Ain Shams University
Faculty of Engineering
Department of Architecture

Smart Architecture Techniques For processing the optical Environment In University Spaces

Presented by

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Statement

This thesis is submitted to Ain Shams University for the degree of Master of Science in Architecture.

The work included in this thesis was accomplished by the author at the Department of Architecture, Faculty of Engineering, Ain Shams University, during the period from “2010 to 2015”.

No part of this thesis has been submitted for a degree or a qualification at any other university or institute.

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Date:

“Live as if you were to die tomorrow. Learn as if you were to live forever.”

Mahatma
Gandhi

Acknowledgments

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Nouran Adel Awad Elkiki
2015
Cairo, Egypt

To my Mom, Dad and Sisters

For all your Support, Encouragement and
Unconditional love

To my fiancé,

Some say that dreams are just dreams, but when I saw you I realized that this is false, you are the person who I always dreamed of, Thanks for always being here with me.

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List of Abbreviations

AOA	Ambient Optic Array
ASE	Annual Sunlight Exposure
AMA	Alexi Marmot Associates
AV	Audio Video
BCS	Building Control System
BEMS	Building Energy Management System
BMS	Building Management System
BSI	Building System Integrator
CBDM	Climate-based daylight modelling
CCTV	Closed Circuit Television Systems
CGI	CIE Glare Index
CICS	Constant illuminance control strategy
CIE	Commission Internationale de l´Eclairage, International Commission on Illumination
CRI	Color Rendering Index
DA	Daylight autonomy
DAcon	Continuous Daylight Autonomy
DF	Daylight Factor
DGI	Daylight Glare Index
DGP	Daylight Glare Probability
DHCS	Daylight harvesting control strategy
DVD	Digital Versatile Disc
EC	Electrochromic devices
ERP	Enterprise Resource Planning
e.g.	exempli gratia (for example)
ERP	Enterprise resource planning
etc.	et cetera (and other similar things)
HVAC	Heating, Ventilating, and Air Conditioning
IB	Intelligent Building
IBI	Intelligent Building Institution

List of Abbreviations

IBM	International Business Machines Corporation
ICLS	Integrated classroom lighting system
ICT	Information and communications technology
i.e.	id est.(that is)
IES	Illuminating Engineering Society (IESNA before)
IESNA	Illuminating Engineering Society of North America
icampus	Intelligent campus
IP	Internet protocol
ISCN	International Sustainable Campus Network
JISC	Jenzabar Internet Campus Solution
LED	Light Emitting Diodes
LEED	Leadership in Energy and Environmental Design system
LEED V4	Leadership in Energy and Environmental Design system, version 4
Low-E	Low emissivity
LCD	liquid-crystal display
NLII	National Learning Infrastructure Initiative
ORBIT	Organizations, Buildings and Information Technology
PC	Personal computer
POCS	Predicted Occupancy Control Strategy
PDLC	Polymer Dispersed Liquid Crystal Devices
ROCS	Real occupancy control strategy
S	Side
sDA	Special daylight Autonomy
SOM	Skidmore, Owings & Merrill - American architectural, urban planning, and engineering firm.
SPT	Single Point in Time
SU	Smart University
SPD	Suspended Particle Devices
UCPH	University of Copenhagen
UDI	Useful Daylight Illuminance
UGR	CIE Unified Glare Rating
VHS	Video Home System
WWR	Window to Wall Ratio

The Researcher Identification

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Abstract

The concept of intelligent and smart buildings became a turning point in architecture and construction fields over the last three decades which transformed the world to be smart world consisting of administrative, educational and service integrated intelligent buildings. As the world shifts to a more services-based economy, smart university should be created as new model of interconnected educational institution. Learning is the main activity at universities. Concept of traditional classrooms at universities has been changed nowadays to be 'smart' Learning spaces which correspond to the needs of our smart building era. These smart spaces contain not only blackboards, seats and tables, but also audio-visual (AV) equipment, video projector and screens, etc. The overarching goal of education is to provide a good visual environment for all the users, including students and instructors. Moreover, this electric evolution affects the visual needs of learning spaces. Therefore, glare control and visual quality became a critical issue for the view of students especially when they focus on the screens. Subsequently, smart learning spaces design and layout have a significant influence on lighting system and visual environment to accommodate the future trends of university learning spaces, provision of daylight in learning spaces can be considered as crucial not only for university but for other educational facilities as well. Many studies confirmed the positive effect of daylight on the learning environment, student performance and energy management of the educational facilities. Hence, using a smart-dynamic- techniques and integrated lighting system can positively contribute the achievement of well daylit learning spaces.

The thesis is discussing the impact of using smart architecture techniques for processing the optical environment in university learning spaces .It consists of four parts and ends with the conclusions and recommendations. the first part (chapter one and two) discusses the evolution of smart technology and how it affects the concepts of buildings especially universities and learning spaces and transforms them from traditional to smart buildings with a fully integrated systems, besides illustrating the classification of learning spaces according to its type to define the significant type that needs to be studied which, in this case, is group teaching/learning spaces. The second part defines a design strategy for optical environment of teaching /learning spaces (Chapter three). The third part, (chapter four) investigates the impact of using smart systems and techniques to improve optical environment in educational spaces. The forth part (chapter five) introduces a design guideline for lecture hall in Cairo as a case study and analyzes its daylighting performance by assuming various window to wall ratios and louvers types along the four basic orientations to investigate the best cases.

Smart Architecture techniques changed lighting design process completely, nowadays by virtue of simulations tools a lot of design concepts could be investigated to get the best case and optimum solution. Grasshopper which is a plugin for Rhinoceros and a parametric modeling and optimization tool was used to automate the simulation process in this thesis. Beside, DIVA plugin for Rhino was used to perform daylighting simulation based on Radiance and DAYSIM simulation engines. These tools allow for annual simulation and Daylight Availability computation as well as measurement of glare probabilities based on the new IES daylighting standard (sDA, ASE and DGP).

This thesis aims to develop flexible design guidelines for group teaching/learning spaces, mainly the lecture halls and their lighting design process template supported by daylight performance-based comparison of the different techniques and parameters along the four orientations. Instructors unanimously preferred the integrated lighting system over traditional lighting systems (switching on/off) in learning spaces, because it delivers an average 20% energy saving codes.

Keywords

- Smart - Technology – university – learning space – Lecture Hall
- Daylight system – Light Management system- Sensors – Dimmer
- Spatial daylight Autonomy sDA – Annual Daylight Exposure ASE – Daylight Glare Probability

Introduction

The concept of intelligent and smart buildings became a turning point in architecture and construction fields over the last three decades, paralleled with advancements in envelope engineering, building science, and information and communications technology (ICT). Therefore various intelligent buildings have been developed with the most advanced technologies and techniques to develop high performing buildings and smart cities which contain full integrated buildings systems (such as; schools, universities, offices and government building systems) with state institutions and international network. These smart cities are commonly seen to be the future of the urban built environment. (1)

As the world shifts to a more services-based economy, smart universities should be created as new model of interconnected educational institution. University campuses are complex, dynamic environments that serve a diverse array of needs and thousands of people. A smart university's goal is for effective learning spaces through the use of services enabled by ICT in particular by supporting the user behavior transformation through the interaction between the user and the building's intelligent energy management system. A smart university expects an impact of substantial energy savings up to 20-30% of total saving by using smart integrated systems with a smart user. (2)

Nowadays the concept of traditional classrooms have been changed to be 'smart' learning spaces which contains not only blackboards, seats and tables, but also audio-visual (AV) equipment, video projectors and screens, computer systems, control systems, etc. At the same time, the overarching goal of education is to provide a good visual environment for all the users, including students and instructors. However this electric evolution affects the visual needs of learning spaces. For example, electronic whiteboards or other e-learning tools may be introduced into university classrooms. So glare control and visual quality become a critical issue for the viewing of students especially when they focus on screens. Smart learning space's design and layout have a significant influence on lighting systems and the visual environment to accommodate the future trends of university learning spaces. (3)

The role of the physical and spatial environment in enhancing teaching and lighting environment has been studied in Clark (2002). (4) A smart learning space which contains technology encourages pedagogy and students' engagement as shown in Figure (I-1). It is important to realize that utilization of daylight is not only an energy-efficiency technology but also an architectural discipline and major factor in occupants' perception and

[1] A.H. Buckman - M. Mayfield - Stephen B.M. Beck, What is a Smart Building?,p93
[2] http://ec.europa.eu/information_society/apps/projects/factsheet/index.cfm?project_ref=297251
[3] Sam C. M. Hui and Kenneth K. Y. Cheng ,Analysis of Effective Lighting Systems for University Classrooms,p2
[4] ibid,p3

acceptance of workspaces in buildings. The dynamic interplay of building form, light, and people is what makes daylighting design so challenging and so rewarding.(1). Because of this, we need firstly to study architectural issues for learning space types and determine in which category we will study the optical environment and the use of smart techniques to improve its optical environment.

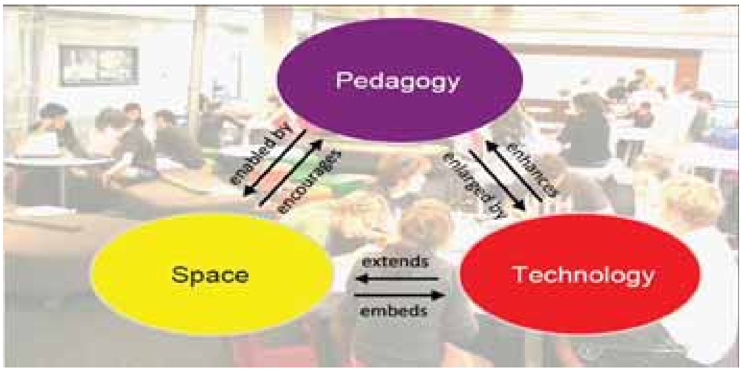


Figure I- 1:Relation between pedagogy,space and technology

Lighting systems are very important for university learning spaces because it affects the learning environment and energy management of the universities. A university's lighting accounts about 30% of energy costs (2). According to an IEA study (IEA 2006), global grid based electricity consumption for lighting was about 2650 TWh in 2005, which was an equivalent of 19% of total global electricity consumption and 15-20% for educational buildings. (3) So the trend is now to use natural light integrated with artificial light and other building systems to achieve even greater efficiency. Daylighting delivers efficient lighting with a physiological and psychological connection to the outdoors. Skylights, windows and tubular daylighting systems can capture, transport and diffuse high quality natural lighting into learning spaces. This helps reduce energy costs by reducing the amount of electric lighting needed during the day. Zachary Schneider of **CMTA Engineers** (4) said that "A substantial amount of energy can be saved by using daylight harvesting, but it also can positively influence student performance," and also "Studies show bringing daylight into a classroom is a very important component of a successful learning environment."(5)

Smart Architecture techniques have changed the lighting design process completely. B virtue of simulations, parametric design and algorithms, the lighting designer can investigate a lot of strategies and lighting systems to get the optimal solution for the learning space lighting and energy consumption. He can also choose smart features and techniques under an integrated systems umbrella.

[1] Christoph Reinhart and Stephen Selkowitz , Daylighting—Light, form, and people,p1
[2] Sei,A Guide To Energy Efficient And Cost Effective Lighting,p1
[3] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, P 139
[4] CMTA Engineers, is a top 60 MEP consulting engineering firm specializing in sustainable, high performance design for education and health care. All design teams are 100 percent LEED Accredited Professionals.
[5] http://www.nab-magazine.com/index.php/features/columnists/69-building-green-schools-with-intelligent-lighting

Therefore, this thesis will suggest a guideline for the more common type of smart learning spaces which is group teaching spaces and the lighting systems that should be designed for enhancing its visual environment and energy consumption.

Research problem

Nowadays, the concept of traditional classrooms has been changed to be 'smart' learning spaces. These spaces require lighting for a variety of educational activities from lectures and group work to audiovisual presentations; unfortunately, many learning spaces lighting systems are still controlled by a simple on/off switch which consume a lot of energy. Universities lighting accounts for about 30% of energy costs [(1)].Therefore efficient learning space integrated lighting systems should be created to allow instructors greater control over learning space lighting and dimmable lighting when they are needed in order to support their ability to maintain a comfortable, engaging learning environment and also saves energy and reduces operation costs.

Research Objectives

Main Goals:

- **Define** guideline for group teaching spaces optical environment by using smart techniques to aid the designers in achieving high performance educational spaces with low energy consumption as well.
- **Explore** the effectiveness of smart techniques to get integrating daylighting and artificial light by computational and building performance simulation tools.

Procedural Objectives:

- Explore the smart university phenomena, its benefits, vision, mission and outline.
- Investigate the effect of smart shading systems on daylighting performance and quality of light inside the educational space.
- Investigate the effect of use smart light fixtures on learning space lighting environment.
- Investigate different WWRs in the four orientations and the effective louver system in each one.
- Explore the effectiveness of using computational methods and Genetic Algorithms in parametric analysis and reaching optimized solutions.

[1] Sei,A Guide To Energy Efficient And Cost Effective Lighting,p1

Methodology

To reach the objectives of this thesis, the research work went through following stages:

- **Theoretical**
  - A theoretical study on the development of smart buildings and systems especially control light system. (chapter one)
  - A theoretical study on smart universities and learning spaces.(chapter two)
- **Analytical**
  - Define design criteria for group teaching spaces spatial environment. (chapter two)
  - Define design strategy for optical environment of group teaching /learning spaces. (chapter three)
- **Practical**
  - Study the impact of smart systems and techniques to improve optical environment in educational spaces.(chapter four)
  - Comparative applied study for Lecture Hall located in the city of Cairo, Egypt. Different types of louvers were analyzed with the use of annual Climate Based Daylighting Metrics (CBDM) and Daylight Glare Probability simulations.(chapter five)

Scope and Limitations

The thesis aims to study the effect of different parameters and smart techniques on the daylighting performance and how it can effect on designing better performance for smart learning spaces especially group teaching/learning spaces. Figure I-2 illustrates the main scope and limitations of this thesis. Although this research is connected to other measurable variables such as thermal comfort, artificial light environment and air ventilation, it mainly is focused on the daylighting quality of the spaces and energy efficiency. The research illustrated different types of fixed and automated daylight systems but the practical part focused on louvers fixed daylighting system and its significant role for daylight enhancement as shading and redirecting systems. Research analysis was conducted using the weather file and under the clear sky conditions of Cairo, Egypt (30° N- 31° E) for a large lecture hall as an example for group teaching spaces. In order to neutralize the effect of the context and surroundings on daylighting performance, the lecture hall was assumed to have an open horizon and no obstructions. IES new metrics and LEED V4 are used in this thesis as rating criteria for the space daylight performance. The simulations and analysis in the practical part were made at two consecutive stages; the objective of the first stage was set to find the optimum window to wall ratios (WWR) based on annual simulation runs at the four orientations. Stage two investigated the possible variation in count and tilting angles of the horizontal, vertical and angled louvers devices for the cases which achieved acceptable performance in stage one. Stage two mainly focuses on the South, East and West orientations as these were found to be the most problematic orientations according to stage one analysis.

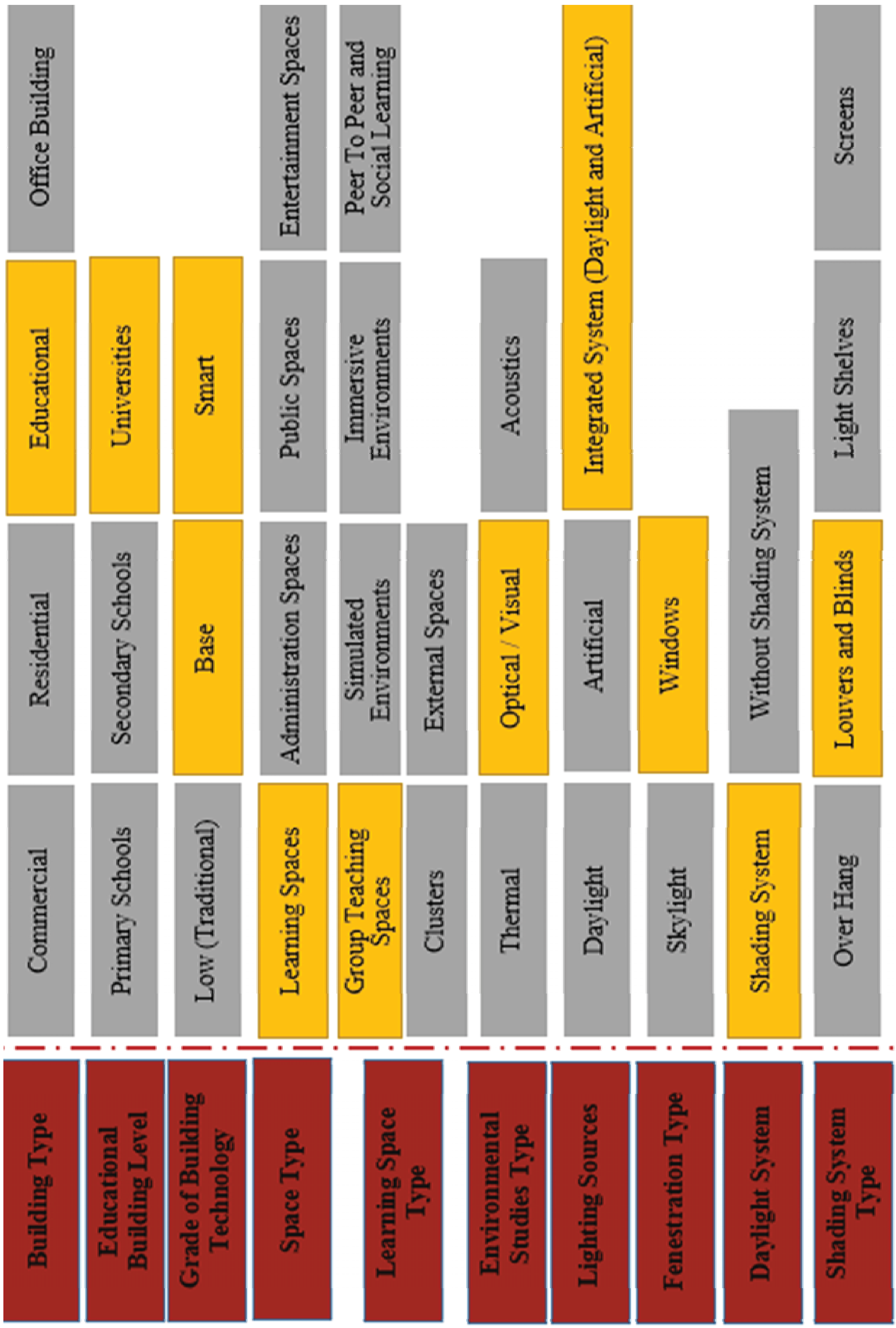


Figure I- 2 : Scope and Limitations

Thesis Structure

Chapter One: Smart Building Overview

The first chapter discussed the evolution of smart technology and how it can affect the building concept and change it from a traditional building to an intelligent building to a smart building, besides reviewing smart systems which control building management especially lighting control system.

Chapter Two: Smart University

This chapter illustrated a review about the concept of a smart university, its mission, benefits, and vision, and also determined the smart university outline. Moreover, the classifications of smart learning spaces were reviewed and also this chapter determined the most common learning space type to study its spatial and lighting environment minutely.

Chapter Three: Optical Environment in Educational Spaces

In this chapter the optical environment components with its quality effect on students' performance were studied. Also, design strategy for optical environment of group teaching /learning spaces was determined and also the latest quantity-quality daylighting metrics and analyzing criteria were studied and discussed.

Chapter Four: Smart Lighting Design Process for Learning Spaces

This chapter studied the impact of smart systems and techniques to improve optical environment in educational spaces. It illustrated the role of lighting management system and how it can be integrated with smart techniques to enhance the performance of the lighting and the space.

Chapter Five: Design Guideline for Lecture Hall (Case Study)

This chapter investigated lighting performance on a lecture hall case study which is located in Cairo, Egypt. The simulation analysis were made at two consecutive stages; the objective of the first stage was set to find the optimum window to wall ratios (WWR) based on annual simulation runs at the four orientations. Stage two investigated the possible variation in count and tilting angles of the horizontal, vertical and angled louvers device for the cases which achieved acceptable performance in stage one. Stage two mainly focuses on the South, East and West orientations as these were found the most problematic orientations according to stage one analysis.

Conclusion and Recommendations:

The study provided recommendations and guidelines for achieving effective smart learning spaces with high performance lighting systems that can enhance the daylighting performance with the use of shading and redirecting systems based on the results from the previous chapters.

Moreover, the results of integrating computational and parametric methods were also presented. And finally, the study presented a group of recommendations for future studies in this field.

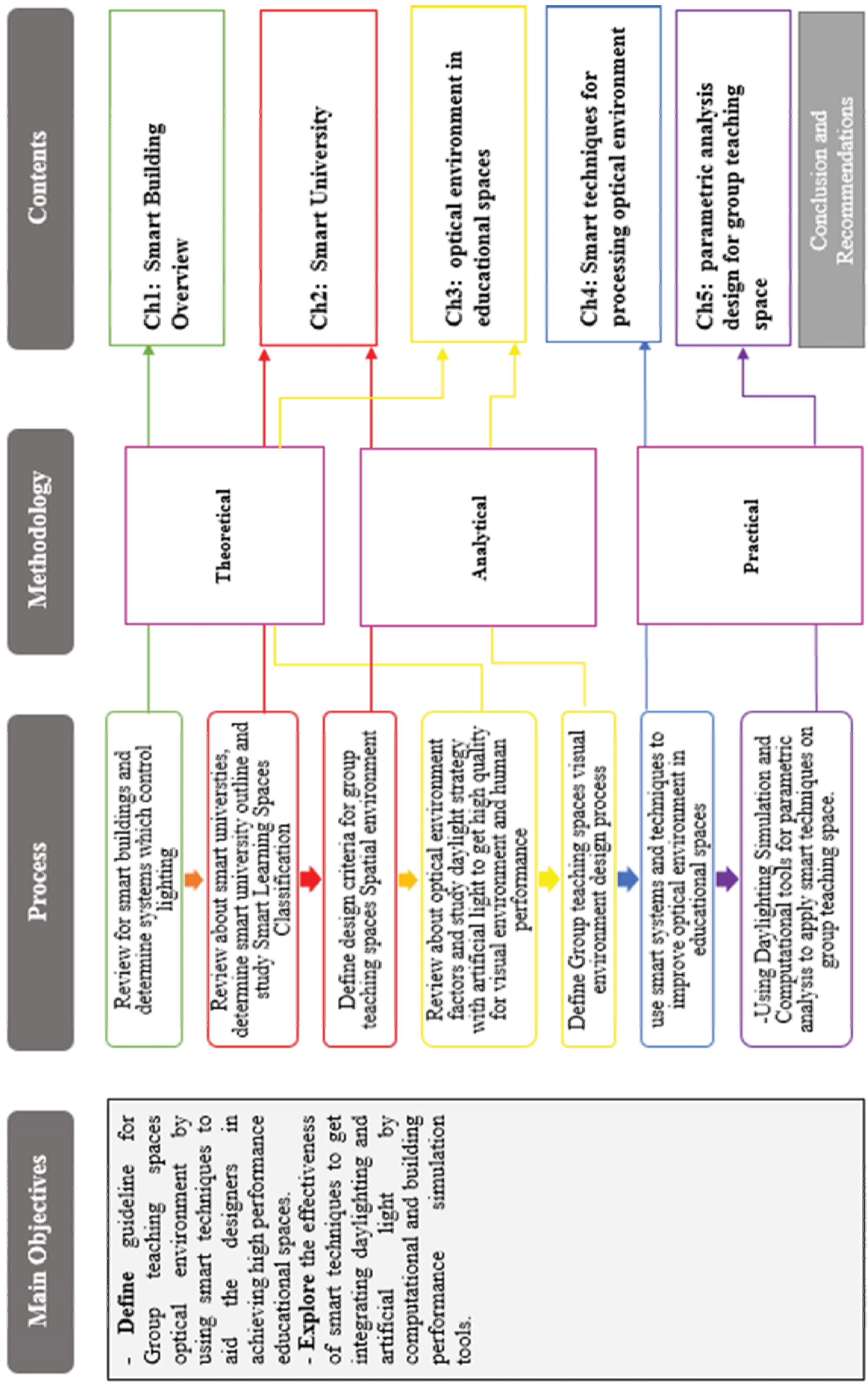


Figure I- 3 : Methodology and structure

1.1. Introduction

The concepts of intelligent buildings and smart buildings have created a turning point in architecture and construction fields over the last three decades. This turning point parallels advancements in envelope engineering, building science and computer technology, as various intelligent buildings have been developed with the advanced technologies and techniques in order to develop high performing buildings. Due to these advancements, smart cities are commonly seen to be the future of the urban built environment. (1)

There are many academic views that discuss the differences between smart and intelligent buildings. Smart buildings are intelligent buildings but with additional, integrated aspects of adaptable control, enterprise, materials and construction. (2) So we need to study intelligent buildings' systems and their background in order to better understand the characteristics of smart buildings.

In 1980 intelligent thinking and technologies started to be a trend in building concept design in the form of intelligent façades, sensors, materials, and even building systems. These trends began a discourse which is now taking place in the profession (3). Intelligent Buildings were advocated by UTBS Corporation (United Technology Building Systems Corporation) in the USA in 1981, and became a reality in July 1983 with the inauguration of the City Place Building in Hartford, Connecticut, USA. (4)

An intelligent building is one that: (5)

- Provides a productive and cost-effective built environment through optimization of its four basic components - structure, systems, services and management - and the interrelationships between them as shown in Figure 1-1.
- Maximizes the efficiency of its occupants
- Allows effective management of resource with minimum life costs

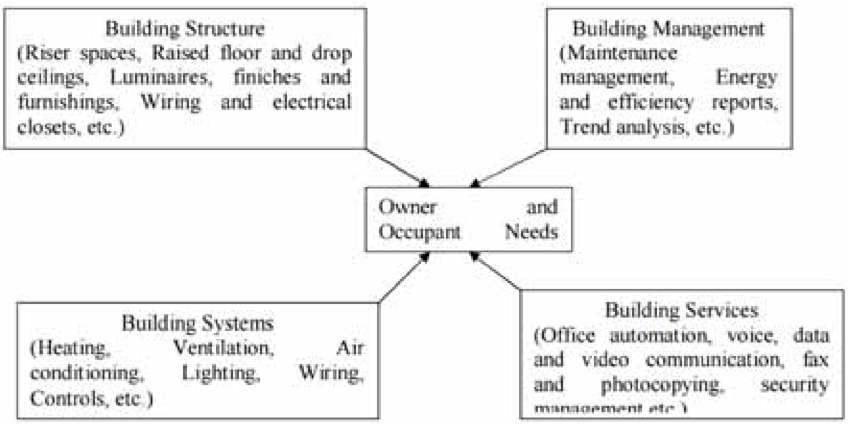


Figure 1- 1: Integration of Intelligent Building components to achieve owner and occupant needs
Source: Intelligent Building Systems, p. 3

[1] Buckman.A.,et.al., What is a Smart Building?, p. 93
[2] ibid , p. 95
[3] El sheikh, m. M., Intelligent Building Skins: Parametric-Based Algorithm For Kinetic Facades Design And Day lighting Performance Integration, , p. 27
[4] Albert, Intelligent Building Systems, p. 2
[5] Dr. D. Kolokotsa, Intelligent Buildings Technology lecture presentation, p. 10

1.2. Smart Building Background

1.2.1. Human Intelligence Lent To Buildings

1.2.1.1. Human Intelligence

The word “intelligent” was first used at the beginning of the 1980s to describe buildings, together with the American word “smart” (1). Intelligence is not an equation of fixed variables; it is a process that is inspired by human intelligence and cognitive capabilities. That being said, all definitions of intelligence acknowledge the influence of humans in terms of behavior and reasoning as shown in Figure 1-2.

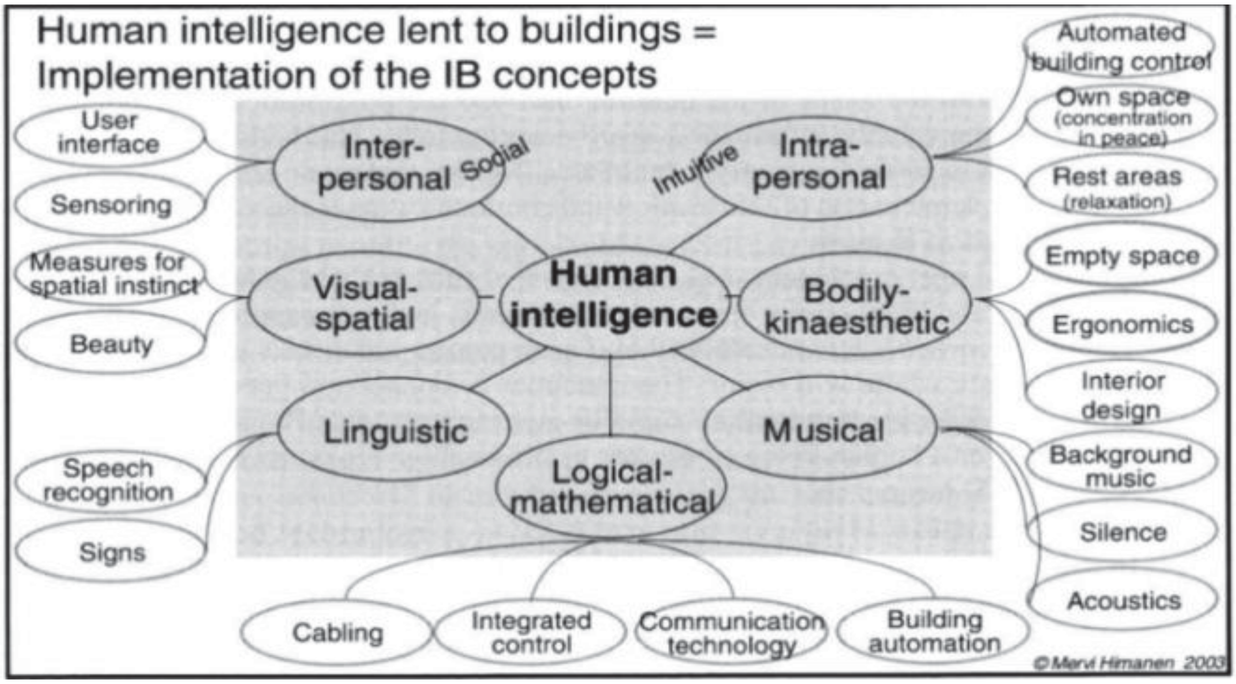


Figure 1- 2: Human intelligence lent to buildings intelligence-Implementation of IB concepts
Source: Intelligent Building Skins, p. 27

People are the nucleus for intelligent building ideas. They adapt to their surroundings psychologically, physically and behaviorally, and often change their environments to be more suitable for them as shown in Figure 1-3. This is a complex interaction, informed by their senses and mediated by their brains. The brain allows people to reason, perceive, and react to their environments, whether tangible or non-tangible. Humans have always been the inspirational model for considering the application of intelligence in buildings. (2)

Clements-Croome provides a relevant definition of the term ‘Intelligence’ (3): “Intelligence is not an attribute, but a complex hierarchy of information processing skills, underlying an adaptive equilibrium between individuals and their environment.”

[1] Wigginton and Harris, Intelligent Skins, p. 20
[2] El sheikh, m. M., Intelligent Building Skins: Parametric-Based Algorithm For Kinetic Facades Design And Day lighting Performance Integration, , p. 27
[3] Clements-Croome, Intelligent Buildings, p. 44

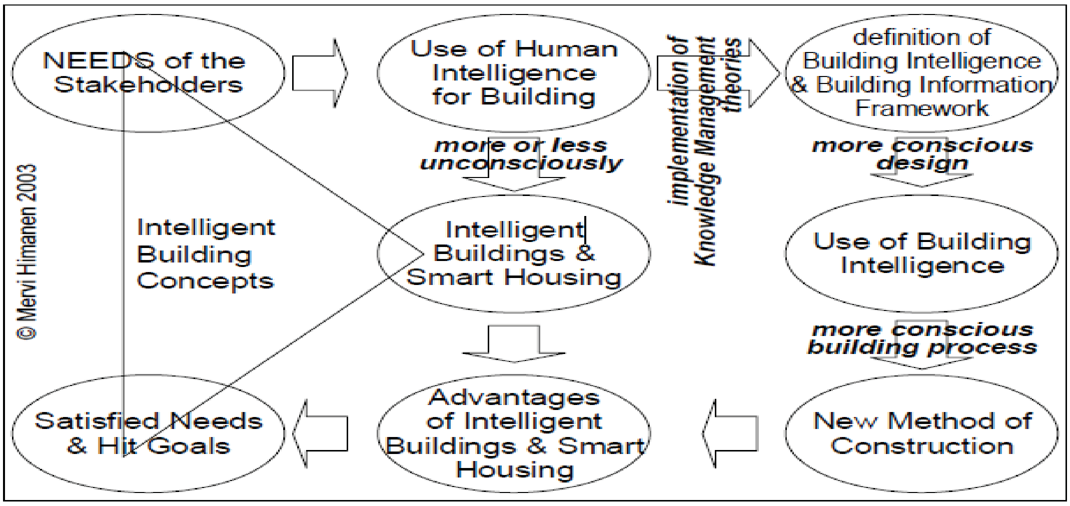


Figure 1- 3: The evolution of using human intelligence to create intelligent buildings in order to satisfy the desires and needs of the community
Source: User Values of Intelligent Buildings paper, p. 2

1.2.1.2. Building Intelligence

According to The Intelligent Building Institute (IBI) "An intelligent building is one which provides a productive and cost effective environment through the optimization of its four basic elements – systems, structure, services, management and the inter-relationship between them. Intelligent buildings help building owners, property managers, and occupants realize their goals in the areas of cost, comfort, convenience, safety, long-term flexibility, and marketability. There is no intelligence threshold past which a building "passes" or "fails." Optimal building intelligence is the matching of solutions to occupant needs. The only characteristic that all intelligent buildings have in common is a structured design to accommodate change in a convenient, cost-effective manner."

The intelligent building should be able to achieve optimal performance by implementing the following processes :[(1)]

- Create a relationship between occupants' behavior and indoor space conditions.
- Automatically adapt and respond to environmental changes and user requirements.
- Expedite cost-effective alteration to occupants' changing behavior, with changing tasks.

Brian Atkin identifies the following three aspects that should be found in intelligent buildings in his book "Intelligent Buildings" as shown in Figure 1-4: [(2)]

- Buildings should 'know' what is happening inside and immediately outside.
- Buildings should 'decide' the most efficient way of providing a convenient, comfortable, productive environment for the occupants.
- Buildings should 'respond' quickly based on occupants' preferences.

[1] El sheikh, m. M., Intelligent Building Skins: Parametric-Based Algorithm For Kinetic Facades Design And Day lighting Performance Integration, , p. 31
[2] Clements-Croome, Intelligent Buildings, p. 45

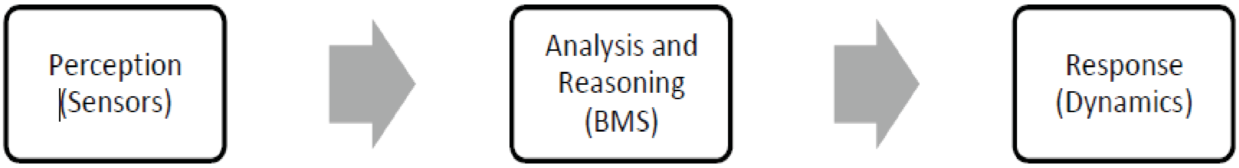


Figure 1- 4: Main Aspect of Intelligent Building according to Brian Atkin
Source: Intelligent Building Skins, p. 32

Mervi Himanen divided the qualities of building intelligence into five main categories which are illustrated in Figure 1-5: [1]

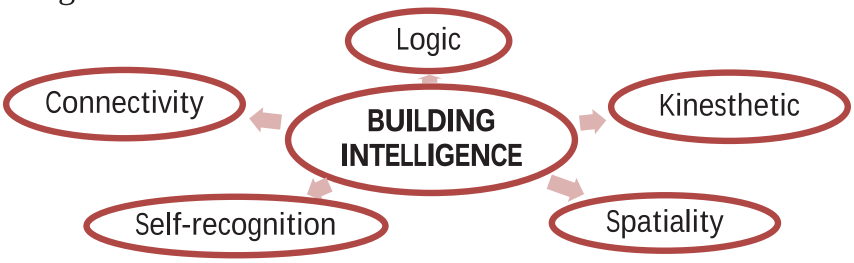


Figure 1- 5: Categories of building intelligence qualities according to Mervi Himanen

1.2.2. Emergence of Building Intelligence in Every Era

According to the previous definitions, intelligent building is not restricted to a particular science or technology. The building which deserves the title of IB is the building which not only accommodates the latest existing technologies but is also capable of accommodating any new technology later. Thus the roots of intelligence have been seen in building throughout ancient civilizations, according to technological possibilities and capabilities of the different eras as shown in Figure 1-6. [2]

Ancient Egyptian Architecture

Pyramids	**Abu Simbel Temple**	**ventilation and daylight**
(Age-construction techniques- air shaft for ventilation)	Sun's rays align twice a year (his date of ascension to the throne & his birthday)	Clear story-grills

Greek Architecture

Automatic doors	Fabricated columns	Air and water pumps	Plumbing	Winch	Surveying tools	Fire hoses

Roman Architecture

Amphitheatre	Bridge	Dam, Arch	Tread wheel	Hydraulics	Lighthouse	Hypocaust

Islamic Architecture

Mashrabiya	Windcatchers	Courtyards	Mosaics	Wind mills	Arch & dome

Figure 1- 6: Roots of building intelligence over the ages

[1] Mervi Himanen ,The Intelligence of Intelligent Buildings, p. 335

[2] ماجدة بدر ، العمارة الذكية كمدخل لتطبيق التطور التكنولوجى فى التحكم البيئى ،ص 7

In the early eighties, as a result of construction expansion and proliferation, developers turned to intelligent buildings in order to gain an advantage over their competitors in building marketing. Telecommunications suppliers were compelled to deregulate remote communication systems and internet services, due to increased competition, and sold them at retail value from long distance carrier services to customers.(1)

Intelligent Buildings (IBs) based on Information Network technology became a reality in July 1983 with the inauguration of the City Place Building in Hartford, Connecticut, USA.(2)

Early IB definitions focused almost entirely on technology related to building automation. After 1985 the concept of adaptability crept into building as buildings then had to be able to respond to organizational change and adapt to new tasks. After 1992, especially in Europe, the IB concept expanded to also include creating an environment that maximized the efficiency of the occupants of the building while at the same time allowing effective management of resources with minimum life-time costs.(3)

1.2.3. Intelligent Buildings Generations

According to the latest studies, the historical development of IB can be divided into different generations through three time periods, as shown in Figure 1-7, from automated to effective buildings. This is in accordance with literature reviews from 2005. The classification of generation was updated to reach smart building generation on 2009 (4) .

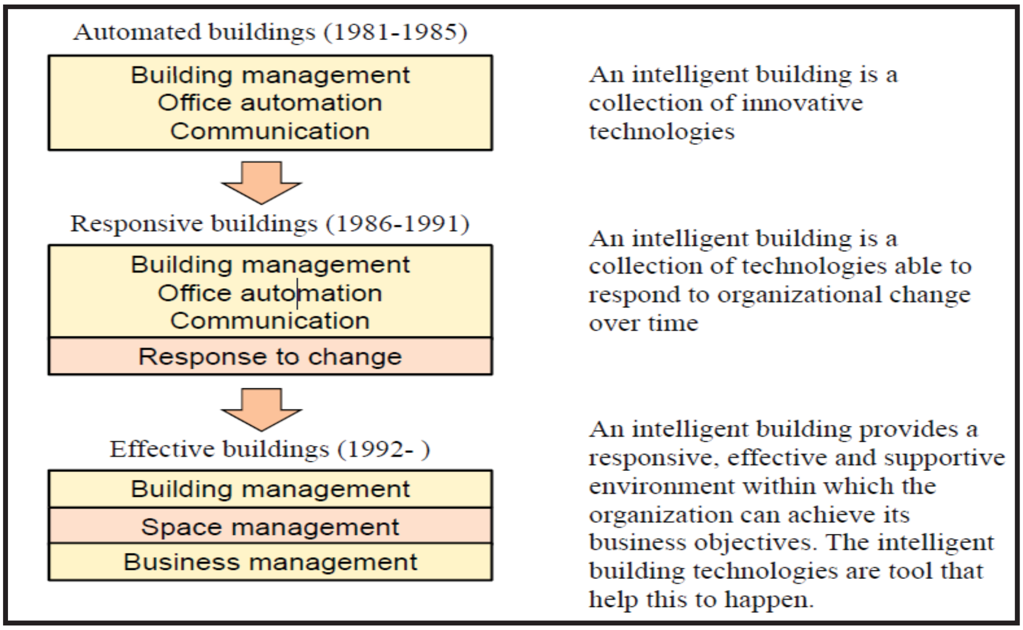


Figure 1- 7: Intelligent Building generations
Source: Building Energy Management & Control Systems -http://www.hku.hk/bse/mech3023/

1 ماجدة بدر، المرجع سابق، ص 27
2 Albert, Intelligent Building systems , p. 1
3 Wigginton and Harris, Intelligent Skins, p. 171
4 Buckman.A.,et.al., What is a Smart Building?, p. 96-101

1.2.3.1. Automated Buildings (1981-1985)

The term "Building Automation" refers to the use of a technology control system to control a building's heating and ventilation system (HVAC), lighting, security, fire alarms, and basically everything else that is related to electricity or technology in a building. But this term is not related to user need or environment change. Thus it simply refers to a collection of innovative technology.

1.2.3.2. Responsive Buildings (1986-1991)

In the 1980s, Duffy and his DEGW colleagues initiated the ORBIT (Office Research: Buildings and Information Technology) in order make an impact on office design with the use of advances in technology. ORBIT studies identified IBs as buildings with integrated management and information communication technologies systems providing a robust infrastructure for information technology – and therefore they were more responsive to changing user demands. (1)

The concept of adaptability in building changed to be able to respond to organizational change and to adapt to new tasks. This response divided into two types as shown in Figure 1-8:

Figure 1- 8: Responsive building types

Static response is a loop in one direction, for example a response due to change in illuminance or temperature, but kinetic response is a closed loop between a large amount of sensors and actuators connected with more than one element, as shown in Figure 1-9, in order to reach an optimized solution for user comfort. (2)

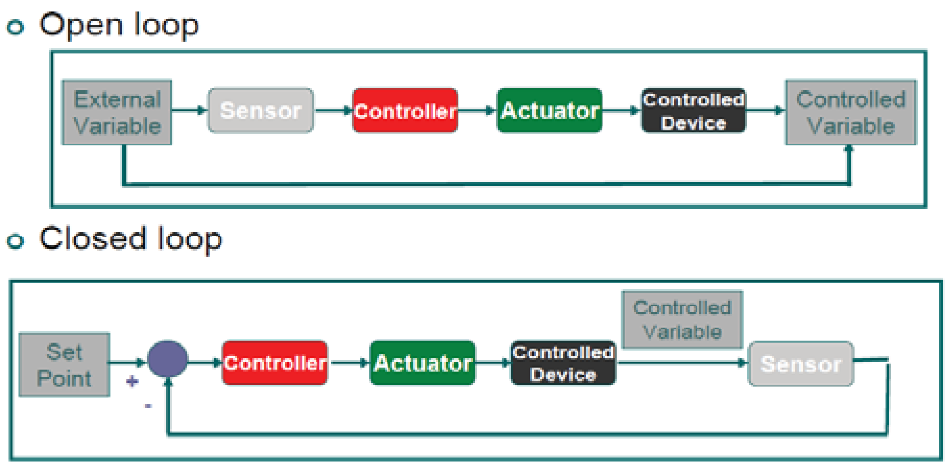


Figure 1- 9: The difference between open and closed loop in responsive building
Source: Intelligent Buildings Technology, Dr D. Kolokotsa presentation, p 25

Still, Intelligent Building Borders (IBB) can be seen as attractive for people who like automatic and responsive systems for controlling buildings and working tasks. But this conventional definition does not extend into the domain of the autonomic 'health' of the building and

1 Cabe offices Guideline, The impact of office design on business performance, p. 7

2 ماجدة بدر ، العمارة الذكية كمدخل لتطبيق التطور التكنولوجى فى التحكم البيئى ،ص 29

maintenance of its optimum environmental conditions by means of instinctive automatic changes to the building.[1]

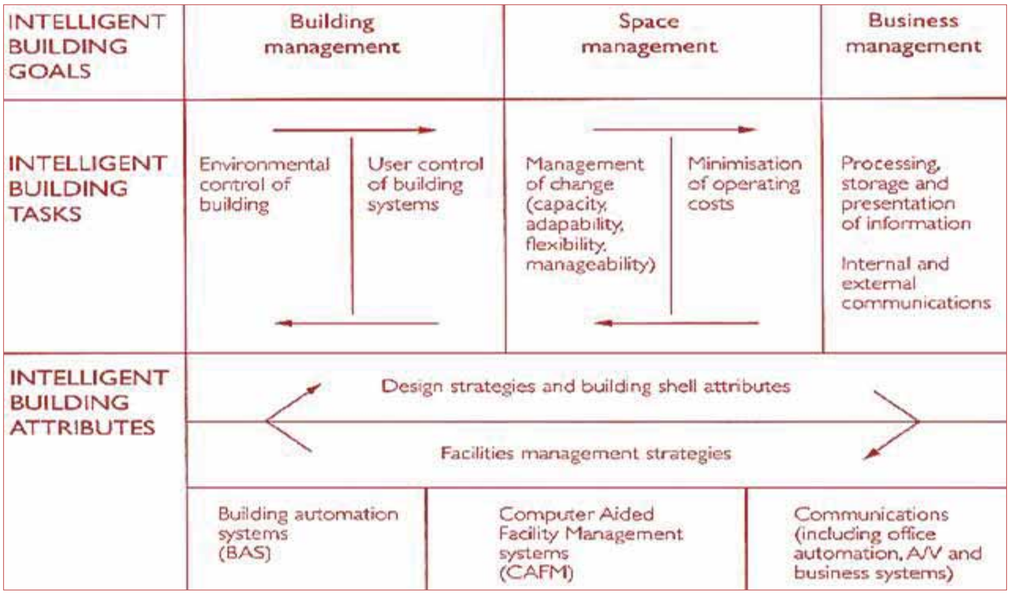
1.2.3.3. Effective Buildings (1992-Till Now)

In 1992, IT consultants in Europe developed the concept of building intelligence. In this model, the focus was on the building's occupants and their tasks rather than on computer systems. Table 1-1 illustrates the latest IB model. [2]

a) **Building Managemen**t is the management of the building's physical environment using both human and computer systems.
b) **Space Management** is the management of the building's internal spaces over time. The overall goals of effective space management are the management of change and the minimization of operating cost.
c) **Business Management** is the management of the organization's core business activities, which is considered a combination of the processing, storage, presentation and communication of information.

Each of the above three goals can be translated into a number of key tasks such as environmental systems, the management of change, the minimization of operating costs and the processing, storage, presentation and communication of information.

Table 1- 1: The latest Intelligent Building model according to IT consultants in Europe



Source: Harrison, Loe & James Read, Intelligent Buildings in South East Asia, E & FN Spons, p. 3

The need for new buildings, which merge both human control and automation in order to achieve the drivers for building progression, has increased lately. Thus a new expression is needed to express this concept. This new concept has been labeled Smart Building. The aim of control within a Smart Building is to provide occupants with information so that they can adapt to the building, as well as the building adapting to their preferences and requirements.

[1] Wigginton and Harris, Intelligent Skins, p. 22.
[2] Ellia.A ,Integrated Value Engineering In The Design Of Intelligent Buildings , p. 52

1.2.3.4. Smart Building - Adaptive and Kinetic Buildings

Smart buildings have been increasingly referenced in both industrial reports (The Climate Group, 2008; Powell, 2010; Harris, 2012) and also in recent academic literature (Cook and Das, 2007; Bach et al., 2010; Kleissl and Agarwal, 2010; Kiliccote et al., 2011; Wang et al., 2012a, b). (1) Just as Intelligent Buildings were developed from automated buildings, Smart Buildings have been developed from Intelligent Building concepts. Katz and Skopek (2009) show that Intelligent Buildings contain aspects of both automation and, similarly, intelligence as both are important aspects of Smart Buildings. (2)

Smart Buildings are Intelligent Buildings but with additional, integrated aspects of adaptable control, enterprise, materials and construction. In Smart Buildings, the four methods used to meet the drivers to building progression are developed alongside each other with adaptability, not reactivity. In order to meet the drivers for building progression, the core ideas of Smart Building design are energy and efficiency, longevity, comfort and satisfaction.(3)

Table 1-2 illustrates that the lower bounds of Smart Buildings are the upper bounds of Intelligent Buildings. These bounds include the ability to integrate intelligence, enterprise, control, and materials and design in an adaptable manner to allow the building to prepare for events before they occur. Moreover, we can predict a significant change in the next generation of building. This future building (Thinking Building) development will create buildings that build upon Smart Buildings by using new technologies, processes and knowledge. (4)

Table 1- 2 : The bounds of Smart Buildings

	Time		
Building Category	Intelligent Buildings	Smart Buildings	Thinking Buildings
Control Flow	Reactive	Adaptive	Predictive
Comfort and Efficiency Information Input	Systems and data integration	Enterprise integration and building as a system approach	Undefined/Ambiguous Data
Occupant Interaction and Efficiency	More control, higher efficiency	Inherent control, higher efficiency	Predictive control, higher efficiency
Materials and Construction	IP backbone used to integrate building service systems	Further integration using middleware, and adaptable building structure with reactive features.	Future technology, control hardware, software and materials
Interaction of Operation with Occupants	Ability to react to occupancy data in real time	Building operation defined by and adapted to building occupants	Effective operation based upon predicted use by occupants for a specified function

Source: What is a Smart Building?, p. 105

[1]Buckman.A.,et.al., What is a Smart Building?, p.97
[2] ibid, p. 104
[3] ibid, p. 96
[4] ibid, p. 104

1.2.4. Intelligent Building Definitions

Up to now, there isn't a universally accepted definition for IBs. However, it appears that most designers agree with the statement that "IBs are not intelligent but they can make the occupants more intelligent." Actually, most existing definitions of IBs around the world are trying to ensure a building is suitable for the occupants to work and live in safely, comfortably, effectively and efficiently.

1.2.4.1. Intelligent Building Definition In Different Countries

i. The Definition of IB in USA Intelligent Building Institute (1)

In accordance with the Intelligent Building Institute (IBI) of USA, an IB is one which provides a productive and cost-effective environment through optimization of its four basic elements, i.e. structure, systems, services and management and the interrelationships between them.

ii. The Definition of IB in Europe (2)

European Intelligent Building Group defined an IB as one that "creates an environment which maximizes the effectiveness of the building occupants while at the same time enabling efficient management of resources with minimum life-time costs of hardware and facilities."

iii. The Definition of IB in Asia(3)

According to Fujie in Japan, The Japanese definition of IBs contains four aspects:

- Receiving and transmitting information and supporting management efficiency.
- Ensuring satisfaction for the people working in them and the rationalization of building administration to provide more attentive administrative services with lower cost.
- Fast, flexible and economical responses to changing sociological environments, diverse and complicated office work and active business strategies.
- Regarding cultural considerations, IBs must maintain an effective working environment, run automatically, and be flexible enough to adapt to changes.

