square	None Absorbant	Poor defined	Small	Far	Clear	Satisfying	Ample
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3							Deep							
	1	Adjacent	S&W			Deep	South-North	Rectangle	S&W		3							Deep							
3	6	Parallel	E&W	South-North		Square	West-East	Square	E&W	Far	4	Small	Rectangle	Semi transparent	H shaped	Close	Yes	Square	Semi Absorbant	Well defined	Regular	OK	Ambiguous	Excellent	Ample
	1	Adjacent	N&E			Square	South-North	Square	N&E		3							Square							
	1	Adjacent	N&W			Square	South-North	Square	N&W		3							Square							
	1	Adjacent	S&E			Square	North-South	Square	S&E		3							Square							
	1	Adjacent	S&W			Square	North-South	Square	S&W		3							Square							
4	2	Single	E	East-West		Square	East-West	Square	E	Regular	2	Average	Elongated Rectangle	Semi transparent	Square	Far	None	Square	Absorbant	Well defined	Large	Close	Clear	Excellent	Absent
	2	Single	W			Square	East-West	Square	W		2							Square							
	1	Adjacent	N&E			Deep	South-North	Rectangle	N&E		3							Deep							
	1	Adjacent	S&E			Extended	East-West	Rectangle	S&E		2							Extended							
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3							Deep							
	1	Adjacent	S&W			Extended	East-West	Square	S&W		2							Extended							
5	3	Single	E	South-North		Square	East-West	Square	E	Regular	2	Average	Elongated Rectangle	Semi transparent	Rectangle	Average	Yes	Square	None Absorbant	Poor defined	Regular	OK	Clear	Satisfying	Enough
	1	Adjacent	N&E			Extended	East-West	Rectangle	N&E		3							Extended							
	1	Adjacent	S&E			Extended	East-West	Rectangle	S&E		3							Extended							
6	2	Single	N	East-West		Square	South-North	Square	N	Far	2	Average	Rectangle	Tint	Square	Average	Yes	Square	Semi Absorbant	Well defined	Large	Close	Clear	Excellent	Ample
	2	Single	S			Square	South-North	Square	S		2							Square							
	1	Adjacent	N&E			Square	South-North	Square	N&E		2							Square							
	1	Adjacent	S&E			Square	South-North	Square	S&E		2							Square							
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3							Deep							
	1	Adjacent	S&W			Deep	South-North	Rectangle	S&W		3							Deep							
7	4	Single	W	North-South		Square	West-East	Square	W	Far	2	Small	Elongated Rectangle	Transparent	Rectangle	Far	Yes	Square	Semi Absorbant	Well defined	Regular	Close	Clear	Excellent	Enough
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3							Deep							
	1	Adjacent	S&W			Deep	South-North	Rectangle	S&W		3							Deep							
8	3	Parallel	N&S	South		Extended	North-South	Rectangle	N&S	Regular	4	Average	Elongated Rectangle	Transparent	Rectangle	Close	Yes	Extended	None Absorbant	Well defined	Regular	Close	Clear	Excellent	Ample
	1	Adjacent	S&E			Extended	South-North	Rectangle	S&E		3							Extended							
9	2	Single	E	East-West		Deep	North-South	Rectangle	E	Close	3	Large	Elongated Rectangle	Semi tint	L-shaped	Average	None	Deep	Absorbant	Well defined	Large	OK	Ambiguous	Satisfying	Enough
	3	Single	N			Extended	East-West	Rectangle	N		3							Extended							
	1	Adjacent	N&E			Extended	East-West	Rectangle	N&E		4							Extended							
	1	Adjacent	N&W			Extended	East-West	Rectangle	N&W		4							Extended							
	1	Adjacent	S&E			Deep	North-South	Rectangle	S&E		3							Deep							
10	1	Single	N	East-West		Square	South-North	Square	N	Far	2	Small	Rectangle & Square	Semi tint	U-shaped	Close	None	Square	Absorbant	Well defined	Small	Far	Clear	Satisfying	Absent
	3	Single	E			Square	East-West	Square	E		3							Square							
	1	Single	S			Square	South-North	Square	S		2							Square							
	4	Parallel	N&S			Deep	South-North	Rectangle	N&S		4							Deep							
	1	Adjacent	N&E			Deep	South-North	Rectangle	N&E		4							Deep							
	1	Adjacent	S&E			Deep	South-North	Rectangle	S&E		4							Deep							
	1	Adjacent	N&W			Extended	East-West	Rectangle	N&W		3							Extended							
	1	Adjacent	S&W			Extended	East-West	Rectangle	S&W		3							Extended							

Screenshot of Developed Survey Database

School ID	Number of Spaces	Schools Performance Data (user survey results)																					
		User Evaluation on Comfort Conditions																Overall Performance Evaluation applying the weights					
		Thermal Condition			Lighting Condition				Accoustic Condition		Physical Condition						Overall Users Satisfaction	Overall Thermal Performance	Overall Lighting Performance	Overal Accoustic Performance	Overall Physical Performance	Overall school Performance	Final Users Evaluation Result
		Ventilation	Temperature	IAQ	Natural Lighting	Artificial Lighting	Glare	Views	Background Noise	Class Noise	Functionality	Accesibility	Circulation	Flexibility	Facility & service	Furniture							
1	2 3 1 1 1	3	5.8	6.4	6.4	7.9	8.4	2.95	3.8	7.1	7.7	8.05	8.8	6.5	5.25	8.1	4.1	4.80	6.84	6.00	7.64	6.32	0.52
2	4 1 1	2.1	4.5	4.9	7.6	8.3	6.8	4.8	2.3	8	3.65	7.05	3.1	4.4	6.8	5.3	4.4	3.62	7.23	6.10	4.91	5.46	0.49
3	6 1 1 1 1	2.8	5	5.3	7	6.8	6.6	5.2	5.6	7	7	3.55	7.1	3.4	8.45	6.4	4.5	4.18	6.63	6.53	6.20	5.89	0.52
4	2 2 1 1 1 1	3.1	7	7.3	7.4	7.3	7.6	3.95	6.8	7.9	7.75	7.7	8	2.8	5.1	8.4	4.8	5.50	6.99	7.53	7.19	6.81	0.58
5	3 1 1	5.4	7.5	7.8	7.8	5.6	6.8	6.3	4.1	8.4	5.15	4.95	5.2	5.7	5.75	6.4	4.3	6.72	6.81	6.97	5.40	6.48	0.54
6	2 2 1 1 1 1	3.9	7	7.5	5.9	8.5	8.4	2.95	6.8	7.9	8.35	8.65	9.4	5.4	8.4	8.6	5.4	5.86	6.81	7.53	8.46	6.73	0.61
7	4 1 1	5.3	3.6	4.1	8.4	8.4	7.4	4.55	7	7.3	7.7	8	8.7	5.3	7	8.3	5.9	4.38	7.67	7.20	7.79	6.76	0.63
8	3 1	4	7.9	8.3	8.3	8	7.8	3.8	4.6	6.5	6.65	8.5	9	6.4	7.95	7.5	4	6.42	7.54	5.87	7.76	6.90	0.54
9	2 3 1 1 1	6	7	7.3	6.6	7.6	8	5.1	6.5	7	7.9	4.6	6.5	5.9	5.95	7.1	4	6.66	7.01	6.83	6.46	6.74	0.54
10	1 3 1 4 1 1 1 1	3.4	4	5	6.3	8.9	8.8	2.35	6.4	6.5	5.85	6.65	4.5	4.6	3.65	6.5	4.3	3.96	7.08	6.47	5.45	5.74	0.50