It is believed that the Japanese definition of IBs is most suitable for formalizing a more universal definition for IBs, mainly for Asia but also one that is extendable to the whole world. In the new definitions of IB in Asia, there are eight "quality environment modules," including: (4)

- Environmental friendly-health and energy conservation (M1)
- Space utilization and flexibility (M2)
- Life cycle costing-operation and maintenance (M3)
- Human comfort (M4)
- Working efficiency (M5)
- Safety-fire, earthquake, disaster and structure etc. (M6)
- Culture (M7)
- Image of high technology (M8)

[1] Asian Institute of Intelligent Buildings, Intelligent Building Index Version 2.0, p. 4-5
[2] ibid, p. 6
[3] ibid, p. 8
[4] ibid, p. 9

1.2.4.2. Evolution of Intelligent Building Definition (According to Generations)

Intelligent building definitions are changed through the fourth intelligent buildings generations as shown in table 1-3.Most of the Intelligent Building early definitions revolved around minimizing the human interaction with the building, which has been evolving to become what can now be seen as automated buildings. Generally, definitions of Intelligent Buildings have expanded to include a number of features in order to accommodate the latest understanding of building requirements. Thus there has been a new trend for building which reconciles both human control and automation in order to achieve the drivers for building progression. [1]

Table 1- 3: Evolution of Intelligent Building definition over last ages

Genera-tion	The viewer	Definition of IB
Automated Buildings (1981-1985)	Cardin, 1983	Buildings which have fully automated building service control systems. [*]
	Toronto International Symposium, 1985,	Intelligent buildings combine innovations, technological or not, with skillful management, to maximize return on investment. [**]
	Fagan, 1985	Buildings which ‘provide information’ for an intelligent operator to act upon.[*]
Responsive Buildings (1986-1991)	Duffy, 1986	Buildings which are ‘more than ordinarily responsive’ to changes in security, external environment, and tenant demand and which offer shared tenant services[*]
	David Boyd, 1987	Buildings that contain high levels of advanced industrial technology and that can also adapt their internal environments in response to external conditions and forces have been termed intelligent buildings.[*]
	Brian Atkin	Intelligent buildings “know” what the environmental conditions are both outside and inside, and “decide” how to provide a convenient and comfortable environment for occupants, and “respond” promptly to occupant requests.[***]
	Robathan, 1989	An intelligent building is one that creates an environment that maximizes the efficiency of the occupants of the building while at the same time allowing effective management. [*]
	David S. Brockfield, 1989	The type of building which harnesses and integrates all levels of IT from data processing to environmental control and security.[*]

[1]Buckman.A.,et.al., What is a Smart Building?, p. 96-101

[*] M. Wingginton and J. Harries. Intelligent skins, p. 172-173

[**] D. Clements, intelligent buildings design, management and operation, p. 6

[***] K. Shherbini and R. Krowczyk overview of intelligent architecture, p. 139

	Dr. Dave Leifer, 1989	Buildings which predict the user demands upon themselves and their plant systems, rather than simply reacting to them.*
	Ken Yeang 1990	Intelligent buildings, as an ideal system, 'means an automated enclosure and support servicing system that is capable of responding both environmentally and physically to the activities, needs and requirements of its users, to the external environment, and to exchanges between the system and its environment.'****
Effective Buildings (1992-2005)	David Boyd, 1994	An intelligent building is one that maximizes the efficiency of the occupants while at the same time minimizing the costs associated with the building.
	Walter Kroner	An intelligent building would be one that can anticipate conditions and forces acting on the building. Such a building may change its color, envelope configuration, orientation and composition *
	Addington and Schodek	Describe the term "intelligent" using these three characterizations: environmental characterizations, cognition characterizations (information systems, expert systems, artificial intelligence) and implementation characterizations (methods of operation and control). ****
Smart Building (Adapted building) 2005-till now	CABA, 2008	Smart Buildings have the ability to "figure out behavior and behave according to impacts of parameters around it"*****
	Clements-Croome 2009	An Intelligent Building is one that is responsive to the requirements of the occupants, organizations and society. It is sustainable in terms of energy and water consumption besides minimally polluting in terms of emissions and waste. It is also healthy in terms of well-being for the people living and working within it and functional according to the user needs. *****
	Kiliccote *et al.* (2011)	Smart Buildings are self-aware and grid-aware, interacting with a smart grid whilst focusing on the real-time demand side response and an increased granularity of controls. *****
	Wang *et al.* (2012)	Address both intelligence and sustainability issues by utilizing computer and *intelligent* technologies to achieve the optimal combinations of overall comfort level and energy consumption. *****
	A.H. Buckman, M. Mayfield and Stephen B.M. Beck (2014)	Smart Buildings are buildings which integrate and account for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at the core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction. The increased amount of information available from this wider range of sources will allow these systems to become adaptable, and enable a Smart Building to prepare itself for context and change over all timescales. *****

**** V. Kathy, geoffrey thün, Responsive Building Envelopes, p. 77

*****Buckman.A.,et.al., What is a Smart Building?, p. 96-101

1.2.5. Intelligent Building Characteristics

Through previous studies, we can extract the evolution of intelligent building characteristics in each generation as shown in Figure 1-10 .

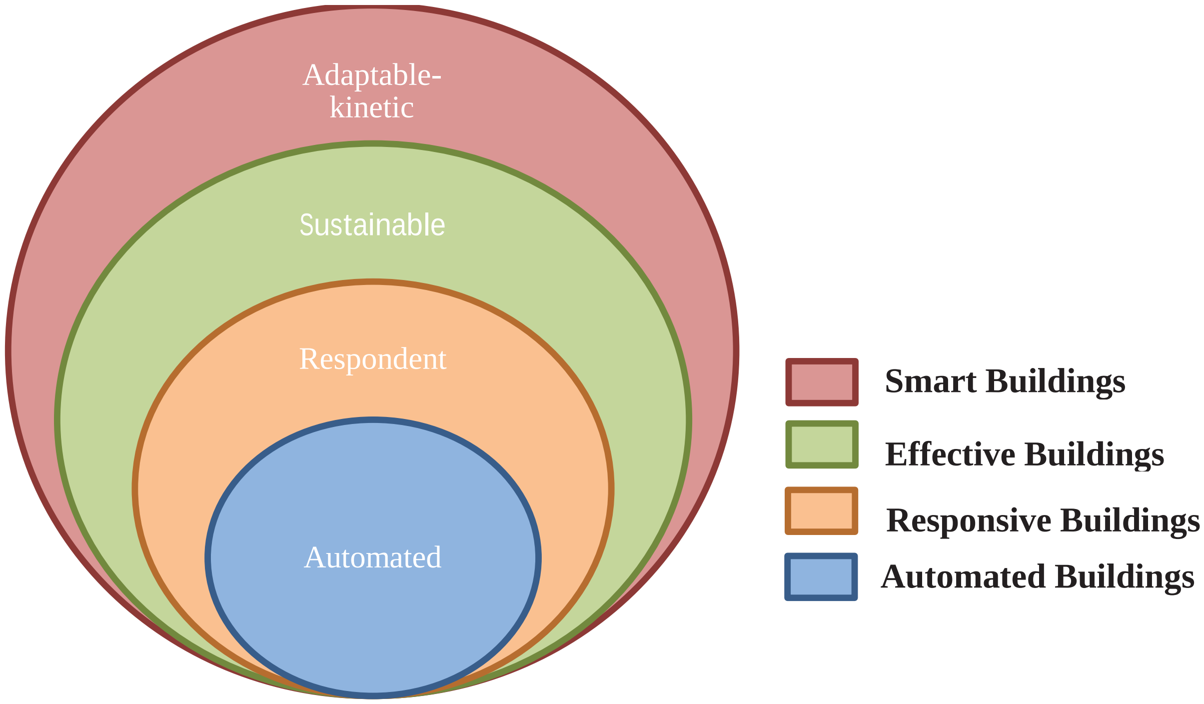


Figure 1- 10: Evolution of Intelligent building characteristics

1.2.5.1. Automated Buildings

The early definitions for Intelligent Buildings are those which have a fully automated building service control system. Automation is the using of control systems and information technologies to reduce the need for human work in the production of goods and services in the scope of industrialization. Automation is a step beyond mechanization .Moreover, it replaces manual operations with computer procedures (1). The term mechanization is often used to refer to the simple replacement of human labor by machines. (2)

1.2.5.2. Responsive Buildings

Buildings should know what is happening both inside and outside of themselves and decide the best way of providing a convenient, comfortable and productive environment for the occupants and then respond quickly based on occupants' preferences. In this phase, the building should learn how to respond with the right decision not just as an automated system, but it still doesn't achieve the most efficient and economical solutions. Dr. Dave Leifer defined it in 1989 as buildings which predict the user demands upon them and its plant systems, rather than simply reacting to them.

[1] S. http://www.pcmag.com/encyclopedia/term/38258/automation
[2] http://www.britannica.com/EBchecked/topic/44912/automation

1.2.5.3. Effective Buildings

The main characteristic of effective buildings is sustainability which has been used as a theoretical framework to study intelligent architecture. The three dimensions of sustainability, environmental, social and economic, are explored in the intelligent buildings context as follows: (1)

Environmentally: A building that knows when and where it is occupied can limit its own energy use by confining the operation of power-hungry HVAC and lighting systems to the hours and areas of the building when they are needed (Wu and Noy, 2010).

Social Issues: The social implication of intelligent technologies on our lifestyles needs delicate attention so as to ensure an enriching environment to make life meaningful amidst all the technological progress. Riewoldt (1997) and Mazza (2008) assert intelligent spaces should use technology to humanize living environments and help reunite people with their socio-cultural and natural environment in aesthetic, ergonomic and ecological terms. Maximizing occupant comfort, acceptability, performance, safety and efficiency is the recipe for social sustenance of the intelligent building concept.

Economic Issues: Economic sustainability is the term used to identify various strategies that make it possible to utilize available resources to the best advantage and in a way that encourages responsible use of these resources. Humane (2003), Gray (2006), Katz and Skopek (2009) and Matthew et al. (2009) recognize the benefits of the 'Intelligent building concept' as a decrease in building maintenance and energy costs, increase in productivity, rental incomes, investments, occupancy rates, retention, and accommodation of flexibility.

1.2.5.4. Smart Buildings

The main characteristic of smart building is the adaptability. The Adaptability within and integration between all aspects of the building will allow the differentiation between previous generations of buildings and Smart Buildings. Creating an adaptable building through the design and integration of the four methods in Figure 1-11 in order to meet one or more of the drivers can be defined as a smart system. (2)

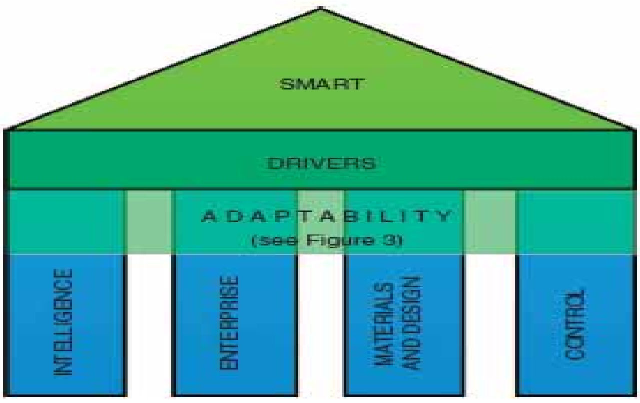


Figure 1- 11: Method of creating an adaptable building
Source: What is a Smart Building?, p. 99

[1] T. Gadakari Can Intelligent Buildings Lead Us to a Sustainable Future?
[2] Buckman.A.,et.al., What is a Smart Building?,p99

The buildings need to be kinetic to adapt to different cases .Fox (2000) defines kinetic architecture as "a building with variable location or mobility and/or variable geometry or movement."[1]

1.3. Intelligent Building Control Systems (BCS)

New technologies are designed to make buildings immediately run more efficient tasks. Streamlined systems simplify operator access to multiple systems, centralized information and systems that are able to communicate with one another, improve building performance, reduce operational, management and maintenance costs, and increase tenant attraction and retention, which then increases workplace performance.[2]

Building intelligence starts with monitoring and controlling information services known as Building Control System (BCS). BCS is able to optimize environmental and safety aspects in an economical way. This is achieved by using computers. [3]

1.3.1. Component Elements of Intelligent BSC

Intelligent building systems are explained as individual systems where each one controls its elements as shown in Figure 1-12 and then gathers together with the others into an integrated system. Information transferred between systems should be processed and analyzed in Building Control System (BCS) which works as a building's brain. The goal should be reaching an optimum solution. [4]

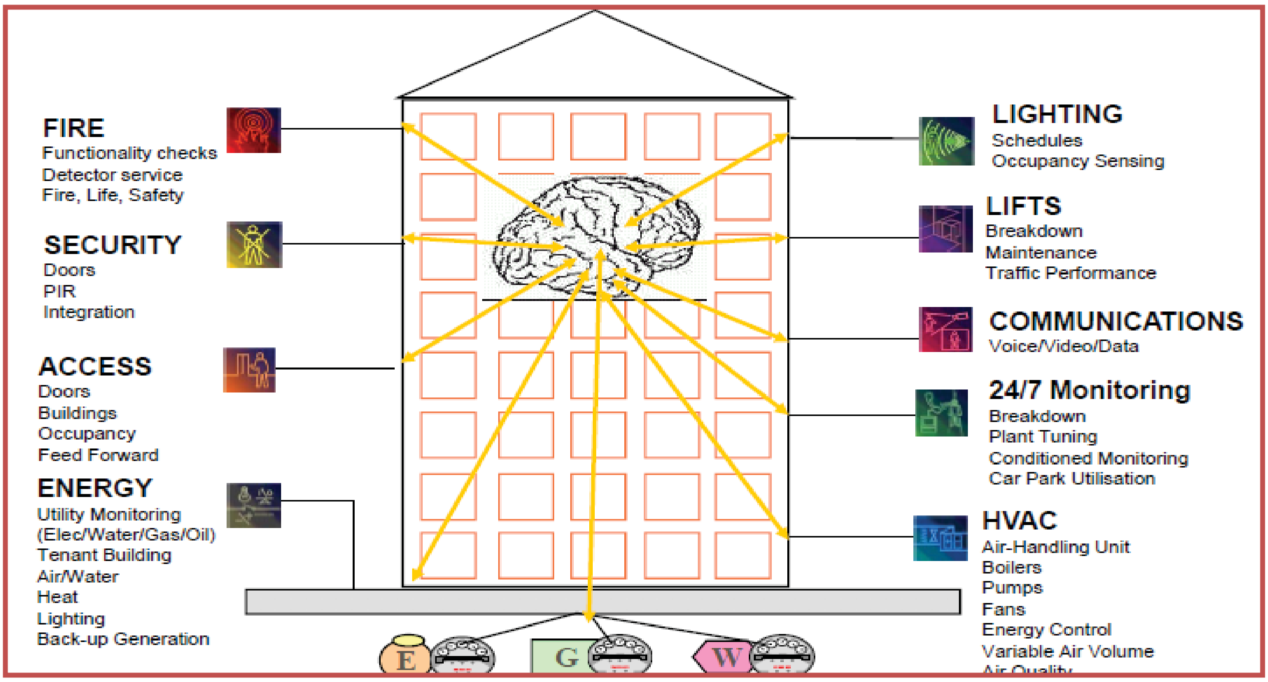


Figure 1- 12: Intelligent BSC Component Elements
Source: Continental Automated Building Association

[1] K. Sherbin & Krawczyk, Overview of Intelligent Architecture, on ASCAAD Conference, p. 142
[2] Boma, Integrated Systems, p. 3
[3] http://www.kmccontrols.com/products/
[4]K. Sherbini & Krawczyk, Overview of Intelligent Architecture, on ASCAAD Conference, p. 140

1.3.2. Intelligent BCS Basic Criteria

Accordingly, the basic criteria of the intelligent building needs is consist of six components as shown in figure 1-13 and their work flow is illustrated in figure 1-14.

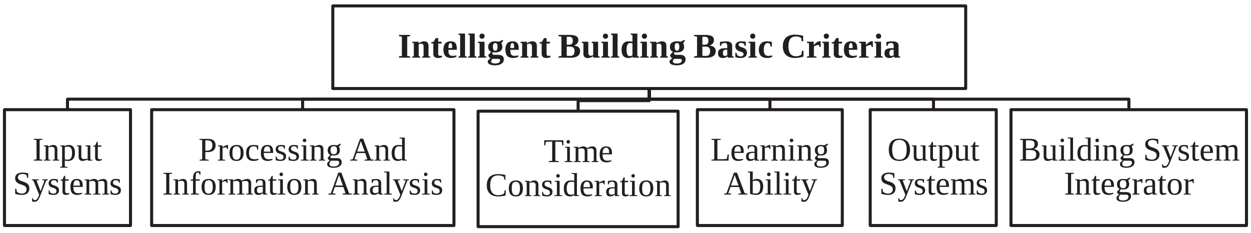


Figure 1- 13: Basic criteria of Intelligent Building

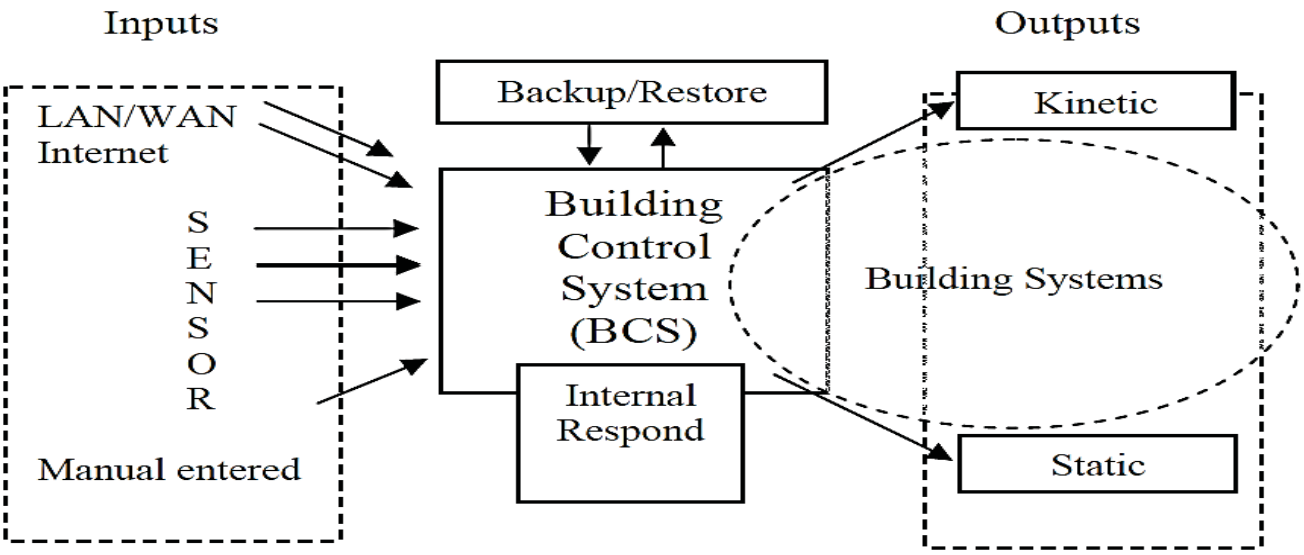


Figure 1- 14: Work flow of BSC components
Source: Overview 0f Intelligent Architecture, P. 10

1.3.2.1. Input Systems

Each system in the intelligent building should have a means of collecting input information. Systems can obtain information in four different ways: sensors (real time), internal backup and restored information, manually entered information (programming and reprogramming) by users, and online connection (Internet) as shown in table 1-4. (1)

[1]ibid, p. 139

Table 1-5 : The input systems components.

INPUT SYSTEMS					
Sensors (exterior-Interior)			**Internal backup and restored information**	**Manually entered information**	**Always being connected online (Internet).**
Security and Safety Sensors	**Weather and Space Quality Sensors**	**System Monitoring Sensors**	• The ability to back up restore cases and information • The system should be able to able to recall previous settings and reset them • Internal backup system should work as memory in the intelligent system	**programming reprogramming by users** • Systems are supposed to accept manual programming by users. At any time, • User should have the ability to reprogram the main system according to new circumstance	• Get online information from different companies, to be updated and perform well • It should be able to communicate with different companies to update their drives. All data collected will be delivered to the data processing application
• Fire and smoke detection • Photo optics access • Accelerat-ion, shock, and vibration • Motion and human presence	• Temperature • Humidity • Solar Radiation • Pressure • Light • Flow (Liquid and Gas) • Air Contents • Moisture • Chemical measurement	• Structural system monitoring • Mechanical system monitoring (e.g. HVAC system) • All other systems that require monitoring			

1.3.2.2. Time Consideration

In establishing intelligent criteria, time is a critical component for an intelligent system. All responses and decisions must happen at or within a required time. For example, fire alarms should start on time, but smoke from a fire may be analyzed as cigarette smoke at first. Thus the system will not recognize it as fire smoke until sometime later. At this point, the system must be able to adjust its sensitivity and analyzing process to respond to fire smoke the next time. This is referred to as learning ability. (1)

1.3.2.3. Learning Ability Heuristics

Heuristics can be defined as a set of rules that increases the probability of solving a problem. Conceptually, it is about the ability to learn from experience. Adjusting decision time is an example of reprogramming and adjusting the system setting on the basis of new information; information can come from people or sensors. (2)

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2 K. Sherbini & Krawczyk, Overview of Intelligent Architecture, on ASCAAD Conference, p. 142

1.3.2.4. Processing And Information Analysis

Information processing is performed in the building control system (BCS) by collecting all information inputs together as one unit. The BCS controls each system individually. The place where all systems integrate is called the Building System Integrator (BSI). For systems to be integrated they should have addresses that other systems recognize. (2)

1.3.2.5. Outputs Systems

Information processing is performed in the building control system (BCS). The BCS controls all systems as one unit and controls each system individually. The place where all systems integrate is called the building system integrator (BSI). For systems to be integrated, they should have addresses that other systems recognize. External response is the result of internal responses formed according to processed information. An external response can take two forms as shown in figure 1-15. (2)

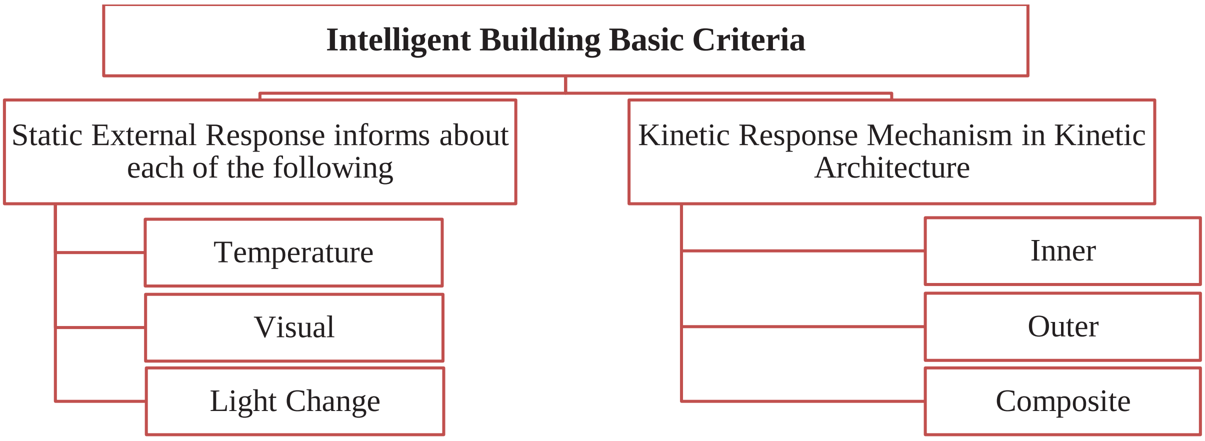

Figure 1-15: Intelligent Building Basic Criteria

1.3.3. Building System Integrator (BSI)

System Integration: "Enabling different systems to cooperate, Heading to good working environment qualifications" Clements-Croom.

Building system integration takes place at physical, network and application levels. Integrated systems share resources. This sharing of resources underpins the financial metrics and improved functionality of integrated systems. System integration involves bringing the building systems together both physically and functionally.

Integration is a basic engine in intelligent building criteria this was confirmed by Ranee Vedamuthu in his intelligent building definition :[1]

> “An intelligent building is in essence one that integrates various systems (such as lighting, heating, air conditioning, voice and data communication and other building functions) to effectively manage resources in a coordinated mode to maximize occupants performance, investment and operating cost, savings and flexibility "

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1.3.3.1. The Growth of Building System Integrator (BSI).

There is a key differentiation between integrated and interfaced systems. Interfaced systems are standalone systems that share data, but continue to function as standalone systems. Integrated systems aim to create a single database, a meta-database, thus reducing the cost and support for synchronizing separate databases [1]. Before 1980, the automation of building systems was achieved at the level of the individual apparatus or device. After 1980, intelligent building systems entered the integrated stages. There has been great progress in the integration of IB systems in terms of both technology and scale. IB systems after 1980 can be divided into five stages as shown in Figure 1-16: [2]

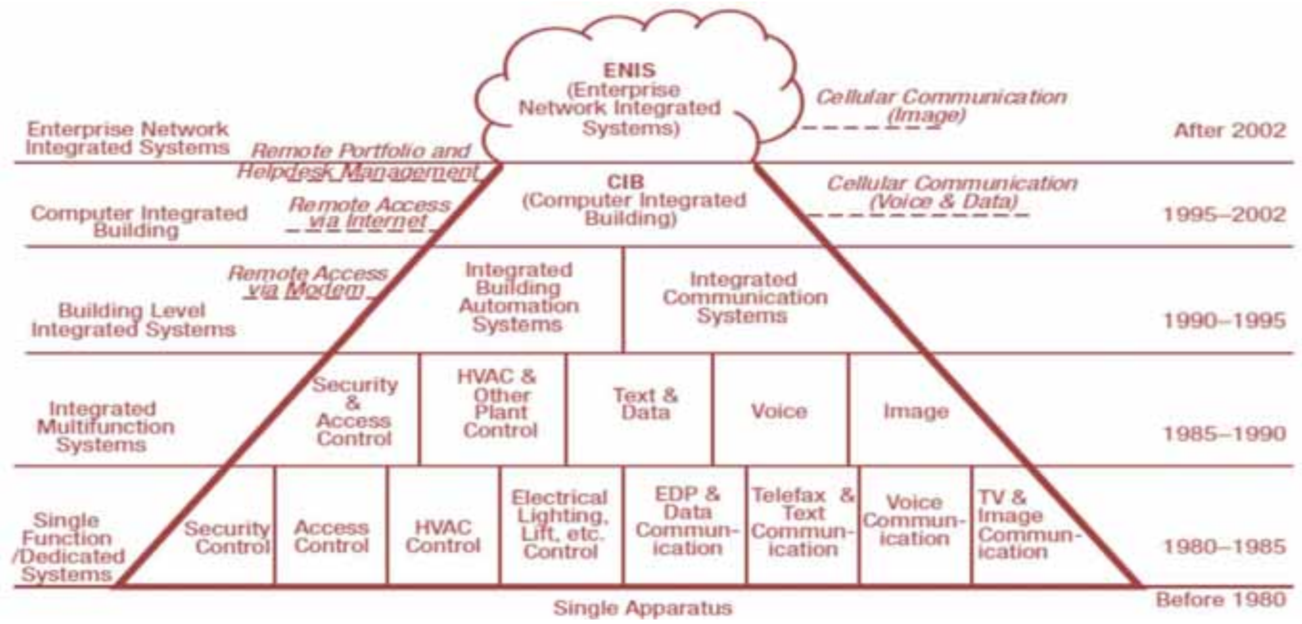


Figure 1- 16: Integrated building pyramid
Source: Intelligent Buildings and Building Automation, p. 7

i. Integrated Single Function/Dedicated Systems (1980–1985)

All the BA subsystems (including security control, access control, heating, ventilation and [HVAC] control, lighting control, lift control, other electrical systems, fire automation; etc.) and CA subsystems (including electronic data processing [EDP]) and data communication, telefax and text communication, voice communication, TV and image communication, etc.) were integrated at the level of a single or individual function subsystem.[3] Integration and communication between the automation systems of different subsystems was impossible.

ii. Integrated Multifunction Systems (1985–1990)

Security and access control were integrated. The automation systems of building plants or services systems were integrated. There were unified networks for text and data communication, voice communication and image communication respectively. [4] Figure (1-17)

[1] Sinopoli, James M. Smart buildings systems for architects, owners and builders, p. 4-8
[2] Wang, Shengwei. Intelligent building and building automation, p. 7
[3] ibid, p. 8
[4] ibid, p. 8

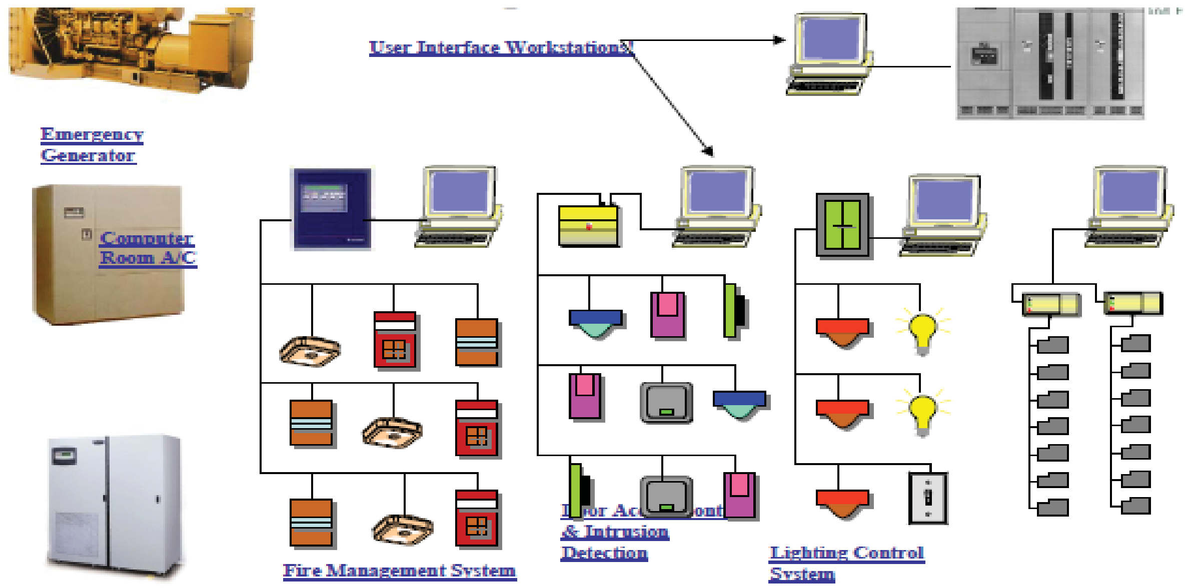


Figure 1- 17 : Typical Building Approach to Automation
Source: Intelligent Buildings Systems Workshop presentation, p. 38

The integration of systems with the same nature or similar functions was achieved.

iii. Building Level Integrated Systems (1990–1995)

Both BA and communication systems were integrated at building level as building automation system (BAS) and integrated communication system (ICS) [1] .Figure 1-18 illustrates the workflow of systems in building integrated systems Level.

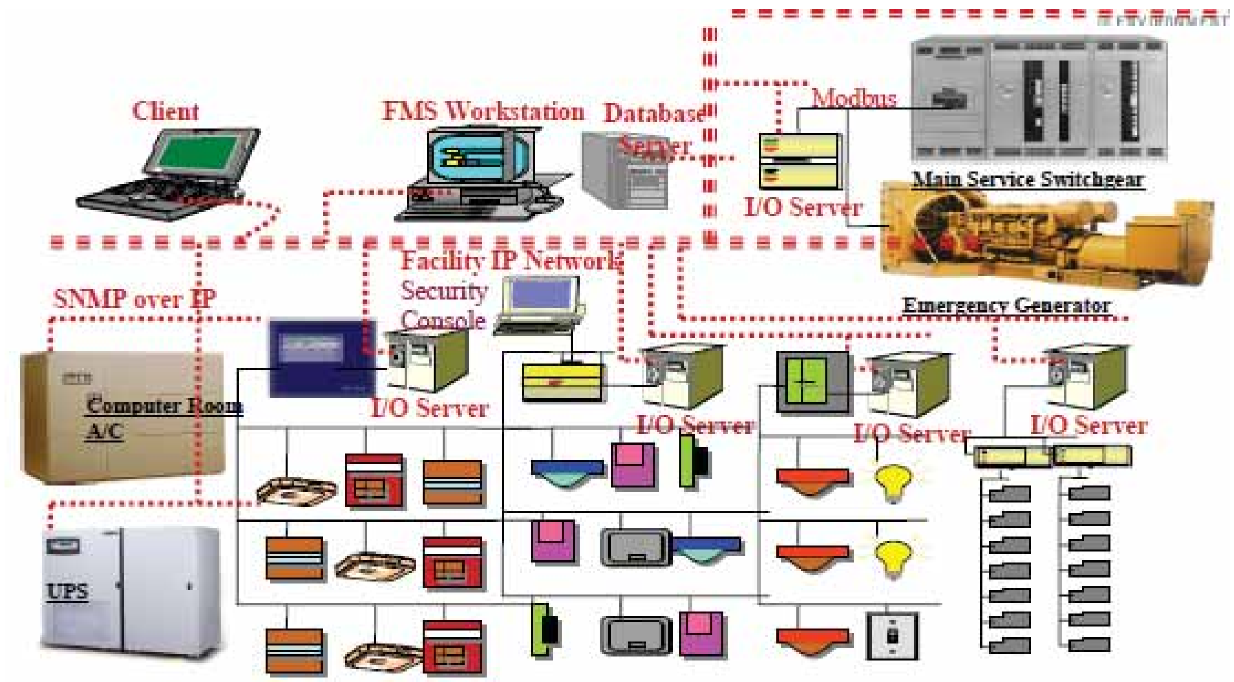


Figure 1- 18: Partial Integration Concept of Intelligent Buildings
Source: Intelligent Buildings Systems Workshop presentation, p. 39

At this stage, a BA system could be accessed remotely via telephone network using a modem while the cellular phone for voice and data communication was introduced to the market.

[1] ibid, p. 8

iv. Computer Integrated Building (1995–2002)

Convergence networks became available and were progressively used in practice through Internet Protocol (IP) network technologies and increased network capacity [1]. Figure 1-19 illustrates the workflow of systems in Full Integration Concept of Intelligent Buildings Level. The integration was at the building level. Remote monitoring and control could be achieved via the Internet.

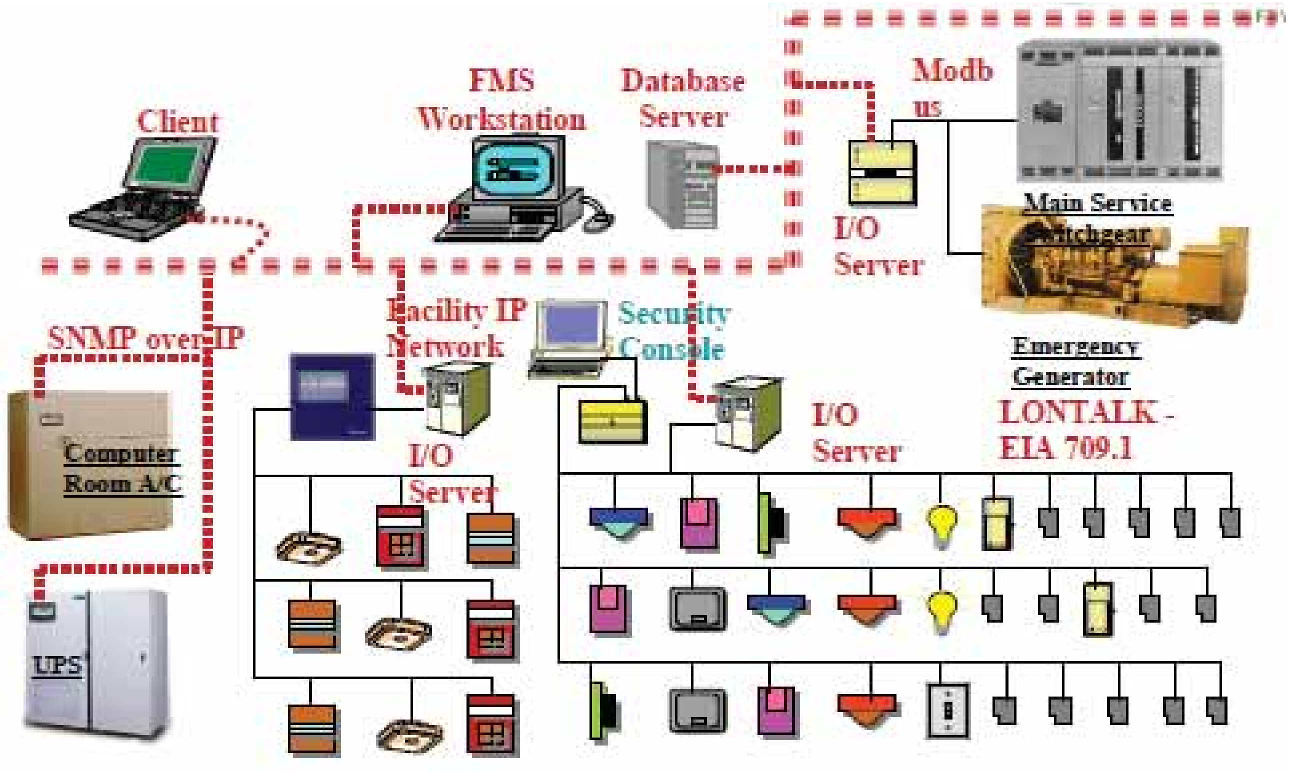


Figure 1- 19: Full Integration Concept of Intelligent Buildings
Source: Intelligent Buildings Systems Workshop presentation, p. 40

v. Enterprise Network Integrated Systems (2002)

Intelligent building systems are not enclosed within buildings anymore. They are merged with IB systems in other buildings as well as other information systems via the global Internet infrastructure. Integration and management at this level became possible due to the applications of advanced IT technologies such as Web Services, XML, remote portfolio management and helpdesk management, among others. In terms of communication, image communication via cellular phones has been brought into practical use. [2] The intelligent systems can now be integrated and managed at the enterprise or city level as shown in figures 1-20 and 1-22. [3]

[1] ibid, p. 8
[2] ibid, p. 8
[3] Check Appendix A page ( ) for more information about smart cities

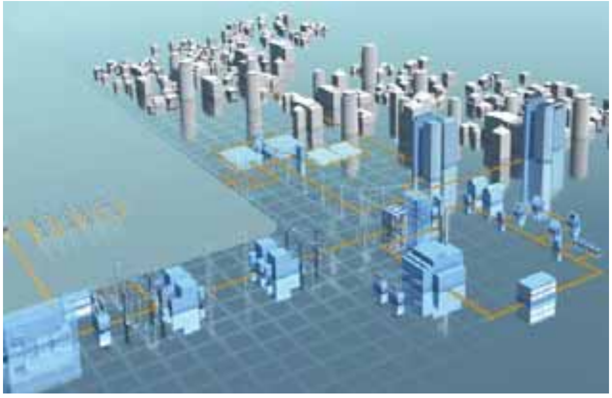


Figure 1- 20: smart city work flow
Source: usa.siemens.com/buildingtechnologies

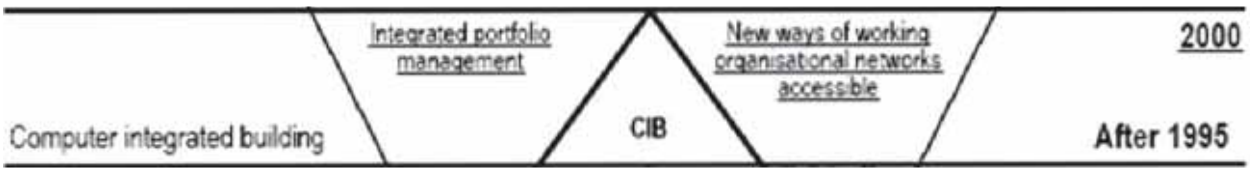
Figure 1- 21: Integration of smart city systems
Source:http://blog.ideas4all.com/es/files/2013/01/Smart-city.jpg

The Smart Grid Reference Architecture is intended as a template for Smart Grid architects to follow as they build Smart Grid Information and Communications Technologies (ICT) architecture for their utility, regardless of the architect's specialty (transmission, distribution, metering, IT, communications). Another aspect emphasized in this reference architecture that could lead to considerable cost and time savings for utilities is the implementation of data services and data management. Greater access to and use of data is critical to the realization of a grid's ability to accommodate new capabilities while improving security, reliability and quality.

In 2010 NIST commissioned the Smart Grid Interoperability Panel's (SGIP) and the Smart Grid Architecture Committee (SGAC) in order to lead its Smart Grid Conceptual Architecture Project (SCAP). The SCAP working group took top down and bottom up approaches to establish a foundation for the development of smart grid business requirements.[1]

1.3.4. Computer Integrated Building

As shown in the previous section, the integration in this stage was at the building level. Remote monitoring and control could be achieved via the Internet. Integrated portfolio management is a more efficient component in this system.



Chua (1999) looked into the importance of incorporating Energy Management and Control System into building automation systems in order to manage the energy consumption effectively.[2]

[1] SCE-Cisco-IBM SGRA Team, Smart Grid Reference Architecture, p. ix
[2] Ler, Eng Loo, Intelligent Building Automation System, p. 6

1.3.4.1. Intelligent Building Management Solution(IBMS)

Intelligent Building Management Solution **(IBMS)** is designed from five layers: visualization, intelligence, interconnection, instrumentation and physical components. As illustrated in Figure 1-22. Each layer identified provides an important aspect of the solution. (1)

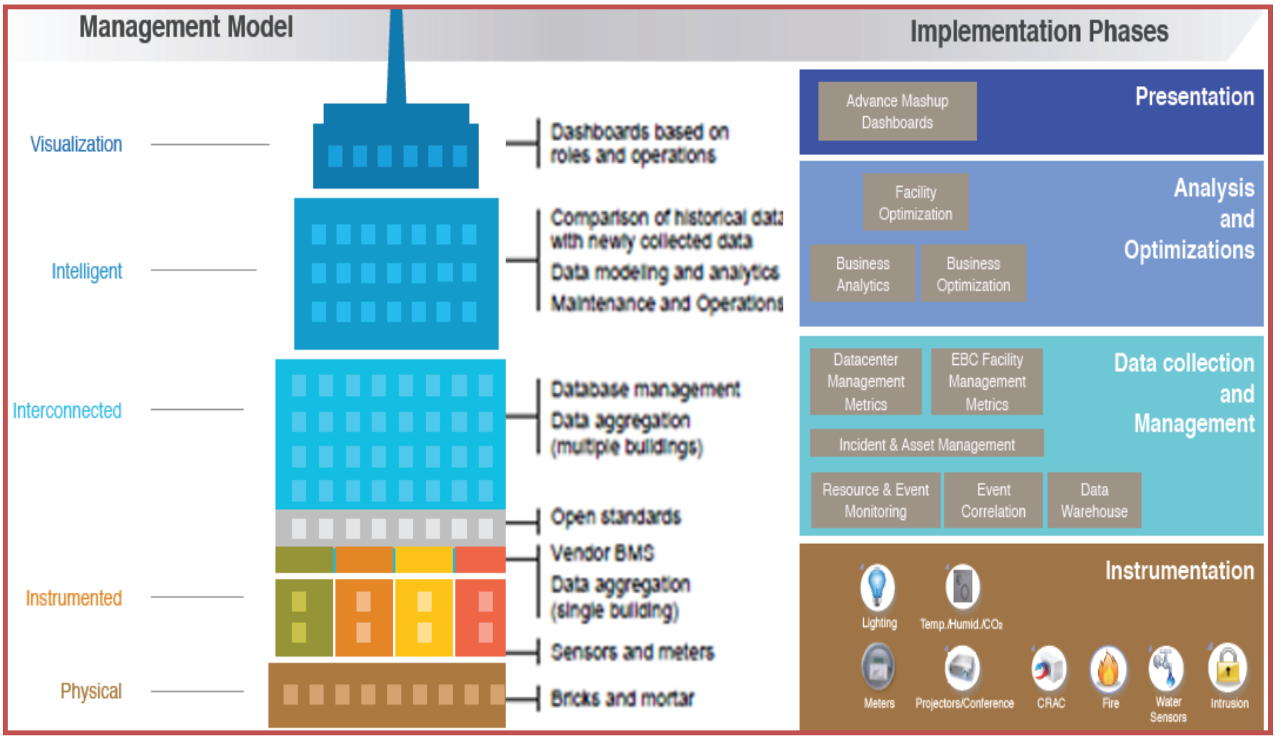


Figure 1- 22: Layers of Intelligent Building Management Solution
Source: Intelligent Building Management IBM white paper, p. 4

i. **<u>The physical layer:</u>** contains the actual equipment and physical elements that need to be monitored. A site assessment is made with the owner or operators to determine what systems to monitor.

ii. **<u>The instrumented layer</u>**: contains the integrated building management system which collects all of the real-time meter and sensor data. It aggregates this data into meaningful and actionable information. This layer contains two domain areas.

iii. **<u>The intelligence layer:</u>** provides the analytics, maintenance and operational activities and transforms existing energy-rich data into intelligent information. It enables management to act immediately in response to events. Maintenance and operational activities are also enhanced with more information coming from BMS analytics and real-time alerts so technicians can quickly identify problems and resolve them.

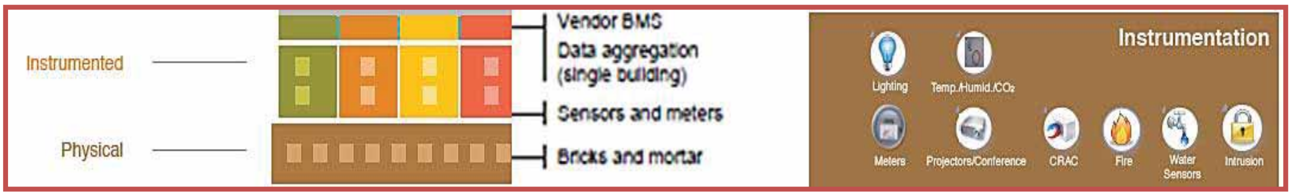
iv. **<u>The visualization layer</u>**: makes valuable cross-system information viewable on a single dashboard. Combining previously unrelated data and business logic from two or more sources can create new insights which then allow information to be analyzed and

[1]IBM, Smarter Cities Series A Foundation for Understanding IBM Smarter Cities , p. 9

compared at the local, regional and global levels. By using the dashboard, the operator can launch other applications that are appropriate to the context of the work. [1]

1.3.5. The Instrumented Layer Integrated Building Management System

The instrumented/physical layers correspond to define what, where, and how sensors are installed and thereby set the scope and level of details such that data can be collected for subsequent analysis. [2] (Figure 1-23)



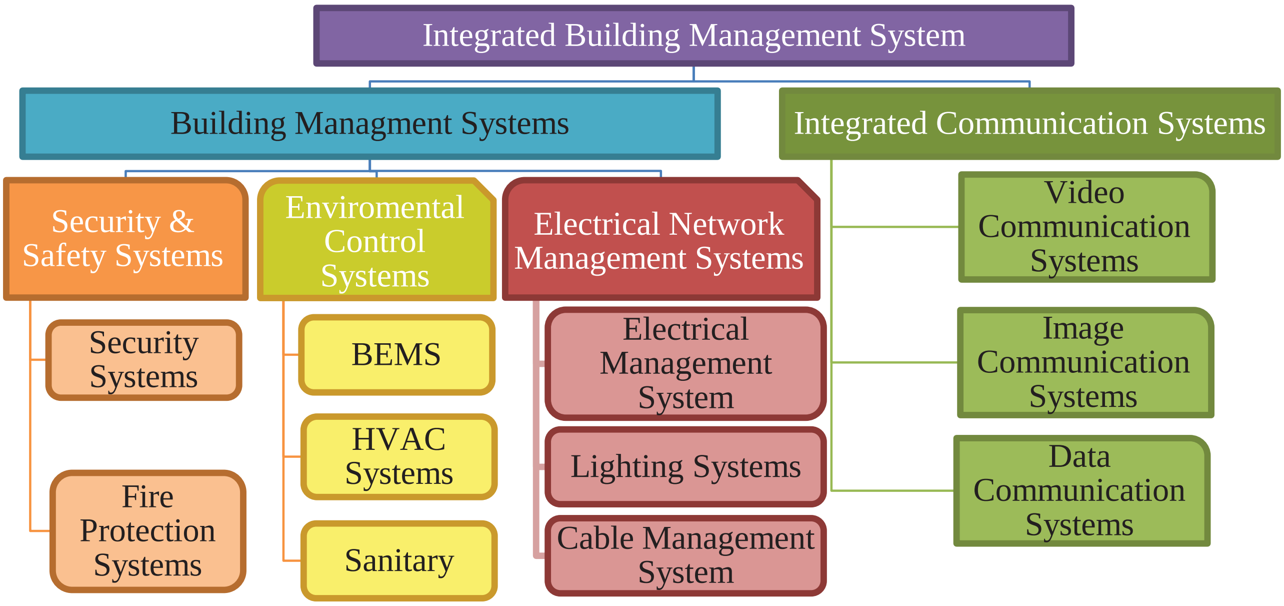


Figure 1- 23: Integrated Building Management System

Theories differ for Intelligent Systems classification. It had been previously sorted into main systems and secondary ones and then the Washington Science Academic sorted it into information and work place systems and facilities management. Intelligent & Integrated Infrastructure in buildings (I&I) sorted it to four integrated phases in pyramid stages [3], from systems to sub systems to integrated systems as shown in Figure 1-24.

[1] IBM, Intelligent Building Management white paper, p. 4
[2] BOMA, Increasing Building and Workplace Performance, p. 9
[3] ماجدة بدر ، العمارة الذكية كمدخل لتطبيق التطور التكنولوجى فى التحكم البيئى ،ص70

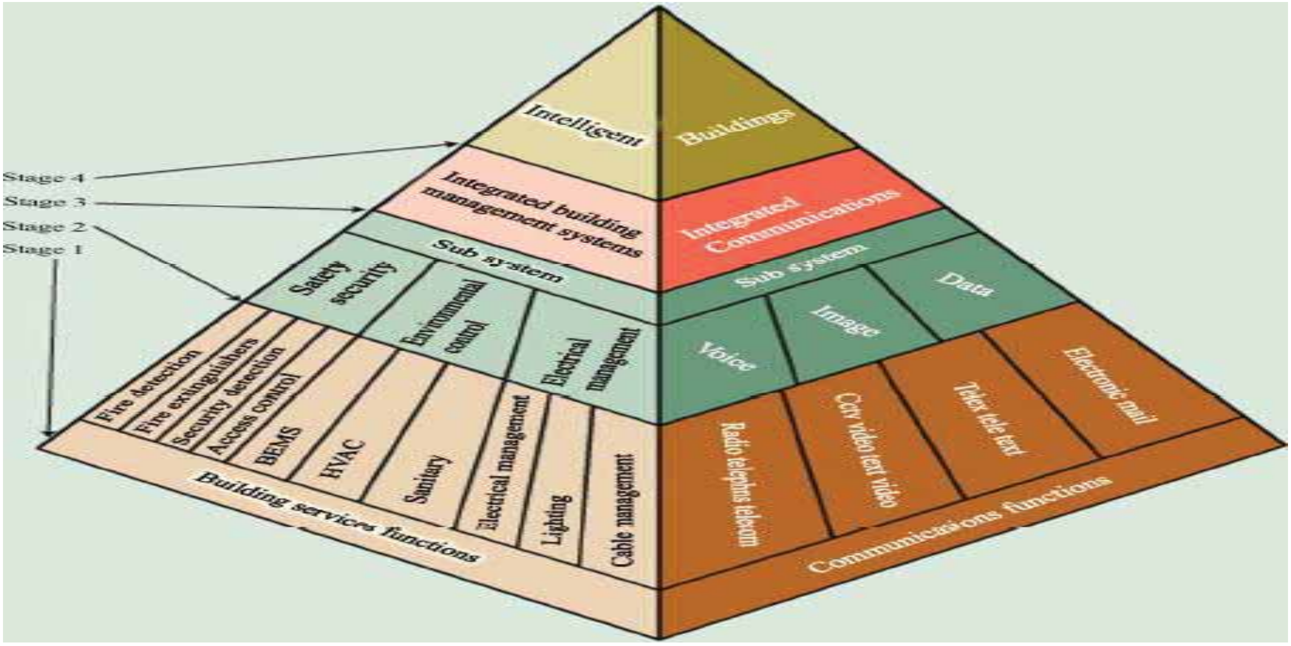


Figure 1- 24: Intelligent Systems classification into four pyramid stages according to I&I
Source: (I&I Limited)

1.3.5.1. Building Management Systems

A smart building should have an advanced building management system with an open programming language. It requires middleware to normalize and standardize all data from sub-systems as shown in Figure 1-25.The user interface in the advanced systems, such as displays and dashboards, is completely configurable and customizable by users with access via a browser. The system is capable of data exchange with information in enterprise and business level software which provides a suite of software applications such as energy management, building performance analytics, alarm management, and automatic fault detection and diagnosis.

Brooks (2011) suggests that Intelligent Buildings are equivalent to the BMS. [(1)]

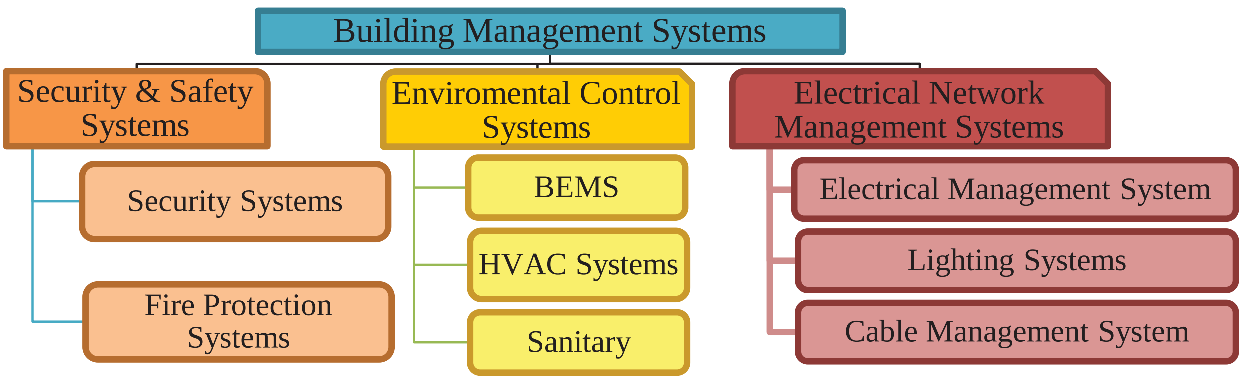


Figure 1- 25: Building Management Systems components

[1]Buckman.A.,et.al., What is a Smart Building?, p. 96

Central control and BMS integration are important for university campuses to simplify operations and maintenance which then provide centralized management software with reporting and alerting capabilities to identify energy anomalies and maintenance issues.

This thesis will focus on optical environment. Through studding systems in Figure 1-25, environmental and electrical systems were found by the mind controller which was responsible for taking appropriate economic and environmental decisions to get the best lighting solution while also providing visual comfort for users.

i. Environmental Control Systems

A smart building should have an advanced environmental control systems to adapt with building environment and achieve the maximum energy consumption. The environmental control system consists of three main components system as shown in figure 1-26.

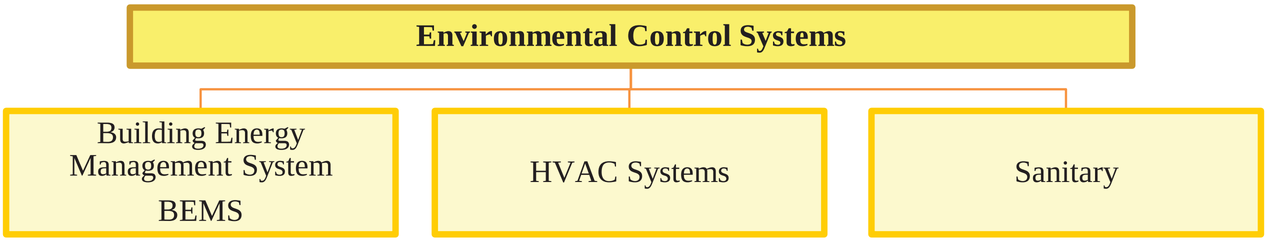


Figure 1- 26: Environmmental Control Systems

A. <u>Building Energy Management Systems</u>

The primary energy sources for buildings are electricity and gas. Solar and alternative sources are rare although some buildings have their own electricity generating capability to complement grid supply. [(1)] Building energy management is generally considered to be the best solution for energy consumption over and above the basic management by exception process. Energy management is generally prioritized on a life cycle cost basis. In addition to this, it must suit the building's operational profile both during normal hours of operation and after hours. These decisions have a life time effect on the building and even the best energy management system cannot solve major equipment selection deficiencies. BEMS consists of sub systems as shown in Figure 1-27. These sub systems allow building operators to integrate lighting systems with other building services such as heating, cooling and ventilation to get the right decision in order to achieve a global energy approach for the whole building, in particular for green buildings or energy-producing buildings. [(2)]

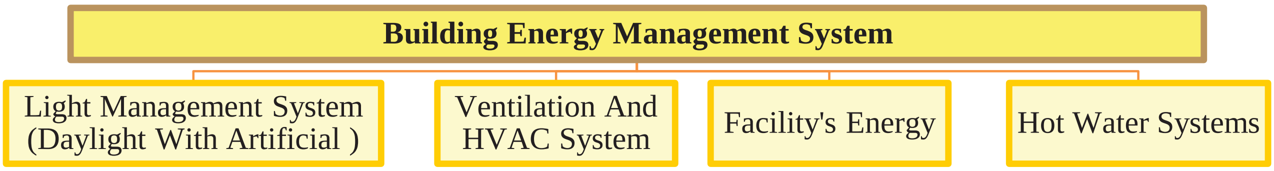


Figure 1- 27: BEMS Control Energy Consumption By Mangening

[1] ماجدة بدر ، العمارة الذكية كمدخل لتطبيق التطور التكنولوجى فى التحكم البيئى ،ص 80

[2] IEA ,Guidebook on Energy Efficient Electric Lighting for Buildings, p.147

A.1. Lighting Management System (LMS) [1]

Lighting Management Systems combine light control strategies to maximize the total system efficiency. The main purpose of these systems is to reduce energy consumption while providing a productive visual environment. This includes each of the follows: [2]

- Providing the right amount of light
- Providing the light where it's needed
- Providing the light when it's needed

The Follwing Figure 1-28 illustrates the components of a lighting control system and it will be discussed in detail in chapter 4

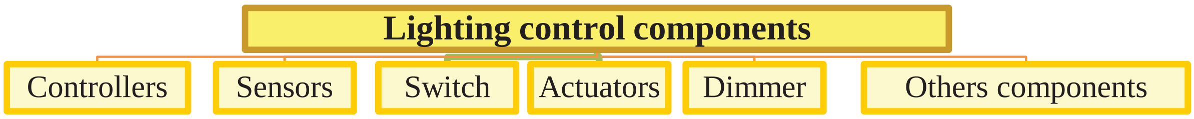


Figure 1- 28: Lighting control components

A.2. Heating, Ventilating, and Air Conditioning Systems (HVAC)

Heating, ventilation, and air conditioning (HVAC) systems, which are illustrated in Figure 1-30, maintain the climate in a building. HVAC systems control the temperature, humidity, air flow and the overall air quality. A typical system brings in outside air, mixes it with air returned from or exiting the system, filters the air, passes it through a heating or cooling coil to a required temperature and then distributes the air to the various sections of a building.[3]

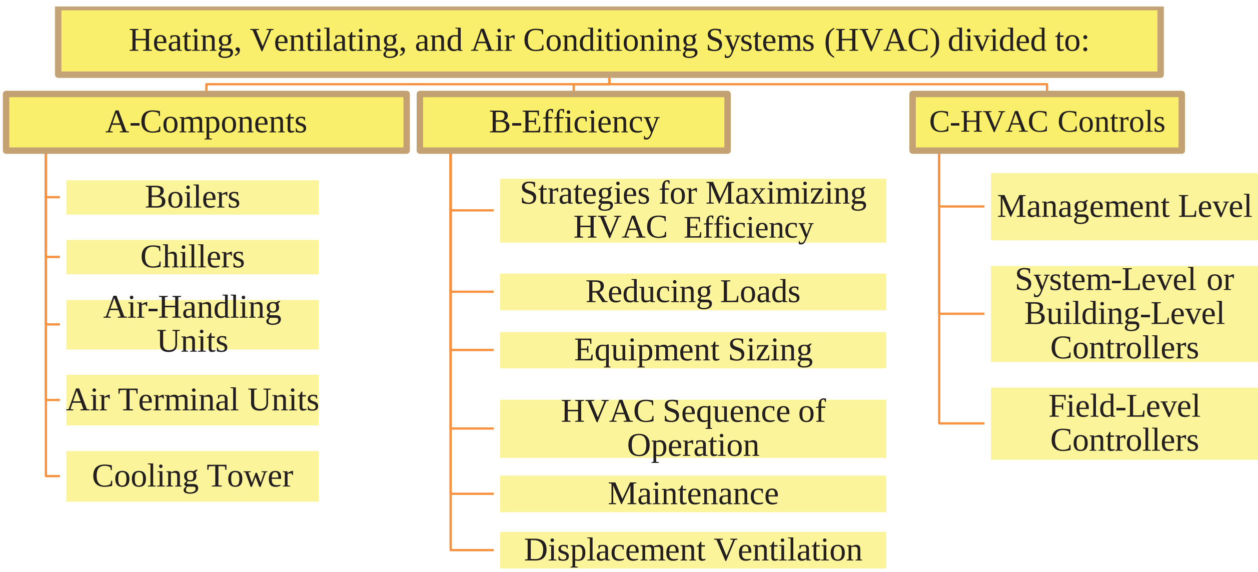


Figure 1- 29: Heating, Ventilating, and Air Conditioning Systems (HVAC)

ii. Electrical Network Management Systems

Electrical network management systems have a significant role in reduce energy consumption. They are responsible for all building connections .Figure 1-30 illustrates the main three systems components for the electrical network management systems.

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[1] Check Appendix B:Sample for Lighting Management System of The Lutron Company Quantum
[2] IEA ,Guidebook on Energy Efficient Electric Lighting for Buildings, p. 145
[3] Sinopoli, James M. Smart buildings systems for architects, owners and builders,p. 32

Figure 1- 30: Electrical Network Management Systems

A. Electrical Management System

The Electric Power Management System (EPMS) monitors the power distribution system for usage and quality. The EPMS, together with the HVAC system and the lighting control system, is integral to overall energy management aimed at controlling usage and costs. In addition, the EPMS is a tool in managing and ensuring the quality of the power. Quality power refers to a power source free from surges, sags, and outages that may affect the facility's reliability and safety. [1]

B. Lighting Systems

The need for lighting control systems in a building varies by the type of building, spaces within the building, time of day and occupancy of the building. Consequently the control strategies and functions of a lighting control system can vary greatly.

The lighting control system distributes power to the available lighting units in a typical fashion as shown in Figure 1-32. It inserts digital control and intelligence in many, if not all, of the devices controlling the lighting such as the circuit breaker panel, wall switches, photo cells, occupancy sensors, backup power and lighting fixtures. The control system significantly increases the functionality and flexibility of the lighting system by providing digital control and intelligence to the end devices. [2]

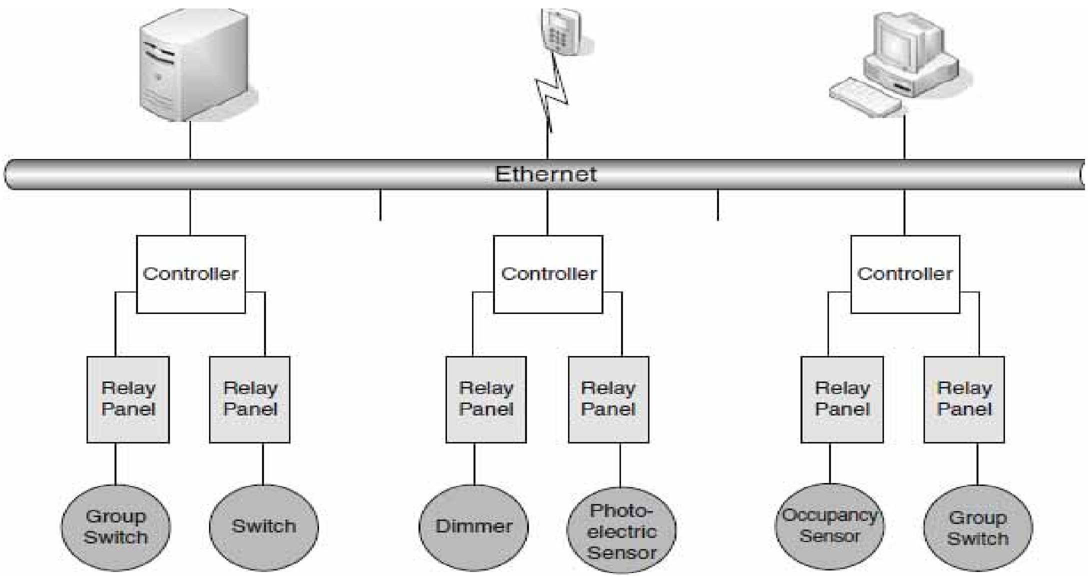

Figure 1- 31: Work flow of a lighting control system
Source: Smart Building Systems for Architects, Owners, and Builders, p. 49

[1] ماجدة بدر ، العمارة الذكية كمدخل لتطبيق التطور التكنولوجى فى التحكم البيئى ،ص 84

[2] Sinopoli, James M. Smart buildings systems for architects, owners and builders,p. 48

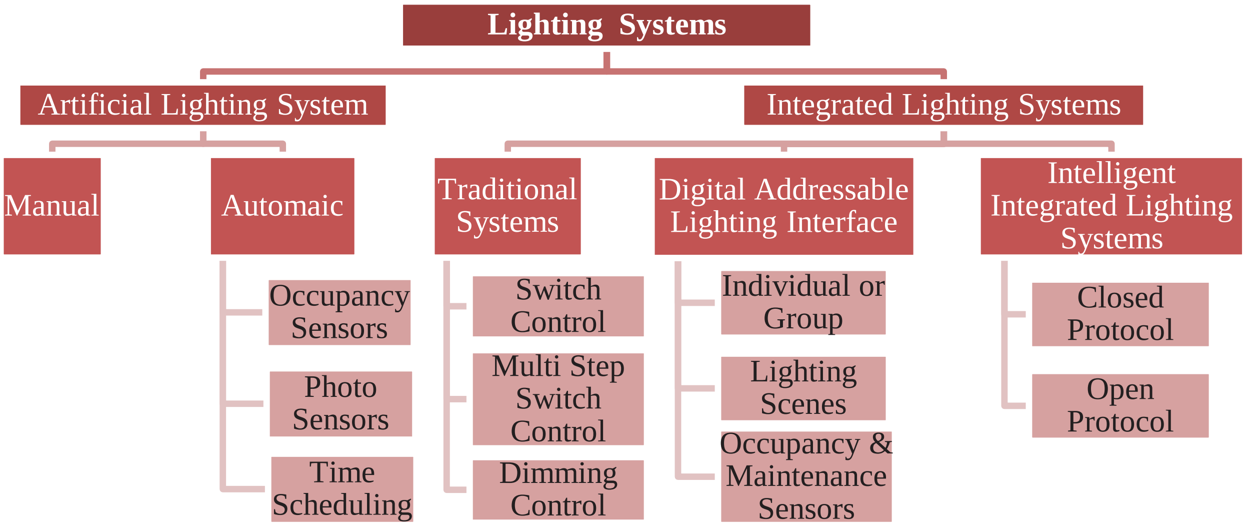

Figure 1- 32: Types of lighting systems

1.3.6. Integrated Building Systems Managing Protocols

BMS uses communication protocols which are rules that electronic components or microprocessors use when communicating with one another [1]. Protocols are languages by which two devices communicate and exchange data. [2] Figure 1-34 illustrates levels of protocols which included :[3]

- Device Level (Modbus, Canbus, BACNet etc.)
- Building Level (BacNet, Proprietary etc.)
- Enterprise Level (Web, XML)

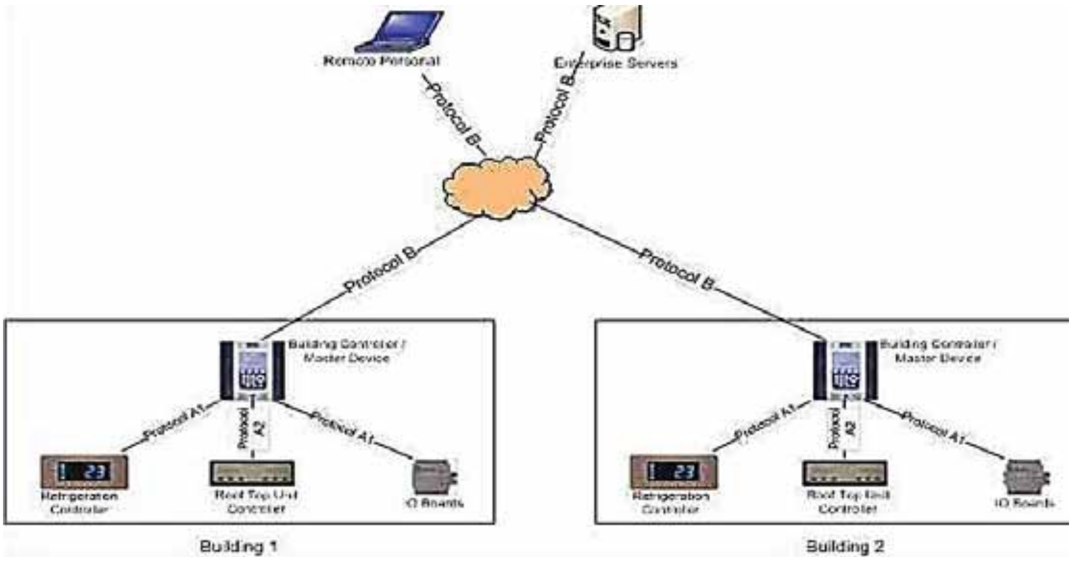

Figure 1- 33: Level of protocol work flow from device level to enterprise level
Source: Managing Your Building Automation System, p. 6

[1] BACnet, LONtalk and Modbus are examples of protocols used by typical building services equipment in office buildings
[2] http://singh360.com/bms-protocols/
[3] Richard Albrecht ,Managing Your Building Automation System, p. 6

Protocol in the BMS world is considered the communication language between the building systems and other smart city systems. There are main four types for the level of protocol communication as illustrated in table 1-4. [(1)]

Table 1- 4 : Types of communication protocols

Protocol Type	Open	Standard	Inter-operable	Proprietary (close)
Definition	When the creator of the protocol makes it readily available to everyone through their web-site.	Protocol requires all parties to agree on a data structure that can be implemented on their respective devices.	When a controller from one vendor can be easily replaced with a controller from a different vendor.	When a protocol is restricted to the creator of the device because the creator does not share the data structure.

Standard protocol is the preferred type to be under control at a given time but only under supervision of specific organizations.

1.4. Conclusion

Intelligence is not an equation of fixed variables but is instead a process that is inspired by human intelligence and cognitive capabilities. Humans have always been the inspirational model for considering the application of intelligence in buildings. Therefore people are the nucleus for intelligent building ideas. They built IB to adapt to their needs and to be more suitable for them.

Intelligent Buildings are being developed into smart buildings as a new generation of buildings which are being built with additional integrated aspects of adaptable control, enterprise and materials and construction

This chapter discussed how the Intelligent and smart buildings became a turning point in architecture and construction fields, parallel to advancements in envelope engineering, building science and information and communications technology (ICT).Moreover, various intelligent buildings have been developed with the most advanced technologies and techniques to develop high performing buildings in smart cities. These smart cities contain fully integrated buildings systems (such as schools, universities, offices and government building systems) with state institutions and an international network. Because of this advanced technology, they are commonly seen to be the future of the world. AT the same time, concept of traditional classrooms at universities has been changed nowadays to be 'smart' Learning spaces which correspond to the needs of our smart building era. Therefore the next chapter will discuss the smart university and learning spaces.

Furthermore, this chapter highlights the systems which are responsible for the efficient and smart lighting design process in Building Management System to study them in detail in the following chapters. These systems are BEMS, which is a sub system of Environmental Control Systems, and Lighting Systems, which is a sub system of Electrical Network Management Systems.

[1] http://singh360.com/bms-protocols/

2.1. Introduction

Before the nineteenth century, universities were built from robust stone and brick with basic gas, water and electrical systems [(1)]. In the beginning of the nineteenth century and with the inspiration of the Industrial Revolution, new construction devices began to appear such as steam engines, machine tools and optical surveying. Also new materials were used like steel, cement, reinforced concrete and glass in universities construction. Since the 1970s, computer and telecommunication technology has been changing human life. These changes have outpaced the theories guiding such technologies. In the 1990s, social and personal life was affected by computers and telecommunication revolution, which then had a clear effect on the construction systems and building materials. This resulted in the conversion of universities from traditional to intelligent campuses to better accommodate students' needs. [(2)]

The sustainability movement has appeared to parallel to this growth of technology with the target of energy consumption reduction. In 2007 International Sustainable Campus Network (ISCN) was founded to provide a global forum to support leading colleges, universities, and corporate campuses in the exchange of information, ideas, and best practices for achieving sustainable campus operations and integrating sustainability in research and teaching[(3)]. In 2008 the University of Copenhagen (UCPH) established the Green Campus Office to develop strategies for campus sustainability activities with the two key goals of energy efficiency and CO_2 reduction. [(4)]

University campuses are complex, dynamic environments that serve a diverse array of needs for over thousands of people. The challenges faced by university leaders are daunting: reduced endowments, shrinking budgets, rising energy costs, aging systems and equipment, increasing enrollment, rising crime on campus and the pressure to demonstrate a commitment to sustainability. These issues have to be dealt with while simultaneously keeping to their core organizational goals and strategies of delivering the best education, research, and development outputs to attract the best faculty and students in international competition[(5)]. This can be achieved by using intelligent techniques which enable interaction with diurnal and seasonal changes and human beings in the surrounding environmental context, in order to get a reduction in the energy consumption inside indoor spaces. The use of these intelligent techniques provides the owner, operator and occupant with flexible, effective, comfortable and secure environment through the use of integrated technological building systems, communications and controls.[(6)]

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[1] Buckman.A.,et.al., What is a Smart Building?, p. 93
[2] Khaled Sherbini&Robert Krawczyk, Overview Of Intelligent Architecture,p.2
[3] Http://Www.International-Sustainable-Campus-Network.Org/About/Purpose.Html
[4] IARU, Green Guide For Sustainability,p.14
[5] Shan Bates, Creating An Efficient Campus
[6] Intelligent Buildings Systems Workshop Presentation ,p. 17

2.2. Educational Institutions after the Technology Evolution

Educational institutions face big change to transform their relationships with the students, the teachers, and the workers of tomorrow due to technological evolution. New generations of educational institutions have appeared such as "School 2.0 Architecture", "Virtual Campus", Enterprise Resource Planning School (ERP school), "Edutainment", Smart campus and "Hyper connected Learner" [(1)]. Figure 2-1 illustrates the example the school ERP web-based School Automation and Management Software .Technologies also have effected the education process through changing curriculum exchange in different ways. They have enhanced personal learning environments through wireless networks and mobile devices, plus the internet and high-quality digital learning resources provide the ability to access many of these resources from home and the workplace.

Figure 2- 1 : ERP School web-based School Automation and Management Software
Source: http://scs.ramittek.com/

[1] EBTIC, The Intelligent Campus,P1

2.3. Smart University (SU) Basics

2.3.1. Definition of Smart University

A central university serves a diverse array of needs for thousands of people with the main aim of learning lifecycle enhancement in order to keep pace with the modern techniques in a sustainable environment. These techniques included controlling with intelligent management system under the supervision of smart government connected to smart grid.

An intelligent campus can be defined as: "having the faculty of thinking, reasoning and understanding, with the capability of not only making adjustments but also learning and adapting in response to the changing circumstances, forced the campus to try to deliver a high value education environment"(1).

A smart university must have six main aims as shown in figure 2-2 to reach its goal and to be up to date with the tremendous technological progress.(2)

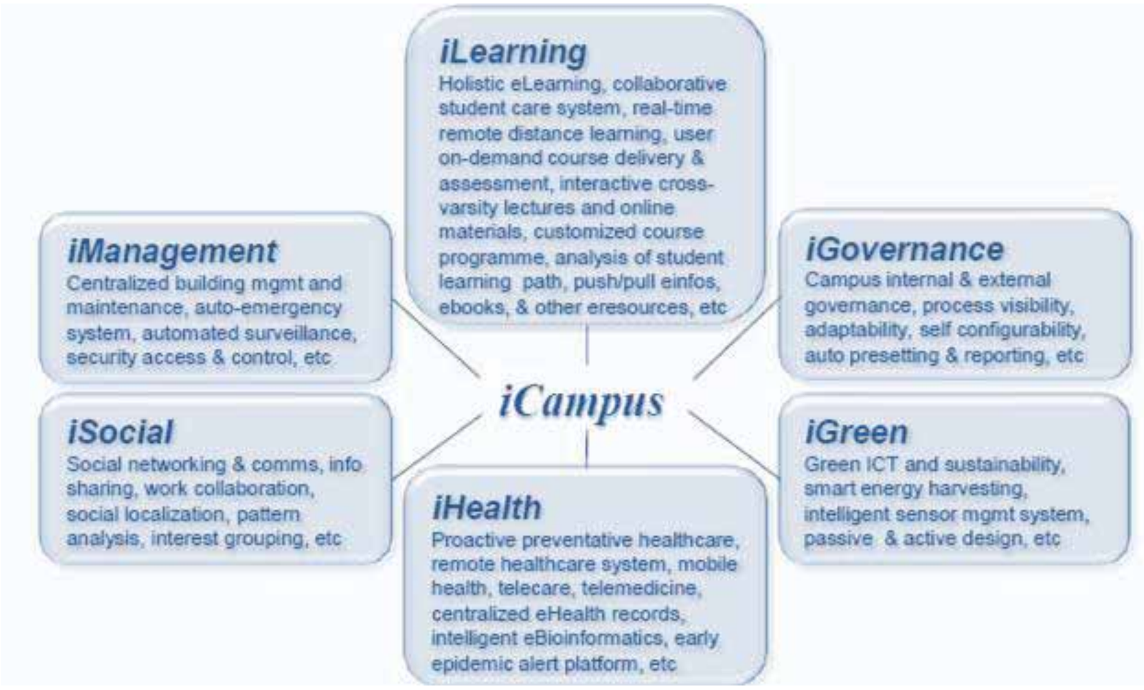

Figure 2- 2 : Main aims of smart campus
Source: Smart Collaborative Learning in an Intelligent Campus Environment, p. 5

The need for intelligent environmental education buildings is greater now than ever before simply due to:

a) The pressures of a growing world population. The implementation of new technologies and the need to protect and conserve our natural resources are greater, more complex critical, and too often more controversial than ever.

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1 ibid
2 Benjamin Hirsch ,Smart Collaborative Learning In An Intelligent Campus Environment,P4

b) A learner today uses the Web extensively for information, communication, collaboration, and socializing. Learners prefer to interact with information and receive near-instantaneous responses. More than traditional forms of study, engaging students in active learning and collaboration typically results in greater mastery and transferability. Using digital archives, databases, library, and the tools of a profession to build their own understanding is better than being told the conclusions. [1]

2.3.2. Benefits of Smart University

Universities must be a place where new generations learn the updated techniques to better serve our society and environment. Thus smart green universities will have many benefits in many fields as shown in figure 2-3.

Education

- Effective learning model so as to maximize the learning potential of the students and as such improve the overall quality of learning.
- Enables a new set of teaching and management capabilities to the faculty.

Society

- Improved quality of student/teacher, teacher/teacher and student interactions. Evidence of increased levels of student interpersonal competencies and team work.
- Behavioral changes related to retention, vandalism, absenteeism, suspensions, expulsions, disciplinary incidents, violence, disruption in class, lateness, racial incidents, and smoking. Produces a new generation who can interact with new technology with environmental thinking at the same time.

Economy

- Operations-related impacts account for over 80% of life cycle impacts in buildings. Owners' operating costs are significantly lowered as a result of more efficient operations and better control thus enhancing a building's asset value by enhancing connectivity between building systems and users.
- Ensuring continued and improved intelligent operation, maintenance and optimization.

Figure 2- 3 : Smart university benefits

[1] NLII, Leading The Transition From Classrooms To Learning Spaces, p. 2

2.3.3. Mission of Smart University

1. **Buildings and Spaces** :that promote intellectual and social exchange: Comprised of exterior spaces (including streets, walkways, greens, courtyards, plazas, gardens and playing fields) and interior spaces (lobbies, atriums and internal connectors)[1]
   - Design flexible multi-use spaces in the design of new and renovated spaces to accommodate changing needs and functions over time. Design to make use of the vertical dimension of facilities.
   - Design to integrate previously discrete campus functions.
   - Design features and functions to maximize teacher and student control.
   - Design to maximize alignment of different curricula activities.
   - Design to maximize student access to, use of and ownership of the learning environment.
2. **Functionality:** University buildings must effectively meet the programmatic needs of its users, both spatially and environmentally. They should be designed for flexibility and adaptability. As user needs and technological requirements evolve over time and so the building should be able to accommodate some level of adaptation and reconfiguration without exorbitant expense or structural modification. Whenever possible a building should be designed in such a manner that it can accommodate an addition or additions over time. [2]
3. **Economy:** As a state-supported institution with many important programs and many pressing needs, it is important that buildings are constructed in a cost effective manner.
   - Buildings design must be economical over their life-cycle
   - Careful analysis and decision-making are required to insure that the university receives the greatest possible value for the funds expended.
   - Develop campus buildings and infrastructure design to achieve energy efficiency in a systematic fashion.
4. **Quality:** It is essential that universities can be constructed to the highest standards of quality possible with the funds available. The standards of high quality will affect material selections, systems choices and design aesthetics. This sense of permanence and quality has a significant impact on prospective students, faculty and staff when they are considering joining a university community.
5. **Sustainability:** This includes durability and maintainability as well as concepts of “green” building. The aim should be to develop buildings that require less

[1] Jill Blackmore , Centre For Research In Educational Futures And Innovation, p.5
[2] Design Guidelines,University Of Massachusetts Amherst ,p. 5

maintenance and operational investment over time while continuing to serve the needs of users. Figure 2-4 shows main principles of sustainability on a campus. (1)

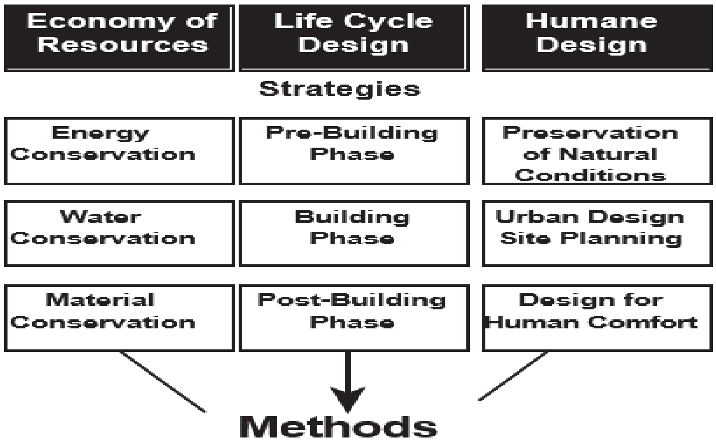

Figure 2- 4: Main principles of sustainability in smart campus
Source: Introduction to Sustainable Design, p8

- In order to achieve smart sustainable campuses data, voice, and video must converge with security, HVAC, lighting, and other electronic controls on a single network platform that facilitates user management, space utilization, energy conservation, comfort and systems improvement. (2)

- The common aspects for campuses can be extracted from previous goals and demonstrated in figure 2-5.

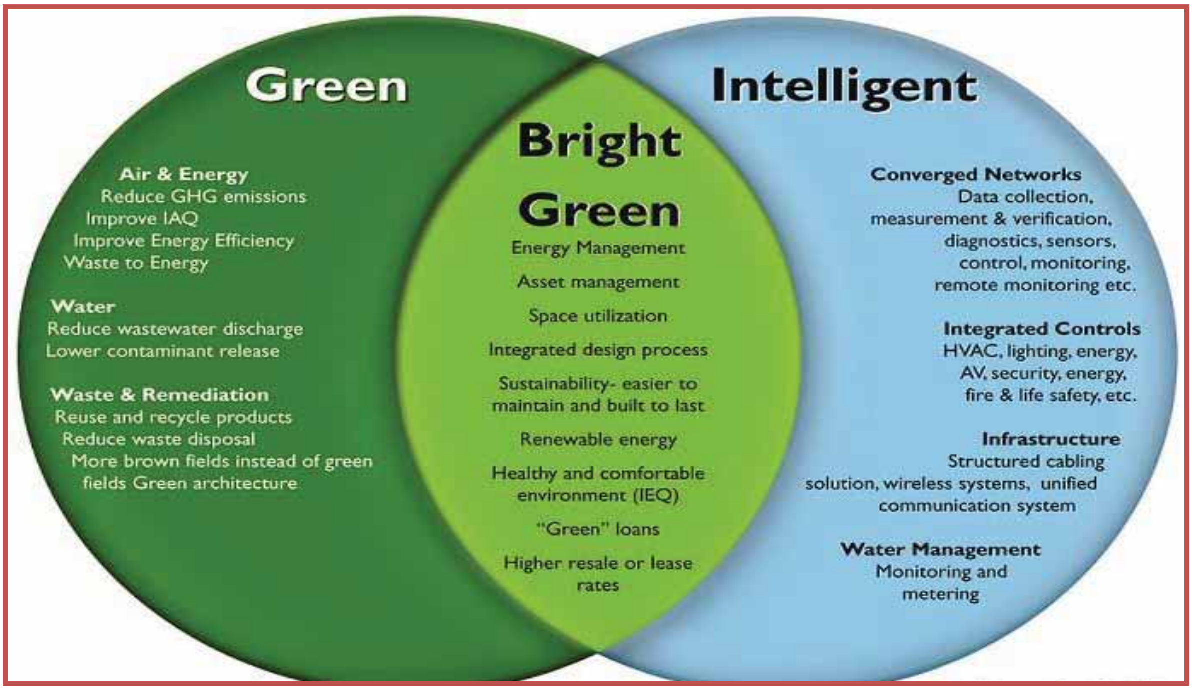

Figure 2- 5: Main Aspects and attributes of smart campus
Source: Bright green building, p. 5

[1] Jong-Jin Kim,Introduction To Sustainable Design, p. 7
[2] Cara,Bright Green Building, p. 5

2.3.4. Vision of Smart University

The goal of a smart university is to create a brilliant university that maintains the highest value and comfort at the lowest environmental cost with implementation of intelligent technologies and processes. As well as to have the “green” results and also for the campus to be able to accommodate some level of adaptation and reconfiguration without exorbitant expense or structural modification. Whenever possible it should accommodate an addition or additions over time.

Smart university is complex and consists of a lot of systems and functions which are uniquely compatible with environmental needs and resources as shown in figure 2-6. [1]

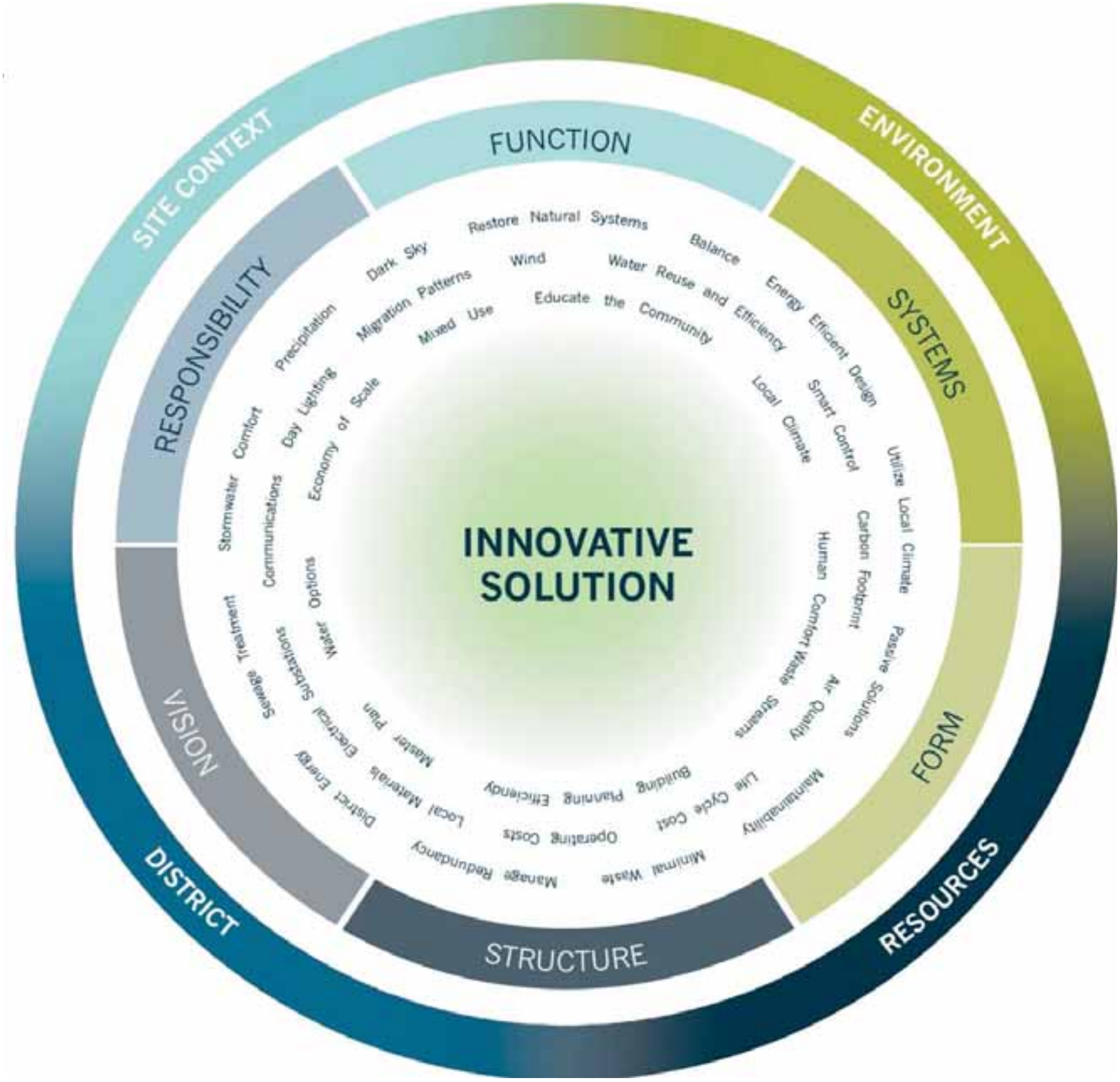

Figure 2- 6 : Smart university vision
Source: Sustainable Engineering+ Design-Som Brochure

[1] Som, Sustainable Engineering +Design-Som Brochure, p.11

2.3.5. Smart University Outline

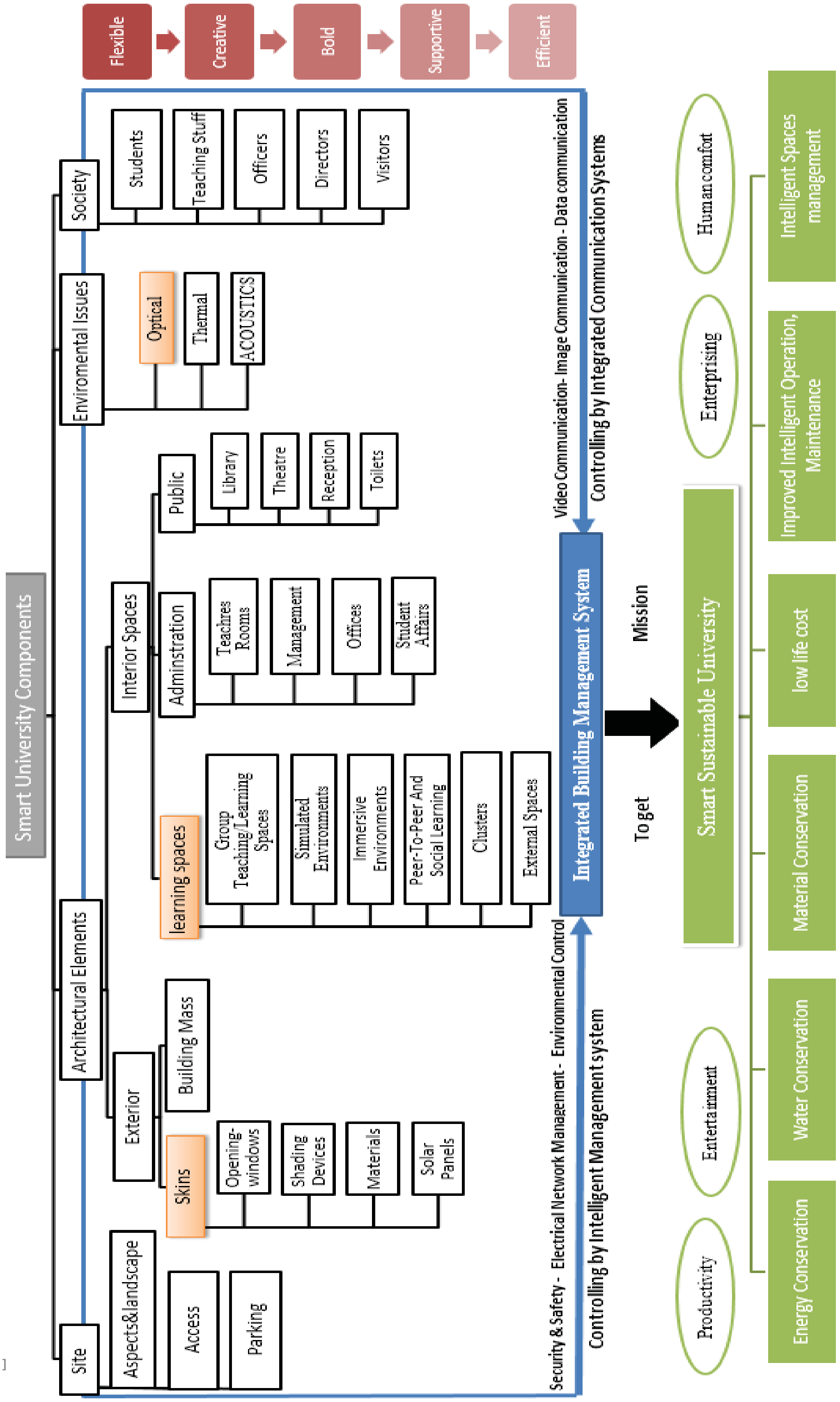

Figure 2- 7: Smart University outline

In this thesis, we'll study how to use smart integrated systems to control architecture elements and process learning spaces optical environment at university institution

2.4. SU Learning spaces

Learning is the main activity at universities. The learning environment is composed of students, teachers and the physical environment. Lately learning processes can occur in different physical environments whether in classroom spaces as formal learning or by unplanned interactions among individuals as informal learning. Learning spaces areas (physical or virtual), which represent more than 60% of all university spaces, can have an important impact on the learning process. They can bring people together. They can encourage exploration, collaboration, and discussion. But a learning space can also carry an unspoken message of silence and disconnectedness. This is the ability of a space to define how one teaches in colleges and universities. (1) Learning space is being designed or reshaped in response to changing educational styles, to incorporate new information technology and to allow for changing abilities of learners.(2)

2.4.1. Learning Spaces Historical Review

Previously a classroom was the place where students came together for formal learning. However, the Internet has changed concepts of place, time, and space. Space is no longer just physical but it now incorporates the virtual. New methods of teaching and learning have emerged to improve acquisition of knowledge. As a result the concept of a classroom has expanded and evolved. The space is no longer defined by "the class" but by "learning." Not only the internet but also technology has brought new techniques which have changed the behavior of the learning process to be smart. Thus smart learning spaces are the result of the information revolution. Smart learning space design has emerged as an important consideration for colleges and universities. (3)

2.4.2. Specification of Learning Space

A learning space should be able to motivate learners and promote learning as an activity, support collaborative as well as formal practice, provide a personalized and inclusive environment, and be flexible in the face of changing needs. So it should be: (4)

- Flexible: to accommodate both current and evolving pedagogies.
- Future proofed: to enable space to be re-allocated and reconfigured.
- Bold: to look beyond tried and tested technologies and pedagogies.
- Creative: to energize and inspire learners and tutors.
- Supportive: to develop the potential of all learners.
- Enterprising: to make each space capable of supporting different purposes.

[1] Diana G. Oblinger, Learning Spaces , p. 1.1
[2] AMA, Spaces For Learning, p. 6
[3] NLII, Leading The Transition From Classrooms To Learning Spaces, p. 1
[4] JICS, Designing Spaces For Effective Learning, p. 7

2.4.3. Basics Aspects for learning spaces location on SU Layout

2.4.3.1. Site And Spatial Relationships

Learning spaces preferably should be placed on the lower floors of buildings to provide better student access and more convenient instructional support services. In the case that a learning space is located on upper floors, the stair towers and the doors into stair towers must accommodate the number of students who may leave and arrive at the same time. They also should to be separated from noise generating activities inside or outside the building. To reduce external noise, sound buffers must separate learning spaces from areas such as streets, parking lots, housing areas, plazas or other areas where students gather, recreation sites, athletic fields, trash pickup sites, and loading docks. To reduce internal noise, classrooms should be isolated from building mechanical systems, elevators, restrooms, vending areas and other noise generating areas. .(1)

The location of learning spaces and their relationship to natural daylight should also be considered. Natural light is required in all learning spaces except immersive classes. Spaces with windows facing north can be more easily designed to provide adequate blackout capability and energy efficiency than spaces with windows facing other directions. These should be architecturally treated with passive design to get the visual comfort for students and teachers and increase their productivity. (2) This will be discussed in detail next chapters.

2.4.3.2. Accessibility

i. Building Entrances

The main issue in determining building entrances is the directions from which students and other pedestrians approach the building. A learning space should be near a building's main entrances to limit the distance students must travel through non-instructional areas to reach it. Large numbers of students walking through hallways can disturb classes already in session. Larger capacity classrooms should be located closest to the building entry. There should be a plan for a flow of students between classes that is double the capacity of the rooms served by an entrance. Students often arrive for class at the same time that other students are leaving it. (3)

ii. Doors

The door width of a learning space should be compatible with the space size and students' density on it. There should be one entrance for spaces with less than 50 student and two for more than 50. A panel mustn't be less than 0.90m and it also should have a vision panel from shatter-resistant glass with an area less than 2.5 m^2 in order to prevent injury when being opened. Doors should also have levers (not knobs) for easier use by people with

[1] Victor Aulestia, Lecture Hall Design Standards ,p. 2
[2] Design Guidance: Learning Environments, University Of Cincinnati , p.7
[3] Classroom Design Manual ,University Of Maryland ,p.5

disabilities. Kick plates installed on the egress side of doors will protect them from bumps and scratches.

Doors should be located in places which minimize congestion problems in the corridors when classes are changing. When possible doors should be recessed into the room so that the door does not swing into the corridor or hallway. If it is necessary for the door to open into the corridor, some kind of visual identification (such as the tile pattern on the floor) can be used to indicate the amount of space that the door will occupy when it swings open as shown in figure 2-8. Doors should not swing into the primary flow of traffic. This will minimize the danger of someone in the corridor walking into the leading edge of the door. [1]

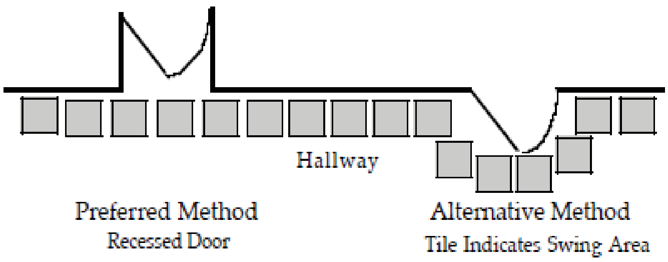

Figure 2- 8 : Recession of door into the space or visual identification with different floor pattern
Source: Classroom Design Manual University of Maryland, p. 6

iii. Accessible Routes and Fire Safety

An accessible route must connect accessible buildings or main entrances with all accessible spaces and elements within the university. It should also serve as a means of emergency egress or connect to an accessible area of rescue assistance marked with appropriate signage. Where audible alarms are required by life safety codes, visible alarms must be provided which signal the same audible alarms areas. [2]

iv. Signage

Learning spaces should have a room identification number on the wall next to the door. These numbers should be accessible to and meaningful to all students in accordance with local code. There should be information located inside and outside classroom regarding how to report problems with physical facilities and with classroom equipment. [3] Digital signage is a very compelling technology. Most people will pay attention to a plasma or LCD display. It's a communication system that's effective, immediate, and dynamic. It can be used in spaces to inform a person who is outside what class is currently inside and it can change automatically. [4] Figure 2-9 illustrates a sample for digital signage network system in educational spaces.