Screenshot of Developed FES Model Outputs

School ID	Number of Spaces	Thermal Condition Factor – Ventilation & Temprature: Opening position	Opening location	Building orientation	wind direction	Space layout	Lighting Condition Factor – Natural Daylight: Class Orientation	Class Geometry	Opening location	Glare Condition: Opening distribution	Number of Openings	Accoustic Condition Factor – Class Noise Level: Space layout
1	2	Single	W	West-East		Square	West-East	Square	W	Close	2	Square
	3	Single	S			Square	South-North	Square	S		2	Square
	1	Adjacent	N&W			Deep	West-East	Rectangle	N&W		3	Deep
	1	Adjacent	S&W			Extended	South-North	Rectangle	S&W		3	Extended
	1	Adjacent	S&E			Extended	South-North	Square	S&E		2	Extended
2	4	Single	W	South-North		Square	West-East	Square	W	Regular	2	Square
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3	Deep
	1	Adjacent	S&W			Deep	South-North	Rectangle	S&W		3	Deep
3	6	Parallel	E&W	South-North		Square	West-East	Square	E&W	Far	4	Square
	1	Adjacent	N&E			Square	South-North	Square	N&E		3	Square
	1	Adjacent	N&W			Square	South-North	Square	N&W		3	Square
	1	Adjacent	S&E			Square	North-South	Square	S&E		3	Square
	1	Adjacent	S&W			Square	North-South	Square	S&W		3	Square
4	2	Single	E	East-West		Square	East-West	Square	E	Regular	2	Square
	2	Single	W			Square	East-West	Square	W		2	Square
	1	Adjacent	N&E			Deep	South-North	Rectangle	N&E		3	Deep
	1	Adjacent	S&E			Extended	East-West	Rectangle	S&E		2	Extended
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3	Deep
	1	Adjacent	S&W			Extended	East-West	Square	S&W		2	Extended
5	3	Single	E	South-North		Square	East-West	Square	E	Regular	2	Square
	1	Adjacent	N&E			Extended	East-West	Rectangle	N&E		3	Extended
	1	Adjacent	S&E			Extended	East-West	Rectangle	S&E		3	Extended
6	2	Single	N	East-West		Square	South-North	Square	N	Far	2	Square
	2	Single	S			Square	South-North	Square	S		2	Square
	1	Adjacent	N&E			Square	South-North	Square	N&E		2	Square
	1	Adjacent	S&E			Square	South-North	Square	S&E		2	Square
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3	Deep
	1	Adjacent	S&W			Deep	South-North	Rectangle	S&W		3	Deep
7	4	Single	W	North-South		Square	West-East	Square	W	Far	2	Square
	1	Adjacent	N&W			Deep	South-North	Rectangle	N&W		3	Deep
	1	Adjacent	S&W			Deep	South-North	Rectangle	S&W		3	Deep
8	3	Parallel	N&S	South		Extended	North-South	Rectangle	N&S	Regular	4	Extended
	1	Adjacent	S&E			Extended	South-North	Rectangle	S&E		3	Extended
9	2	Single	E	East-West		Deep	North-South	Rectangle	E	Close	3	Deep
	3	Single	N			Extended	East-West	Rectangle	N		3	Extended
	1	Adjacent	N&E			Extended	East-West	Rectangle	N&E		4	Extended
	1	Adjacent	N&W			Extended	East-West	Rectangle	N&W		4	Extended
	1	Adjacent	S&E			Deep	North-South	Rectangle	S&E		3	Deep
10	1	Single	N	East-West		Square	South-North	Square	N	Far	2	Square
	3	Single	E			Square	East-West	Square	E		3	Square
	1	Single	S			Square	South-North	Square	S		2	Square
	4	Parallel	N&S			Deep	South-North	Rectangle	N&S		4	Deep
	1	Adjacent	N&E			Deep	South-North	Rectangle	N&E		4	Deep
	1	Adjacent	S&E			Deep	South-North	Rectangle	S&E		4	Deep
	1	Adjacent	N&W			Extended	East-West	Rectangle	N&W		3	Extended
	1	Adjacent	S&W			Extended	East-West	Rectangle	S&W		3	Extended

School ID	View Condition: Opening size	Shape of opening	Glass Type: Glass transmissivity	Background Noise: School Geometry	Distance from noise	Existence of barriers	Class Noise Level: Material quality	Functionality & movement: Space outline	Space size	Accessibility: Travel distance	Circulation facilities	Facility & Service: Public spaces	Outdoor spaces	Model Overall Performance Results: Overall Thermal Performance	Overall Lighting Performance	Overall Accoustic Performance	Overall Physical Performance	Model Masured Perfoormance	Model Assessment: Absolute Error	% Error
1	Large	Elongated Rectangle	Semi Tint	L-shaped	Average	None	None Absorbant	Well defined	Large	Close	Clear	Satisfying	Enough	0.20	0.26	0.52	0.86	0.46	0.06	12%
2	Average	Elongated Rectangle	Semi transparent	Rectangle	Close	None	None Absorbant	Poor defined	Small	Far	Clear	Satisfying	Ample	0.33	0.50	0.64	0.52	0.50	0.00	1%
3	Small	Rectangle	Semi transparent	H shaped	Close	Yes	Semi Absorbant	Well defined	Regular	OK	Ambiguous	Excellent	Ample	0.26	0.54	0.71	0.42	0.48	0.04	7%
4	Average	Elongated Rectangle	Semi transparent	Square	Far	None	Absorbant	Well defined	Large	Close	Clear	Excellent	Absent	0.20	0.38	0.64	0.95	0.54	0.04	7%
5	Average	Elongated Rectangle	Semi transparent	Rectangle	Average	Yes	None Absorbant	Poor defined	Regular	OK	Clear	Satisfying	Enough	0.26	0.50	0.45	0.48	0.42	0.12	22%
6	Average	Rectangle	Tint	Square	Average	Yes	Semi Absorbant	Well defined	Large	Close	Clear	Excellent	Ample	0.62	0.29	0.62	0.72	0.56	0.04	7%
7	Small	Elongated Rectangle	Transparent	Rectangle	Far	Yes	Semi Absorbant	Well defined	Regular	Close	Clear	Excellent	Enough	0.58	0.59	0.48	0.80	0.61	0.02	3%
8	Average	Elongated Rectangle	Transparent	Rectangle	Close	Yes	None Absorbant	Well defined	Regular	Close	Clear	Excellent	Ample	0.18	0.26	0.70	0.92	0.52	0.03	5%
9	Large	Elongated Rectangle	Semi tint	L-shaped	Average	None	Absorbant	Well defined	Large	OK	Ambiguous	Satisfying	Enough	0.44	0.42	0.29	0.72	0.47	0.07	13%
10	Small	Rectangle & Square	Semi tint	U-shaped	Close	None	Absorbant	Well defined	Small	Far	Clear	Satisfying	Absent	0.70	0.65	0.23	0.38	0.49	0.01	2%