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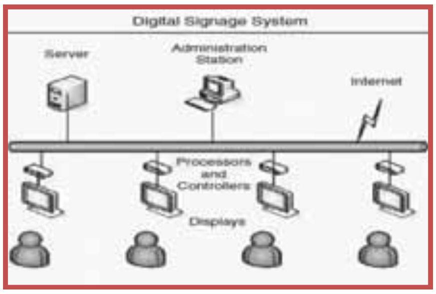
[1] ibid ,p. 6
[2] ibid ,p.12
[3] ibid ,p. 12
[4] Sinopoli, James M ,Smart Building Systems For Architects, Owners, And Builders Page 98,101



Education

- Class schedule
- Campus television network
- Registration and orientation information
- Schools news and weather announcements
- Local event calendars
- Media retrieval for education
- Distance learning

Figure 2- 9: Uses of Digital Signage in Education spaces
Source: Smart Building Systems for Architects, Owners, and Builders page 98,100

2.4.4. Trends for Enhancement Learning Spaces

Enhancement of physical, spatial, lighting, and thermal environments plays a significant role in enhancing teaching and lighting environment Moreover, A smart learning space which contains technology encourages pedagogy and students' engagement. (Table 2-1)

Table 2- 1: Trends of enhancement quality of learning spaces


Industry Trends Affecting Quality of School Environment

Heating, Ventilating, and Air Conditioning Systems
- Temperature distribution monitoring that can control and track temperature in all spaces in school building—even sections of a classroom
- Improved air filters to remove particulates and provide a healthy environment

Furniture
- Reconfigurable furniture in classrooms to support different learning situations
- Tables, storage, display boards, and seating that can be easily moved, offering greater flexibility

Technology
- One network for data, voice, video, and wireless communication based on an Internet Protocol (IP) platform
- Building networks for monitoring and communicating lighting, fire, security, heating and cooling, and energy use, with the possibility of individualized controls
- Technology embedded in classrooms to support interactive whiteboards, easy Internet access at the desktop, and videoconferencing

Design
- Spaces designed with learning scenarios in mind
- Focus on sustainable design in schools of the future

Lighting
- Emphasis on daylight in learning spaces
- Energy-efficient and aesthetically pleasing lighting

Noise
- Noise monitoring in classrooms to maximize acoustic quality for all students

Source: American Architectural Foundation, Report From the National Summit on School Design, A Resource For Educators And Designers, US2006, p 44

2.4.5. Smart Technology Impact on Learning Spaces Design

Technological signals effect student use of technology as well as the teaching and learning process, infrastructure models, and integrated management systems. How an educational institution implements and integrates these emerging technologies will be a key factor in whether it succeeds in the coming years. [(1)]

General teaching spaces have been changed in the last century in order to bring classrooms into the modern century. Classroom have been arranged to be tutor-focused with one-way facing and presentational arrangement which has seating arranged in either a U shape or in straight rows. Technologies have subsequently been added such as interactive or conventional whiteboards mounted on the wall behind the main speaker, ceiling-mounted projectors with cabling to a laptop, a wireless network or wired computers but these have rarely altered the dynamics of the overall classroom design. These technologies convert learning spaces to be smart and effective. [(2)]

2.4.6. Classification of Smart Learning Spaces at SU

Learning spaces should be designated according to type of teaching and their space specific requirements. For example with a space that is needed for student laboratories analysis for both the learning activity and the associated physical spatial needs should be described to design it. MIT's aerospace engineering program defined learning modes based on four attributes: [(3)]

- Size (large versus small project)
- Length of time (class session versus semester-long)
- Space type (dedicated versus flexible)
- Interaction (individual versus group)

By virtue of technology, learning is no longer limited to a traditional classroom space. New types of learning spaces not only incorporate technology, but they also create new patterns of social and intellectual interaction. Taken altogether these trends suggest new strategies for overall campus design. In essence the entire campus becomes an interactive learning device. Smart learning spaces have been classified into following types [(4)]:

- Group teaching/learning;
- Simulated environments
- Immersive environments
- Peer-to-peer and social learning
- Clusters
- External spaces.

Table 2-2 illustrates the difference between each type of learning space, with examples for its; spaces, size & form, furniture and the impact of technology in it.

[1] IBM, Education For A Smarter Planet: The Future Of Learning, p. 3
[2] JICS, Designing Spaces For Effective Learning, p. 10
[3] NLII, Leading The Transition From Classrooms To Learning Spaces, p. 3
[4] AMA, Spaces For Learning, p. 6

2.5. Group Teaching/Learning Spaces

Group teaching/learning spaces mainly consist of classrooms and teaching halls which are considered the main spaces for the formal learning process at the university and are a direct reflection on a university's image. They represent around 10-25% of the total university space and more than 40% of all learning space areas. So they'll discussed in detail in the next part. [(1)]

The following aspects should be determined in the group teaching space design process:

1. Students' density and the related space type.
2. Space size proportions and height.
3. Grade of technology that will be used in the space and display mode.
4. Furniture type related to space capacity and the optimum width and depth of the seating area based on seat spacing. Then select the space suitable furniture layout.
5. Location and size of access aisles and decisions on where the walls of the learning room should be located. Aisles leading to front of room shouldn't be less than 90 cm.
6. The instructor area should meets the minimum dimensions of the used technology.
7. Display mode that will be used and the number of screens based on seating capacity, room type, and teaching goals. Then determine the location, size, and orientation of each screen and viewing angles from each screen and insure all seats are have clear line of sight.
8. Finishes for the space's surfaces such as walls, floor, ceiling, and work surface.
9. Studding lighting, thermal and acoustics environment and decisions on window size and placement.

In this thesis we will focus on studding lighting environment, taking in consideration to preserve acoustics and thermal comfort for students and teacher.

2.5.1. General Aspects in Group Teaching Learning Space

2.5.1.1. Students Density

Group teaching/learning spaces need to be large enough to comfortably accommodate the number of students planned for each area. Group teaching spaces are classified into two main categories according to the number of students in each space as shown in figure 2-24 with each category divided to sub-categories. [(2)]

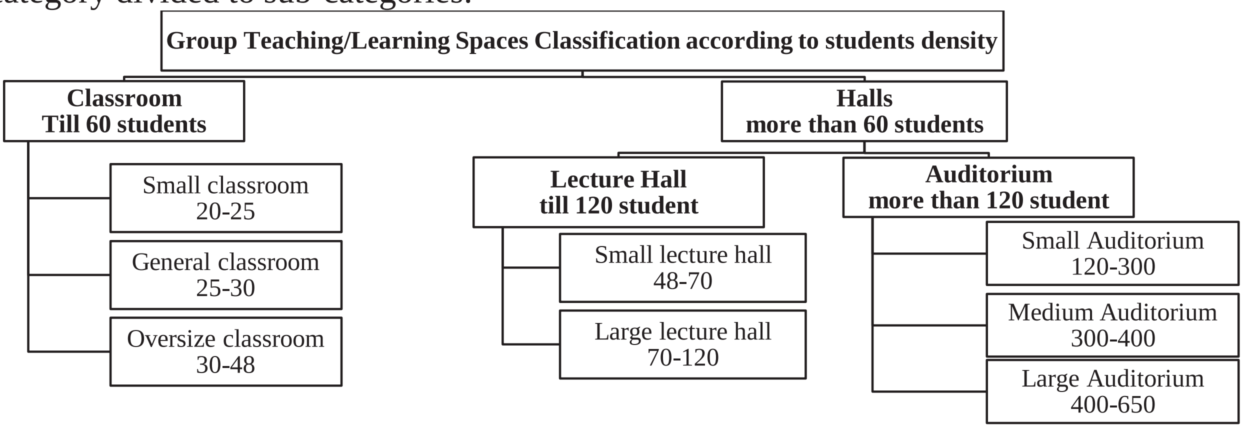


Figure 2- 24: Classification of Group teaching/learning spaces according to students' density

[1] Paulien & Associates-Inc, Utah System Of Higher Education , p. 34-45
[2] Design Guidance: Learning Environments, University Of Cincinnati , p. 35-36

2.5.1.2. Space Design and Proportions

A space's proportions have a big impact on seating capacity, sight lines, and the ability of instructors and students to interact with each other, even in small rooms. (1) The following factors should be achieved within a studying space in accordance to its type:

- There shouldn't be any obstructions like columns anywhere in the classroom that would obscure vision. The front wall of the room behind the instructor area should have no protrusions into the room so that a chalkboard/ marker board can be installed across the entire wall of the instructor area and that screens can operate without obstructions. (2)
- Student sight lines must be within < 90o horizontally and < 15 o vertically. (3)
- Ceiling heights depending on the size of the room and also the selected display modes. Clear space is needed above the ceiling, away from mechanical and utility systems (4)

2.5.1.3. Grade of Space Smart Technology (5)

i. Type (A) Low-Tech Learning Space

Space has no dedicated audio/visual technology. A projection screen or flat white wall for projection by portable devices is required. Drop in the ceiling for a data projector and conduit for a wall mounted LCD would be appropriate steps in case of renovation.

ii. Type (B) Basic Technology Learning Space

Space should have single projection screen display, wall plate with VGA and audio connections for user laptop, network connection and nearby wall power plate for laptops. Features include wall plate connections for hooking up a DVD/VHS player, iPod, digital cameras or other audio or video display devices. Ceiling mounted audio speakers are recommended when audio quality is important.

iii. Type (C) Smart Learning Space

This type of space has the same features of Basic Technology Learning space in addition to having a Smart Sympodium interactive computer monitor which creates a virtual whiteboard. This digital whiteboard allows users to write in digital ink over applications, write electronic notes, and capture whatever is displayed on the computer screen as a graphic file for distribution to class participants. The virtual whiteboard gives the presenter unlimited chalkboard space without the need to erase to make room for additional notes.

2.5.1.4. Furnishing

i. Furnishing Layout and Student Seating Area and Work Surface

Furniture layout should encourage active student involvement. It differs according to the capacity of the room. Some layouts are mobile so they can be moved and shaped into a variety of layouts and other are fixed. The needs of a class should be discussed separately in order to decide which type is appropriate. One percent of student work stations should be

[1] Ki, Higher Education,P7
[2] General Lecture Hall Design Guidelines, University Of Maryland ,p. 5
[3] University Of Guelph, Guidelines & Specifications For New Classroom ,p. 3
[4] Classroom Design Manual, University Of Maryland ,p. 25-26
[5] BAYLY, N., ET.AL., Emory College Classroom Design Guide,p. 27-28

aisle seats with no armrests on the aisle side for students using wheelchairs. And 10% of those should be for left handed arm chairs.

Table 2- 3 illustrates different types of work stations and square meter needed for each one.

Movable Furniture		Fixed Furniture:	
Tables and chairs	Tablet armchairs	continuous tables	chairs w/ folding tablet arms
1.85 m^2	1.6 m^2	1.5 m^2	1.3 m^2

ii. Instructor Work Station (Figure 2-25)

The instructor's furniture should be coordinated with other furniture in the room. The size of the instructor area in the front of the learning room is another important design consideration. This area should be: (1)

- Deep enough to accommodate a multi-media instructor workstation and a reference table and provide ample circulation space between the workstation and screens, marker boards, and the seating area.
- Wide enough for marker boards and at least one projection screen to be used at the same time, spaced far enough apart so that light on the board does not spill over onto the screen.
- High enough to give all students a clear view of projected images.

Instructor station size and shape depend on display mode and audio video (AV) system used in the learning space. Figure 2-25 shows a sample for a high technology instructor work station with: Learning space pc, One Large or Two Regular LCD Projector, Crestron Touch Panel, Control Overall Volume, Dvd/VHS Player, Document Camera, Wall Mounted Speakers or a House Pa System. Smart Sympodium. (2)

Figure 2- 25: Instructor work station
Source: Technology In A Lecture Hall, p. 1

iii. Guest Speaker Table

In learning spaces seating up to 48 students, a table should be provided near the instructor workstation for guest speakers according to space capacity with the dimensions: width 90cm and depth 45 cm. Larger learning spaces and auditoriums are often used for panel discussions should be supported by a large table (w=1.5, D=0.6m) and chairs according to its space capacity (one chair for learning space less than 80 student, two chairs for halls less than 120 students, and three chairs for halls more than 120 students). (3)

[1] Design Guidance: Learning Environments, University Of Cincinnati , p.7
[2] Knight Campus It Team ,Technology In A Lecture Hall, p.1
[3] Design Guidance: Learning Environments, University Of Cincinnati , p.35-36

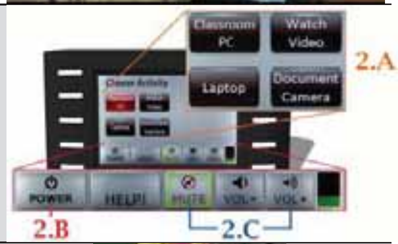
2.5.1.5. Display Modes

Every learning space should be connected to university network for voice, data, and video communication to can accommodate both video and computer generated displays modes at any time integrated with chalkboard and white/marker board as traditional display ways. A lot of different display modes have been used in group learning spaces as shown in table 2-4. The type of display mode and amount of equipment used in each space should be related to space type and capacity. [(1)]

Table (2- 4) illustrates Display modes could be used in Group learning/teaching spaces

Display ways	Function	Figure
Chalkboard and marker board	• To write and take quick notes for facilitate explanation.	
Learning space P.C,	• To research, create, interact with and playback images, videos, and audio. It should be connected to internet and the university network.	
DVD/VHS	• To playback videos on DVD and VHS formats.	
Projector	• To project the image from the learning space PC, DVD/VHS player, document camera and/or a laptop or other mobile device. • Projectors are to be mounted on the ceiling approximately 3m. from screen. • The projector must be hung from structural support and not from the suspended ceiling grid. • Slide projector carts preferred to be used in small learning spaces with movable furnishings to accommodate the furniture layout used.	**Ceiling projector**  **Slide Projector** 
Screen	• To display data from projector.	
overhead Projector	• To project transparencies through the LCD projector.	

[1] General Lecture Hall Design Guidelines, University Of Maryland , p.19

Document camera	To project transparencies, 3D pictures and videos through the LCD projector instead of overhead projector.	
Smart Sympodium	To digitally annotate lecture notes and PowerPoint presentations on PC.	
Crestron panel	To operate the LCD projector and select a media source.	
Sound system voice amplification	To allow the instructor the maximum flexibility of movement throughout the lecture hall and clear sound for students.	

In the following part, main display modes which effect furniture layout will be discussed briefly to determine its place and amount according to space capacity.

i. Chalkboard and White /Marker board

The board should be mounted 90cm above the floor with 1.2m height. Its surface should be low-gloss white porcelain enamel steel surface that is easy to clean. A continuous marker tray should be fixed below it. The board is illuminated by a separate switch which can be independently controlled. In a large auditorium setting, a wall mounted vertical traveling whiteboard may be recommended to provide several board surfaces which can be utilized at the same time. [(1)] Figure 2-26 illustrates fixed and travelling boards shapes.

Figure 2- 26 : Fixed and movable white boards
Source: Emory College, Learning space Design Guide, p. 25

[1] BAYLY, N., ET.AL., Emory College Classroom Design Guide, p.25

ii. Screen

The preferred screen location is at the front corner of the room, angled toward the center of the room, with a maximum of a 45-degree horizontal angle from the perpendicular to the center of screens and a maximum of a 35-degree vertical angle from the perpendicular to the top of each screen as shown in figure 2-27. Screens should be located, sized and mounted as high as practical so students in all seats can easily see the entire projected image without discomfort or image distortion. In spaces with one screen, the screen should be on the right side of instructor area to avoid situations where the instructor must stand in front of the screen. The bottom of the screen should be no lower than the bottom of the white board. (1)
After the determination a space capacity and size, the following factors must be considered to determine screen design.

- Screens count, location, size, and orientation.
- Viewing angles from each screen and insure all seats are within them. Determine optimum width and depth of the seating area based on seat spacing guidance.

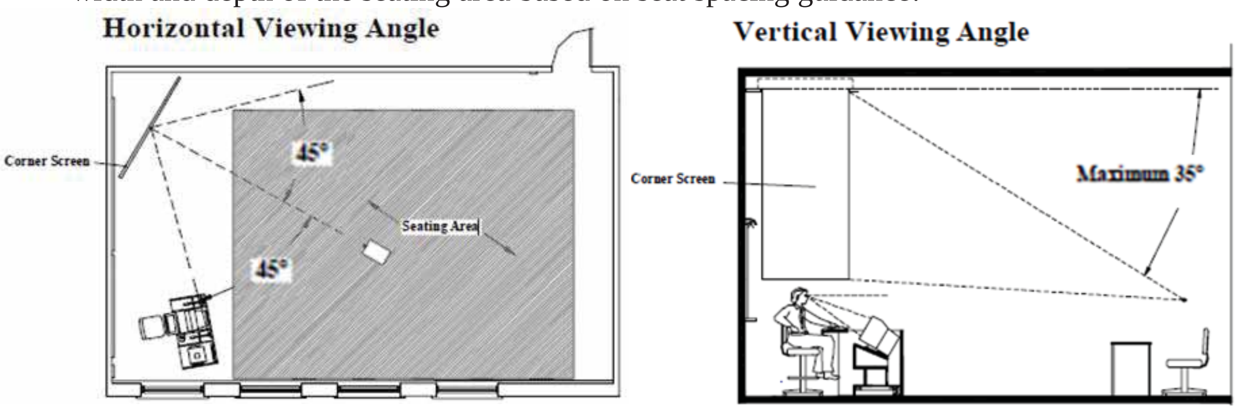


Figure 2- 27: Screen Angles and location inside Group learning/teaching spaces
Source: Emory College Learning space Design Guide, p.36

Screen size depends on space capacity and size. Screen height should equal 20% of distance from the farthest seat away from the screen. Accordingly screen width is determined by the aspect ratio width: height of projected images which differs due to screen type. The traditional ratio is 4:3 and the HDTV technology ratio is 16:9. Distance between the screen and the first row in a small learning space should equal screen width and in large spaces it should equal 1.5 of the screen width. (2)

iii. Audio system

Spaces with capacities greater than 100 shall be equipped with voice amplification systems with a wireless microphone to allow the instructor the maximum flexibility to move throughout the space. A sound system separate from the voice amplification system should be installed to handle other sound sources. The system should be capable of amplifying the soundtrack of videotapes, films, audiotapes, compact discs, videotape, DVD's, etc. Distribution from the system can be fed into speakers properly mounted on either side of the instructor area. Audio speakers should be located on each side of the screen, near the top of the screen. Spaces with seating for more than 50 students may need additional speakers mounted in the ceiling for adequate coverage for all areas of the room. (3)

[1] Calvin Information Technology , Smart Classroom Design Considerations ,p.2
[2] Design Guidance: Learning Environments, University Of Cincinnati , p.40
[3] General Lecture Hall Design Guidelines, University Of Maryland , p.28

2.5.1.6. Finishing

The selection of color and the reflectance values of finish materials must be considered for all group teaching spaces.

Table 2- 5 illustrates the expected surfaces reflectance values (1)

Ceilings	80 percent or higher
Walls	50 to 70 percent
Floors	20 to 40 percent
Desktops	25-45 percent

Source: Learning space Design Manual University of Maryland, p.11

i. **Walls**: should have a durable finish to allow washing. Soft matte finish marks easily and is difficult to clean so it should be avoided. Wall surfaces should be painted in a light color. A darker contrasting shade of color is acceptable on the front teaching wall. (2)

i. **Floors**: should be vinyl or rubber tile with smooth surface and should multi-colored or patterned. No solid color should be installed. Using carpet and wood aren't ideal in spaces with movable furniture due to the hindrance of use and higher degree of maintenance needed but carpet/wood can be used in fixed furniture spaces like auditoriums. (3)

ii. **Ceiling:** Due to the increasing number of AV items being installed in ceilings (projectors, speakers, mics, etc.,)in addition to lighting fixtures and HVAC systems, a ceiling grid is preferred over drywall or plaster which can be more expensive and time-consuming to maintain and repair. (4)

iii. **Work surfaces:** should have a matte finish. A person's eyes move toward the brightest object in its field of vision. Thus lighting should highlight what is most important to see the task at hand. The desk surface should contrast from the book and computer screen. (5)

2.5.1.7. Windows and Lighting

Windows should be placed away from walls that are near parking lots, exhaust fans, vehicular and pedestrian walkways, and building cooling towers. Many factors, including anticipated types of learning activities and projected use of audiovisual materials, should be considered to determine whether to include windows in new construction and where to place them.

The two primary purposes of learning space windows are aesthetic and environmental. The presence of windows in a room provides visual contact and sensory stimulation with the world outside. The design response is to include an ample provision for natural light penetration taking into account that all windows in learning spaces should be operable and should be on the side of a room and not located in the front or rear of a room.

Window treatments should be opaque and should be capable of eliminating all outside light from reaching the projection screens. They must be robust enough to resist the abuse of daily use. In general universities install window treatments, such as horizontal blinds, shades or roller blinds as needed. The next chapter will study this issues in detail.

[1] General Lecture Hall Design Guidelines, University Of Maryland , p.8
[2] Ki, Higher Education, p.7
[3] BAYLY, N., ET.AL., Emory College Classroom Design Guide, p.14
[4] General Lecture Hall Design Guidelines, University Of Maryland , p.25
[5] Ki, Higher Education, p.7

2.5.2. Special Aspects for Group Teaching Learning Space Types

2.5.2.1. Classrooms

A classroom is a space used primarily for scheduled classes of multiple academic disciplines with a seating capacity of 21 to 55 students. Classrooms have moved from the traditional model to more dynamic and successful environments. This change has paved the way for more active student engagement. It has also changed the lecture-based learning space toward a studio environment, which grew interaction more than the typical lecture-based learning space. The original motivations for these changes were to encourage more discussion, both within the regular class structure and in breakout groups. [1] Figure 2-28 illustrates how learning spaces can accommodate the learning process needs.

Figure 2- 28: Different solutions for the same classroom to accommodate various learning process
Source: learning space Design Overview New York University, p.10-13

i. Size and Proportions

Classes which are too wide make it hard for instructors to maintain eye contact and typically have poor sightlines. Deeper rooms make it hard for students in rear rows to interact with instructors and other students. Spaces that are nearly square or have a shape based on "viewing angles" from projection screens almost always work out best to encourage interactive discussion while providing good sight lines as is shown in figure 2-29.[2] The preferable dimensions of a learning space have a 2:3 or 3:4 width to length ratio.[3]

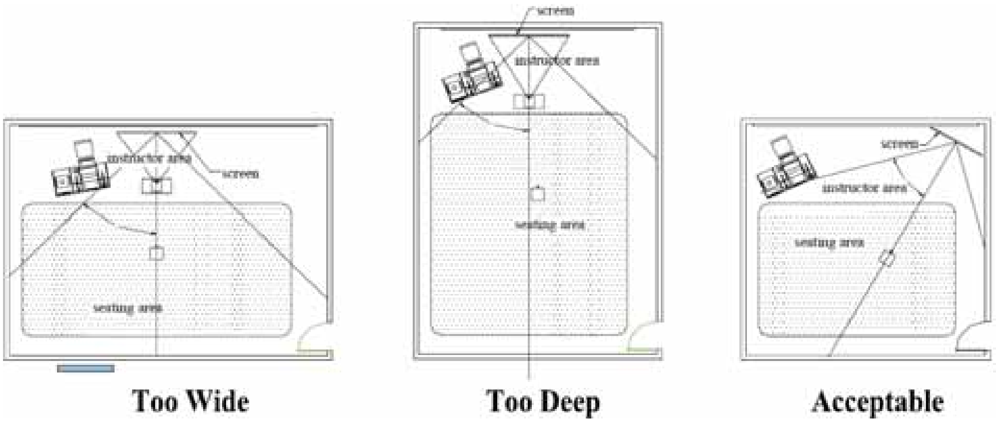


Figure 2- 29: Nearly square proportion with a good viewing angle towards the screen is more acceptable form than the deep or wide one at Group teaching spaces
Source: Learning Environments, p.9

[1] Ki, Higher Education, p.7
[2] General Lecture Hall Design Guidelines, University Of Maryland , p.5
[3] General Assignment Classrooms,University Of Washington, p.3

ii. Furnishing

A. Student Seating Area and Work Surface

Learning spaces seating up to 60 students should be designed with individual desks or tables and movable chairs for each student in order to give instructors the flexibility to break classes down into small groups and then quickly move furnishings back into a traditional layout that faces boards and screens. The work surface should have a width of 0.7 m, depth of 0.5 m and height of 0.75m. Student desks shall be designed to accommodate right and left-handed students as well as students in wheelchairs as shown in figure 2-30. [1]

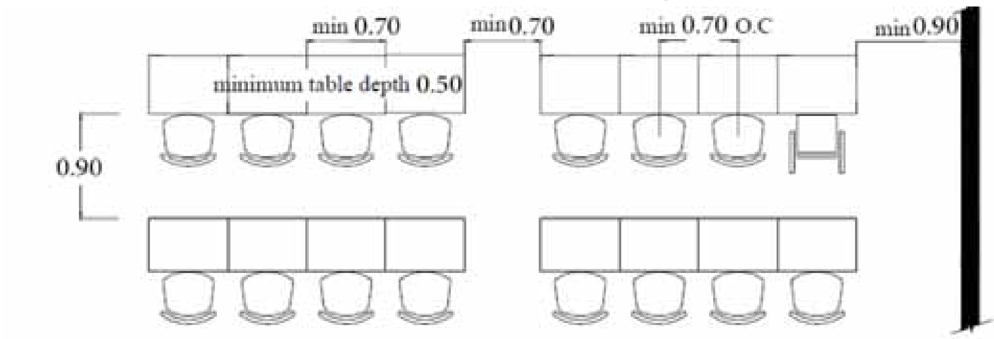


Figure 2- 30: Size of student work station in classrooms
Source: Learning Environments, p. 27

B. Instructor Work Station

A sturdy table or desk should be placed at the front of the room as part of the instructor area. This area also should include either a tabletop or free-standing floor podium with a minimum surface of 0.45*0.60m. For universal access, it is best to use a height-adjustable podium or a combination of table and podium. There should be a stool or chair available for the instructor. In learning spaces with one screen, an instructor workstation on the left side of the instructor area, marker boards in the center, and a screen in the right corner usually works well.

The instructor area should include enough space so that the first row of seats is far enough from the screen for good viewing. In addition the shape of the room is critical. If a room is too narrow, then the instructor area will not require as many square meters as if a room is wide. [2]

Figure 2- 31: Instructor work station in classroom
Source: Emory College, Learning space Design Guide, p. 25

[1] Design Guidance: Learning Environments,University Of Cincinnati , p.17
[2] General Lecture Hall Design Guidelines, University Of Maryland , p.26

C. Furnishing Layout

Stations for students should be mobile, especially for persons who use wheelchairs, and available in a variety of locations and different layouts to encourage interaction between teacher and students as shown in figure 2-32 , figure 2-33 and figure 2-34. The locations of doors and aisles also effect the amount of space available for seating. In addition the “station factor” of the proposed seating can vary depending on the type of seating selected and whether it’s installed in a small room or a large room. Large rooms benefit from economies of scale.

I. Small Learning Space

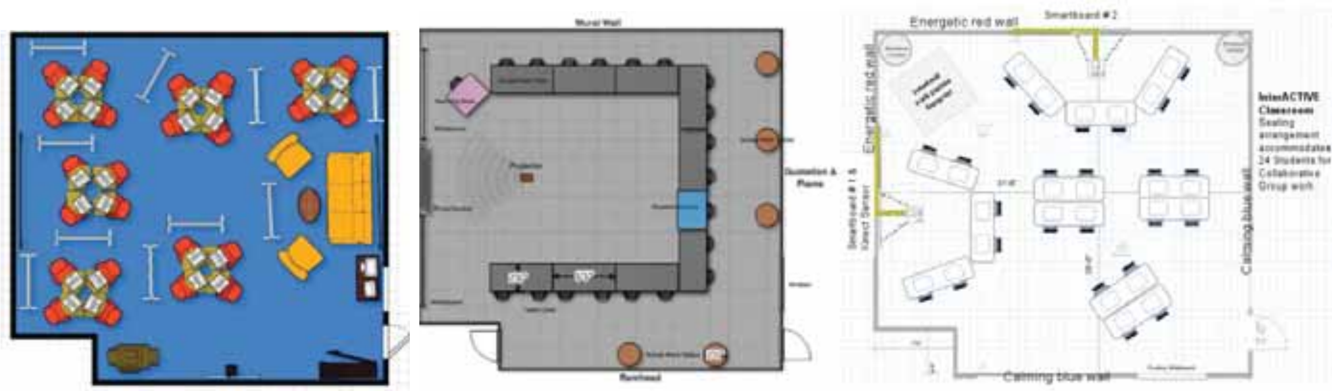


Figure 2- 32: Examples for various furniture layouts at small classroom, instructor can use movable furniture for different layouts according to type of teaching method in each class
Source: Learning space. NEXT, p. 3-4

II. General and Oversize Learning Space

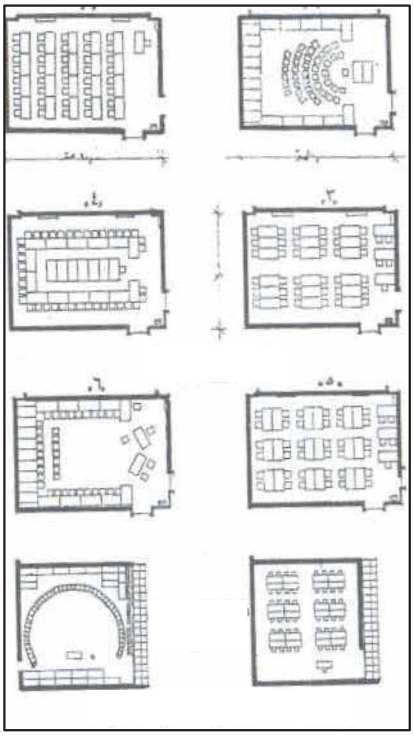


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Figure 2- 33: Furniture for general classroom.
Source: Arabic Neufert, p. 250

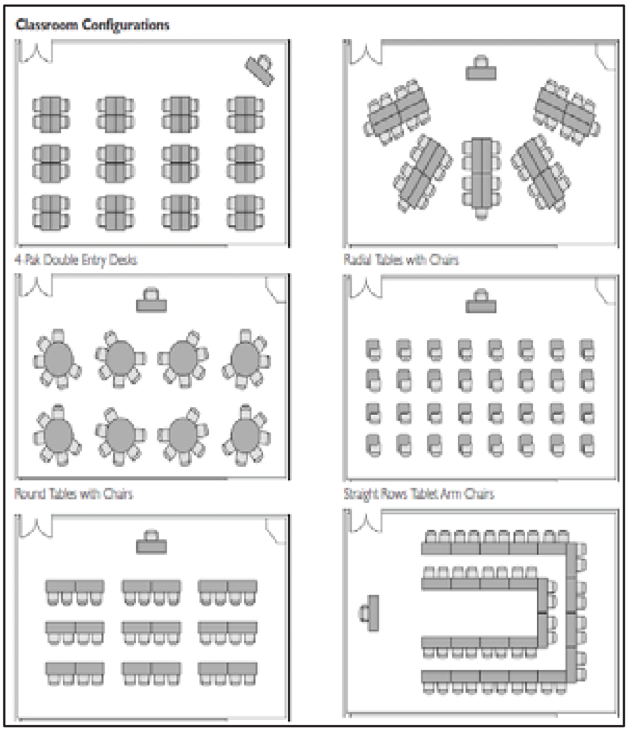


Figure 2- 34: Furniture layout for oversize classroom
Source: Higher Education, p. 8

2.5.2.2. Teaching Halls

A teaching hall is defined as a large space used primarily for scheduled classes of multiple academic disciplines with a seating capacity of 48 or more. It is classified according to student capacity into either a lecture hall (capacity until 120 students) or auditorium (capacity more than 120 students). Auditoriums may also serve non-instructional purposes. Halls typically have a multi-media audio-visual system, with seats oriented towards the front of the room and writing surfaces for each student. (1)

i. Proportions and Dimensions

Small lecture halls (under 100-student capacity) may have a sloped or tiered floor while some may have a flat floor and the larger halls must be sloped or tiered to provide good sight lines. The slope of the floor in a large room or lecture hall should be no more than 1:12 to provide good sight lines and acoustics. A modified fan-shaped design is often best. In this configuration, student seating can be arranged to provide good viewing angles from all seats. Spaces that are wider will require a much deeper instructor area in order to maintain good viewing angles. (2)

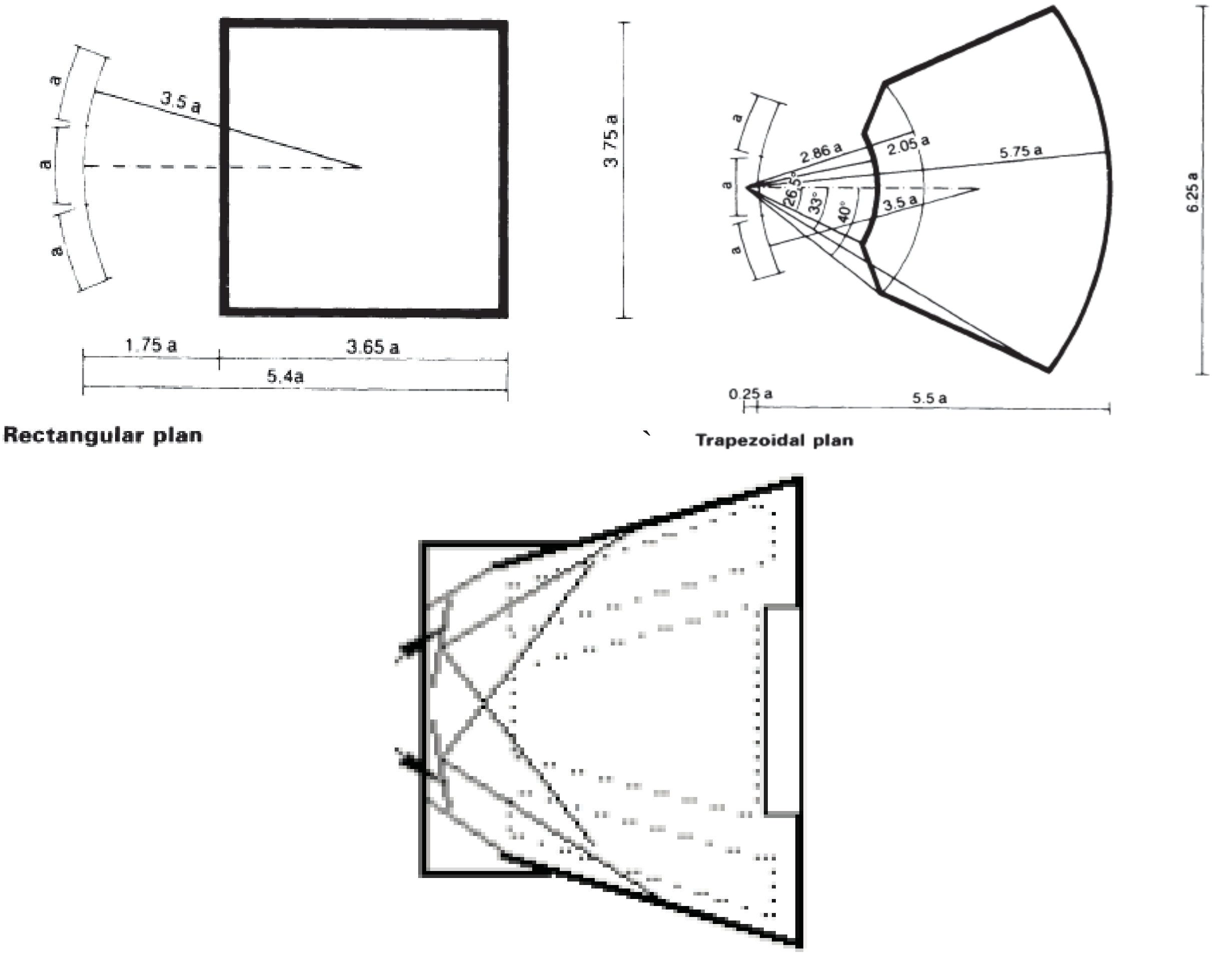
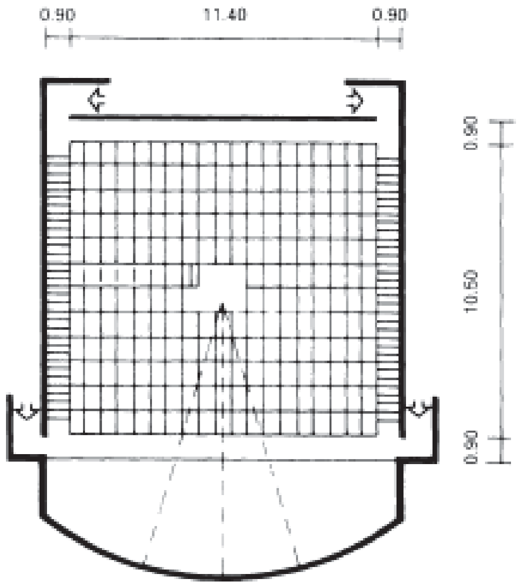


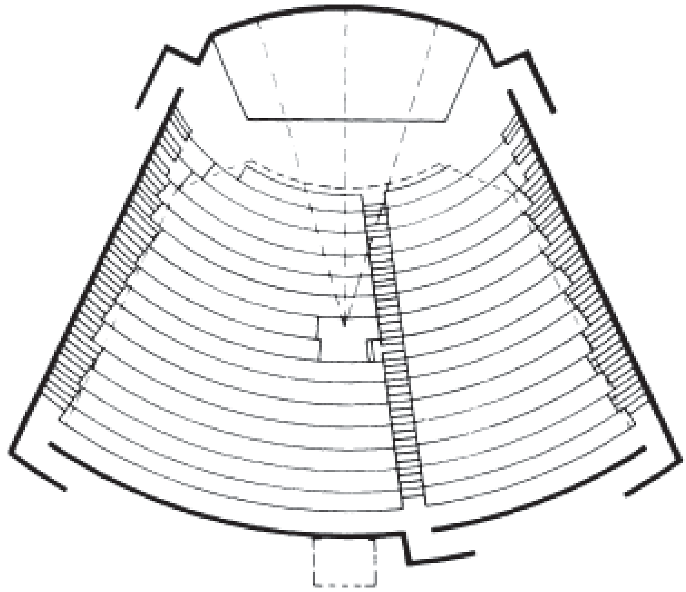
Figure 2- 35: Proportions of Lecture halls students' area
Source: Neufert, p.316

[1] Design Guidance: Learning Environments,University Of Cincinnati , p.5
[2] ibid, p.31

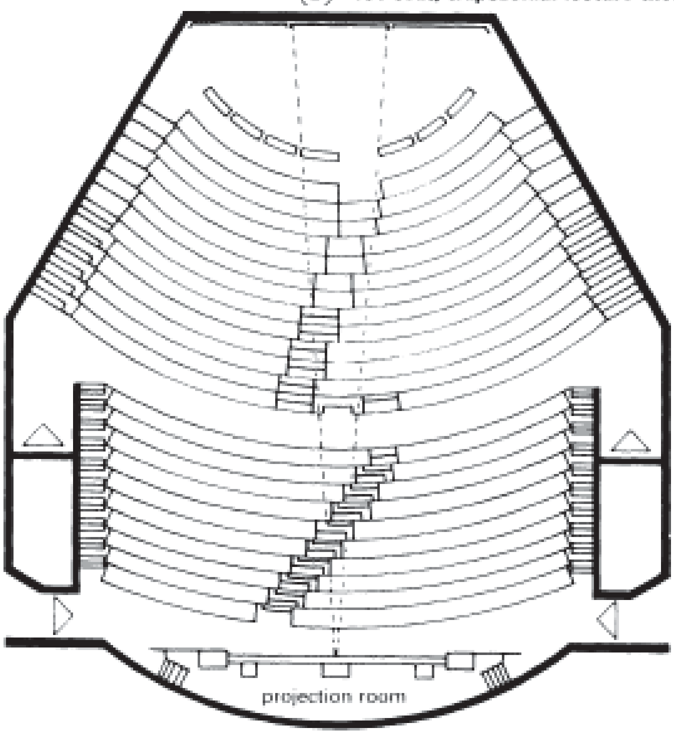
To minimize room depth in large auditoriums (400 or more seats), use of balconies or auditorium-style seats with tablet arms (instead of task chairs behind writing surfaces) should be considered. [1]



200-seat, rectangular lecture theatre



(2) **400-seat, trapezoidal lecture theatre**



800-seat lecture theatre

Figure 2- 36: Proportions of Large Auditorium students' area
Source: Neufert, p. 316

[1] ibid, p.20

ii. Furnishing

A. Student Seating Area and Work Surface

In teaching halls, fixed work surfaces can be arranged to allow students to more easily communicate with each other and the instructor. This is encouraged as long as good sight lines to screens and marker boards are provided. It is important to insure all students can see all screens.

Auditoriums with 200-399 seats shall be designed with continuous fixed work surfaces, tiered floors, and upholstered movable chairs with adjustable-height seats and backs. Comfortable auditorium-style seats with tablet-arms can be used in larger auditoriums to reduce room depth and costs. [1]

The recommended amount of space needed per student in large halls for comfortable seating is 70x90cm and on average 60x80cm =. 0.50m2. .These numbers include spaces in larger lecture theatres and are the most cramped conditions as shown in figure 2-37 and 2-38. In smaller lecture theatres, the average comfort space is 0.80-0.95m2. [2]

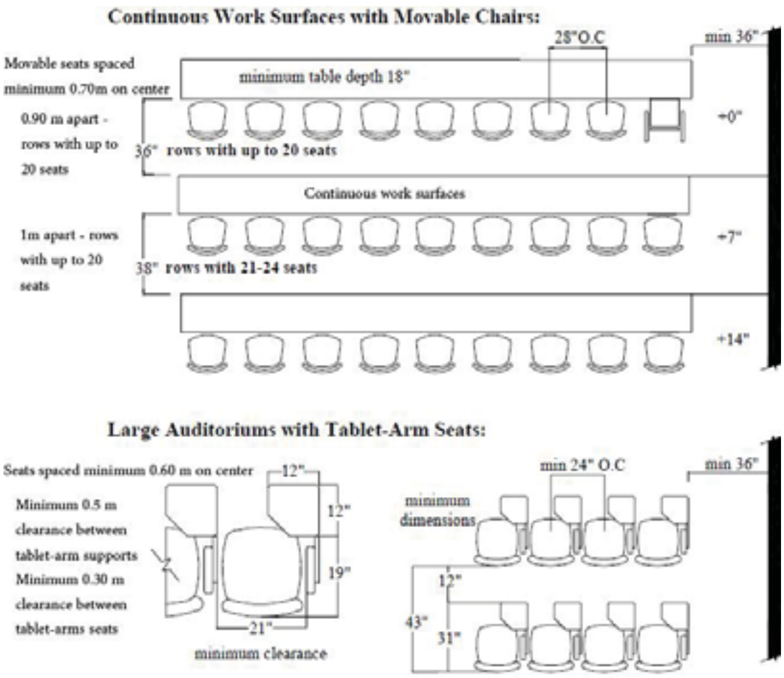


Figure 2- 37 : layout for Furniture Types in Halls
Source: Learning Environments, p. 27

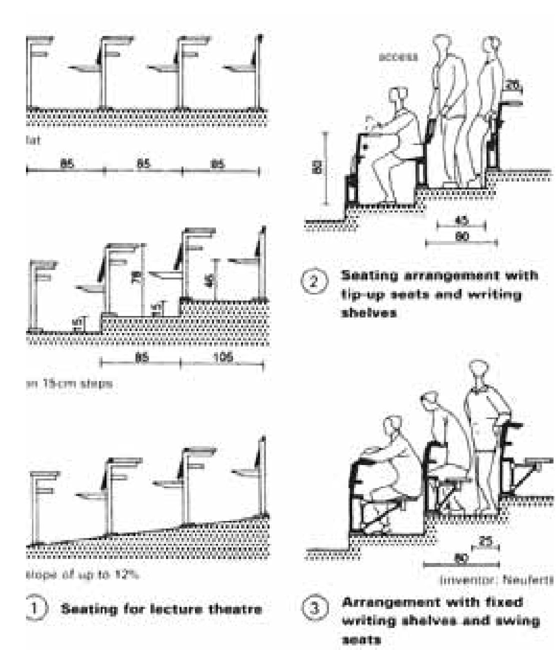


Figure 2- 38: Section for Halls furniture
Source: Neufert, p.317

B. Instructor Work Station

In large rooms with multiple screens, a workstation located on the left side of the instructor area, near the marker board and overhead projectors, usually works well, but a more central location may be preferable in some rooms. Tables used for panel discussions or references are also needed.

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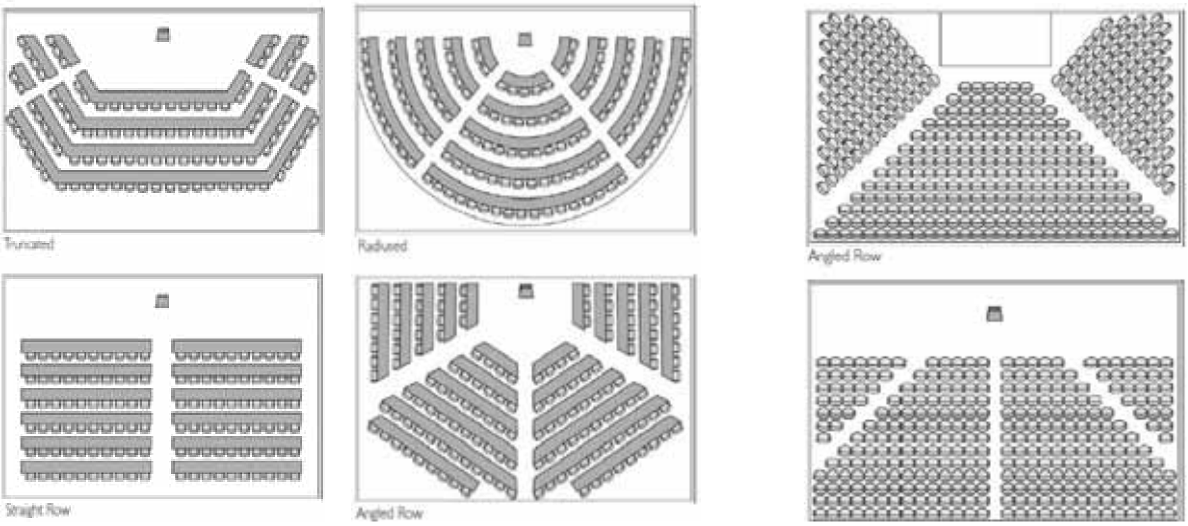
[1] ibid, p.17
[2] Neufert , p. 318

C. Furnishing Layout

In large capacity rooms of more than 100 students, fan-shaped seating is the best layout to provide clear viewing angles and acoustics. In fixed seating, stagger the seats to provide clear viewing angles and maximum incline. (1) The distance from the screen to the first row of seats should be no less than 1.5 - 2 times the screen width (2). Figure 2-39 illustrates different layout for student seats and work surfaces for lecture halls and auditoriums.



I. Lecture halls plans **II Auditorium plans**

Figure 2- 39: Furniture layout for lecture and auditorium halls

Source: Higher Education, p. 5

III. Sections

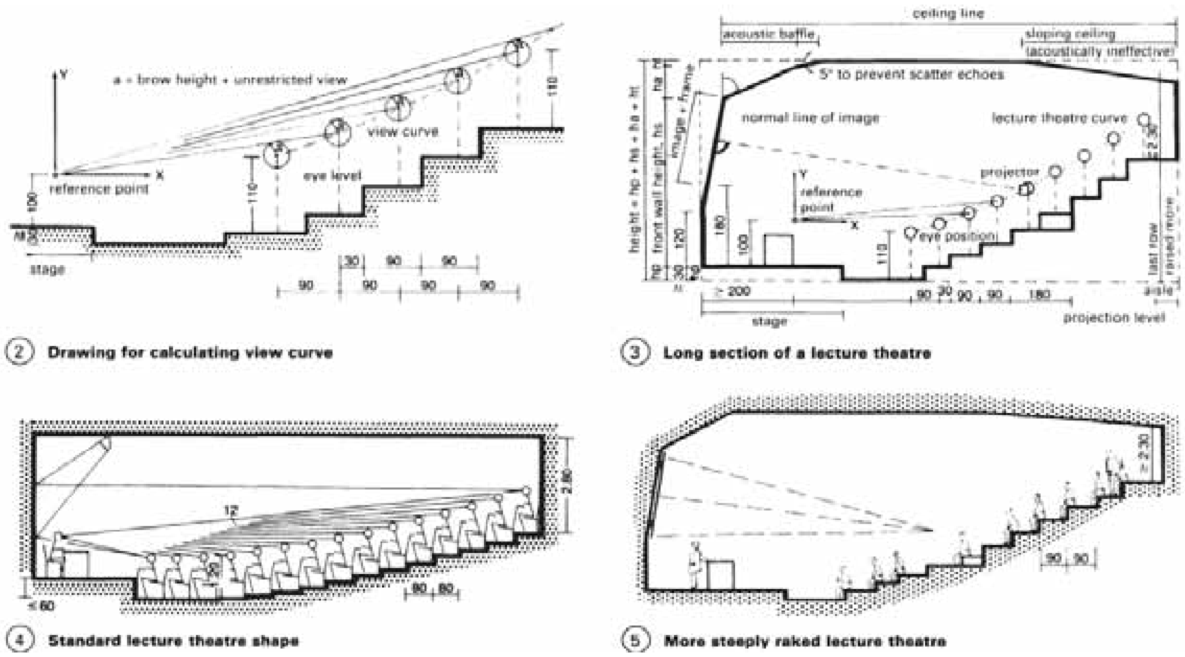


Figure 2- 40: Section for Halls levels

Source: Neufert, p. 317

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1 General Assignment Classrooms,University Of Washington, p.3

2 Design Guidance: Learning Environments,University Of Cincinnati , p.32

2.6. Conclusion

Smart universities, which are currently a new trend due to the evolution of smart techniques and technology, should be created in order to maintain the highest value and comfort at the lowest environmental cost with the implementation of intelligent technologies and processes. As well as the "green and sustainability" movement, they should be able to accommodate some level of adaptation and reconfiguration without exorbitant expense or structural modification. Whenever possible they should accommodate an addition or additions over time.

University campuses are complex and dynamic environments that serve a diverse array of needs for thousands of people. They contain many different types of spaces such as spaces for learning, administration, services and public spaces. Learning is the main activity at universities. The learning environment is composed of students, teachers and the physical environment. The concept of traditional classrooms on campus has evolved into the idea of 'smart' learning spaces which correspond to the needs of our smart building era. Nowadays students prefer to interact with information and receive near-instantaneous responses so they need a different learning environment which engages them in active learning and collaboration. A responsive learning space design approach would help designers create more innovative and sustainable learning environments. Therefore a learning spaces design process must focus on the role of the social environment (students- teachers) and how the physical environment may be structured to support learning and assist facilitators and learners in their work.

Different classifications of university learning spaces had been illustrated with their significant requirements of size, furniture and also the type of technology that should be used in each one. They are classified into six major types: Group Teaching/Learning spaces, Simulated Environments, Immersive Environments, Peer-To-Peer and Social Learning, Clusters, and External Spaces. According to that Group Teaching/Learning spaces, which consist basically of classrooms and teaching halls, were founded to be the main spaces for formal learning process at the university. It represents around 10-25% from total university space and more than 40% of learning spaces areas, so it had been chosen to study its visual environment requirements and investigate lighting performance in the next chapter.

By understanding and using previous studies and studying a lot of universities learning space and lecture halls guidelines [(1)], Table 2-6 illustrates group teaching spaces types, sizes, furnishings and the display modes anticipated for instructors and students.

[1] Guidelines Of University Of Cincinnati, La Trobe University, Emory College, University Of Maryland, University Of Pittsburgh Institutional And University Of Washington

Table 2- 6 : Group Teaching /Learning Space Design Requirements for Each Type Spatial Environment

<table>
<tr><th colspan="3" rowspan="2">Group Teaching /Learning space type</th><th rowspan="2">Students Capacity</th><th rowspan="2">Square meter</th><th colspan="2" rowspan="2">Clear Ceiling height (m)</th><th rowspan="2">Furnishings</th><th rowspan="2">Display modes</th></tr>
<tr></tr>
<tr><td colspan="2" rowspan="3">Learning space</td><td>Small learning space</td><td>20-25</td><td>45-50 m²</td><td colspan="2">3 m</td><td>• Movable tables & chairs
• Instructor desk</td><td>1 slide projector
1 screen
1 whiteboard</td></tr>
<tr><td>General learning space</td><td>25-30</td><td>50-60 m²</td><td colspan="2">3 m</td><td>• Movable tables & chairs
• Instructor desk</td><td>1 slide projector
1 overhead projector or
1 screen
2 whiteboards</td></tr>
<tr><td>Oversize learning space</td><td>30-48</td><td>60-100 m²</td><td colspan="2">3.5 m</td><td>• Fixed writing surfaces & movable chairs
• Instructor desk
• Guest table for one speaker</td><td>1 projector-2 screens
1 overhead projector or
1 document camera
2 whiteboards
1 voice amplification</td></tr>
<tr><td rowspan="6">Halls</td><td rowspan="3">Lecture Hall</td><td rowspan="2">Small lecture hall</td><td rowspan="2">48-70</td><td rowspan="2">Till120 m²</td><td>Rear</td><td>Front</td><td rowspan="2">• Fixed writing surfaces & movable chairs
• Instructor desk
• Guest table for two speakers</td><td rowspan="2">1 projector-2 screens
1 overhead projector or
1 document camera
3 whiteboards
1 voice amplification</td></tr>
<tr><td>2.5m</td><td>3.6m</td></tr>
<tr><td>Large lecture hall</td><td>70-120</td><td>120-250 m²</td><td>2.5m</td><td>4.6m</td><td>• Fixed writing surfaces & movable chairs
• Instructor desk
• Guest table for three speakers</td><td>2 projectors
1 w/screen – 2 s/screens
1 overhead projector or
1 document camera
1 whiteboard
1 voice amplification</td></tr>
<tr><td rowspan="3">Auditorium</td><td>Small Auditorium</td><td>120-300</td><td>250-450 m²</td><td>2.5m</td><td>4.6m</td><td>• Fixed writing surfaces & movable chairs
• Instructor desk
• Guest table for three speakers</td><td>3 projectors
1 w/screen – 2 s/screens
1 Overhead Projectors or
1 Document camera
1 whiteboards
1 voice amplification</td></tr>
<tr><td>Medium Auditorium</td><td>300-400</td><td>400-500 m²</td><td>2.5m</td><td>5.4m</td><td>• Fixed writing surfaces & movable chairs
• Instructor desk
• Guest table for three speakers</td><td>3 projectors
1 w/screen – 2 s/screens
1 overhead projector or
1 document camera
1 whiteboard
1 voice amplification</td></tr>
<tr><td>Large Auditorium</td><td>400-650</td><td>500-850 m²</td><td>2.5m</td><td>5.4m</td><td>• Auditorium seats with tablet arms
• Instructor desk
• Guest table for three speakers</td><td>3 projectors
1 w/screen – 2 s/screens
1 overhead projector or
1 document camera
1 voice amplification</td></tr>
</table>

3.1. Introduction

Lighting and visual systems are very important for universities, and especially their learning spaces, because they effect the learning environment performance and university energy management. They also play a significant role in enhancing a space's physical environment. (1) Moreover, due to the increased use of media and technology in learning spaces, the design of easy-to-use, adjustable lighting systems is more important than ever.(2)

There are continuing challenges and opportunities for lighting designers of educational facilities. New educational buildings reflect new philosophies of education and new technologies for instruction. Many existing educational buildings need retrofitting to improve the visual environment and reduce energy usage. Innovative lighting designs are often required to meet new visual needs and reduce energy consumption by replacing the old lighting fixtures and system with smart ones. (3)

Numerous studies have indicated a direct connection between good lighting and a student's ability to learn, so new lighting technologies have been developed. For instance, dimming capabilities have been improved, more precise metrics for the measurement of color production, color rendering and light quality have been developed, and sophisticated lighting control systems have been expanded, which saves more energy. (4)

Student vision depends mainly on light. Lighting should provide visual conditions in which students and instructors can function effectively, efficiently, and comfortably. The majority of previous studies have recommended illuminance for specific applications or visual tasks. However, not only is light illuminance but also all components which enhance visual environment should be studied to increase student productivity. (5) Patterns of light and dark affect perceptions of the space and emotional and physiological responses, and thus they are essential in gathering information about the physical space. Good-quality lighting can support visual performance and interpersonal communication and improve feelings of well-being. Poor-quality lighting can be uncomfortable and confusing and can inhibit visual performance. (6)

This chapter highlights some of the basic relationships between light and vision and also introduces a wide range of lighting and visual system design criteria to get visual information from spatial environments of group teaching spaces and increase optical environment quality.

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[1] Hui, Sam CM, and Mr Kenneth KY Cheng. Analysis of Effective Lighting Systems for University Classrooms, p. 1

[2] Classroom Design Manual Guidelines for Designing, Constructing, and Renovating, Instructional Spaces at the University of Maryland, p. 26

[3] IESNA, Lighting Handbook, p. 12.1

[4] Http://Thesextantgroup.Com/Lighting-For-Learning-New-Learning-Models-Challenge-Traditional-Lighting-Methods/

[5] IESNA, Lighting Handbook, p.10.1

[6] ibid, p. 3.1

3.2. Optical Information and Visual Perception

The pioneering perception psychologist, J. J. Gibson, defined the optical information that is available to the eye by ambient optic array (or AOA). "AOA is the structured pattern of light reaching the viewer from all possible directions. It is called 'ambient' since the observer is literally surrounded by light from all directions [as shown in Figure 3-1]." (1)

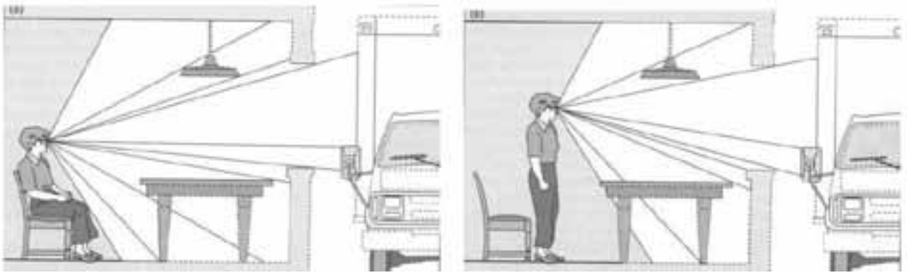

Figure 3- 1: The AOA changes as the viewpoint changes when the observer stands and sits
Source: Visual Perception for Visualization and Multimedia Group, p. 10

Perception is the ultimate output of the visual system. Visual perception depends on AOA and is defined as the process of acquiring knowledge about our visual environmental objects and events by extracting information from the light they emit or reflect. So our visual perception depends heavily on three factors:

(a) Light
(b) Human visual system that observes the light
(c) Interaction of light with surfaces

In the next section all terms related to these three factors will be studied minutely to achieve a good visual/optical environment.

3.2.1. Light

Light is the medium that allows the human visual system to operate. With light we can see and without it we cannot. According to the last theories of optics, light consists of small packets of energy called photons that behave like particles in some respects and like waves in certain respects.(2) So we can say that light is the small portion of the electromagnetic spectrum that the human eye is sensitive to. Waves can be described either by frequency or by the wavelength of the visible spectrum, which is measured in nanometers, as shown in Figure 3-2. (3)

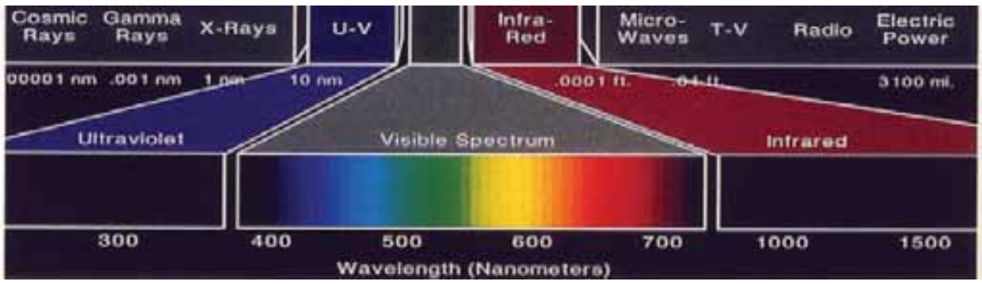

Figure 3- 2: Visible spectrum of light –light as wave
Source: Daylighting workshop guideline, p. 2

[1]Aditi Majumder, Visual Perception For Visualization And Multimedia Group, p. 9
[2] Tsangrassoulis, A., et al., Synthlight Handbook, p. 7-8
[3] Shady Atya, Daylighting Workshop Guideline, p. 2

Our eyes see different wavelengths as different colors. Short wavelengths are seen as blue, md-range wavelengths are seen as green or yellow, and longer wavelengths are seen as red. There is also ultraviolet (shorter than blue) and infrared (longer than red) radiation, but as our eyes are not sensitive to these wavelengths we can't see them. Light is absorbed by special cells within the eye called photoreceptors. This absorption starts a chain of events, chemical changes and electrical signals, which ends up as the sensation of light. The next section will explain what can happen in the human visual system and the function of eye components in visual perception. (1)

3.2.2. Human Visual System that Observes Light

The visual system is an image processing system. It involves the eye and brain working together to interpret the visual environment. (2) The principal optical components of the eye are :(3)

a) **The cornea,** which has air on one side and a liquid substance called aqueous humor on the other. It provides about 2/3 of the eye's optical power.

b) **The pupil** (the back hole in the middle of the iris), which can change its size according to amount of light, enlarging at low light levels and becoming smaller as light levels increase.

c) **The lens,** which has aqueous humor on one side and a jelly-like substance called vitreous humor on the other. It provides about 1/3 of the eye's optical power. It is particularly important because its shape can be changed, which leads to a change in power when you focus your eye. This is called 'accommodation'.

d) **The retina** (the back surface of the eye), which contains millions of light-sensitive cells called photoreceptors. There are two types of photoreceptors, termed rods and cones. They contain chemicals (photopigments) which can absorb light energy and transform it into electrical signals that are sent along the optic nerve to the visual areas of the brain. The brain is responsible for further processing which leads to the perception of color, depth and motion as well as the perception of details.

   i. **Cones,** which are active in daytime and respond to certain colors. However, they can’t respond at very low light levels, such as at night-time and to artificial lights.

   ii. **Rods,** which are more sensitive than cones as it can respond at low light levels, but they do not respond to colors in the dark.

Each of these components, as shown in Figure 3-3, makes light bend to a different degree (each with a different 'refractive index') and, as a consequence, when light strikes one of these curved surfaces its direction is changed.

[1] IESNA, IESNA Lighting Handbook, p. 3.3
[2] ibid, p. 3.1
[3] Http://Www.Ergonomics4schools.Com/Lzone/Light.Htm

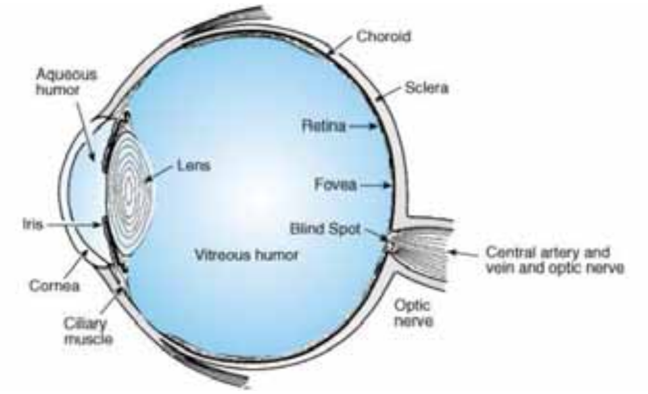

Figure 3- 3: Eye components (human visual system)
Source: IESNA lighting Handbook, p. 3.2

3.2.3. Interaction of Light with Surfaces

When light strikes a surface, the surface reflects, absorbs and transmits light in different proportions. Reflectance is an indicator for how much light hitting a surface will be reflected back, while transmittance indicates how much light will go through an object. Absorption is a measure for how much light is neither transmitted nor reflected, but instead absorbed by the body. All are given as percentages. The sum of reflectance, transmittance and absorption for any material is always 100%. (1)

In perfect specular reflection, like in a mirror, an incoming ray of light is reflected from the surface intact. The reflected ray makes the same angle with the surface as the incoming ray. In pure diffuse reflection, an incoming ray of light is scattered in all directions equally. A viewer would see reflected light from all points on the surface and the surface would appear to be evenly illuminated, which is shown in Figure 3-4. (2)

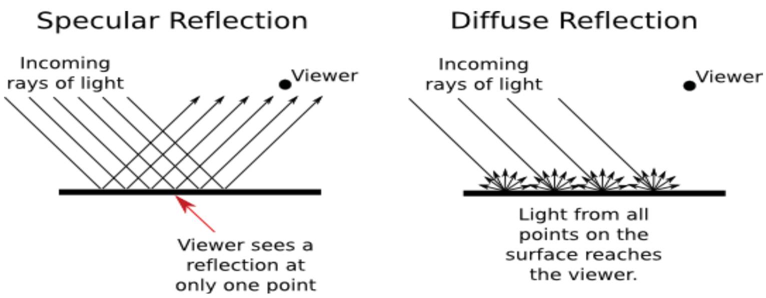

Figure 3- 4: Specular and diffuse reflection
Source: http://math.hws.edu/eck/cs424/notes2013/09_Light_and_Material.html

The light reflected from surfaces can illuminate other surfaces. Then, these surfaces also act like a source that causes illumination. Illuminance and reflectance affect luminance. Matte surfaces of high reflectance (e.g., white-painted walls and light-colored furniture finishes) are effective materials for increasing room surface luminances. Luminaires expressly designed for lighting walls or ceilings are effective tools for increasing room surface luminances. Thus, such surfaces are called secondary light sources. The final effect

[1] Tsangrassoulis, A., et al., SynthLight Handbook, p. 18
[2] Http://Math.Hws.Edu/Eck/Cs424/Notes2013/09_Light_And_Material.Html

of all these is that light is reverberated in all directions filling the proximate scene with light from all different directions. This is very important for vision. Since different amounts of light come from different directions, we are able to see different shapes and surfaces. (1)

3.3. Quality Of Optical/Visual Environment and Its Effect on Student Performance

Light affects human behavior through various processes through visual and non-visual effects of light. Light can act as a stimulator (perception, alertness, etc.) or as an inhibitor (glare, heart rate variability, etc.). Any choice in lighting design will therefore have a significant impact in a space. Increasing the quality of lighting does not mean to use more energy. On the contrary, with careful consideration of the different lighting factors and with proper lighting equipment, the energy consumption of lighting can still be decreased while improving the quality of lighting. (2)

3.3.1. Quality of Visual Environment

Previously studies have shown the effects of lighting conditions on productivity and also indicated that lighting conditions can improve human performance and productivity by providing adequate illuminance for visual tasks. Figure 3-5 illustrates that the main parameters of illuminance environment should be studied to improve lighting quality and also the factors which control human performance and productivity. This should be done in order to reach for visual quality formula for the following lighting design scheme inside learning spaces.

3.3.1.1. Luminous Environment

The luminous environment acts through a chain of mechanisms on human physiological and psychological factors, which further influence student performance and productivity. Luminous environment parameters are actually the tools which the designer can use to design good quality spaces.

A. Illumination sources; either natural, artificial or both, and their respected related strategies.
B. Illumination quantity, whether vertical or horizontal, which mainly depends on type of visual tasks inside the space
C. Illumination quality, which depends on several factors :
   - Illuminance uniformity, which is achieved by good light distribution and a certain luminance ratio.
   - Glare control for light sources either disable or disrupt glare.
   - Color render and temperature
   - Flicker, which mainly come from artificial light used inside the space.
   - Shadows, which depend on positions of light sources and users' positions.
D. Lighting control system will be used either manual or automated system.

[1] IESNA, IESNA Lighting Handbook, p. 52
[2] IESNA, Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 43-44

3.3.1.2. Human Performance and Productivity

Visual comfort is the main factor that is highly dependent on light and visual quality. Light quality can be judged according to the visual comfort and performance, which is visual aspect, required for our activities. It can also be assessed on the basis of the pleasantness of the visual environment and its adaptation to the type of room and activity. This is the psychological aspect. There are also long term effects of light on our health, which are related either to the strain on our eyes caused by poor lighting (again, this is a visual aspect), or to non-visual aspects related to the effects of light on the human circadian system as shown in figure 3-5. [1]

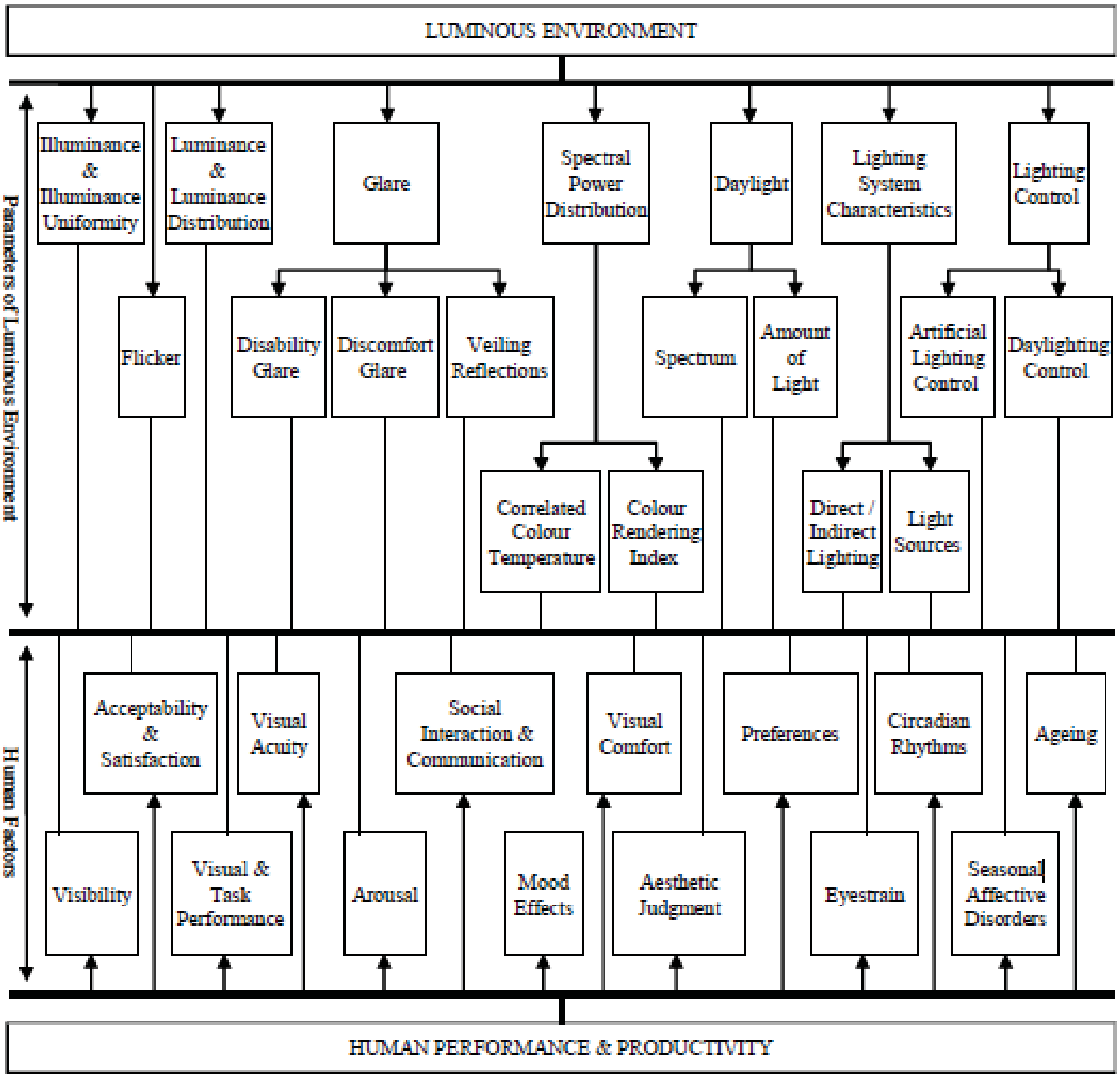

Figure 3- 5: Luminous environment and human performance. (Gligor 2004)
Source: Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 50

[1] ibid, p. 43-44

3.3.2. Impact of Visual Environment on Student Behavior

Lighting profoundly impacts numerous levels of human function such as vision, circadian rhythms, mood, and cognition. Its implicit effects on learning and classroom achievement cannot be dismissed. Several studies have addressed how the quality and color of lighting can either impair or enhance students' visual skills and thus, academic performance. [(1)] Visual impairments alone can induce behavioral problems in students as well as level of concentration and motivation in the classroom. Therefore lighting should be designed to provide students with the right visual conditions that help them to perform visual tasks efficiently, safely and comfortably [(2)]. Both basic light sources can play different roles in enhancing classroom performance such as improving vision, behavior, and academic achievement. Figure 3-6 shows the impact of using integrated systems of artificial light and daylight on student performance.

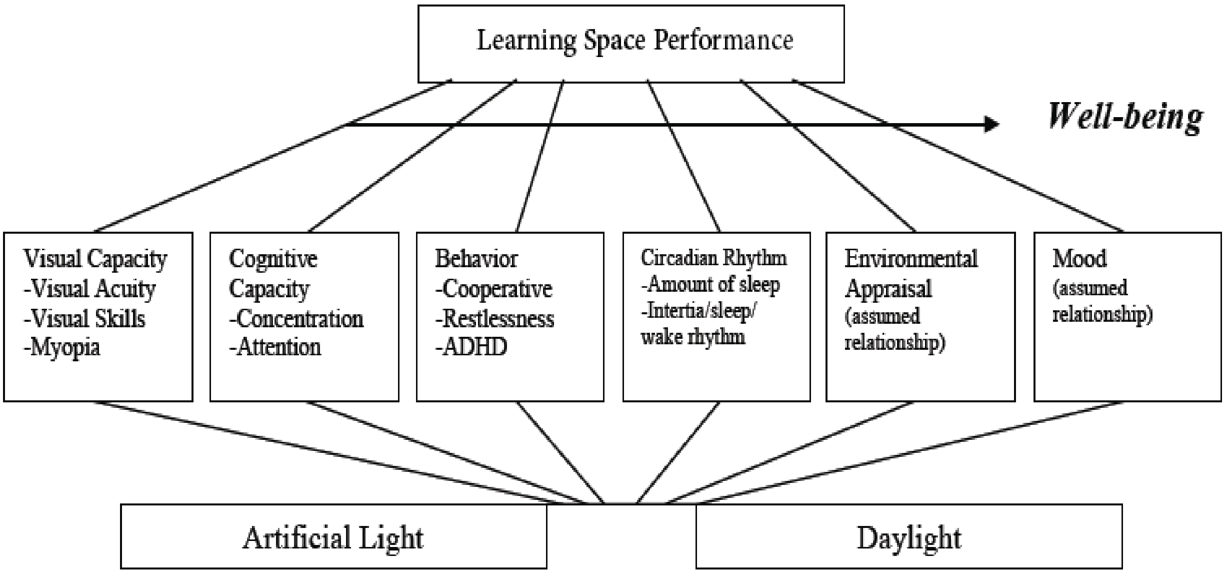

Figure 3- 6: Impact of using integrated system of artificial light and daylight on student performance
Source: Illuminating the Effects of Dynamic Lighting on Student Learning, p. 24

3.3.2.1. Daylighting Impact on Human Performance in Learning Spaces

Daylighting is the practice of using natural light to provide illumination in interior environments. Fifty years ago, practically all educational spaces used daylight as the primary illumination source by using large glass facades. However, users asking to provide air conditioning in learning spaces argued against the use of large expanses of glass and for the thermal impact of artificial light. This caused energy costs to soar. Starting with the energy crises of the 1970s, the glazed areas of buildings came to be regarded by many as an energy liability, seen as increased heating and cooling loads. Since cooling loads typically dominate in non-residential buildings, solar gain through windows became a driving concern. [(3)] By virtue of smart Technology smart glazing, windows and smart shading devices could be used to reduce thermal loads and enhance daylight quality inside learning spaces.

[1] Mott, Michael S., et al. Illuminating the effects of dynamic lighting on student learning, p. 6
[2] IESNA, Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 50
[3] Heschong, Lisa, Daylighting and Human Performance, p. 1-2

Daylight is more preferably used inside learning spaces because it gives off a continuous spectrum of all light wavelengths, including blue, red and green, appearing as a bright white. Daylight is the standard for color quality in lighting, with a Color Rendering Index (CRI) of 100. Daylight is free so it's considered the most energy efficient source of illumination. (1)

Previous studies have found that daylighting in classrooms achieves a 20% improvement in student performance. Also good natural light helps to create a sense of physical and mental comfort. Natural light has a lot of benefits such as changing color which electric lighting does not have. It provides a high quality of light for most visual tasks and is more accurate for viewing colors. (2) Furthermore, other Swedish studies have confirmed that daylighting in classrooms can promote overall health and physical development. Researchers tracked behavior, health, and cortisol (a stress hormone) levels over the course of a year in four classrooms with varying daylighting levels. The results indicate work in classrooms without daylight may upset the basic hormone pattern, and this in turn may influence the children's ability to concentrate or cooperate. (3)

3.3.2.2. Artificial Light Impact On Human Performance in Learning Spaces

Light illumination intensity and color temperature are the two main variables in lighting systems used for artificial lighting indoors. Artificial light intensity should be 500 lux horizontally on the work plane, which is the minimum used to create enough illumination for teachers and students to see given the lack of natural light available in learning spaces. Color temperature, measured in Kelvin, refers to the quality of light hue and runs from "cool" (blue and white) to "warm" (red and yellow) along the radiation spectrum of light. For example, cool white fluorescent lighting is recommended to aid in reading speed and accuracy and attentiveness or focus. On the other hand, warm white lighting can assist in helping adults work together and minimize conflict. (4)

Every space in a university serves a particular purpose, for which there are special architectural solutions for its lighting requirements. As mentioned before, this thesis focuses on group teaching spaces' visual environment requirements, so it will be discussed minutely in the following part.

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[1] http://www.designshare.com/Research/Lighting/LightingEnvr1.htm
[2] The Ministry of Education is the Government's lead advisor on the New Zealand ,Designing Quality Learning Spaces: Lighting, p. 3-7
[3] Patricia Plympton., et al, Daylighting in Schools: Improving Student Performance and Health at a Price Schools, p. 14
[4] Mott, Michael S., et al. Illuminating the effects of dynamic lighting on student learning, p. 14

3.4. Group Teaching Spaces' Visual Environment Design Process

The main goal of educational facility lighting is to provide a visual environment for both students and instructors that is supportive of the learning processes. This can be achieved only if the occupants can see their visual tasks accurately, quickly, and comfortably. (1) The following diagram (Figure 3-7) shows the visual environment design process in group teaching spaces. (2)

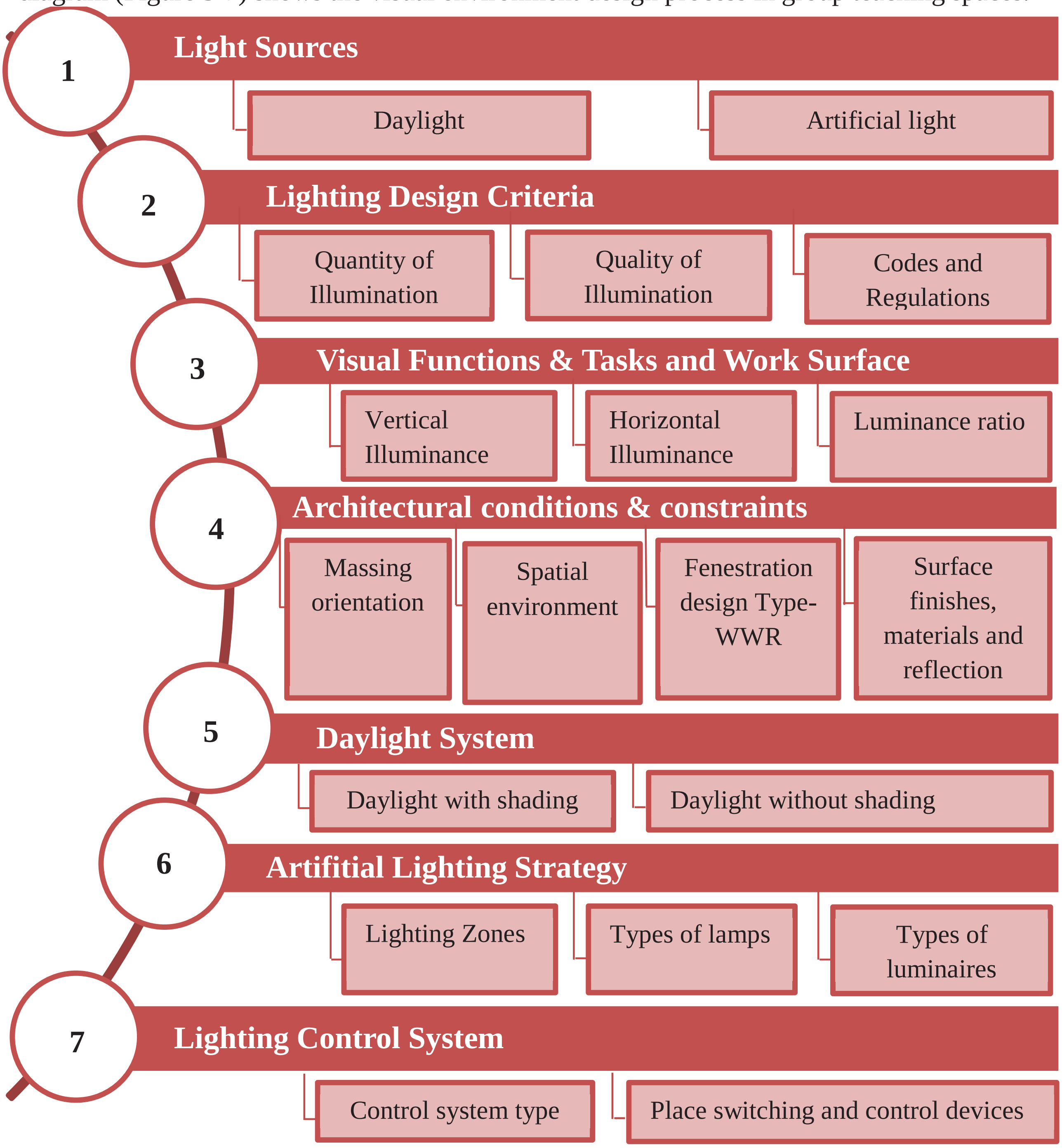

Figure 3- 7: Visual Environment Design Process in Group Teaching Spaces

[1] IESNA, IESNA Lighting Handbook, p. 10.7
[2] Sam C M Hui, Lighting System Design –Design Methods, p. 9

3.4.1. Lighting Sources

The first step in the lighting design process is to know lighting needs for the space to define if this space needs daylight or just depends on artificial lighting. In educational spaces, natural lighting should be the main light source in daytime due to reasons of quality of light, health and sustainability. However, daylight is unpredictable; it varies in intensity, color and direction over time. Therefore, electric lighting should be used to supplement insufficient natural lighting and be the main light source during the hours of darkness. [1] Based on the lighting systems decisions, efficient light sources and luminaires should be selected to provide the proper quantity of high-quality, comfortable lighting. [2] In this step light sources should be bordered along with design process parameters.

3.4.1.1. Daylight

Daylight illumination levels in a space are dynamic. They are constantly changing according to the two variable sources of daylight – the sun and the sky – and interact with the geometry and physical properties of the space, the exterior context and interior conditions. [3] Figure 3-8 illustrates the sequence of the Daylight Design process.

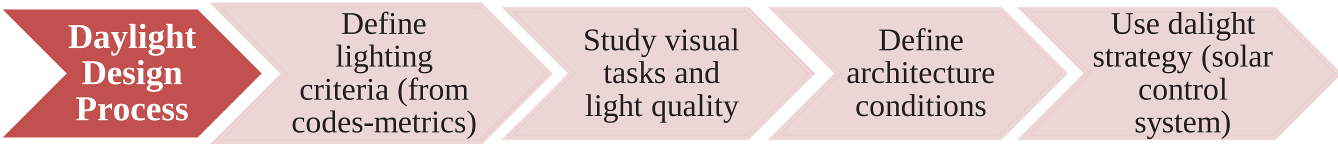

Figure 3- 8: Daylight Design process

3.4.1.2. Artificial light

Artificial lighting currently accounts for the highest proportion of all energy costs in educational spaces, so electric lighting should only be used when it is necessary to make sure that running costs and maintenance are reduced to a minimum. Lighting integration offers the greatest potential for saving energy by applying good management, design, specification and controls. The use of automatic lighting controls can save as much as 30 to 40 percent of electricity consumption when compared to manual switching. [4] It plays a major role in learning spaces, especially in winter, and also is used when windows need to be darkened for media presentations on screens and projectors. [5] Figure 3-9 illustrates the sequence of the artificial light design process.

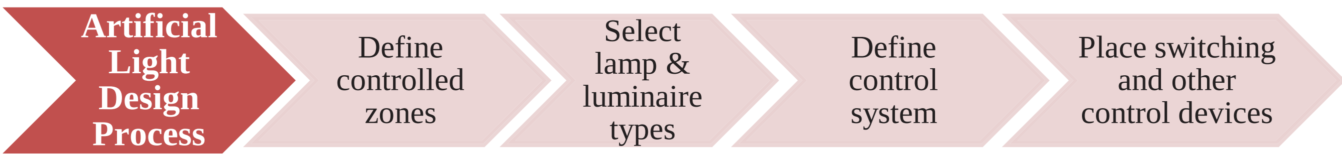

Figure 3- 9 : Artificial Light Design Process

[1] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 11
[2] IESNA, IESNA Lighting Handbook, p. 12.2
[3] Mardaljevic, John, Lisa Heschong, and Eleanor Lee. Daylight metrics and energy savings, p. 1
[4] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 8
[5] Lichtforum,Good Lighting For Schools And Educational Establishments, p. 6

3.4.2. Lighting Design Criteria

Quality and quantity of illumination are interrelated. A lighting system may provide the appropriate illuminance level for a task but cause reflected glare, veiling reflections, and excessive luminance in the field of view, which can compromise visibility and give the impression that the system provides low lighting quality. The most important lighting design factors to be considered in educational spaces are direct glare, horizontal and vertical illuminance, light distribution on surfaces, and light distribution on the task plane (uniformity). (1)

3.4.2.1. Quantity of Illumination

Illuminating Engineering Society of North America (IESNA) sets standards for illumination according to the visual tasks that take place in spaces. Group teaching spaces contain high contract visual tasks of small and large sizes.(2) Reading and writing on paper may require a high level of lighting intensity but for tasks that require working at a computer, lower illuminance levels will make it easier to view a video display(3) which make it fall into category C (300lux) and D (500lux). This is the minimum illuminance that should be provided in the activity area. (4) Illuminance in a teaching space is the average light level required for making it easy and comfortable to carry out educational activities. (5) The illuminance is measured on group teaching space surfaces as horizontal and vertical illuminance according to the visual task. So initially visual tasks should be studied to adjust work surfaces plans and then determine the type of illumination and its quantity. These issues will be discussed in detail in the following visual tasks section.

3.4.2.2. Quality of Illumination

Learning and teaching rely upon good lighting. Most of students' health problems, such as slower reading, poor posture, diminished concentration and long-term weakened vision, are caused by poor lighting. (6) Quality of illumination in group teaching spaces depends on each of the following issues: (7)

- Overall appearance of space and luminaires.
- Color quality and appearance.
- Brightness uniformity of light distribution on room surfaces for controlling direct and reflected glare.
- Reduction of flicker and strobe.
- Uniformity of light distribution on the task.
- Highlighting points of interest like white boards and screens.
- Shadowing (good and bad).

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[1] IESNA, IESNA Lighting Handbook, p. 12.2
[2] ibid, p. 10.17
[3] http://thesextantgroup.com/lighting-for-learning-new-learning-models-challenge-traditional-lighting-methods/
[4] IESNA, IESNA Lighting Handbook, p. 12.2
[5] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 5
[6] ibid, p. 8
[7] Mark Karlen, James R. Benya And Christina Spangler , Lighting Design Basics, p. 66-67

i. Appearance of space and luminaires

Appearance includes both the arrangement of elements, such as furnishings and luminaires, in a space and their relationship to one another. Correct positioning of desks and furniture can enhance quality of light, as shown in Figure 3-10[1]. Style of the luminaires should be coordinated and enhance the design and architecture of the space. Figure 3-11 illustrates the effect of using Indirect luminaire to enhance the smart learning spaces in case of using movable furniture The main task for this arrangement is to avoid "visual clutter," that is, confusing or distracting details in the visual field. The eye is drawn to areas of greater brightness. High levels of contrast ratio between the brightest and the darkest areas can be used as visual cues that assist occupant orientation. Bright areas should be important and preferably impart some visual information, like white boards and screens. Color patterns should also lead the eye to the areas of greatest importance. [2] However, high contrast ratio may be inappropriate and even fatiguing in a collaborative classroom with smaller emissive video displays, so the volume of the space and display directions should be taken in consideration in this part. [3]

Figure 3- 10: Effect of desks position on lighting quality and performance
Source: Good Lighting for Schools and Educational Establishments, p. 4-5

Luminaires with direct and indirect lighting components permit free arrangements of desks, reduce the risk of reflected glare and create a more agreeable lighting atmosphere, as shown in Figure 3-11.[4]

Figure 3- 11: Indirect luminaire is better in smart learning spaces with movable furniture
Source: Good Lighting for Schools and Educational Establishments, p. 5

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1 Winter, Clive. Good Lighting for Schools and Educational Establishments, p. 5
2 IESNA, IESNA Lighting Handbook, p. 10.5-10.6
3 http://thesextantgroup.com/lighting-for-learning-new-learning-models-challenge-traditional-lighting-methods/
4 Winter, Clive. Good Lighting for Schools and Educational Establishments, p. 5

ii. Color

Light colors are preferable, however high reflectance and light colors should controlled to provide uniform high levels of illuminance and brightness. If the recommended reflectance and luminance ratios are met, wall, floor, and furniture colors have high reflectance. (1)

The good color rendering is important. The way we perceive colors under artificial light depends on the color rendering properties of the lamps. Lamps with good color rendering properties produce natural colors, whereas lamps with poor color rendering properties cause color distortion. Figure 3-12 illustrates the difference between good and poor color render. (2) The ability to render colors accurately is measured by the Color Rendering Index (CRI), scaled from 1-100, with natural daylight receiving a score of 100. (3) A scale of 0 to 100 defines the CRI. A higher CRI means better color rendering, or less color shift. CRIs in the range of 75-100 are considered excellent, while 65-75 are good. The range of 55-65 is fair and 0-55 is poor. (4) Color render index importance differs according to space type as in education rooms. In group teaching spaces it is advisable that light sources be selected with a high color rendering index (CRI > 70). Where good color rendering is less important, as in workshops, light sources having a more limited spectrum can be satisfactory. (5)

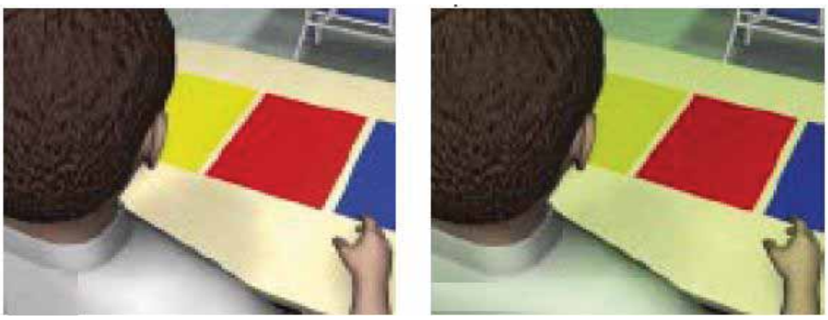

Figure 3- 12: The difference between good and poor color render
Source: Good Lighting for Schools and Educational Establishments, p. 4

iii. Glare

Glare is a common problem in learning spaces. It occurs when a bright image is seen either directly or by reflected light. This can cause significant difficulty with visual tasks. (6) An educational space must minimize glare. Electric or natural light sources that are too bright can produce discomfort and impair vision.(7) A lot of equations and metrics have been developed on glare sensation, which have resulted in glare indices that describe the magnitude of glare discomfort, with high values illustrating an uncomfortable or intolerable sensation of discomfort. Daylight Glare Probability (DGP) is a useful metric that can be

[1] IESNA, IESNA Lighting Handbook, p. 12.2
[2] Winter, Clive. Good Lighting for Schools and Educational Establishments, p. 4
[3] Efficiency Maine, Office And Classroom Lighting, p. 2
[4] Http://Www.Boles.De/Teaching/Mm/Pages/Light-Fundamentals.Html
[5] IESNA, IESNA Lighting Handbook, p. 12.2-10.6
[6] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p.8
[7] IESNA, IESNA Lighting Handbook, p. 12.2

used to examine glare inside a space. It represents the probability that a person (student or instructor) is disturbed by glare and is derived from a subjective user evaluation. Annual DGP uses a simplified method that calculates the vertical illuminance at the eye level as a parameter which can affect the brightness of the space. [(1)] Figure 3-13 illustrates the range of acceptance and rejection levels of DGP.

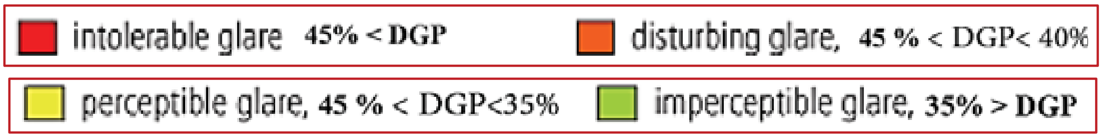

Figure 3- 13: Range of acceptance and rejection levels of DGP
Source: http://web.mit.edu/tito_/www/Projects/Glare/GlareRecommendationsForPractice.html

Glare can be minimized in group teaching spaces by:

- Fenestration controls to prevent direct sunlight from entering classrooms. Shades, blinds and louvers can be used, as well as optical control devices. Prismatic lenses should also be incorporated into the luminaires to minimize glare. In the next chapter this will be explained minutely.
- Matte finishes on furniture, equipment, and room surfaces, and by using low brightness sources. [(2)]
- Choice screens with anti-glare filters should be used and located with a proper orientation to avoid direct sunlight and daylight reflection.
- Careful design of the illuminance of the whiteboard, relative both to sunlight and daylight glare and glare from luminaires. [(3)]

iv. Flicker

Flicker is the rapid variation in light source intensity, usually most pronounced in surrounding vision. [(4)] Flicker can cause discomfort or annoyance to students and instructors as well. It can also produce stroboscopic effects with moving objects, which can be dangerous. Epilepsy can be triggered by low frequency flashes of light, which can occur with some compact fluorescent lamps at ignition, or with discharge lamps towards the end of their life. Problems relating to balance and some brain disorders can also be exacerbated. All these can be avoided by using high frequency control gear. [(5)]

v. Shadows

Where there is light, there are also shadows. Shadows impair effective sight of visual tasks. Shadows close to visual tasks are particularly annoying. This does not mean that shadows must be completely eliminated, but that shading should not be excessively dense. [(6)]

[1] Wienold, Jan, and Jens Christoffersen. "Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras,p. 743–757.
[2] IESNA, IESNA Lighting Handbook, p. 12.2
[3]Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 8
[4] IESNA, IESNA Lighting Handbook, p. 10.5-10.6
[5] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 8
[6] IESNA, IESNA Lighting Handbook, p. 12.2

To ensure that shadows do not impede views when writing, light should fall - for a right-handed person - from the left because if the light comes from the right, writing will occur in the shadow of the writing hand, as shown in figure 3-14. (1)

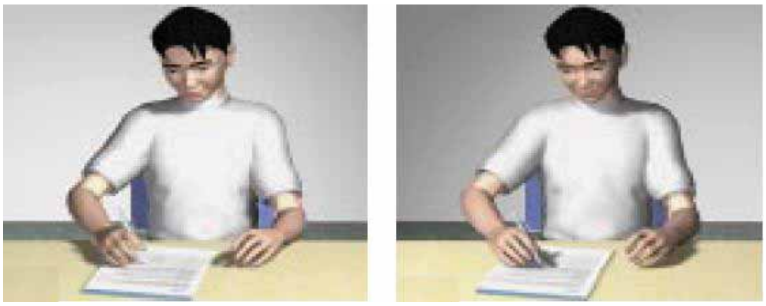

Figure 3- 14: Effect of light and shadow direction on a visual task
Source: Good Lighting for Schools and Educational Establishments, p. 4

3.4.2.3. Codes, Metrics and Rating Systems

i. Codes and regulations

Codes about educational buildings mainly depend on country-specific regulations. The codes which affect a space's lighting design process are electric codes, building codes, energy codes, and accessibility codes.(2) Beyond these national codes there are also international organizations, like IESNA, which set standards for illumination in buildings to control the quantity and quality of lighting in visual environments in different spaces, and ASHRAE, which is founded in 1894 as a global society advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry. (3)

ii. Metrics

Varieties of daylighting metrics have been proposed in order to understand the impact of daylighting systems on visual comfort and daylight availability in group teaching spaces. New metrics are developed to assess daylight levels and visual comfort and also to overcome the inability of older metrics to assess the dynamic conditions of daylight. IES (IESNA before) sets a lot of metrics to control lighting quantity and quality in interior spaces, as shown in Figure 3-15. Some metrics are limited to use under a specific type of sky while others are limited in the fact they can only be measured for a particular date and time. The aim of the different metrics is to help designers to distinguish well daylit, and comfortable spaces. (4)

Figure 3- 15: Daylight Metrics Types

1 Winter, Clive. Good Lighting for Schools and Educational Establishments, p.4
2 Mark Karlen, James R. Benya and Christina Spangler, Lighting Design Basics, p. 67
3 IESNA, IESNA Lighting Handbook, p. 10.17
4 Gadelhak.Mahmoud, High Performance Facades: Designing Office Building Facades To Enhance Indoor Daylighting Performance, p. 33.34

A. Static Shading Devices

A.1. Quantitative Daylight Metrics

Quantitative daylight metrics are usually used for measuring the internal illuminance of a space, either at a specific moment or annually, for a certain measuring working surface plane. (1) Daylight metrics are divided into two types according to sky conditions. As shown in Figure 3-1, the older ones were measured in a static condition with an overcast sky, which was represented in the daylight factor metric, and the newer metrics mainly depend on Climate-based daylight modelling (CBDM).(2)

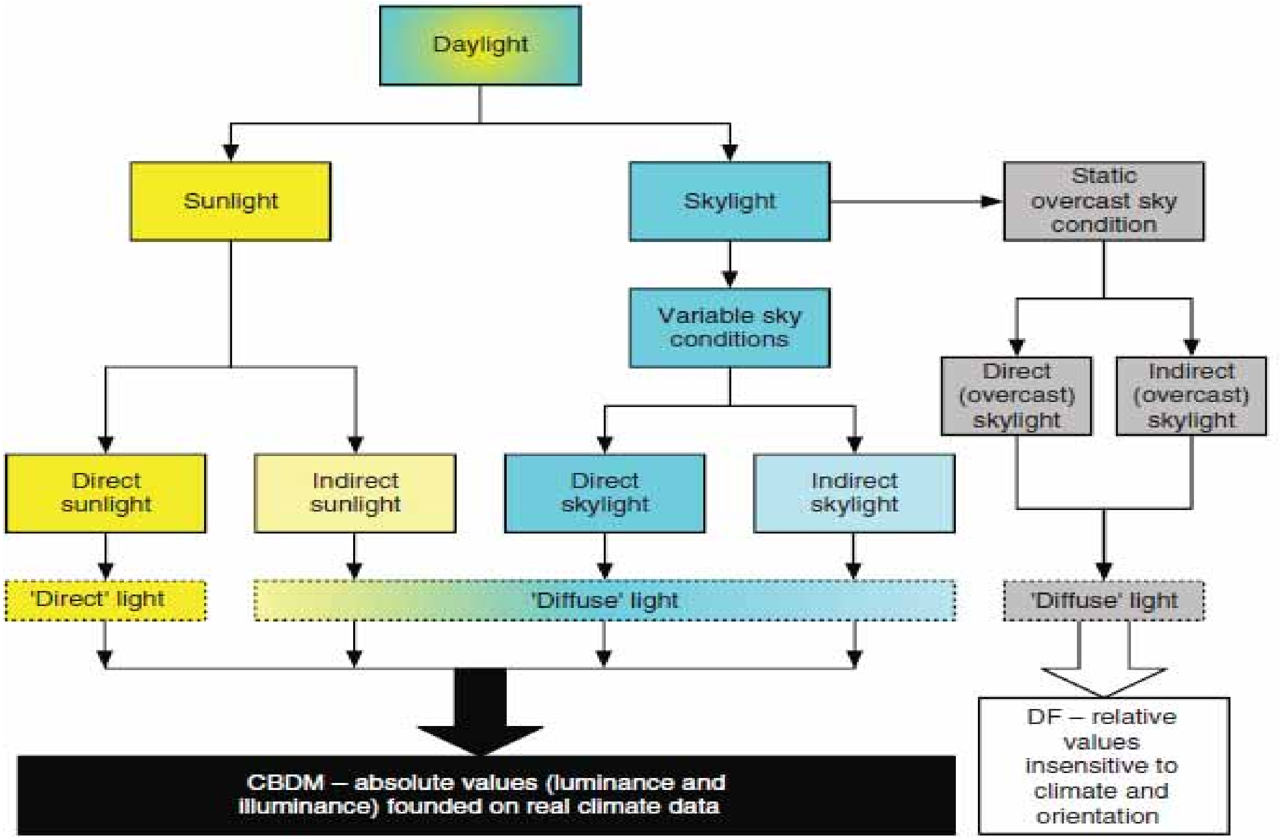

Figure 3- 16: The components of daylight and their relation to the DF and CBDM
Source: Daylight metrics and energy savings, p. 23

In the past, designing for daylight within the learning environment has been a numerical process based on a static overcast sky. The ambition was to deliver a certain percentage of diffuse light into the space (daylight factor (3)) and achieve a degree of uniformity. In reality the result was often as in Figure 3-17 with a low light level at the rear of the space and a very high level adjacent to the windows.(4)

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1 Gadelhak.Mahmoud, High Performance Facades: Designing Office Building Facades To Enhance Indoor Daylighting Performance, p. 33.34
2 J. Mardaljevic, L. Heschong and E. Lee, Daylight metrics and energy savings, p. 23
3 **Daylight Factor (DF)** is defined as the ratio of the internal illuminance at a work plane point in a building to the un-shaded, external horizontal illuminance under a CIE overcast sky
4 Education Funding Agency, EFA daylight design guide version 2, p. 5

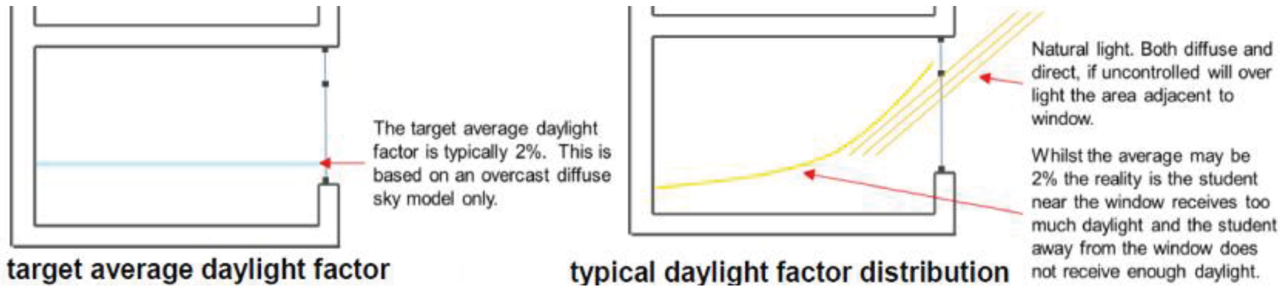

Figure 3- 17: Difference between Target and reality daylight factor distribution
Source: EFA daylight design guide version 2, p. 4

Dynamic daylighting metrics enable us to study the accumulated effect of lighting performance over a year-long period rather than to investigate selected dates and times of the year.(1) Using CBDM in place of daylight factors provides far greater detail about light distribution and intensity which allows learning spaces to be adjusted to maximize the use of sunlight and daylight. Real weather data is used to calculate lux levels and targets can be set which are relative to user needs. (2) Figure 3-18 illustrates examples for room daylight analysis with CBDM metrics and will be later discussed consecutively in detail.