Experts Overall Evaluation Results of Case Study Schools

School 1	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1	1.5	1	1.5	1.25	0.25
Lighting Condition	0.5	1.5	1	1	1	0.2
Acoustic Condition	1	2	2	2	1.75	0.35
Physical Condition	4	4.5	4.5	5	4.5	0.9
Overall Performance	1.63	2.38	2.13	2.38	2.13	0.43

School 2	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	3.5	3	4	4.5	3.75	0.75
Lighting Condition	3	2.5	3.5	4	3.25	0.65
Acoustic Condition	1	1.5	1.5	0.5	1.13	0.23
Physical Condition	1.5	2	2	1.5	1.75	0.35
Overall Performance	2.25	2.25	2.75	2.63	2.47	0.49

School 3	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1.5	1	1	1.5	1.25	0.25
Lighting Condition	0.5	1.5	2	1	1.25	0.25
Acoustic Condition	3	2.5	2.5	2	2.5	0.5
Physical Condition	4	4.5	3.5	3	3.75	0.75
Overall Performance	2.25	2.38	2.25	1.88	2.19	0.44

School 4	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1	1.5	2	1.5	1.5	0.3
Lighting Condition	1	1.5	1	1	1.13	0.23
Acoustic Condition	3	3.5	2.5	3	3	0.6
Physical Condition	4	4.5	4.5	4.5	4.38	0.88
Overall Performance	2.25	2.75	2.50	2.50	2.50	0.50

School 5	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1	1.5	1.5	1.5	1.38	0.28
Lighting Condition	1	2.5	2	1.5	1.75	0.35
Acoustic Condition	2	2.5	2	2	2.13	0.43
Physical Condition	3.5	3	2	3	2.88	0.58
Overall Performance	1.88	2.38	1.88	2.00	2.03	0.41

School 6	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1	1	0.5	1	0.88	0.18
Lighting Condition	1	1.5	2.5	1	1.50	0.30
Acoustic Condition	3	3	4	2.5	3.13	0.63
Physical Condition	4.5	5	5	5	4.88	0.98
Overall Performance	2.38	2.63	3.00	2.38	2.59	0.52

School 7	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1.5	1.5	2	1	1.5	0.3
Lighting Condition	2	2	2	2	2	0.4
Acoustic Condition	4	4	3.5	3	3.63	0.73
Physical Condition	4.5	4.5	5	4.5	4.63	0.93
Overall Performance	3.00	3.00	3.13	2.63	2.94	0.59

School 8	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1	2	1	1	1.25	0.25
Lighting Condition	1.5	1.5	1.5	2	1.63	0.33
Acoustic Condition	2	2	1.5	2	1.88	0.38
Physical Condition	4.5	5	5	5	4.88	0.98
Overall Performance	2.25	2.63	2.25	2.50	2.41	0.48

School 9	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	1	0.5	0.5	0.5	0.63	0.13
Lighting Condition	1	1	1	1.5	1.13	0.23
Acoustic Condition	2.5	2	3.5	3	2.75	0.55
Physical Condition	3.5	3.5	4	3	3.5	0.7
Overall Performance	2.00	1.75	2.25	2.00	2.00	0.40

School 10	School Performance Factor					
	Expert # 1	Expert # 2	Expert # 3	Expert # 4	Overall Score/5	Overall MD/1
Thermal Condition	2	1.5	2	1	1.63	0.33
Lighting Condition	3	2	2	2	2.25	0.45
Acoustic Condition	3.5	3	2.5	3	3	0.6
Physical Condition	2	2.5	2.5	2	2.25	0.45
Overall Performance	2.63	2.25	2.25	2.00	2.28	0.46