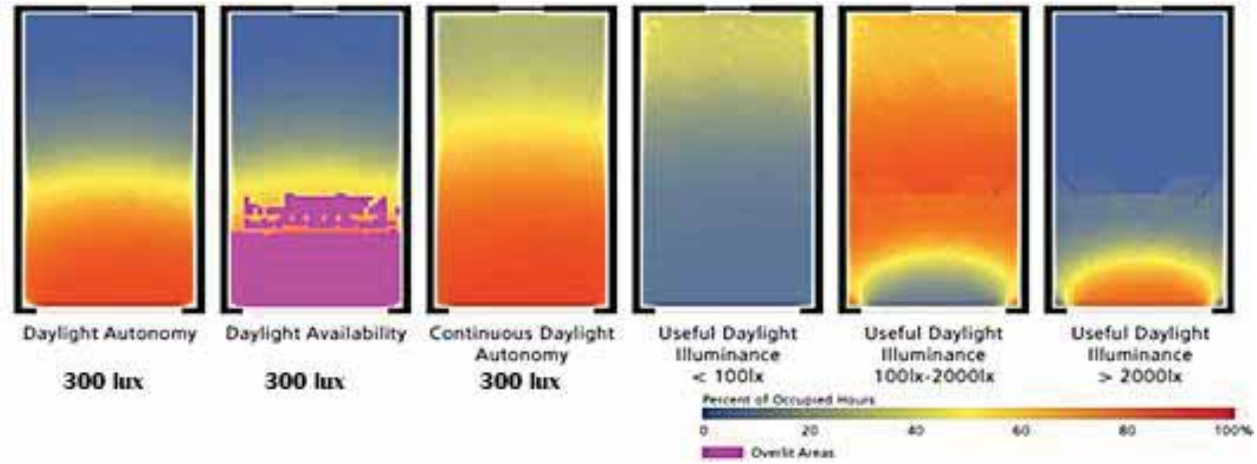

Figure 3- 18: Example for room daylight analysis with CBDM metrics
Source: parametric passive design workshop, p. 30

- ➢ **Daylight Autonomy (DA)** is defined as "the percentage of the occupied hours of the year when a minimum illuminance threshold is met by daylight alone"(3)
- ➢ **Daylight Availability metric** presents three evaluation criteria: "Daylit" areas, similar to DA, for spaces that receive sufficient daylight at least half the time, "Partially Daylit" areas, which are below useful illuminance and "Over lit" areas that provide a warning when an oversupply of daylight (10 times the target illuminance) is reached for at least 5% of the working year. (4)

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[1] Mehlika Inanici, Dynamic Daylighting Simulations from Static High Dynamic Range Imagery. International Building Performance Simulation Association, p. 3392
[2] Education Funding Agency, EFA daylight design guide version 2, p. 5
[3] Reinhart, C. F., et al., Dynamic daylight performance metrics for sustainable building design, 33(7), p.7-16
[4] ibid, p. 17

- **Continuous Daylight Autonomy (DAcon)** was proposed by Rogers (2006). It is a modified version of the daylight autonomy metric. Continuous Daylight Autonomy gives partial count to times when the daylight illuminance at a given point lies below the task/ambient lighting threshold. This method becomes useful for showing the potential energy savings if the electric lights have dimming switch capabilities. (1)
- **Useful Daylight Illuminance (UDI)** is considered another proposed annual daylight metric. As the name indicates, UDI calculates the total number of occupied hours that "useful" daylight enters a space at a select point. Useful daylight is defined as providing ambient light at the work plane at illuminance levels between 100 lx to 2,000 lx. Above 2,000 lx, heat gains and glare become potential problems. Potential UDI metrics give thresholds using bins (too low, useful, and too high) for certain percentages of the work plane. (2)

In this thesis the Daylight Availability metric was chosen to be used for evaluating the studied cases as a quantitative metric for static shading devices. This is because it uses suitable and integrated minimum and maximum thresholds. All other metrics except for the UDI use either a minimum or maximum threshold, but can't be used for both. Although the UDI has both minimum and maximum thresholds, these thresholds are not customizable and are considered very low for the function of the space as defined by the guidelines.

A.2. Qualitative Daylight Metrics

In the past metrics were used to measure the quality of lighting by only checking the occurrence of glare phenomena like: (3)

- Daylight Glare Index (DGI)
- CIE Glare Index (CGI)
- CIE Unified Glare Rating (UGR)
- Daylight Glare Probability (DGP), as previously discussed in the glare section.

Finally, this is the IES approved method of assessing the total dynamic qualities of a daylit space. This method represented in two metrics: Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). Two metrics have been developed to evaluate space daylight for a one year period using two different performance parameters: sufficiency of daylight illuminance and the potential risk of excessive sunlight penetration. Also these metrics can be used by building codes to describe acceptable occupant comfort expectations for daylit spaces. (4) Figure 3-19 illustrates examples of room daylight analysis with sDA and ASE, which will be discussed consecutively in detail.

[1] Reinhart, C. F., et al., Dynamic daylight performance metrics for sustainable building design, 33
[2] ibid, p.16
[3] Wienold, Jan, and Jens Christoffersen. Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras.Energy and Buildings 38 (7), p. 743–757
[4] Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), p. 1

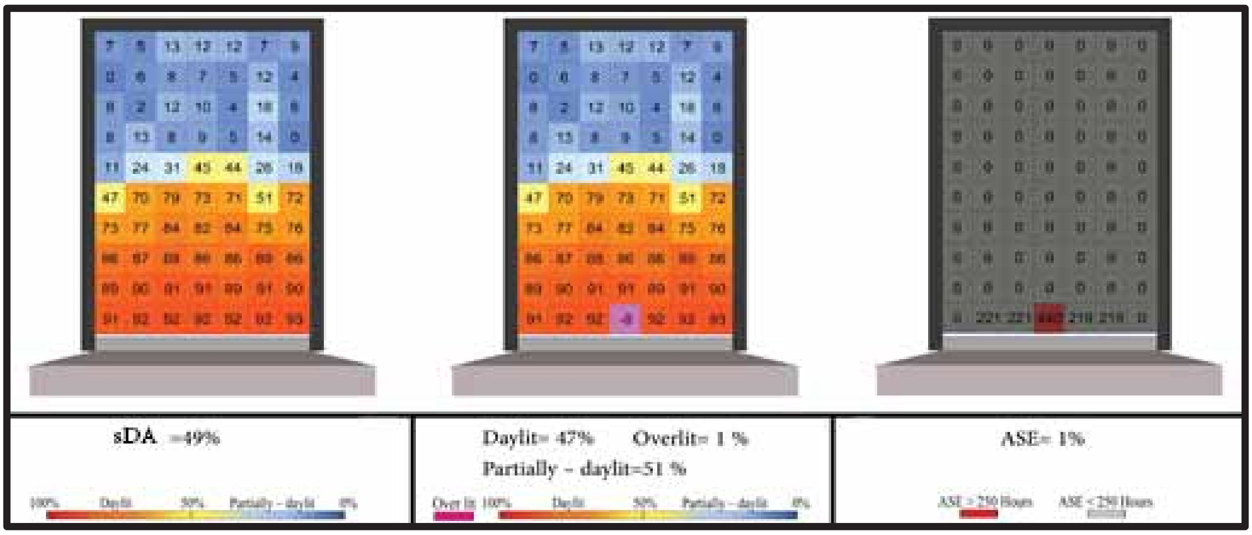

Figure 3- 19: Example for room daylight analysis with sDA, Daylight Availability and ASE

- Spatial Daylight Autonomy (sDA) is a measure of daylight illuminance sufficiency for a given area, reporting a percentage of floor area that exceeds a specified illuminance level (e.g. 300 lux) for a specified amount of annual hours (e.g. 50% of the hours from 8am-6pm) for at least 55% of the floor area. So the Daylight Autonomy value according to Reinhart & Walkenhorst (1), illuminance level and time fraction are included as subscripts, as in $sDA_{300,\ 50\ \%}$.(2)
- Annual Sunlight Exposure (ASE) provides a second dimension of daylight analysis, looking at one potential source of visual discomfort: direct sunlight. ASE measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year, which must not exceed 10% of floor area. In the Radiance software, direct sunlight is calculated using a “zero-bounce” simulation, with only the direct beam from the sun accounted for, where any sensor seeing 1000 lux or more (for $ASE_{1000,250h}$) is counted as being in “direct sunlight”. (3)

B. Automated Shading Devices

Most of the daylighting metrics were not developed with a dynamic system in mind. (4) The Single Point in Time (SPT) is considered the only approved method which accounts for variability in designs such as orientation and shading mechanisms. (SPT) is the method in which illuminance calculation is measured at a certain work plane for a specific time of the year. The time can be selected to represent an average daylight condition such as on the three critical sun paths of summer/winter solstices and spring equinox, as shown in Figure 3-20. The selected point in time should be representative of the building’s occupancy schedule and relevancy to the design goals for the space. (5)

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[1] Reinhart, C. F., et al., Dynamic daylight performance metrics for sustainable building design, 33(7)
[2] Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), p. 1-2
[3] ibid, p. 10-11
[4] Siva Ram Edupuganti, Dynamic Shading: An Analysis, p. 2
[5] Energy Design Resources, Understanding Daylight Metrics, p. 7

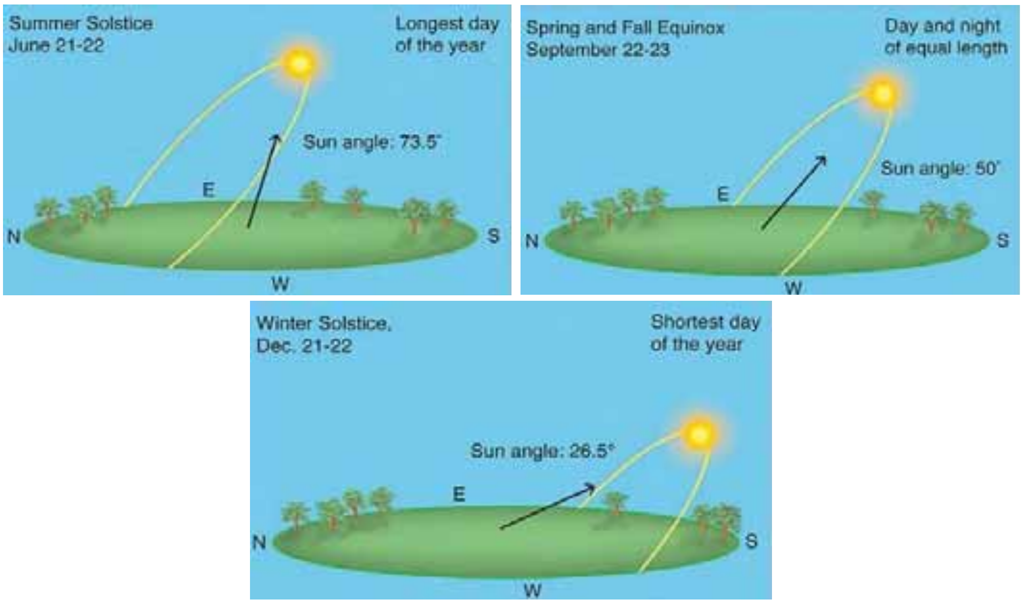


Figure 3- 20: The three critical sun paths which are used in illuminance calculation for smart shading device or in glare calculations

Source: http://www.naturephotographers.net/articles1209/ab1209-1.html

iii. Rating systems

Previous daylight metrics were used to set a criteria for rating systems and create programs to help distinguish well-lit, comfortable environments throughout the day and year. [(1)]

There are a lot of rating systems for environmental design and daylight. LEED [(2)] is the most popular and effective rating system which aims to build energy targets and create stringent building codes. These in turn exert pressure on lighting designers to reduce total lighting loads while planning lighting systems that provide productive, pleasing, and safe lighting. [(3)]

In the earliest versions of LEED educational space was considered well lit if the average daylight factor was four to five percent, dependent on the level of sky illumination (at least 300 lux). With 25,000 lux outdoors on a bright cloudy day, a 2% daylight factor indoors would give 500 lux at that point. [(4)]

LEED version 4, which launched November 2013, adopted the new metric of sDA and ASE. It awards up to 3 points for showing that an educational space is well daylit by demonstrating through annual computer simulations that annual sunlight ($ASE_{1000, 250}$) of no more than 10% is achieved, and then it gives the educational space credits as following: [(5)]

- 2 points – for showing 55% $sDA_{300/50\%}$
- 3 points – for showing 75% $sDA_{300/50\%}$

The sDA and ASE calculation grids should be no more than 0.60m at a work plane level of 0.76m.

[1] Energy Design Resources, Understanding Daylight Metrics, p. 2-6

[2] LEED Stands For Leadership In Energy And Environmental Design. LEED Green Building Rating System Is The USGBC's Primary Vehicle For Promoting Sustainable Design And Construction. The LEED Standard Was Created Through Volunteer Committees.

[3] Http://Www.Boles.De/Teaching/Mm/Pages/Light-Fundamentals.Html

[4] BRANZ , Designing Quality Learning Spaces: Lighting, p. 9

[5] LEED,LEED v4-BD+C: Schools -Daylight**, p. 1-2**

3.4.3. Visual Functions and Tasks Work Surface

Visual tasks in educational facilities vary in size, contrast, viewing direction and distance. The activities occur in group teaching spaces sorted by the following categories: (1)

a) Presentations, where students sit addressed by a teacher or pupil speaking from a specific location. This mainly occurs in halls and auditoriums. In these spaces the lighting has three principal roles: to light the desks, the speaker and the board, which may be interactive whiteboards.

b) Interactive learning, where teaching takes the form of group discussion. In this configuration, which mainly occurs in classrooms, teachers and students might sit anywhere. In these spaces the lighting needs to reveal the space without creating shadows in any part of the room.

There are both near and far visual tasks, of small and large size, on matte and glossy surfaces. Students are often required to rapidly adjust from reading at a desk to reading from a chalkboard, and from looking almost straight down to looking along or above the horizontal. Figure 3-21 represents main tasks in group teaching spaces. Whiteboards are more preferable than chalkboards because of their high reflectance and, in combination with dark marking pens, high contrast can be achieved.

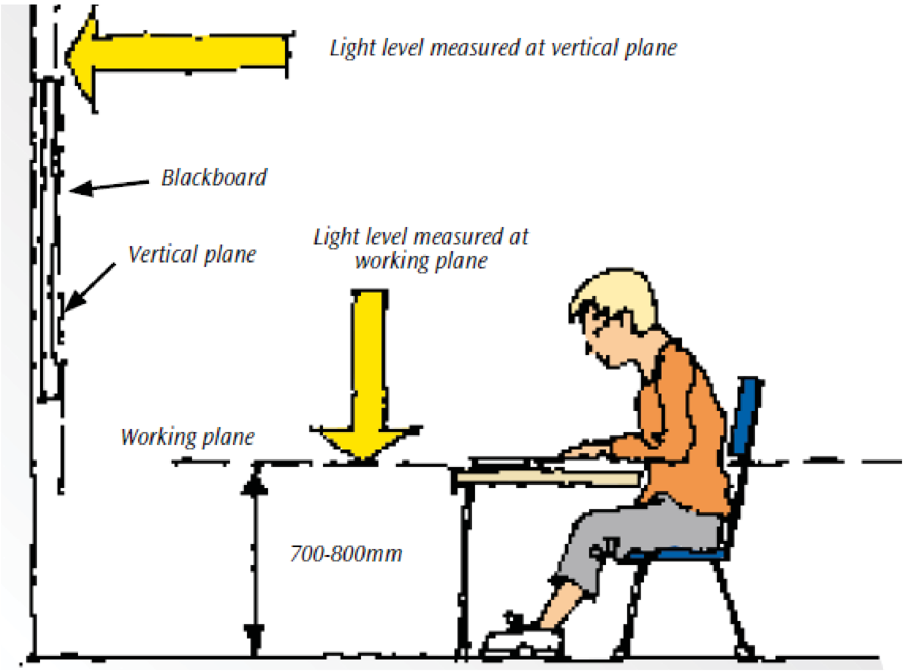


Figure 3- 21: Main Tasks in Group Teaching Spaces
Source: Designing Quality Learning Spaces: Lighting, p. 9

Illuminance is evaluated according to each visual task level as shown in table 3-1. Decreased illuminance is provided for the less demanding tasks and increased illuminance at each specific task location where a high illuminance is required. So we need to determine which tasks need horizontal illuminance and which need vertical one.

[1] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 27

Table 3- 1 : Main tasks in group teaching spaces with the requirements for illuminances

Task	the teacher	the student	Standard Illuminance	
			In the class	In general
1	Writing on blackboard	Reading on blackboard	500 lux (vertical)	200 lux
2	Talking to the students	Paying attention to the teacher	300 lux	300 lux
3	Showing a presentation (slides, powerpoint, television program, etc.)	Looking onto the screen	300/10 lux	10 lux
4	Paying attention to working students	Writing, reading drawing, etc.	300 lux	300 lux
5	Coaching computer activities	Looking to the computerscreen and the paper	50 lux	300 lux above the computer
6	Preparing lessons	Not present	300 lux	50 lux

Source: Lighting in schools, p. 1

3.4.3.1. Horizontal Illuminance(1)

Horizontal illuminance is the density of luminous flux falling onto a horizontal surface, measured in lux (lumens per square meter) or foot-candles. For interior educational spaces, the plane on which the illuminance is specified and measured is assumed to be a horizontal plane 0.76m above the floor.

3.4.3.2. Vertical Illuminance (2)

Vertical illuminance is the density of luminous flux falling onto a vertical surface, measured in lux (lumens per square meter) or foot-candles (lumens per square foot). Whiteboards and screens represent vertical task plans in group learning spaces and must not receive high intensive direct lighting.

3.4.3.3. Luminance Ratio

The brightness of the various surfaces in the normal field of view must be kept within accepted limits. When the eye fixates on a task, an adaptation level is established. As the eye shifts from one luminance, such as a book, to another luminance, such as the whiteboard, it must adapt to the new level. If there is much difference between the two levels, a period of time is required for the eye to adjust itself to the new situation, which can slow visual performance. Further, if the difference is great, discomfort and fatigue can be experienced. For good visual performance and comfort, the luminance of any surface normally viewed directly should not be greater than five times the luminance of the task. No large area, regardless of its position in the room, should have less than one-third the luminance of the task, as shown in Figure 3-22. (3)

The general approach to providing low luminance ratios over the entire visual field is to limit the luminance of luminaires and fenestration and increase the luminance of all interior

[1] ibid, p. 10.5-10.6
[2] ibid, p. 10.5-10.6
[3] ibid, p. 12.4

surfaces. Two ways to augment surface luminance are to increase the reflectance of the surface and the quantity of light onto the surface.

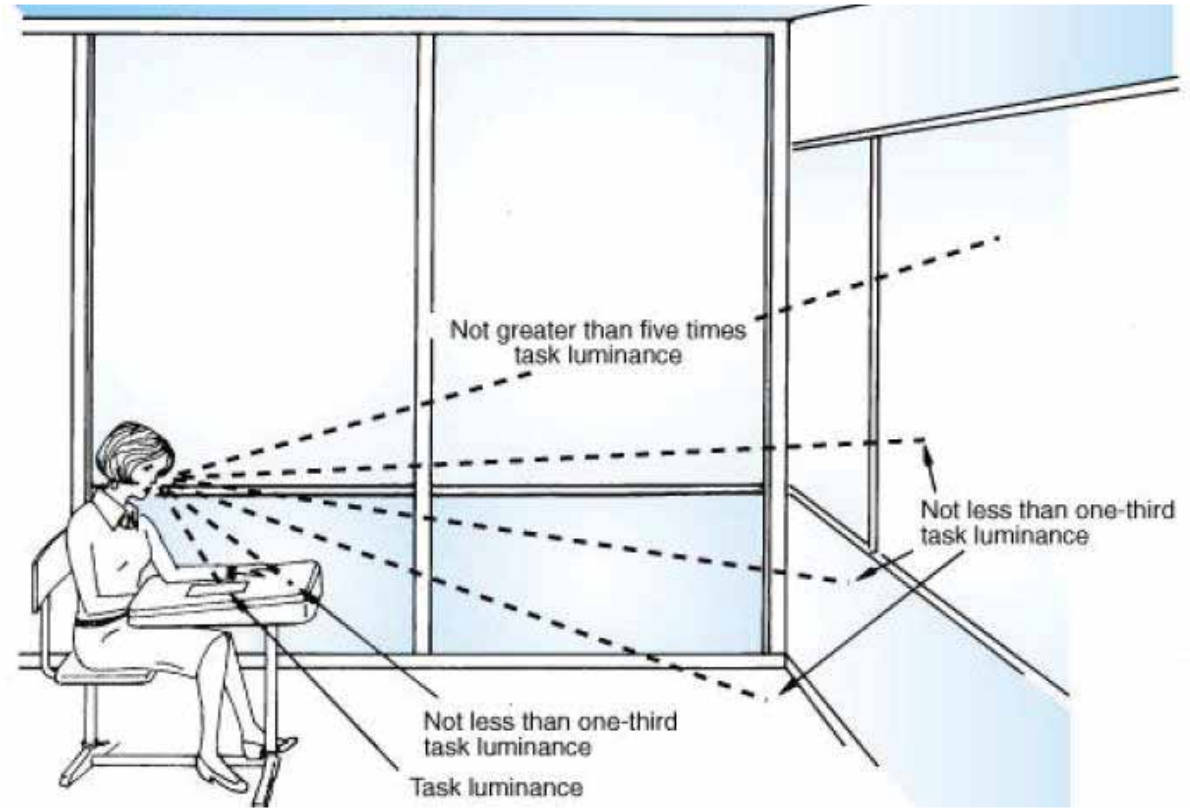


Figure 3- 22: Illuminance ratios between work surfaces in a learning space
Source: IESNA lighting Handbook, p. 12.4

3.4.4. Architectural Conditions & Constraints

Daylighting design should be fully integrated with the architectural expression of the building inside and outside. This means full integration of various systems including the building envelope and interiors. (1) So in this step architectural conditions that may affect lighting design decisions should be recorded. The main conditions that most frequently affect lighting design are massing orientation, spatial environment components, fenestration design (type, location and size) and surface finish materials. (2)

3.4.4.1. Space Orientation

Spatial orientation has a significant impact on space daylighting and thermal performance. Wide elevations should be faced towards the North and south while minimizing facade exposure to the East and West elevations. In turn, this will enhance :(3)

- Thermal environment by reducing the heat gain of the space and therefore reducing the energy consumption.
- Daylight environment by allowing for easier control of solar penetration through the implementation of exterior shading.

[1] Energy Design Resources, Understanding Daylight Metrics, p. 6
[2] Mark Karlen, James R. Benya And Christina Spangler, Lighting Design Basics, p. 67
[3] Bakar N. and Steemers K, Daylight Design of Buildings, p. 45

3.4.4.2. Spatial Environment and Teaching Space Dimension

The spatial variable in this context refers to space proportions and ceiling height, furniture (type, layout and size), and also the location of the screens and whiteboard. For example, teaching spaces will have more satisfactory daylight if their depth is no greater than the width and the depth does not exceed twice the height of the window head. (1) Chapter two discusses this issue in detail to achieve effective spatial environment.

3.4.4.3. Fenestration Design

i. Opening Type

There are a lot of types of daylight openings in group teaching spaces. Figure 3-23 illustrate illustrates fenestration types, which are classified into two main categories: side-lighting and top lighting. (2) This thesis will focus on side lighting (window type).

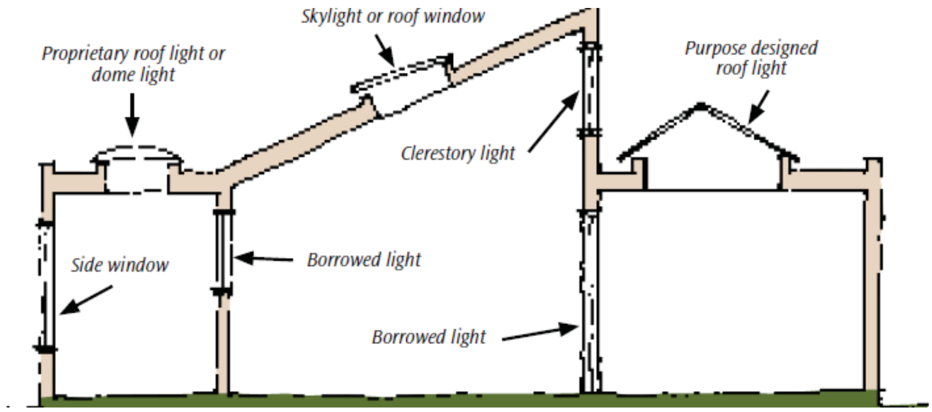


Figure 3- 23: Samples of Fenestration Types
Source: Designing Quality Learning Spaces-Lighting, p. 9

ii. Window Design

Windows play such an important role in teaching spaces that there is invariably excellent energy-saving potential from dimming and switching electric lights. Most of learning space's windows reach almost to the ceiling above a solid spandrel and are usually more than 0.76m high. Windows should always be perpendicular to the usual line of sight between the teacher and the students. (3)

Window design involves climate and solar conditions based on location and space type. Within these conditions, several design variables can strongly influence the impact of windows on energy performance and the learning environment. Figure 3-24 illustrates the main window design parameters that should be considered in the design process to reduce glare, uncomfortable temperature extremes, stuffy air and noise pollution and help create more comfortable and productive learning environments. (4)

[1] The Ministry of Education is the Government's lead advisor on the New Zealand ,Designing Quality Learning Spaces: Lighting, p. 11
[2] Bruce Coldham, Daylight in School Classrooms, p. 8
[3] IESNA, IESNA Lighting Handbook, p. 12.6
[4] Efficient Windows Collaborative, The Efficient Windows Collaborative Tools for Schools, p. 2

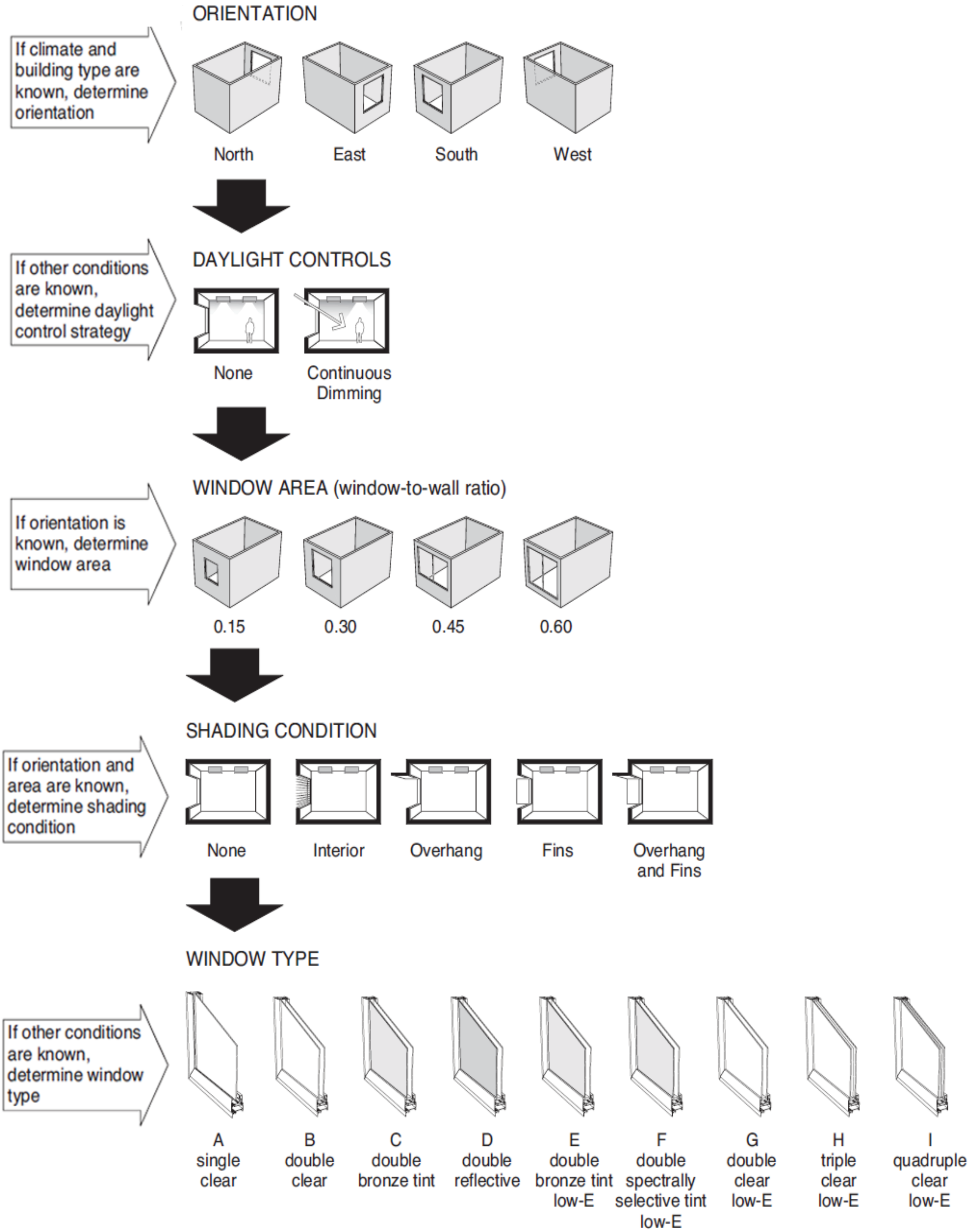


Figure 3- 24: Windows design parameters
Source: The Efficient Windows Collaborative Tools for Schools, p. 3

A. Orientation

The orientation of learning space windows determines the potential for solar heat gain, daylight and glare. South and north are the favorable orientations in learning spaces. South is most likely to allow daylighting throughout the day. Indirect and ambient light through north-facing glazing can also be substantial. However, east and west are usually the least favorable orientations because they do not allow for control of solar radiation and glare. (1)

B. Daylight controls

If the space location and window orientation allow for sufficient daylighting, an integrated daylight control system should be considered early in the design process. There are a lot of smart daylight control fixtures that can be used to dim or switch off lights when sufficient daylight is available. These capabilities depend on the daylight control system and strategy and will be discussed in detail later. (2)

C. Window to wall ratio (WWR)

Windows should be sized to provide daylight and views to access the learning space while avoiding glare and solar heat gain. Size of windows depends on their placement and orientation. If windows face east or west, glare and solar heat gain are more difficult to control. Therefore it's better to avoid large windows on east and west façades and limit overall vertical window area to be no more than 35 % of the gross exterior wall area. However, north- and south-facing windows should be sufficiently large to provide daylight but be provided with a solar control system to minimize glare and increase light quality.(3)

D. Shading condition

Shading can be designed so that it controls solar heat gain but permits daylight access. For instance, light shelves can shade large window areas while redirecting visible light through high clerestory windows onto the room's ceiling. To darken the room for projections, some form of operable shading is also required in most classrooms. (4) Shading condition should be defined after choosing the daylight system of the space as will be discussed later on.

E. Window glazing type

Once orientation, daylighting, window area and shading conditions are known, the window type must be chosen. When windows are installed, particularly on the south side of the building, it is recommended that tinted glass with a low E rating be used. This reduces the heat transfer from the outside to the inside of the room. Double or even triple glazed windows assist in reducing heat transfer as well as provide a barrier to exterior noise which might enter the room. (5)

[1] ibid, p. 2
[2] ibid, p. 4
[3] ibid p. 4
[4] ibid, p. 5
[5] University of Pittsburgh Institutional, Classroom and Lecture Hall Design, p. 5

3.4.4.4. Surfaces Finish Materials and Reflection

Walls and blinds should have non-specular surfaces with 40 to 60 percent reflectance and be light colored to avoid excessive luminance ratios between windows and wall surfaces. The ceiling should be even more highly reflective (white) and non-specular, because the ceiling is most important in reflecting light downward toward tasks on desktops as indirect luminaires. It also is necessary to avoid obvious brightness differences between the ceiling and the luminaires. Floors provide the secondary background for desktop tasks, so they also should be non-specular. The materials for floor coverings should have a reflectance of about 25%. Figure 3-25 illustrates reflectance percentage for group teaching space surfaces. (1)

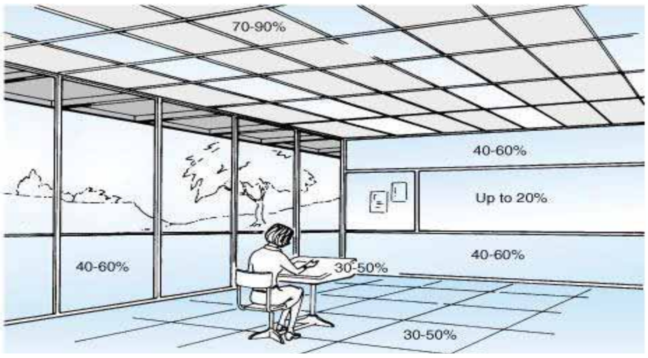


Figure 3- 25: Reflectance Percentage for Group Teaching Space Surfaces
Source: IESNA lighting Handbook, p. 12.3

3.4.5. Daylighting System

Daylighting systems combine glazing with solar control systems in order to enhance the delivery or control of light into a space. (2) Solar control systems may be static or dynamic depending on control system use and space needs. Figure 3-26 illustrates the main types of solar control systems and table 3-2 discussed them in detail with their main criteria. The following key parameters should be considered in choosing solar control system elements:

- Site daylighting conditions—latitude, cloudiness, obstructions
- Daylighting objectives and daylighting strategies implied in the architectural design
- Window scheme and function and operational constraints fixed/operable.
- Energy and peak power reduction objectives and economic constraints
- Integration constraints—architectural/construction integration

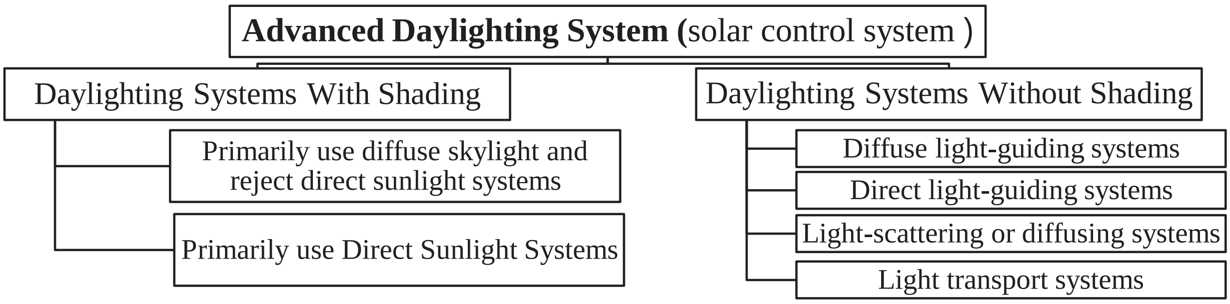
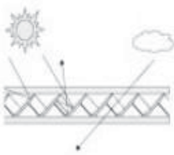
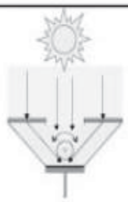
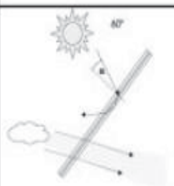


Figure 3- 26: Main types of solar control systems

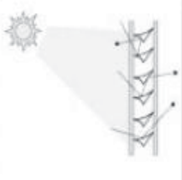
[1] IESNA, IESNA Lighting Handbook, p. 12.3
[2] Johnsen, Kjeld, and Richard Watkins. "Daylight in Buildings." , p. 3

Table 3- 2 : Solar control systems elements in detail with their choosing elements criteria

1. Shading Systems											
Category	Type/name	Sketch	Climate	Location	Criteria for the choice of elements						
					Glare protection	View outside	Light guiding into depth of room	Homogeneous illumination	Saving potential (artificial lighting)	Need for tracking	Availability
1A Primary using diffuse skylight	Prismatic panels		All climates	Vertical windows, skylights	D	N	D	D	D	D	A
	Prisms and venetian blinds		Temperate climates	Vertical windows	Y	D	Y	Y	Y	Y	A
	Sun protecting mirror elements		Temperate climates	Skylights, glazed roofs	D	N	N	Y	N	N	A
	Anidolic zenithal opening		Temperate climates	Skylights	Y	N	N	Y	Y	N	T
	Directional selective shading system with concentrat-ing Holo-graphic Optical Element (HOE)		All climates	Vertical windows, skylights, glazed roofs	D	Y	N	D	Y	Y	T
	Transparent shading system with HOE based on total reflection		Temperate climates	Vertical windows, skylights, glazed roofs	D	Y	N	Y	Y	Y	A

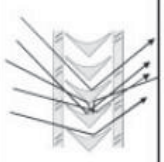
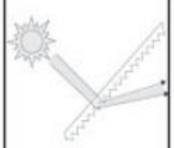
(Abbreviations in table: Y=yes, D=depends, N=no, A=available, T=testing phase)

1. Shading Systems

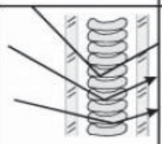
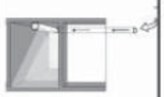
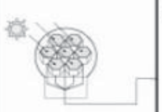
Category	Type/name		Climate	Location	Criteria for the choice of elements						
					Glare protection	View outside	Light guiding into depth of room	Homogeneous illumination	Saving of energy for artificial light-ing	Need for tracking	Availability
1B Primary using direct sunlight	Light guiding shade		Hot climates, sunny skies	Vertical windows above eye height	Y	Y	D	D	D	N	T
	Louvres and blinds		All climates	Vertical windows	Y	D	Y	Y	Y	Y	A
	Light shelf for redirection of sunlight		All climates	Vertical windows	D	Y	Y	Y	Y	N	A
	Glazing with reflecting profiles		Temperate climates	Vertical windows, skylights	D	D	D	D	D	N	A
	Skylight with Laser Cut Panels (LCPs)		Hot climates, sunny skies, low latitudes	Skylights	D		Y	Y	Y	N	T
	Turnable lamellas		Temperate climates	Vertical windows, skylights	Y/D	D	D	D	D	Y	A
	Anidolic solar blinds		All climates	Vertical Windows	Y	D	Y	Y	D	N	T

(Abbreviations in table: Y=yes, D=depends, N=no, A=available, T=testing phase)

2. Daylighting systems without shading included

Category	Type/name	Sketch	Climate	Location	Criteria for the choice of elements						
					Glare protection	View outside	Light guiding into depth of room	Homogeneous illumination	Saving of energy for artificial lighting	Need for tracking	Availability
2A Diffuse light guiding systems	Light shelf		Temperate climates, cloudy skies	Vertical windows	D	Y	D	D	D	N	A
	Anidolic Integrated System		Temperate climates	Vertical windows	N	Y	Y	Y	Y	N	A
	Anidolic ceiling		Temperate climates, cloudy skies	Vertical facade above view-ing window		Y	Y	Y	Y	N	T
	Fish System		Temperate climates	Vertical windows	Y	D	Y	Y	Y	N	A
	Zenith light guiding elements with HOEs		Temperate climates, cloudy skies	Vertical windows (especially in court-yards), skylights		Y	Y	Y	Y	N	A
2B Direct light guiding Systems	Laser Cut Panel		All climates	Vertical windows, skylights	N	Y	Y	Y	Y	N	T
	Prismatic panels		All climates	Vertical windows, skylights	D	D	D	D	D	Y/N	A

(Abbreviations in table: Y=yes, D=depends, N=no, A=available, T=testing phase)

2. Daylighting systems without shading included											
Category	Type/name	Sketch	Climate	Location	Criteria for the choice of elements						
					Glare protection	View outside	Light guiding into depth of room	Homogeneous illumination	Saving of energy for artificial lighting	Need for tracking	Availability
2B Direct light guiding Systems	HOEs in the skylight		All climates	Skylights	D	Y	Y	Y	Y	N	A
	Sun-directing glass		All climates	Vertical windows, skylights	D	N	Y	Y	Y	N	A
2C Scattering systems			All climates	Vertical Windows, skylights	N	N	Y	Y	D	N	A
2D Light transport	Heliostat		All climates, sunny skies				Y		Y	Y	A
	Light Pipe		All climates, sunny skies				Y	Y	Y	N	A
	Solar Tube		All climates, sunny skies	Roof			Y	D	Y	N	A
	Fibres		All climates, sunny skies				Y		Y	Y	A
	Light-guiding ceiling		Temperate climates, sunny skies				Y	Y	Y	N	T

Source: Daylight in Buildings, p. 5-8

(Abbreviations in table: Y=yes, D=depends, N=no, A=available, T=testing phase)

Universities install horizontal blinds or louvers in learning spaces' windows because they can controlled glare, redirect daylight and guide lighting into the space. Also the automated blinds can control the view and room darkness during presentations. The blinds should be installed so that they cover the window opening as completely as possible. If horizontal static blinds and louvers do not provide adequate light blocking, some other type of treatment, such as automated blinds and louvers, may be needed. [1]

3.4.5.1. Louvers and Blinds System[2]

i. Components

Louvers and blinds are composed of multiple horizontal, vertical, or sloping slats. There are various kinds of louver and blind systems, some of which make use of highly sophisticated shapes and surface finishes.

ii. Production

Exterior louvers are usually made of galvanised steel, anodised or painted aluminium, or plastic (PVC) for high durability and low maintenance. Interior venetian blinds are usually made from small- or medium-sized PVC or painted aluminium. The slats can be either flat or curved. Slats are usually evenly spaced at a distance that is smaller than the slat width so that the slats will overlap when fully closed. Slat size varies with the location of the blinds; exterior, interior, or between the panes in a double-paned window. Exterior slats are usually between 50 and 100 mm wide while interior slats are usually 10 to 50 mm wide.

iii. Location in Window System

Louvers or blinds can be located on the exterior or interior of any window or between two panes of glass. Louvers are generally situated on the exterior of the facade; blinds are fitted inside or between glazing as shown in Figures 3-27, 3-28 and 3-29

iv. Louvers and Blind Control Types

Fixed systems are usually designed for solar shading and operable systems can be used to control thermal gains, control glare and redirect daylight. Movable systems need to be responsive to outdoor conditions. Sunlight and skylight may be reflected to the interior depending on slat angle, slat surface treatment and the spacing between slats.
Louvers and blinds can be operated either manually or automatically. Automatically controlled louvers and blinds can increase energy efficiency if controlled to reduce solar gain and admit visible dynamic daylight. However, automatic systems can produce discomfort in occupants who dislike the feeling of not having personal control over the system. Manually operated systems are generally less energy-efficient because occupants may or may not operate them optimally. In the next chapter we will study how smart responsive systems control louvers and blinds fully integrated with the building system.

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[1] R. L. Allen, et al. , Classroom Design Manual University Of Maryland, p. 25
[2] Johnsen, Kjeld, and Richard Watkins. "Daylight in Buildings." , p. 4.22

Figure 3- 27: Examples for external louvers
Source: Solar Shading Louver Systems, p. 11-23-26

Figure 3- 28: Internal blinds on classroom

Source: Good Lighting for Schools and Educational Establishments, p. 4

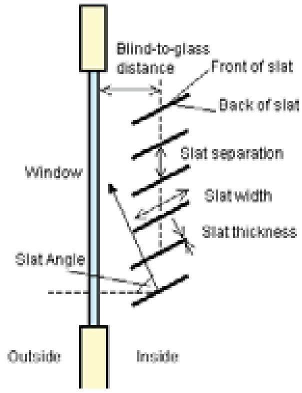

Figure 3- 29: Section of blinds

Source:http://www.designbuilder.co.uk/helpv2/Content/_Window_blinds_Slat_data.htm

3.4.6. Artificial Light Strategy

Electrical/artificial light is used in learning spaces when daylight fades later in the day, on overcast days, or when additional lighting is needed for specific tasks. Therefore electric lighting design must be flexible and carefully integrated with daylighting design. Artificial light installation must provide: (1)

- close work lighting – often supplementary to daylighting so specific tasks can be carried out accurately and comfortably.
- combined lighting – daylighting complemented by artificial lighting where the daylighting is reduced (e.g. in deep rooms or as daylight fades).
- full electric lighting – when daylight is insufficient (e.g. in the evening or at night).

Today, economical operation of lighting systems is assured by energy-efficient lamps and operating gear, high-grade luminaires with high light output ratios, and lighting control systems which automatically adjust the brightness of lamps to suit the daylight component available and deactivate lighting when a room is not used. Modernizing lighting systems when premises are refurbished can reduce the annual lighting costs of old educational establishments by more than 60 **%.**(2)

[1] The Ministry of Education is the Government's lead advisor on the New Zealand ,Designing Quality Learning Spaces: Lighting, p. 24
[2] Winter, Clive. Good Lighting for Schools and Educational Establishments, p. 6

3.4.6.1. Lighting Zones According to Visual Tasks

The most important element of this part of the lighting design process is getting light where it is needed for the visual functions performed in the space. (1) Learning spaces should organize lighting into a number of zones according to visual tasks and distribute lamps and luminaires on these zones according to the following factors: (2)

- Position and orientation of desks (this may not be predictable)
- Location of chalkboard or whiteboard and screens
- Location and proximity of windows
- Ceiling height
- Photometric characteristic of luminaires
- Flexibility of the space for other functions

These zones can be combined and switched to create a number of different lighting scenarios. The four following zones are the main possible lighting zones in most group learning spaces:(3)

- Zone 1: Main learning space area (student seating area): This zone services students and allows them to read and take notes in class.
- Zone 2: Instructor workstation: The light direction above the instructor workstation should be controlled separately whenever possible to allow instructors to see their materials while conducting a class with the rest of the lights off for projection.
- Zone 3: White board: white board area of the room should be controlled separately from the rest of the room. (4) Board lighting should also allow for proper illumination of the board. Proper illumination is defined as an average of 40 lumens across the surface of the board with no area dipping below 20 lumens.
- Zone 4: Aisles and tiered floors at large halls: Step lights are required in tiered halls. (5) Aisle lighting should be connected to emergency lighting/generator in all lecture halls. However the lighting should not interfere with the room's projection capability/visibility from the student prospective. (6)

Larger Auditoriums which are used regularly for public activities, seminars and conferences will also require additional spotlight circuits for flexible illumination of presentation zones, displays, committee tables, and the like. Lighting must be planned so as to provide quality illumination of the subject while protecting projection screens from unwanted wash or spill.(7)

Figure 3-30 illustrates lighting zones in a typical small classroom and figure 3-31 illustrates these zones in lecture halls.

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1 Mark Karlen, James R. Benya And Christina Spangler, Lighting Design Basics, p. 68-69
2 IESNA, IESNA Lighting Handbook, p. 12.7
3 CCWG, Emory College Classroom Design Guide, p. 15
4 General Lecture Hall Design Guidelines, University Of Maryland , p. 18
5 University of Guelph, Guidelines & Specifications For New Classroom Construction or Renovation, p. 3
6 General Lecture Hall Design Guidelines, University Of Maryland , p. 27
7 ibid, , p. 27

By virtue of smart technology and according to the previous zones, control strategy can be designed to control light and conserve energy. This issue will be discussed in detail in the next chapter.

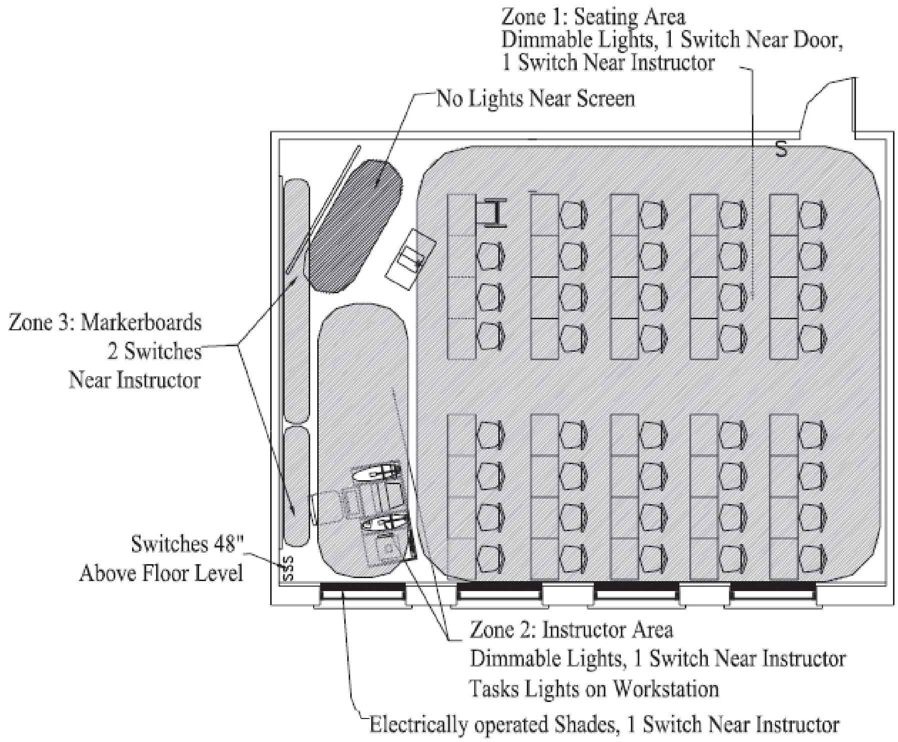

Figure 3- 30: Typical Small Classroom lighting zones
Source: Learning Environments, P53

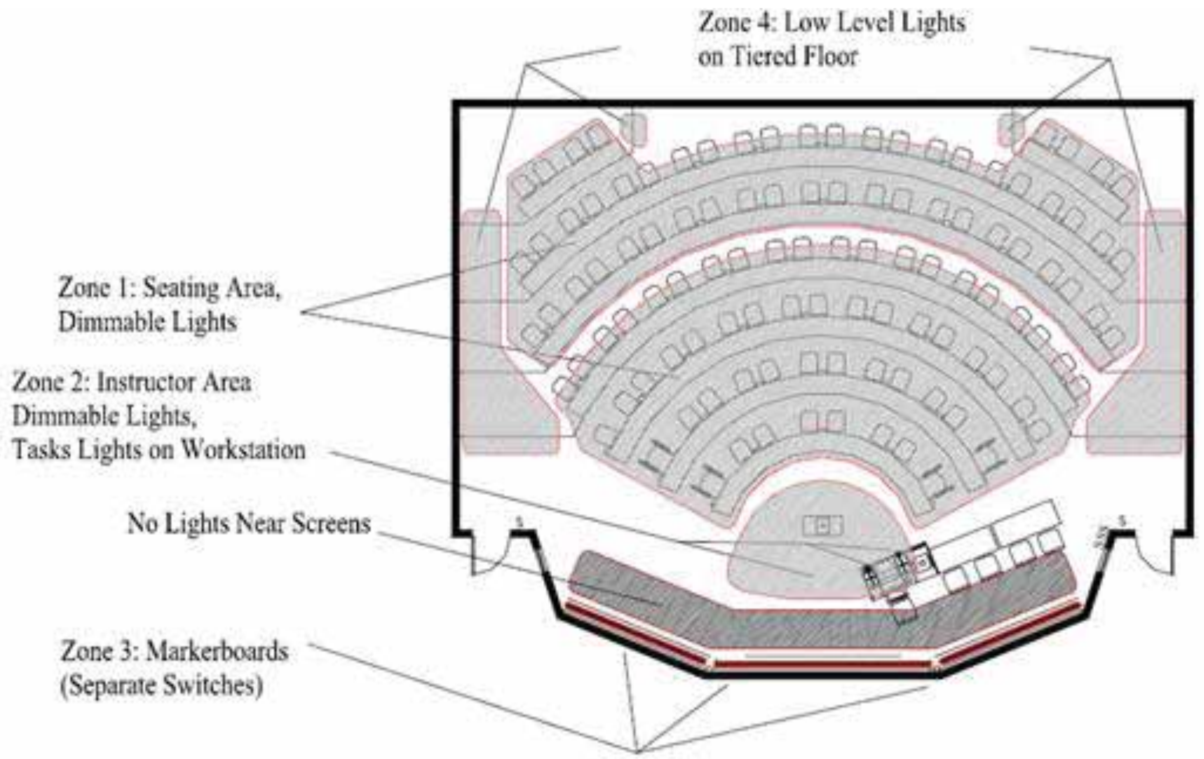

Figure 3- 31: Typical Lecture Hall lighting zones
Source: Learning Environments, P53

3.4.6.2. Lamps

The purpose of a lamp is to convert electrical power (watts) into visible light (lumens). The efficiency of the lamp is measured in lumens of light per watt of electricity. The energy(watts) largely ends up as heat thus highly inefficient lamps with excessive lighting will cause the building to overheat. (1)

Previously incandescent lamps were used in smart control learning spaces because they were the only lamps that provided dimming control despite its low efficiency. However fluorescent lamps now can be dimmed with ballasts technology. Table 3-3 shows that the common incandescent lamps have low efficiency. They should not be used except in some exceptional circumstances for display lighting.

Table 3- 3: Efficacy of various lamps types

Lamp group	Type of lamp	Efficacy (lumens/lamp watt)
Incandescent	Tungsten filament – common GLS (general lighting source)	8-12
	Tungsten halogen	12-24
Linear fluorescents	Triphosphor T5, 16mm	88-104
	Triphosphor T8, 26mm	88-100
Compact fluorescent		50-85
High intensity discharge	High pressure sodium	65-140
	Metal halide	70-100

Source: Standard Specifications Layouts and Dimensions- Lighting in Schools, P 13

The key to selection of the right lamp for each space and task is precise design. Modern light sources such as LED, fluorescent, induction, and HID offer far superior efficiency in their ability to transform electrical energy into visible light. The use of these light sources is becoming more prevalent as the costs of initial research and development are amortized and the scale of production reduces unit costs. (2) The Main issues for various lamps type which are used in learning spaces should be defined according to lamp characteristics (3).Following are the main characteristics that influence lamp selection: (4)

- Efficiency- lumens of light per watt of electricity
- Color perception of the lamp – does the light appear warm or cool?
- Color rendering accuracy – does the lamp show true colours or not?
- Lamp life
- Dimming capabilities
- Instantaneous light – does the lamp take some time to reach full output?
- Instantaneous re-strike – does the lamp take some time to switch on when hot?

[1] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 13
[2] Http://Www.Boles.De/Teaching/Mm/Pages/Light-Fundamentals.Html
[3] Check Appendix C : The Main issues for various lamps type
[4] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 13

Following are the main aspects for fitting the lamps in different learning spaces according to their specifications: (1)

- Compact fluorescent lamps are now the most usual replacement for the common incandescent lamps. Compact fluorescents can have an integral or a separate control gear. Lamps with an integral gear are a direct replacement for standard incandescent lamps.
- Linear fluorescent Triphosphor T5 and T8 linear fluorescents are efficient in many situations due to their high efficacy. The light output is higher than that of compact fluorescents and they should be used in areas where illumination requirements are relatively high. They would be appropriate in general teaching areas, light and heavy practical areas, staff, administration and resource areas. However the higher light output demands greater glare control by the luminaire.
- High pressure discharge light sources are suitable for large volume spaces that require high light output. Although high pressure sodium light sources present very high efficacy, the quality of light is not good enough to distinguish colors clearly so metal halide discharge lamps are preferred because of their good color rendering.

There are a lot of developments in lighting with the use of light emitting diodes (LED).These incorporate a high purity semiconductor which, when activated electrically, generates light. Some of the latest developments use lenses on the top of the LED to direct the light coming out, either concentrating it in narrow and long light beams or wider and shorter light beams.

3.4.6.3. Luminaire

The luminaire holds the lamp and directs light in the required direction. The luminaire is known as the frame to which lamps and other required components (such as ballasts, reflectors, lamp sockets etc.) are fixed. It includes all these components for connecting them to the electricity supply. It also provides the optical control which ensures that the light is directed to where it is required as well as shielding it from those areas where it is not needed. This involves the use of reflectors, refractors and/or diffusers. (2) There are various types of diffusers available used in ceilings and wall mounted luminaries, such as:

- Prismatic – which scatters the light
- Louvered – which shields and directs the light.

i. Ceiling Mounted Luminaire

The type of luminaire selected depends on the ceiling height and type. In high-ceilinged spaces, suspended direct-indirect luminaires provide down lighting and reflected light from the ceiling. Well-designed indirect lighting systems provide low-brightness and shadow-free illumination. Many learning spaces however have low ceilings that necessitate ceiling-mounted or recessed luminaires. (3) One of the critical factors affecting the choice of luminaire is the way light is distributed (how much is directed downwards, outwards and upwards).The light distribution of luminaires may be: (4)

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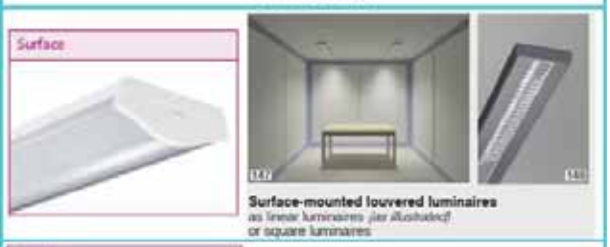
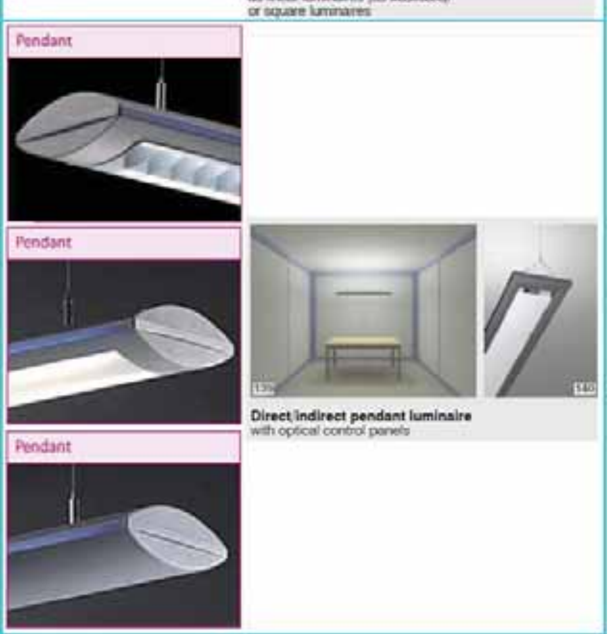
[1] Standard Specifications Layouts And Dimensions- Lighting In Schools,UK DCSF, p. 15
[2] ibid, p. 13-15
[3] IESNA, IESNA Lighting Handbook, p. 12.6
[4] BRANZ , Designing Quality Learning Spaces: Lighting ,P27

• Direct: all the light is directed down to the working plane as it is with recessed luminaires.
• Semi-direct: some light is directed down and some is allowed to reflect off the ceiling and walls to light the working plane.
• Indirect: all the light is reflected from walls and ceiling to the working plane.

Luminaires with direct and indirect lighting components also permit free arrangements of desks, reduce the risk of reflected glare and create a more agreeable lighting atmosphere. [(1)] Pendant luminaires are able to provide a good balance between direct and indirect lighting and are the most suitable for teaching spaces in general.Table 3-4 illustrates different types of luminaire and the qualifications of each one.

Table 3- 4: Types and qualifications of luminaires

Selecting luminaires for classroom lighting		
Recessed	• generally only suitable for suspended ceilings • generally give direct light • may be fitted with a range of diffusers • may have a high degree of glare • do not light the ceiling	
Surface mounted	• suitable for most ceilings • may give direct light and some indirect light, depending on the design and type of diffuser used • may throw some light on the ceiling • glare is reduced by some indirect lighting	
Pendant	• suitable for most teaching spaces • may give direct light and a high proportion of indirect light, depending on design • can light the ceiling • minimum glare and even spread of light	

Source: Standard Specifications Layouts and Dimensions- Lighting in Schools, Designing Quality Learning Spaces-Lighting, Designing Quality Learning Spaces: Lighting

[1] Winter, Clive. Good Lighting for Schools and Educational Establishments ,P4

ii. Wall mounted luminaire for whiteboards

Proper selection and installation of the board lighting luminaire should ensure that the lamps in the fixtures will not be visible to students seated in the front rows. Whiteboard lights should be far enough away from the surface to avoid having the light trapped above the board as shown in figure 3-32. Board lighting should not cast any light on projection screens. Whenever possible this should be achieved by placing the lighting behind the screens (between the screens and the whiteboard) and sitting it directly on the top edge of the board. This requires that the lighting have a narrow profile so the screen doesn't need to be too far forward. In cases where the nature of the screen mounting precludes this, lighting fixtures should be selected that sufficiently control the spread of the light so that no light spills over onto the adjacent projection screen. [1] Figure 3-33 illustrates different profiles for whiteboard lighting luminaires and their area for illumination.

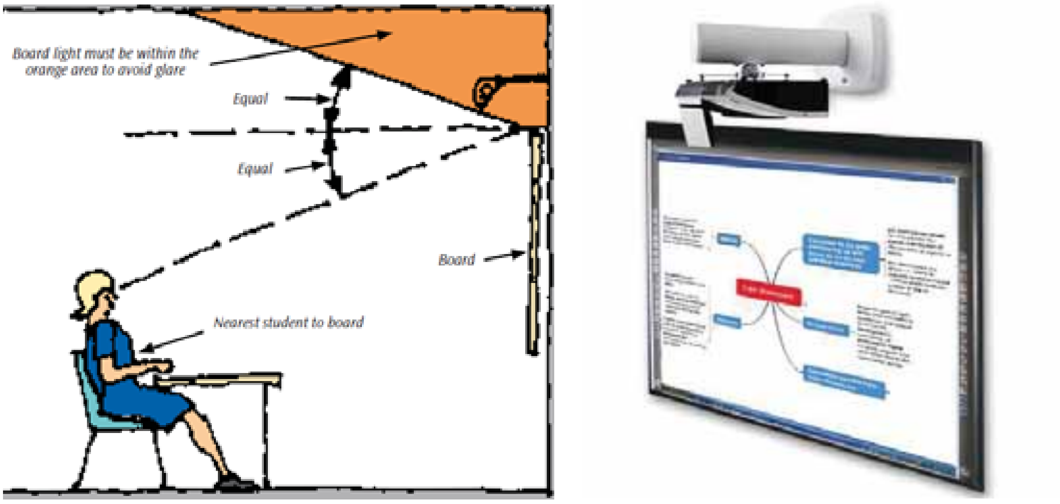


Figure 3- 32:shape and location of white board wall mounted luminare
Source: Designing Quality Learning Spaces: Lighting, p. 32

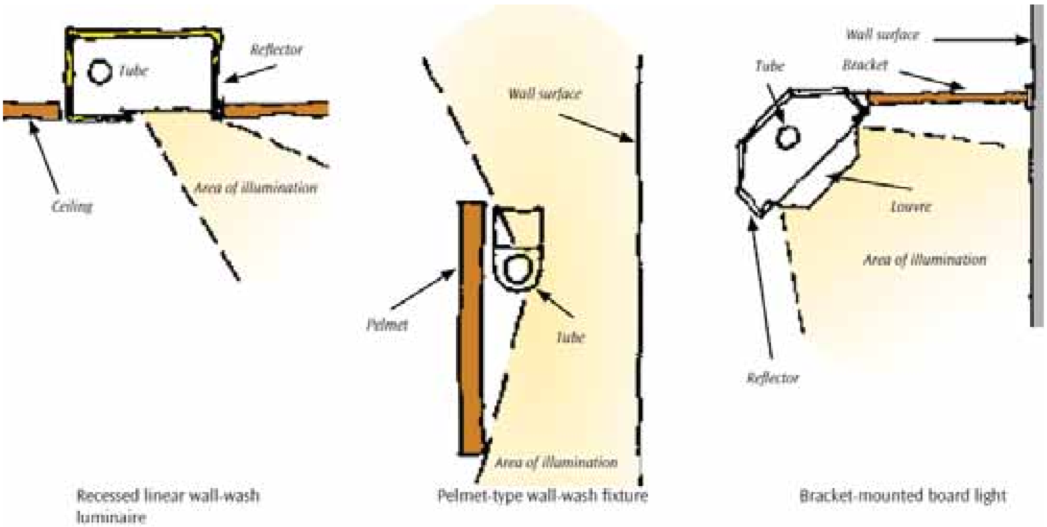


Figure 3- 33 : Vertical Illuminance-Lighting for Interactive Whiteboards

[1] Classroom Design Manual Guidelines for Designing, Constructing, and Renovating, Instructional Spaces at the University of Maryland , p. 25

Source: Designing Quality Learning Spaces: Lighting, p. 32

3.4.7. Lighting Management and Control System

Due to the increase of environmental concerns, lighting control systems will play a significant role in the reduction of energy consumption of the lighting without impeding comfort goals. The main purpose of these systems is to reduce energy consumption while providing a productive visual environment. This includes: (1)

- Providing the right amount of light
- Providing that light where it's needed
- Providing that light when it's needed

3.4.7.1. Types of Control System

Each zone where lighting is to be used should be evaluated for the best strategy of control. There are two main types of zone control. The first one is manual control which includes the way the switches are linked to individual and groups of luminaires which will disscused in this section. The second one is automated control which can react to presence detection, daylight availability or time of day. Automated control will be disscused in detail in the next chapter.The main control strategies are outlined below in figure 3-34. (2)

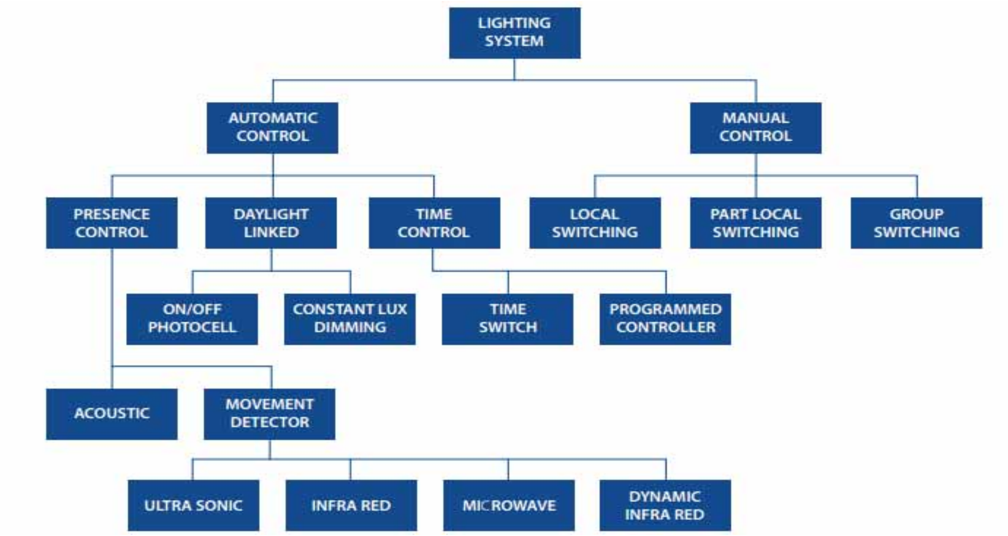


Figure 3- 34: Types of Lighting control systems
Source: Lighting Controls, p. 2

These cortrols can be used for switching or dimming and are fixed either :

- wired (such as the standard wall switch)
- ceiling mounted pull switches

Part switching and group switching allows a certain number of luminaires or lamps to be controlled from local locations e.g. with appropriate separate 'zones'. On bright days the luminaires closest to the windows would not need to be switched on and would therefore save energy. While manual controls are cheap to install, they still rely on the occupants turning lights off when they are not needed. Table 3-5 illustrates differences between manual and swiching group lights.

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[1] General Lecture Hall Design Guidelines ,University Of Maryland , p. 18
[2] Seai , Lighting Controls, p. 1-3

Table 3- 5: The difference between manual control switches and switching group lights

Selecting lighting controls	
Switching lights in groups	• allows lights to be turned off, or dimmed, in part of a room that has sufficient daylight • a bit more expensive to wire groups of lights to separate switches
Manual control switches	• education about saving power may lead to savings • lights are likely to be left on even when there is sufficient daylight

Source: Designing Quality Learning Spaces: Lighting, p. 28

Lighting management systems are particularly useful in assembly halls. Artificial light is perferd in large audoturiums. At the push of a button, they enable pre-defined lighting scenes to be created for every occasion. Entrance areas, seating areas and stages can thus be bathed in the right quantity of light delivered in the right kind of beams. (1)

3.4.7.2. Place switching and Other Control Devices

This step in the lighting design process is primarily one of logic and common sense. User paths, space usage, and user convenience should be studied as a guide to good switching and control systems. (2) Learning space lights should conveniently be controlled from the instructor station and clearly labeled. In addition lighting control should have a minimum of four options: full-on, two projection settings (medium and low) and full-off. (3) Back-lit switches should be placed at every learning space entrance to provide at least minimal room illumination so users never need to enter a dark room. (4)

Repeated experience and familiarity with control technology creates workable and user-satisfying solutions. However there are more recent developments in controls that automate energy management or user convenience functions which will be discussed in detail next chapter. (5) Figure 3-35 illustrates samples for switches that should be installed in learning spaces.

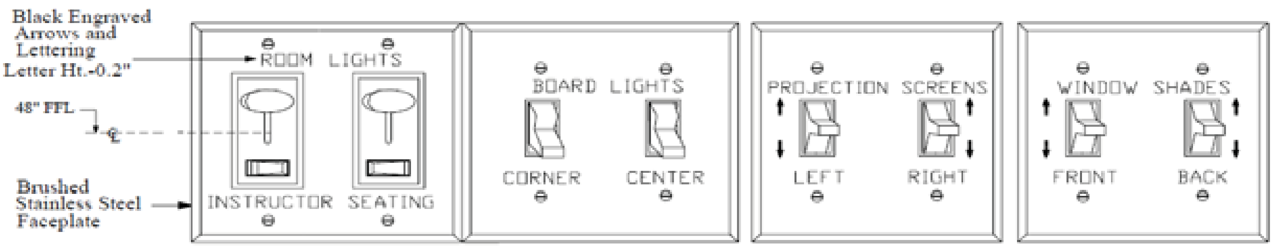


Figure 3- 35: Samples for switches at learning spaces
Source: Learning Environments, P55

[1] Winter, Clive. Good Lighting for Schools and Educational Establishments , p. 12
[2] Mark Karlen, James R. Benya And Christina Spangler , Lighting Design Basics, p. 67
[3] General Lecture Hall Design Guidelines ,University Of Maryland , p. 5
[4] The University of Iowa ,General Assignment Classroom Design Standards, p. 2.2,6
[5] Mark Karlen, James R. Benya And Christina Spangler , Lighting Design Basics, p. 67

3.5. Lighting Special Needs in Smart Learning Spaces [(1)]

Smart learning spaces, especialy in small classrooms which have movable furninture, are often used by different classes have special needs. In many cases they are occupied by univeristy groups in the mornings, by project groups in the afternoon and used for other education courses in the evening. As a result desks and chairs are repeatedly rearranged to meet the different requirements. So daylight and artificial lighting need to be harnessed to cater for this flexible space use.

The main issues with daylight design here is when desks are assembled in u-shaped arrangements or put together to form group desks, as many of the group face the window. On a sunny day, the luminance for anyone looking out of the window may be tens of thousands of candelas, whereas the luminance for eyes turned into the room is considerably lower. So for balanced brightness distribution, louver blinds or vertical blinds are needed to control daylight incidence according to the position of the sun for avoiding glare. Modern lighting control systems with daylight senosors automatically adjust the angle of the blinds and adapt the artificial lighting component accordingly. Classes no longer need to be interrupted while someone closes or opens blinds or regulates the room lighting.

Artificial lighting for variable layouts of desks needs to be designed to minimize glare. Lamps should not be directly visible from anywhere in the room. Luminaires with direct/indirect lighting components and appropriate shielding are particularly suitable here. They permit free arrangements of furnishings and largely avoid direct glare and reflected glare on glossy materials. They also encourage communication-intensive teamwork .

3.6. Conclusion

The main goal of educational facility lighting is to provide a visual environment for both students and instructor that are supportive of the learning processes. Daylighting achieves a 20% improvement in student performance in learning spaces. Therefore natural lighting should be the main light source in the daytime due to reasons of quality of light, health issues and sustainability. However it is unpredictable as it varies in intensity, color and direction over time so artificial light should be used to supplement natural lighting.

The visual environment design process in learning spaces consists of many steps. Those steps start with defining light sources that should be used inside the space, then defining visual tasks and the illuminance needed for them according to codes, regulations, international metrics and rating system as shown in following tables (3-6) and (3-7). Also the strategy for the daylight and artificial light system should be defined and finally the suitable control system which will manage these system together must be choosen.

[1] Winter, Clive. Good Lighting for Schools and Educational Establishments , p. 10

Table 3- 6: Conclusion for Metrics according to LEED V4 and Approved IES

Metric			Sky Types	Minimum Threshold	Maximum Threshold	Annual Calculations
Quantity Metrics	Static shading device	Daylight Factor	CIE Overcast	2-5 %	NA	Yes
		Daylight Autonomy	All	300	NA	Yes
		Continuous Daylight Autonomy	All	300 (partial count for points below)	NA	Yes
		Useful Daylight Illuminance	All	100	2000	Yes
		Daylight Availability	All	300	3000	Yes
	Dynamic shading device	Single Point in Time	All	300 lux	NA	No
Quality metrics		Spatial daylight autonomy sDA	All	55% LEED 2 points 75 % LEED 3 points	NA	Yes
		Annual sunlight exposure $sDA_{300, 50\ \%}$	All	0%	10%	Yes

Table 3- 7: Illuminance values according to visual tasks inside group teaching learning space

Task	Teacher	Student	Standard Illuminance
1	Writing on whiteboard	Reading whiteboard	500 lux (vertical)
2	Talking to the students	Paying attention to the teacher	300 lux
3	Showing presentation on screens	Looking onto the screen	300/10 lux
4	Paying attention to working students	Writing and reading	300 lux

A university prefers to install blinds or louvers in learning spaces' windows because they can controlled glare, redirect daylight and guide lighting into the space. Also the automated ones can control the view and room darkness in case of presentations but only when they are under control of the instuctor.

Provision of daylight inside learning spaces needs large glass windows. The large expanses of glass and the thermal impact of artificial light cause an increase in energy consumption. Therefore smart technology, smart glazing, windows and smart shading devices should be used to reduce these loads and also to enhance daylight quality inside learning spaces as will be discussed in the next chapter.

4.1. Introduction

Sustainable issues and smart architecture have been raised as hot topics especially in designing learning spaces and educational institutions in order to reduce energy consumption and increase a space's efficiency at the same time. According to the studies of previous chapters, lighting and lighting control systems represent a significant contribution to the energy consumption of learning spaces and of a university. Therefore, they need to be studied and redesigned using the new methods such as smart techniques and smart systems to provide learning spaces with a high quality of visual environment compatible with their new needs. This chapter will discuss how smart architecture changed the daylighting design process for smart learning spaces as shown in figure 4-1.

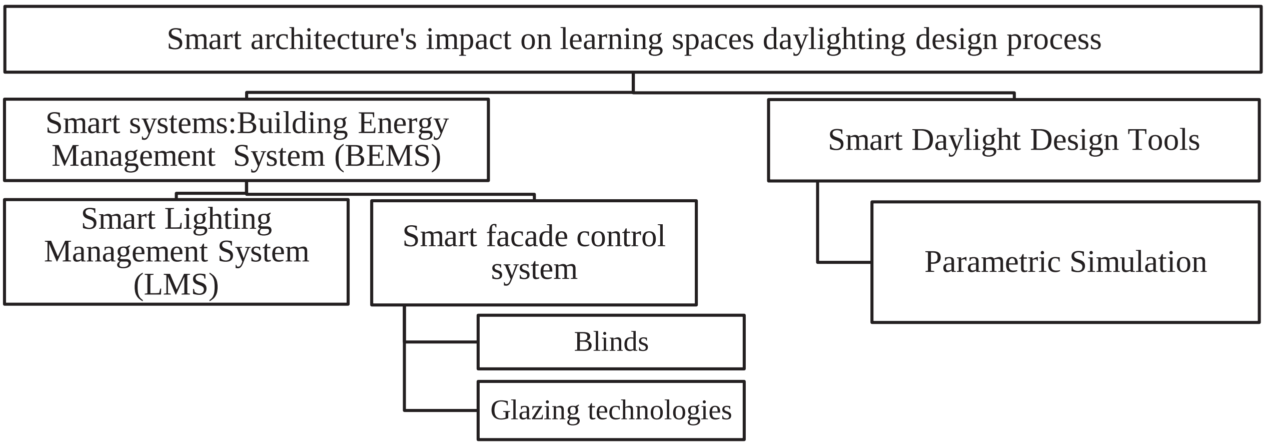


Figure 4- 1: Smart Architecture's impact on learning spaces daylighting design process

The smart integrated lighting system is controlled either by Lighting Management System (LMS) only or by integration between LMS with Building Energy Management System (BEMS) (1). A lot of strategies and solutions can be used by LMS and BEMS to reduce lighting energy consumption and enhance a spaces behavior. BEMS has three levels of integration LMS, LMS integrated with smart façade and LMS integrated with smart façade and HVAC.

Façades are the energy filters that should be the starting point of the building design process. A smart façade system creates the possibility for overall energy reduction for heating, cooling and lighting. Moreover it can prevent solar heat radiation from entering the building when it is not needed. The two main components which control these issues are windows and shading devices (blinds or louvers). Therefore, this chapter focusses on standalone LMS and BEMS in integration level of LMS with smart façade.

Daylight harvesting is the most important strategy of LMS which can lead to a significant reduction of energy consumption by smartly adjusting the light flux according to the daylight level. The operating hours can be reduced by adjusting lighting according to predicted or real occupation strategies.

[1] ICLS, Breakthrough Lighting For Today's Changing Classrooms , p. 2-3

Smart architecture simulation tools have completely changed lighting design processes. Nowadays by simulations, parametric design and algorithms, a lighting designer can investigate a lot of strategies and daylighting systems to find the optimal solution for the learning space lighting and energy consumption. He can also choose smart features and techniques under an integrated systems umbrella.

4.2. Role of Smart Integrated Systems in Smart Universities

A smart system is an autonomous operation which detects the environment changes through sensors and acts to correct the offset caused by the environment. Moreover the systems continually perform to reach the optimal result that is pre-defined in the system. A smart university aims to get effective learning spaces by using information and communications technology (ICT). Smart systems help achieve this goal by supporting the user behavior transformation and the interaction between the user and the building's intelligent energy management system. A smart university can expect an impact of substantial energy savings of up to 20% of total saving by using smart integrated systems with a smart user. So the effective smart integrated system should balance the preset definitions with the user preferences, therefore creating a bidirectional learning process between the building and the users (1).

According to the previous studies in chapter one, integrated systems range in levels of effectiveness. The best one of these levels is Enterprise Network Integrated System which provides a full integration to the university with other educational and state institutions in addition to connection with international information system to achieve the maximum reduction of energy consumption. This thesis focusses on reducing lighting loads at learning spaces which is the function of Building Energy Management system (BEMS) in Computer Integrated Building level as discussed before. Therefor it will be discussed in the following part in order to study its main missions.

4.3. Smart Building Energy Management System

Building Energy Management System (BEMS) is one of sub components of an environmental control system. It is the place where the system chooses the effective control strategy to be used from the following strategies in order to get maximum energy saving at the university:

- LMS: which is the main system for controlling lighting strategies.
- LMS integrated with smart façade (shading and windows).
- LMS + smart façade + HVAC.

Figure 4-2 illustrates the levels of BEMS integrations and the effect of this integration on total energy consumption. The energy consumption is reduced whenever the BEMS integration level is increased, i.e. the maximum energy consumption is reached in the case of non-control and it is gradually decreased by using; LMS then LMS integrated with smart façade and the maximum conservation is achieved in level of integration between LMS+ smart façade +HVAC.

[1] http://ec.europa.eu/information_society/apps/projects/factsheet/index.cfm?project_ref=297251

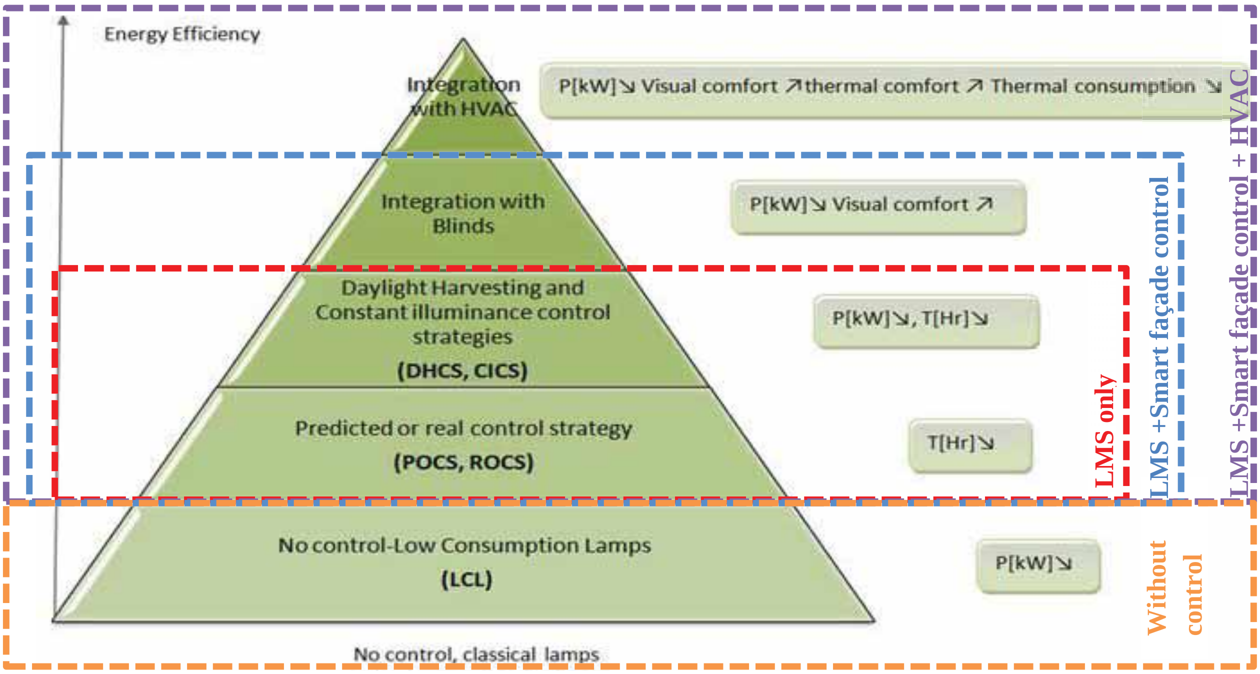


Figure 4- 2: Relation between control level and energy efficiency.
Source: IEA, Guidebook on Energy Efficient Electric Lighting for Buildings, p. 143

4.3.1. Lighting Management System (LMS)

The manual control, which is just an on/off switch for individual luminaires or a group of luminaires, is not efficient enough for energy efficiency as it depends on the behavior of the user. Lighting Management System (LMS) is responsible for the lighting control system and as well as strategy. Lighting control system reduces lighting power during electricity peak-use periods which is when energy rates are at the highest. An optimal lighting control system's performance needs not only to reach a good performance with respect to saving electrical energy, but also to be accepted by students and the instructor as well. Thus it should take into consideration the following performance parameters: [(1)]

- Visual performance and comfort.
- Building energy use.
- Cost effectiveness.
- Ease of use.
- Maintenance
- Flexibility (versatility).
- Systems integration.

ASHRAE 90.1 [(2)] sets the following rules for a building's and space's light control system to achieve user convenience and also save energy. Then it sets the work flow, which is illustrated figure 4- 3, for designing the control lighting steps in a building and a space as well[(3)].

[1] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 143
[2] ASHRAE, founded in 1894, is a global society advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry.
[3] http://www.lutron.com/en-US/Education-Training/Pages/EnergyCodes/Ashrae.aspx

- Buildings larger than 465m^2 must use an automatic control device to turn off lighting in all spaces.
- Space that is enclosed by ceiling-height partitions must have at least one control device that independently controls the general lighting in the space. Each control device shall be activated either by an automatic motion sensor or manually by an occupant.

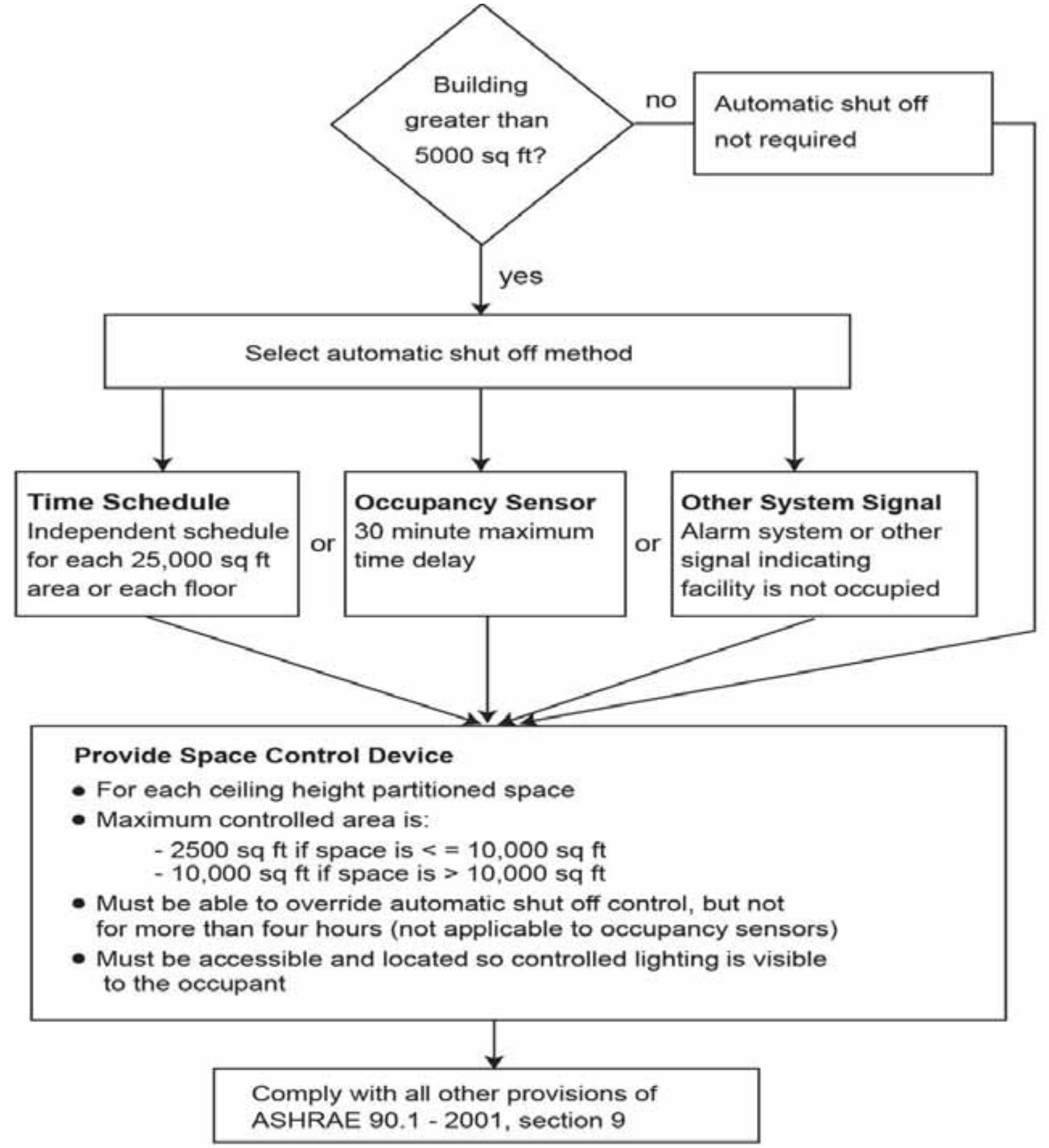


Figure 4- 3: Automatic Lighting Shut Off Compliance Guideline for ASHRAE 90.1 – 2001
Source: Lighting Control Best Practice Guide, p. 57

Therefore lighting controls should be configured to manual-on operation or, if automatic-on is desired, the space must be wired and controlled such that no more than 50% of the general lighting will turn on automatically.

4.3.1.1. Lighting Control System Mission in Smart Learning Spaces

The external daylight conditions, the occupancy and the use of smart learning space are constantly changing. Control of a lighting system is required to meet these changes. The main mission of lighting control systems in universities and learning spaces is to save their energy and provide them with various visual modes.

i. Energy conservation [1]

According to Energy Information Administration (EIA) electricity expenditures account for 72% of energy costs in educational buildings and of that, more than half is for lighting energy costs. Annual lighting energy consumes around 36 billion kWh as shown in figure 4-4. Also another study determined that electrical costs account for half of the total utility costs incurred by educational facilities. Therefore a global grid based electrical consumption for lighting, which depends mainly on lighting control systems, should be designed.

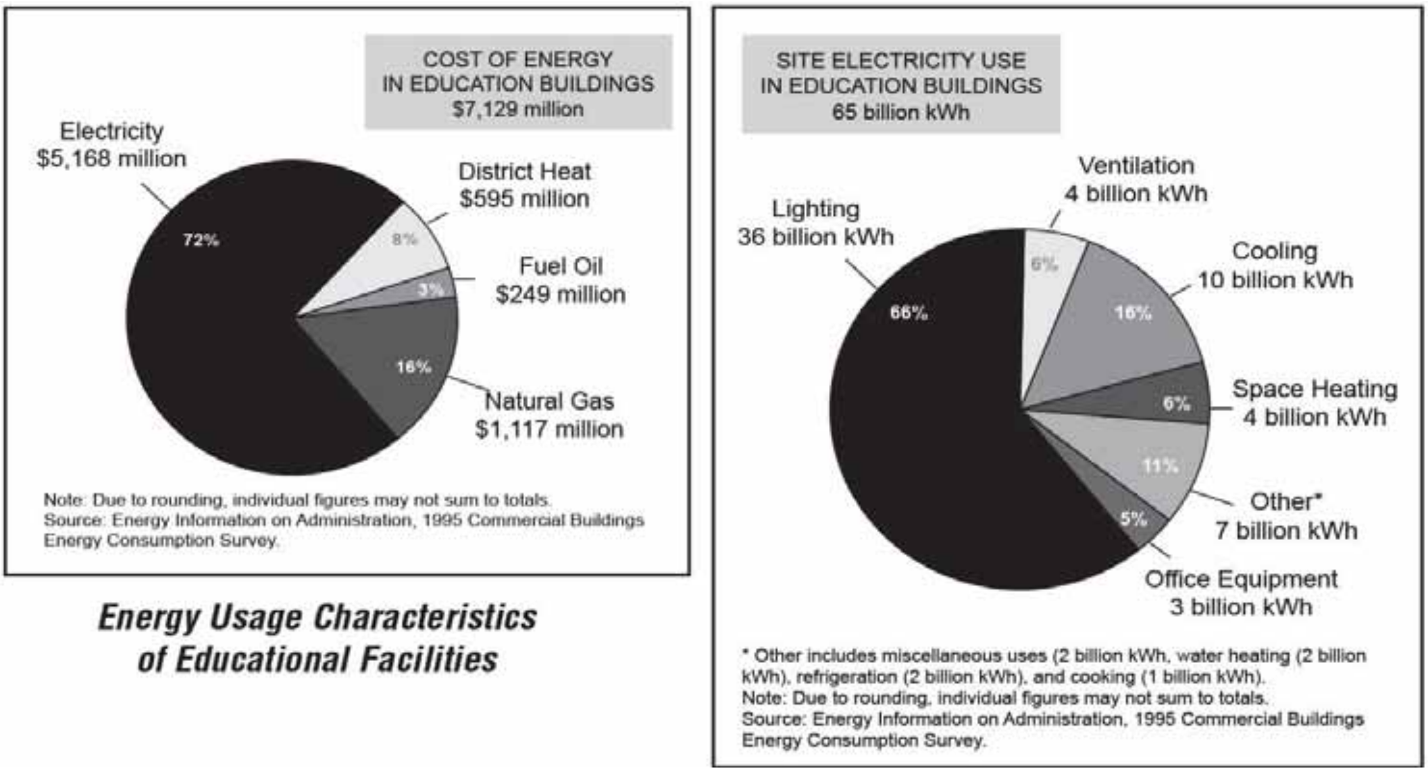


Figure 4- 4: Energy usage characteristics at educational facilities according EIA
Source: Lighting Control Best Practice Guide, p. 2

The use of lighting controls can reduce these expenditures significantly. Expected savings from the use of occupancy sensors in learning spaces alone can range from 10% to 50%. These savings are realized simply by turning lighting off when the rooms are unoccupied and lighting is not necessary. Other lighting controls can reduce lighting energy usage as well. For instance the EPA has estimated that the use of daylighting controls can result in savings ranging from 15% to 40%. Perhaps most importantly, these savings can be realized without affecting the quality of educational activities or the efficacy of the learning environment.

[1] The Watt Stopper, Lighting Control Best Practice Guide, p. 2

ii. Create More Flexible Space with Various Visual Modes

Control of a lighting system is required to be adaptable with the requirements of variable visual environments which are needed for different activities or functions inside learning spaces. For instance a lecture theatre is often used for PowerPoint presentations so the luminance level in the space should be at a lower level, thus allowing the audience to see the slides presented on the screen clearly and comfortably. When the instructor is speaking without a PowerPoint presentation, a higher luminance level is preferred to allow pleasant and effective communication. With the use of LMS, building operators will be able to record lighting scenes or predefine scenarios for these different needs. For instance a simple push on a button could select a video projection scenario which would consist of dimming light level, lowering blinds and setting down the screen. [1] Figure 4-5 illustrates a sample for teacher control station programing and how it enables him fully control lighting inside a learning space in order to accommodate different scenarios and strategies related to what teaching process will be used.

Teacher Control Station Programming

The Academy Pack is versatile and can be configured for any number of lighting and daylight scenarios including skylights and shade control. Shown below are several examples of typical classroom configurations. Whether it's time to view a movie or focus on the whiteboard, lighting levels in multiple zones can be pre-configured or adjusted for each activity.

TYPICAL PROGRAMMING	BUTTON FUNCTION
TEACH / PRESENT - turns on partial lighting and enables the photosensor and occupancy sensor	SCENE
AV - light level is reduced and the photocell is disabled	SCENE
ENABLE SLIDER - allows dimming of lights in an active zone (dimming only)	SCENE
ALL ON - turns on all of the lights (switching only)	SCENE
ALL OFF - turns off all of the lights	SCENE
WHITEBOARD - turns on the lights above the whiteboard	TOGGLE ON/OFF
DOWNLIGHTS - turns on the downlight luminaires	TOGGLE ON/OFF
UNDER CABINET - turns on the lights under cabinetry	TOGGLE ON/OFF
ENERGY SAVER - turns on the minimum amount of lighting	OVERRIDE/TIMER
QUIET TIME - the occupancy sensor is disabled, leaving the light level unaffected for one hour	OVERRIDE/TIMER

Figure 4- 5 : Teacher control station programing
Source: Academy Pack Lighting- Control & Design Guideline, p. 6

In addition, a learning space could have visual modes settings consisting of Normal, Focus, Energy, and Calm, which were designed to correspond with various learning spaces activities. These settings can be selected by the instructor via a control panel as shown in figure 4-6, the following are the main functions for each mode: [2]

- The Normal setting can be used for regular learning spaces activities.
- The Focus setting can be employed when students have to concentrate, such as for tests.
- Energy is a setting designed for use during times of day when students experience a reduction in energy, usually in the morning and breaks.
- The Calm setting is designed for group activities requiring cooperation or to support the students in settling down when students are overactive.

[1] Wang, Shengwei. Intelligent building and building automation, p. 207-208
[2] Mott, Michael S., et al. Illuminating the effects of dynamic lighting on student learning. p. 25

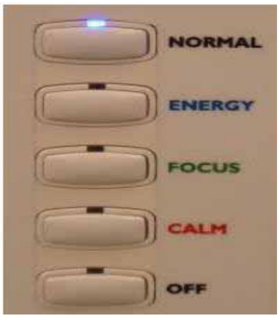


Figure 4- 6: Modes of lighting at learning spaces
Source: Illuminating the Effects of Dynamic Lighting on Student Learning, p. 24

4.3.1.2. Energy Conservation Strategies of Lighting Control System

Smart integrated systems should be installed in learning spaces to achieve the following lighting control strategies. These strategies may be achieved manually or automatically depending on user needs and the level of integration between BEMS and LMS systems. (1) Moreover each of these strategies must provide a level of room darkness when learning space is dimmed for projection (2). During these times of darkness, special lighting on the instructor's equipment rack or technology controls should be installed. (3)

i. Predicted Occupancy Control Strategy(POCS) (4)

The Predicted Occupancy Control Strategy (POCS) is used to reduce the operating hours of lamps. It saves energy by turning lighting on and off according to a preset daily time schedule as shown in figure 4-7. Schedules usually vary according to the university's occupancy. The systems assist university operation managers to avoid having the lighting on during unoccupied hours, mainly at night and at weekends.

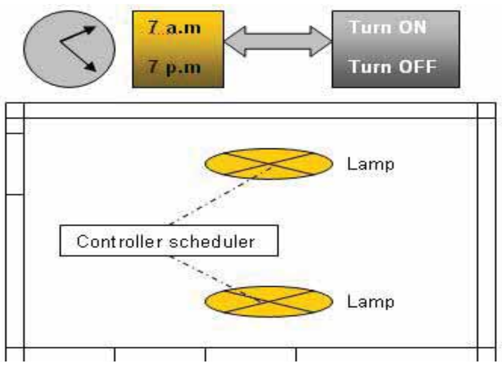


Figure 4- 7: Predicted Occupancy Control Strategy components
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 144

ii. The Dusk or Dawn Control Strategy

The Dusk or Dawn Control Strategy is a type of predicted occupancy strategy based on sunrise and sunset which can be calculated for a university's location. Light is switched on automatically when it gets dark and off when there is enough daylight as shown in figure

[1] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 144-150
[2] The University of Iowa ,General Assignment Classroom Design Standards, p. 2.2,5
[3] General Lecture Hall Design Guidelines ,University Of Maryland , p. 18
[4] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 145

4-8. This strategy is not necessarily achieved with an outdoor daylight sensor, but it can be achieved by a scheduler.

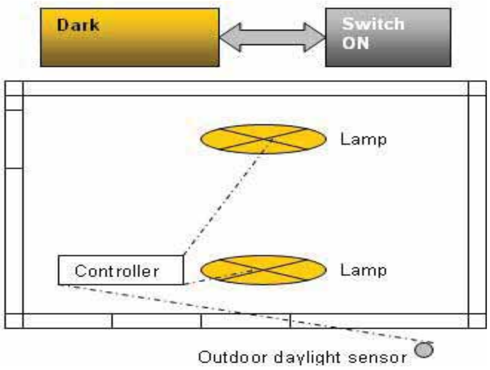


Figure 4- 8: The Dusk or Dawn Control Strategy components
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 145

iii. Real Occupancy Control Strategy (ROCS)

Real Occupancy Control Strategy limits the operation time of the lighting system based on the occupancy of the space as shown in figure 4-9. A delay time, which ranges typically from 10 to 15 minutes, can be programmed to prevent the system from turning the lights off while the space is still occupied. (1)

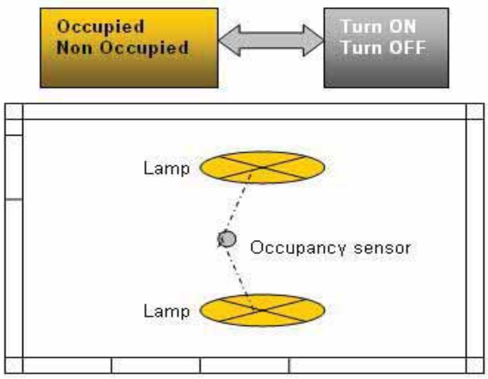


Figure 4- 9: Real Occupancy Control Strategy components
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 145

Sometimes in large lecture halls and auditoriums space is divided to zones. The system detects when the room is occupied and then turns the lights on according to following cases depending on the zones in figure 4-10:(2)

- Case 1: Whenever the lecture hall is unoccupied, the lighting in the lecture hall will be turned OFF.
- Case 2: When a small number of students occupies the hall, (e.g. only zone (a) and zone (d) occupied by student) all the lights in this zones should be turned ON.
- Case 3: Whenever the lecture hall is full occupied, the lightings in the lecture hall will be turned ON.
- Case 4: Lecturers are having presentation on the projector screen.

1 IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 145
2 Design Guidance: Learning Environments, University Of Cincinnati p. 52-55

Figure 4- 10: Studesnts area zones
Source: Learning Environments, p. 53+editing by researcher

iv. Constant Illuminance Control Strategy (CICS)

The Constant Illuminance Control Strategy uses a sensor to measure the lighting level within a space or determines the predicted depreciation of the lighting level. If the light level is too high, the system's controller reduces the lumen output of the light sources. If the light level is too low, the controller increases the lumen output of the light sources as shown in figure 4-11. The result is a system that minimizes lighting energy use while maintaining uniform and constant lighting levels.

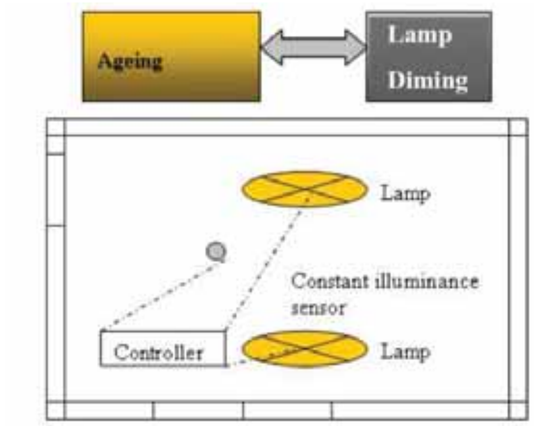


Figure 4- 11: Constant Illuminance Control Strategy components
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 146

v. Daylight Harvesting Control Strategy [1]

The Daylight Harvesting Control Strategy (DHCS) allows facilities to reduce lighting energy consumption by using daylight, supplementing it with artificial lighting as needed to maintain the required lighting level. The Daylight Harvesting Control Strategy uses a photocell to measure the lighting level within a space, on a surface or at a specific point. If the light level is too high, the system's controller reduces the lumen output of the light sources. If the light level is too low, the controller increases the lumen output of the light sources as shown in figure 4-12. Sensors are often used in large areas, with each sensor controlling a separate group of lights in order to maintain a uniform lighting level throughout the area. The result is a system that minimizes lighting energy use while maintaining uniform lighting levels. This system can also provide the constant illuminance strategy.

[1] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 146-147

Figure 4- 12: Daylight Harvesting Control Strategy components
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 146

The previous strategies should be used inside smart learning spaces not only for providing them with a good visual environment but also for the reduction of their energy consumption. Table 4-1 illustrates comparison for the advantages and disadvantages for each strategy and also the spaces for which they are used.

Table 4- 1: Lighting control strategy analysis

Strategy	Predicted occupancy	Real occupancy	Constant illuminance
Main Advantages	-Low costs -Easy to install and use - 10 to 20 % gain	-Relatively low costs -High rate of energy saving for space with intermittent occupation for example when people regularly go through (20 to 50%[1]).	-Constant light level considering aging. - 5 to 15% gain
Main Disadvantages	-Setting of clock has to be changed if operating hours change.	-Ultrasonic sensor can be fooled by HVAC systems (vibration of air flow) -low precision sensors will cause uncomfort for the occupant.	-Sometimes high costs. -Not easy to configure.
Main Usages	-Classrooms, -Meeting rooms -Offices (open space). -Store, supermarket -Museum	-Corridors, stairwells -library stack areas, -Storage rooms -Warehouses -Toilet.	-Offices (open space), - Classrooms, - High-rise office buildings - Retail facilities.
Basic Components	-Scheduler -Time clock -Switch -Dimmer	-Occupancy sensor (Infra red or/and ultrasonic) -Switch -Dimmer	-Photosensor -Dimmer

Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 152

4.3.1.3. Components of Lighting Control System

It is possible to control each luminaire or an entire building or floor area by a connected centralized system. The lighting control system distributes power to the available lighting units in a typical fashion as shown in figure 4-13. It inserts digital controls and intelligence in many, if not all, of the devices controlling the lighting such as the circuit breaker panel, wall switches, photo cells, occupancy sensors, backup power and lighting fixtures. The control system significantly increases the functionality and flexibility of the lighting system by providing digital control and intelligence to the end devices.(1) Figure 4-14 illustrates the main components of lighting control system.

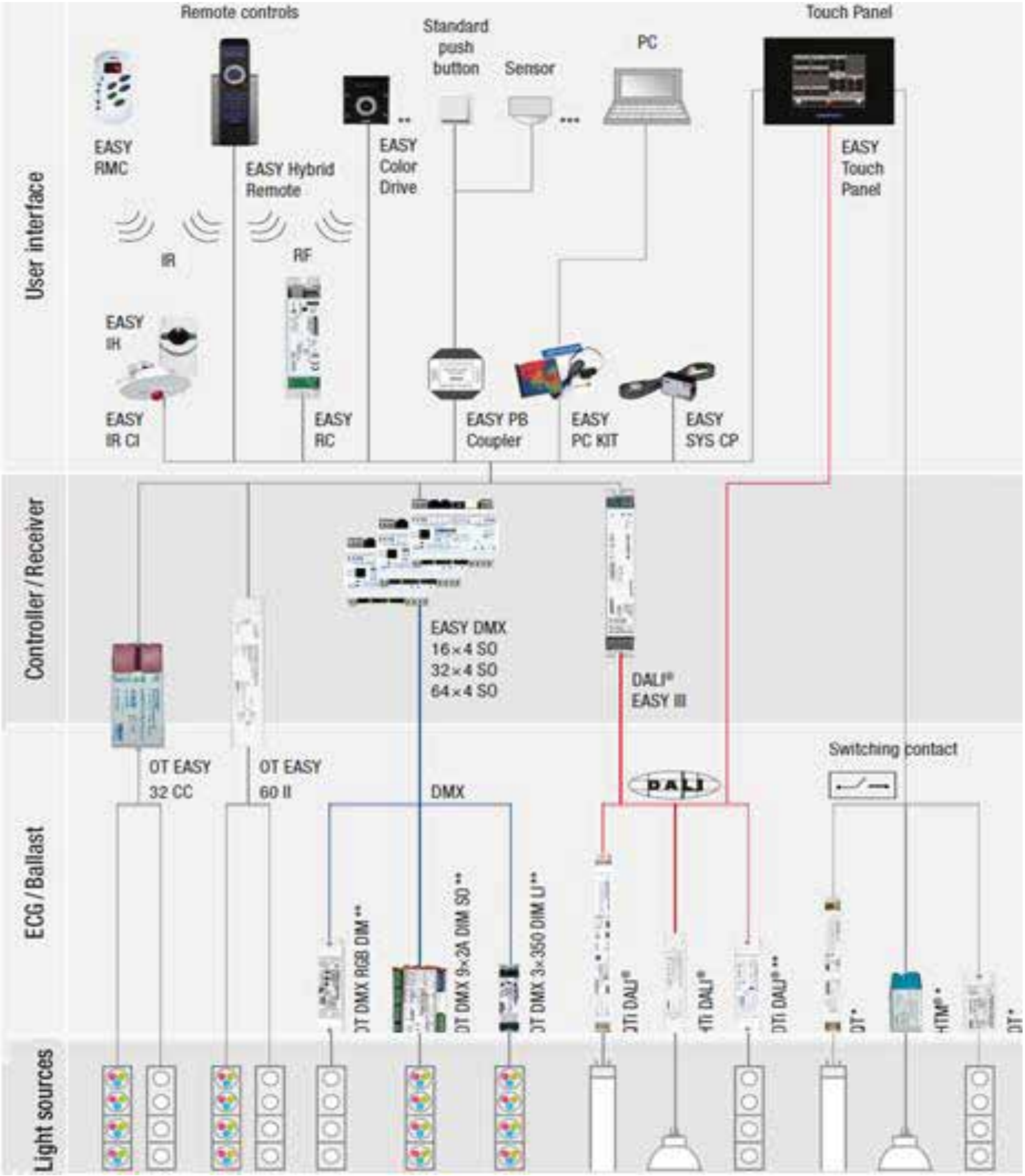


Figure 4- 13: The work flow of lighting control system –KNX control system
Source: Light Management Systems: Ambience. p. 14

[1] Sinopoli, James M. Smart buildings systems for architects, owners and builders, p. 48

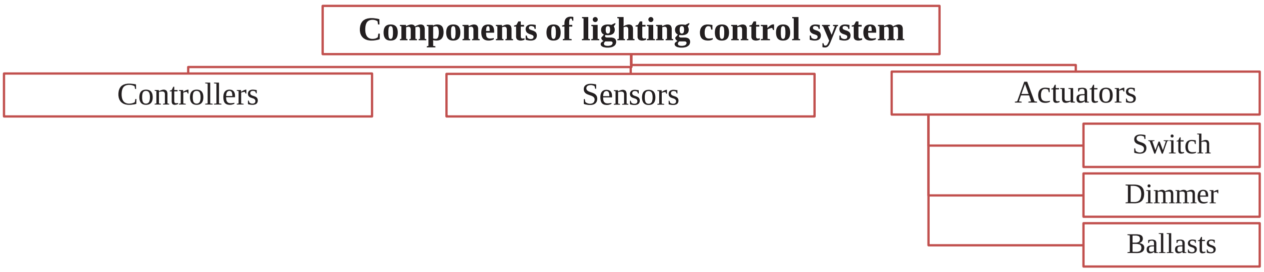


Figure 4- 14: Components of lighting control system

i. Controllers

A lighting controller is an electronic device used in building to control the operation of one or multiple light sources at once. (See figure 4-15)

Figure 4- 15: Samples for controller device
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 158

A controller is located at the beginning of a circuit (normally the distribution board or the ceiling space) and incorporates an algorithm to process the signal from the sensors and convert it into a command signal that is received by the dimming or switching unit. [(1)] The majority of lighting controllers can control dimmers which control the intensity of the lights. Other types of controllers can also control lighting according to specific scenarios. Lighting controllers communicate with the dimmers and other devices in the lighting system via an electronic control protocol (DALI, DMX, ZigBee, KNX, etc.). Controllers vary in size and complexity depending on the types of spaces and buildings scale. Figure 4-16 illustrates the workflow for the most common protocol used for lighting today which is Digital Addressable Lighting Interface (DALI). [(2)]

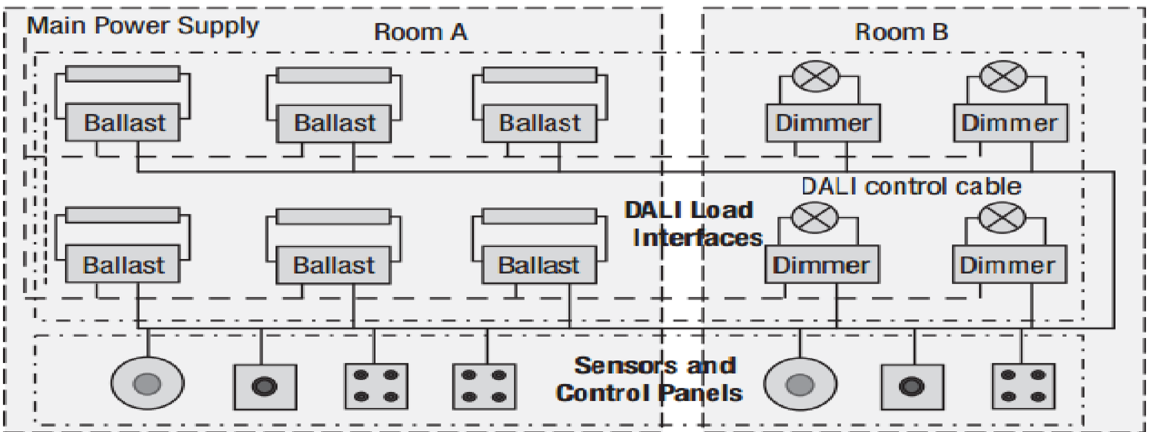


Figure 4- 16: An example of lighting-control systems using DALI protocol
Source: Intelligent Buildings and Building Automation, p. 216

[1] Johnsen, Kjeld, and Richard Watkins. "Daylight in Buildings." , p. 5-7
[2] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 157

ii. Smart Sensors

Smart Sensors are designed to reduce the wastage of energy used for artificial lighting in buildings and are ideally suited to education facilities. (1) They measure or detect a real-world condition, such as motion or light level, and convert the condition into an analog or digital representation through the use of a fully networked lighting control.

A. Specifications of Smart Sensors

- Performance factors: range, accuracy, repeatability, sensitivity, drift, linearity and response time.
- Practical economic considerations: costs, maintenance, compatibility with other components and standards, environment and sensibility to noise.

B. Types of Smart Sensors at Learning Spaces

There are many types of smart sensors that could be used for energy saving in fields such as: environment, lighting, weather, moisture, humidity, etc. This section focusses on sensors that could be used to reduce lighting loads. These sensors are divided to two main categories which are illuminance sensors and occupancy sensors as shown in figure 4-17.

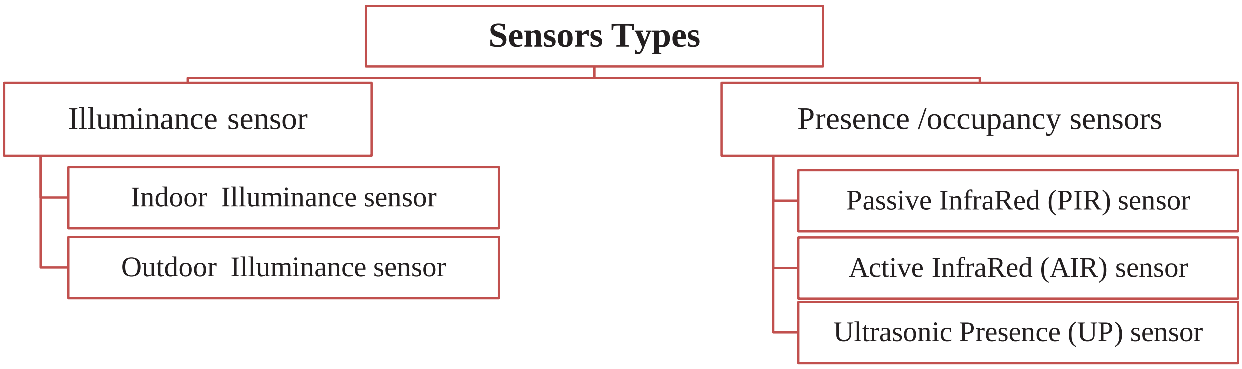


Figure 4- 17: Types of Smart Sensors

B.1. Illuminance sensor

Illuminance sensors indicate the illuminance level in the sensor detection area. They are used to measure indoor illuminance on a working plane and outdoor illuminance as well. Table 4-2 illustrates the difference between them. Illuminance sensors are mostly used to switch or to dim luminaires. Some basic illuminance sensors enable day/night detection. An illuminance sensor commands the lighting control system to dim or to switch on/off according to the daylight level. Illuminance sensors have to be placed so that they can measure the light levels which are most representative of the space. It is useful to mark the illuminance sensor's position in the lighting control panel so that building operators can find them in the future. (2)

1 Motion Sensors: The Schools Guide, My Smart, p. 1
2 IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 157-158

Table 4- 2 : The input/output and applications of the two types of illuminance sensors.

Component	Information Inputs/Outputs	Applications in buildings
Indoor illuminance sensor	Input : Illuminance on the work plane Output : Analogue or/and digital signal to controller	Visual comfort Energy consumption
Outdoor illuminance sensor	Input : Outdoor illuminance Output : Analogue or/and digital signal to controller	Energy consumption.

Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 158

B.2. Presence sensors

Presence sensors detect the presence of occupants in a space by detecting their movements. Below are the main types of presence sensors that can be used in smart learning spaces:

B.2.1. Passive Infra-Red (PIR) sensor

These sensors are the most common sensors used in buildings. PIR sensors are usually equipped with Fresnel lenses that define the zone of detection. Two kinds of PIR are usually distinguished: the movement sensor, which is illustrated in table 4-3, and the occupancy sensor. They have the same working principle but differ in the number of scanned areas.

Table (4- 3) : PIR input/outputs and function.

Component	Information Inputs/Outputs	Applications in buildings
PIR sensor	Input : Movement Output : Analogue or/and digital binary signal (occupied/not occupied)	Security Visual comfort Energy consumption

Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 158

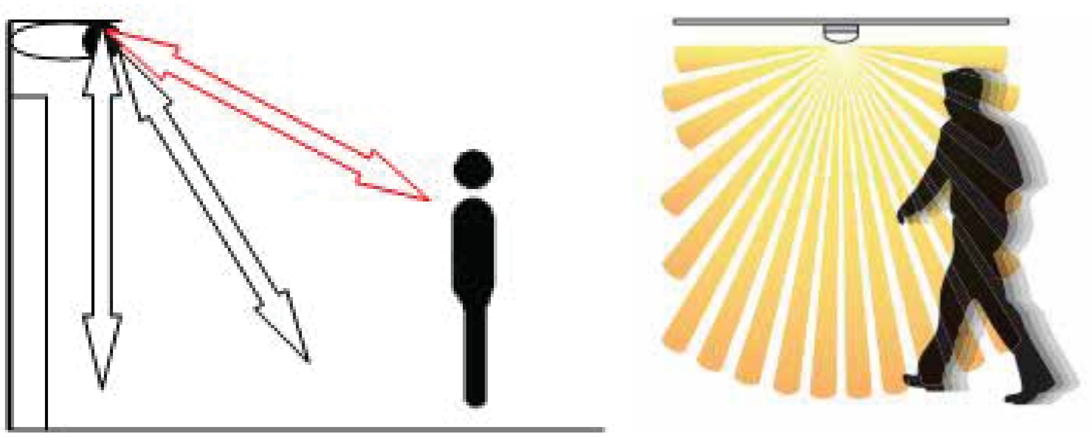
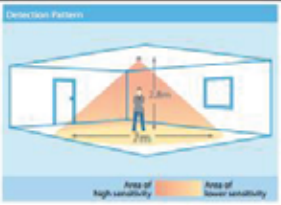
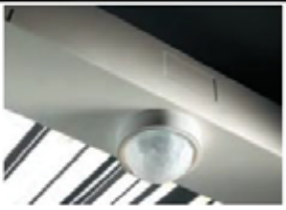
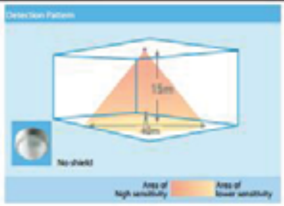
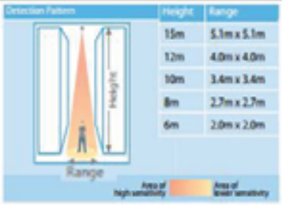
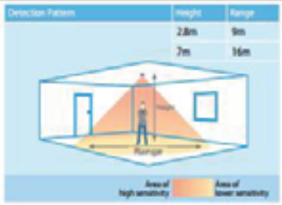


Figure 4- 18: Passive Infra-Red (PIR) sensor
Source: Sensors for an Energy Conscious World, p. 5

There are some types of sensors which can integrate more than one function, i.e. they can integrate between the measurements of illuminance and occupancy detection. These sensors are called Multi-function PIR sensors. Table 4-4 illustrates different types of multi-function PIR sensors. It mainly discusses their mission and their detection space pattern.

Table 4- 4 :Multi-function PIR sensor analysis.

Ceiling Mounted Detector	High Sensitivity Detector
  These compact detectors provide automatic control of lighting, heating and ventilation loads • Available in PRM and Direct Dimming versions • Flush or surface mount • Lux level settings for daylight harvesting • Detection pattern – 7m at 2.8m high • Up to 20 DALI or DSI dimming ballasts (DD) • Up to 10 1-10V analogue dimming ballasts (AD) • Presence or absence detection	  Hi-Sense is an increased performance PIR presence detector developed for lighting control in areas with demanding spaces and increased mounting heights or where higher sensitivity is required. • Suitable for Lighting, Heating or Ventilation • Available in PRM and Direct Dimming versions • Lux level settings for daylight harvesting • Adjustable masking shields to tailor detection zones • Verify feature to reduce false triggering • Detection pattern – 40m at 15m high • Up to 20 DALI or DSI dimming ballasts (DD) • Up to 10 1-10V analogue dimming ballasts (AD) • Presence or absence detection
High Bay Detector	**Miniature Detector**
  The EBDSPIR-HB presence detector provides the focussed detection of movement in high bay lighting applications such as warehouses and factories • Suitable for Lighting, Heating or Ventilation • Available in PRM and Direct Dimming versions • Lux level settings for daylight harvesting • Up to 20 DALI or DSI dimming ballasts (DD) • Up to 10 1-10V analogue dimming ballasts (AD) • Presence or absence detection	  This small, unobtrusive but highly capable detector is supplied pre-wired with a connector that snap fits into the power supply unit (PSU) for ease of installation and comes with a flush mounting ring for easy fitting into the ceiling. • Ultra compact design • High sensitivity head for increased detection range • Suitable for Lighting, Heating or Ventilation • Available in PRM and Direct Dimming versions • Lux level settings for daylight harvesting • Up to 10 DALI or DSI dimming ballasts (DD)

Source: Sensors the quick guide, p. 3-4

B.2.2. Active Infra-Red (AIR) sensor

Active Infra-Red devices use infrared technology. These sensors depend mainly on the air fraction between two devices; the infrared diode (sender), which constantly or episodically sends infrared rays into the controlled area, and then monitors the reflected wave levels as shown in figure 4-19. Non-appearance of a reflected ray or a modification of its properties (wavelength or amplitude) indicates a change occurred in the detection zone. [(1)]

[1] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 159

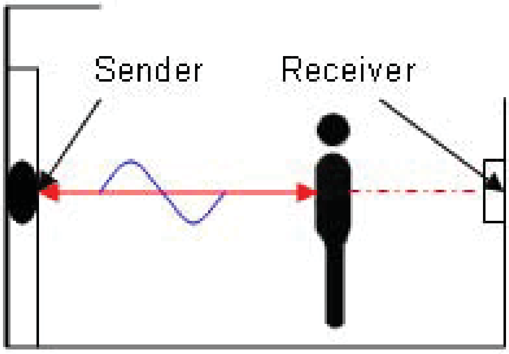


Figure 4- 19: Active Infra-Red (AIR) sensor
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 159

B.2.3. Ultrasonic Presence (UP) sensor

Ultrasonic devices send out inaudible sound waves. At the same time, it is scanning for sound waves which are reflected at a specific rate as shown in figure 4-20. It detects a frequency shift between the emitted and reflected sound waves. The movement by a person or object within a space causes a shift in frequency which indicates that something or someone has moved in the detection zone and the sensor interprets as occupancy. While UP occupancy sensors have a limited range, they are excellent at detecting even minor motion [(1)].

Figure 4- 20: Ultrasonic Presence (UP) sensor
Source: Sensors for an Energy Conscious World, p. 5

B.2.4. Passive Dual Technology Sensors

These sensors combine the two technologies of PIR and the ultrasonic presence detections as shown in figure 4-21. They see and hear the occupant so that presence is detected even if there is no movement. Therefore it is a more preferred sensor because UP and PIR need to detect occupancy to turn lighting on. Dual technology sensors minimize the risk of lights coming on when the space is unoccupied due to false triggering. Continued detection by only one technology then keeps lighting on. Dual technology sensors offer the best performance for most applications. [(2)]

[1] Sensors for an Energy Conscious World, H-Moss, p. 5
[2] ibid, p. 5

Figure 4- 21: Dual technology sensor
Source: Sensors for an Energy Conscious World, p. 5

The Passive Infra-Red (PIR) sensor, Ultrasonic Presence (UP) sensor and Passive Dual Technology sensors are the three presence sensors types that could mainly be used in learning spaces especially for group teaching/learning spaces. The following table illustrates the comparison of benefits for these types of sensors.

Table (4- 5): Analysis for learning spaces presence sensors

Passive Infra-Red (PIR) sensors	Ultrasonic Presence (UP) sensors	Passive Dual Technology Sensors
• Long range detection • Reliable triggering • Cost efficient	• Detect small motion • See around obstructions • Cost efficient	• Track occupancy on with two sensing methods • Minimize false triggering • Consistent, reliable operation

C. <u>Position of Smart Sensors</u>

Positioning the sensors cannot be neglected. For obvious practical reasons, presence sensors are never actually placed on the work plane. They may be mounted on ceilings or walls. This is unlike illuminance sensors which sometimes may be fixed on work plane task surface especially in close loops. (1)

It is highly important for movement sensors to have a good view of the space so that they correctly can detect the movement in the area. Careful placement of occupancy sensors is required to prevent false alarms, i.e. occupancy sensors should not be mounted in the direction of a window. Although the wavelength of infrared radiation to which the chips are sensitive does not penetrate glass very well, a strong infrared source such as a vehicle headlight or sunlight reflecting from a vehicle window can overload the chip with enough infrared energy to fool the electronics and cause a false alarm. A person moving on the other side of the glass however would not be "seen" by the device. Figure 4-22 illustrates layout example for sensors position in a large classroom. (2)

[1] Mukherjee, Satyen, et al. Closed loop integrated lighting and daylighting control for low energy buildings, p. 9-255, p. 9-259
[2] James Sinopoli , Smart Building Systems for Architects, Owners, and Builders, p. 54

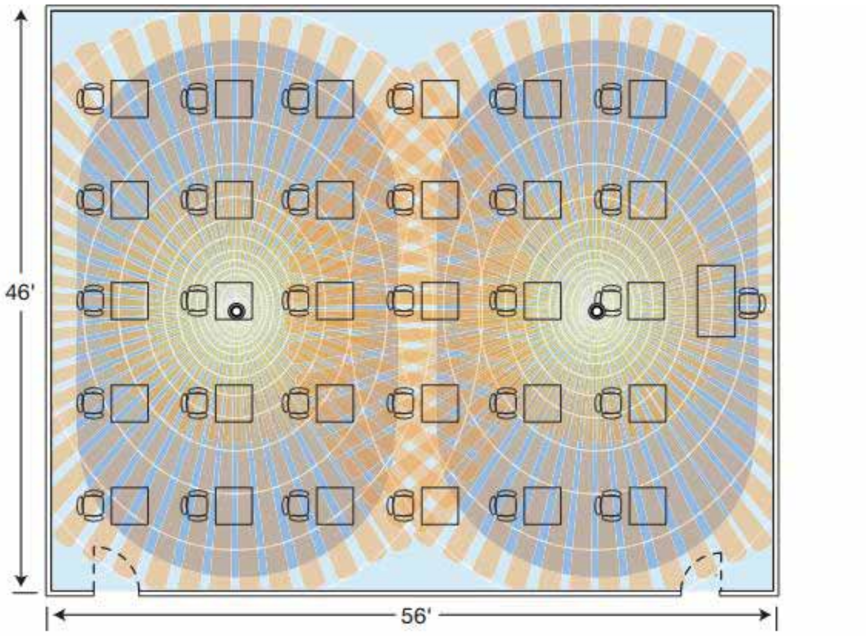


Figure 4- 22 : Sensors typical layout and coverage patterns for a large classroom
Source: Sensors for an Energy Conscious World, p. 16

iii. Actuators

Actuators are used for automation in all kinds of technical process. Depending on their type of supply, the actuators may be classified as pneumatic, hydraulic or electric actuators. They convert the real-world conditions into an analog or digital representation and deliver it to all control system components. Below are the basic types of actuators, which are used in smart lighting control systems. [(1)]

A. Smart Switch

The switch is the most common interface between the lighting system and the occupant. Smart switches can integrate several modes:

- On-off switch: which may have either a motion sensor or open automatically if it detects any movement as shown in figure 4-23 and figure 4-24 or illuminance sensor for daylight as shown in figure 4-25.
- Timer for switch-off as shown in figure 4-26.

Figure 4- 23: Switch on /off device with motion sensor technology- Faces of the switch
Source: http://www.gadgetify.com/flick-switchless-light-switch/

[1] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 161

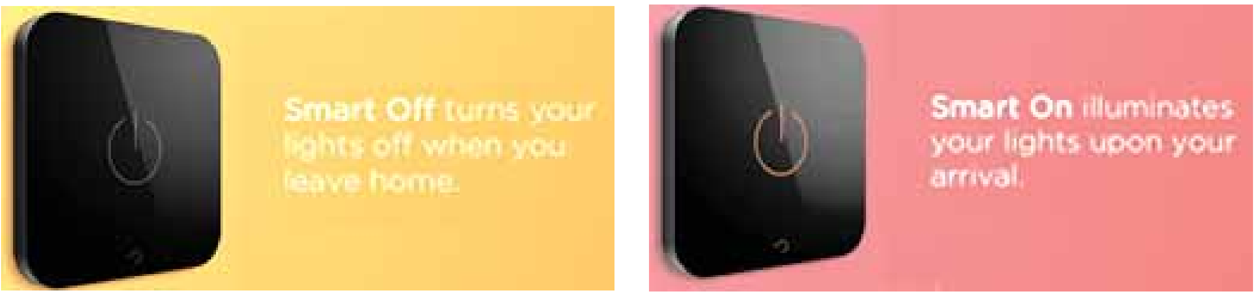


Figure 4- 24: Switch on /off device with motion sensor technology
Source: https://navigationstack.wordpress.com/2014/03/06/futuristic-goldee-smart-light-controller-reinvents-the-light-switch/

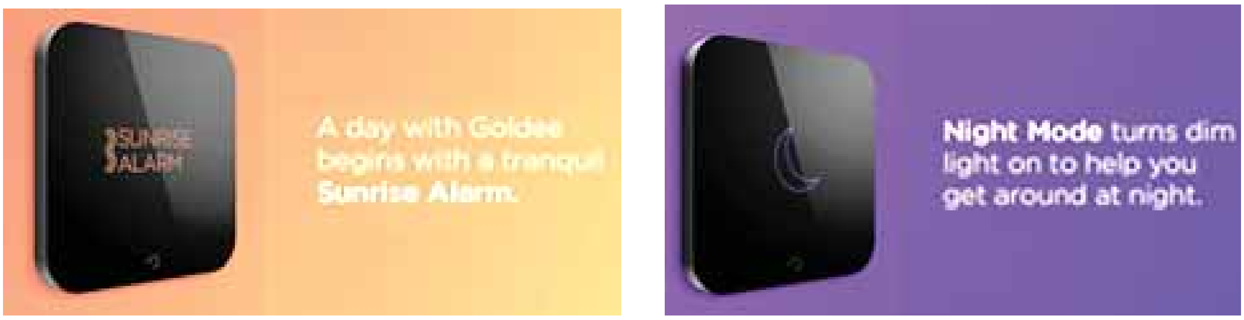


Figure 4- 25: Switch on /off device with illuminance sensor technology
Source: https://navigationstack.wordpress.com/2014/03/06/futuristic-goldee-smart-light-controller-reinvents-the-light-switch/

Figure 4- 26: Timer for switch-off
Source: http://www.apartmenttherapy.com/5-ways-to-turn-on-lights-when-121857

Switching is appropriate in singly occupied spaces where light level changes are generated by the behavior of that occupant (when the occupant switches the lights on or when the lights are switched on by an occupancy sensor). For multiple-occupant spaces, automatic on/off switching must be used with care because it causes unexpected changes in light level while a space is occupied which may confuse or annoy occupants.

B. Dimmer

Dimming systems adapt the light levels gradually, and thus reduce power and light output gradually over a specified range. Dimming can generate important energy savings. The dimming can be achieved through two modes:

- **Continuous dimming :**is a continuous adaptation of the luminous flux of the light source(s) in function of external information. Most of the time this kind of dimming is achieved through a DC control command on the ballast of the luminaire (discharge lamp) or through the transformer (Halogen lamp). Some manufacturers have adopted a standard analogue 0-10 V dimming protocol that allows ballasts from different manufacturers to be used with compatible systems.
- **Step by step dimming :**is a way to control the light output of the luminaires based on a limited number of configurations. The rated dimming levels are based on information generated by the controller, received by the actuator and transmitted to the light source. The number of dimming steps is defined by the protocol used. DALI-based dimming system is an example of this kind of step by step dimming (256 dimmed levels). Switching systems perform very well in climates with stable sky conditions.

C. Ballasts

An electrical ballast is a device that limits the amount of current in an electric circuit. Lights, such as fluorescent and neon lights, need ballasts to control the current flowing through the light. When fluorescent lights are turned on, electricity flows to two electrodes on opposite ends of the lamp causing them to heat up. Then they become hot and emit electrons that collide with and ionize noble gas atoms inside the bulb. This creates a voltage difference between the two electrodes causing electricity to flow between the two electrodes through the gas in the tube. These gas atoms become hot thus vaporizing the liquid mercury inside the tube. The mercury vapor then becomes excited and emits ultraviolet light which hits a white phosphor coating that converts the ultraviolet light into visible light. The main task of ballast is regulating the electricity flowing through the bulb. Figure 4-27 illustrates how it is connected with the other lamp components. Modern ballasts supply the electricity needed to start the lamp and produce light and then regulate the current so that the lamp will produce the desired light intensity. (1)

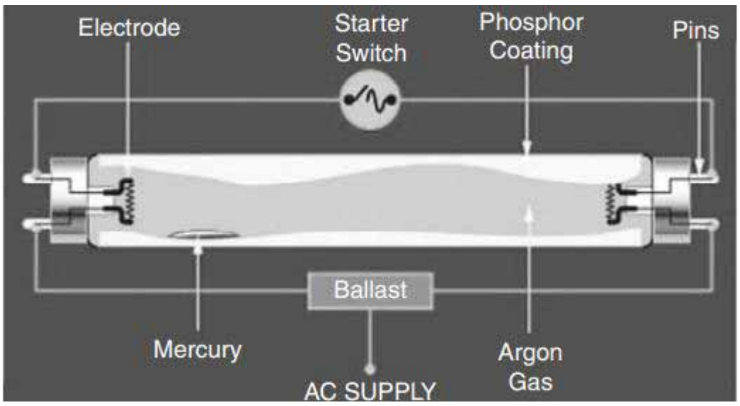


Figure 4- 27: Ballasts location in lamps
Source: Smart Building Systems for Architects, Owners, and Builders, p. 55

[1] James Sinopoli, Smart Building Systems for Architects, Owners, and Builders…p. 4-8

There are two main types of ballasts, electromagnetic and electronic ballasts. Electromagnetic ballasts are the cheaper and the most common option although they are less energy efficient than electronic ballasts. (1)

- Magnetic ballasts: use electromagnetic induction to create the voltages used to start and operate fluorescent lights. They contain copper coils that produce electro- magnetic fields to control voltage. Magnetic ballasts, which have been used in fluorescent lights since their origin, are considered outdated and are being phased out by newer electronic ballasts.

- Electronic ballasts: use solid-state circuitry, rather than magnetic coils, to control voltage to the lamp which makes them more energy efficient. Electronic ballasts are easier to integrate into lighting control strategies e.g. when building energy management systems or using daylight dimming sensors.

4.3.1.4. Type of Lighting Control Needed in University Spaces

LMS is the finest way to control lamps in learning spaces. Its operators will be able to manage lamps in one zone independently. An additional advantage of LMS is their ability to monitor the operation of the lighting systems such as the number of operating hours in a given area and the number of times the lights are switched on. The following table illustrates the advantages and disadvantages for the control strategies and sensors which could be used inside the learning space.

Table 4- 6 : Analysis for lighting control strategies and sensor types in learning spaces

Selecting lighting controls	
Dimming – ability to reduce the light output from the system	• allows illuminance level to be integrated with daylighting • dimmed lighting uses less power • useful to minimise glare in specialist rooms such as computer rooms • useful in audio visual presentation rooms • moderately expensive
Occupancy sensors – turns off lights in unoccupied rooms	• cost-effective • suitable for most general teaching spaces • should be coupled with manual switches to prevent activation when daylight is adequate • ultrasonic sensors are more sensitive, but more expensive, than infra-red
Daylight sensor controls – automatically control lighting levels to integrate with available daylight	• effective at controlling power use • expensive to install • unlikely to be cost-effective

Source: Designing Quality Learning Spaces: Lighting, p. 28

According to New Buildings Institute (NBI 2003), daylight harvesting systems are generally used in spaces that have relatively wide areas of windows or skylights such as

[1]WISIONS, Energy efficient lighting for sustainable development, p. 16

learning spaces. The savings potential varies from 20% (daylight-harvesting alone) to more than 50% (daylight harvesting plus real occupancy). [(1)]

A university consists of a lot of different space types. These spaces needed to be controlled by LMS in order to conserve their energy consumption. For example in large halls, the lighting rows close to the windows, which are usually less than 4m as per best practice, will be controlled with daylight strategy. Table 4-7 illustrates different types of sensors that could be installed in each space and the sensors fixation style.

Table 4- 7 : Type of Lighting Control Needed in University Spaces

Application	Space		Sensor Technology				Sensor Style		
			Adaptive	Dual	Ultrasonic	PIR	Wall Switch	Ceiling	Wall
Office	Office	Small up to 1000 sq. ft.	✓+	✓+		✓	✓+	✓	
		Large up to 2000 sq. ft.	✓+	✓+	✓			✓+	
Open Office	Open Office	up to 2000 sq. ft.	✓+	✓	✓+			✓+	
Storage/ Warehouse	Storage/ Warehouse	Closet up to 1200 sq. ft.				✓+	✓+		
		Warehouse up to 1500 sq. ft.	✓+			✓+		✓+	✓+
Restroom	Restroom	Small up to 400 sq. ft.			✓+	✓+	✓+	✓	
		Large up to 2000 sq. ft.	✓+		✓+			✓+	
Conference Room	Conference Room	Small up to 1000 sq. ft.	✓+	✓+			✓+	✓	
		Large up to 2000 sq. ft.	✓+	✓+				✓+	
Classroom	Classroom	Small up to 1000 sq. ft.	✓+	✓+			✓+	✓	
		Large up to 2000 sq. ft.	✓+	✓+				✓+	
Hallway	Hallway		✓+		✓+	✓		✓+	✓

Source: Sensors for an Energy Conscious World, p. 24-25

[1] NBI. "Advanced Lighting Guidelines 2003", Table 8.4.http://www.newbuildings.org.

4.3.2. Smart Façade Control System

Today new components are coming on the market like smart windows and intelligent automatic blinds. The latest components allow for significant energy savings. These developments of new advanced façade solutions are now integrated with LMS in order to get the optimum solution for energy savings. Moreover smart façade can be integrated into several types of active or passive components that directly impact the heat/cool energy [(1)]. This section will focus on two cases ; standalone smart facde systems and the integration of smart façade components with LMS. Smart façade can be identified with a large list of components influencing the daylighting of the building such as the dynamic glazing systems or the blinds and louvres as shown in figure 4-28.

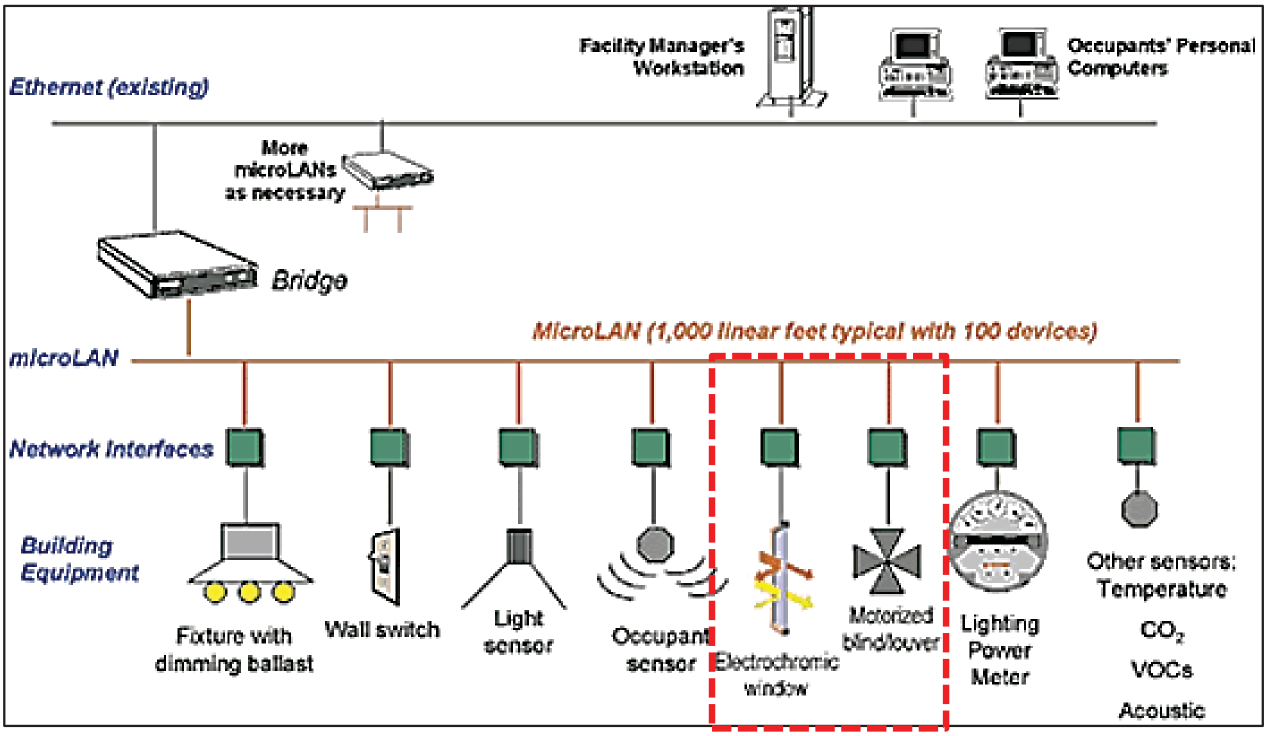


Figure 4- 28: The work flow of BEMS in case of integration LMS with smart façade components
Source: http://www2.lbl.gov/Science-Articles/Archive/sb-EETD-internet-controls.html

The goal of smart dynamic façades would be to save energy in terms of daylighting by adopting a hypothetical dynamic system which adapts to the solar movements. Therefore the following facts should be considered in the communication among the controllers to achieve this maximum energy consevation:

- The light controller can request smart facde compnents for more daylight.
- Smart facde compnents can answer to a request for the artificial light..
- The controller can request the smart facde compnents to reduce solar gains or ask the light to switch on to bring more internal gains.

These decisions depend on the light strategy which is used by BEMS and the level of integration. These strategies will be discussed in the following section.

[1] IESNA ,Annex 45 - Energy Efficient Electric Lighting For Buildings, P 162

4.3.2.1. Energy Conservation Strategies of Blinds Systems [1]

While the majority of façade components, such as windows and louvers, are still manually operated, smart façade systems have been implemented in cutting-edge practices for efficient daylight harvesting and visual comfort control. The following section will discuss the strategies of smart façade system controls that could be used inside learning spaces in order to increase the rate of energy conservation. Blinds controller is used in this section as a sample for smart façade components but it can also be replaced by glazing controller for windows. The strategies are divided into open-loop and closed-loop controls. Open-loop controls are those that adjust the output based on external input only. There is no feedback mechanism to regulate the output. Closed-loop strategies, on the other hand, employ feedback along with external input to regulate the output and meet a certain operating set point or a range of set points.

i. Independent Smart Façade System

A. Open Loop of Smart Façade System

Open-loop smart façade system configuration depends on blind controller and bases its control decisions on outdoor condition as illustrated in Figure 4-29. It deploys/retracts the blinds or opens/closes the blinds' slats to regulate the admission of the daylight and block direct sun beams and to prevent daylight glare. This configuration utilizes external information and/or sensor measurements for daylight illuminance to make control decisions. The external information may be pre-calculated, such as seasonal information. For example the sun's position and the solar radiation type may be examined in order to decide whether to admit or reject solar radiation by opening or closing the blinds or be measured by sun tracker.

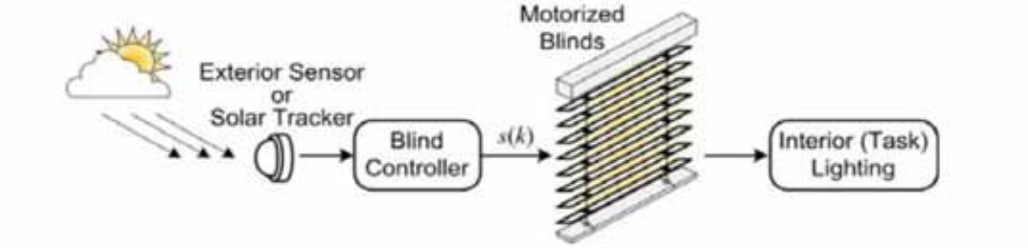


Figure 4- 29: The configuration of open Loop smart façade system
Source: Closed Loop Integrated Lighting and Daylighting Control for Low Energy Buildings-ACEEE Summer Study on Energy Efficiency in Buildings, p. 9-254

B. Closed Loop of Smart Façade System

The closed-loop smart façade system configuration bases its control decisions on the interior lighting condition measured by a photosensor as shown in Figure 4-30. The measurements are compared with the illuminance set point. Depending on these measurements the sensor sees the direct results from façade control actions and the space characteristics which are predetermined on the system. Hence the blinds are opened or closed incrementally with a fixed step until the set point of the interior task plane illuminance is met.

[1] Mukherjee, Satyen, et al. Closed loop integrated lighting and daylighting control for low energy buildings, p. 9-253, p. 9-259

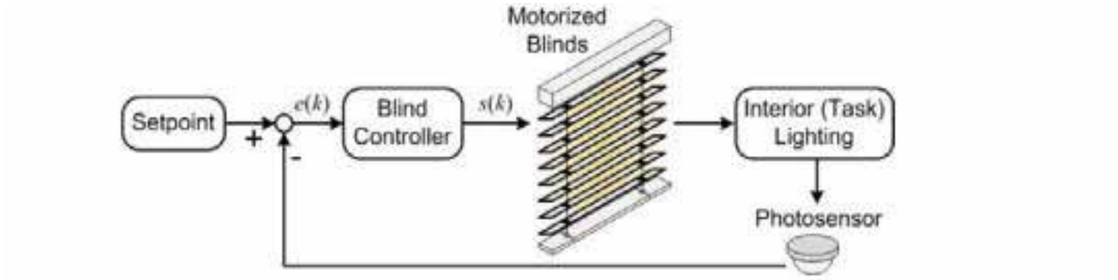


Figure 4- 30: The configuration of closed loop smart façade system
Source: Closed Loop Integrated Lighting and Daylighting Control for Low Energy Buildings-ACEEE Summer Study on Energy Efficiency in Buildings, p. 9-255

ii. Smart Façade System Integrated with LMS

Artificial lighting control and daylight shading control are both essential for regulating interior lighting conditions. It is critical for both systems to complement each other and to create a comfortable visual environment with maximum energy efficiency. The following part discusses the strategies for integrating them with the controllers of smart facade systems.

A. <u>Smart Façade System Integrated with Artificial light</u>

A.1. Opened Loop of Smart Façade System Integrated with closed Loop of Artificial light

The opened loop of a smart façade system integrated with a closed artificial light bases its control decisions on exterior conditions, which are defined either by an exterior sensor or sun tracker, in addition to the interior lighting conditions, which is measured by a photosensor as shown in Figure 4-31. After defining exterior conditions, the blinds are opened or closed incrementally with a fixed step until they axpproximately reach the set point of the interior task. Then a photosensor measures the interior light and changes the electrical light values to reach the interior illuminance set point.

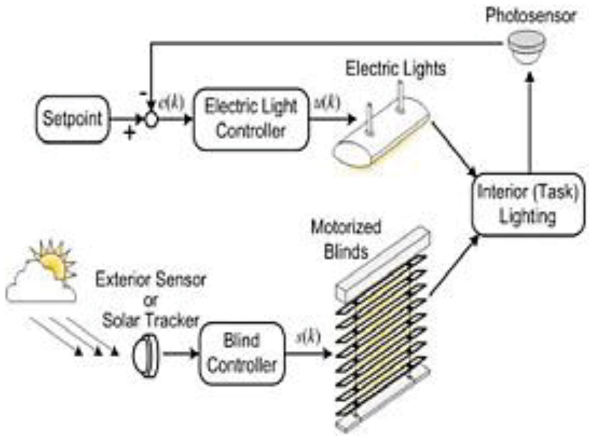


Figure 4- 31: The Configuration of Opened Loop Smart Façade System Integrated with Artificial Light Closed Loop
Source: Closed Loop Integrated Lighting and Daylighting Control for Low Energy Buildings-ACEEE Summer Study on Energy Efficiency in Buildings, p. 9-255

A.2. Closed Loop of Smart Façade System Integrated with closed Loop of Artificial light

The closed loop of a smart façade system integrated with a closed loop of artificial light bases its control decisions on interior photosensors measurements as shown in Figure 4-32.

Depending on these measurements, the sensor sees the direct results from façade control actions and the space characteristics which are predetermined within the system. Hence the blinds are opened or closed incrementally with a fixed step until the set point of the interior task plane illuminance is approximately met. Then photosensors measure the interior light and change the electrical light values to reach the interior illuminance set point.

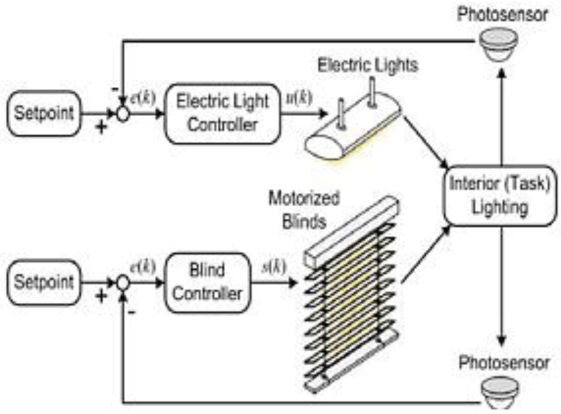


Figure 4- 32: The Configuration of Closed Loop of Smart Façade System Integrated with Closed Loop of Artificial Light
Source: Closed Loop Integrated Lighting and Daylighting Control for Low Energy Buildings-ACEEE Summer Study on Energy Efficiency in Buildings, p. 9-255

B. Smart Façade System Integrated with Artificial Light and Daylight

The smart façade system integrated with artificial light and daylight which is truly considered an integrated closed-loop system is illustrated in Figure 4-33. The goal of this integrated control is to regulate task illuminance at a prescribed set point while maximizing daylight utilization, hence minimizing electric lighting load. In this strategy, both systems share the information from a single photo sensor that measures interior task illuminance. The operation of such a system is as follows. When more light is required to meet the set point and blinds slats are partially open, the controller will first open the blind slats incrementally to admit more daylight. If the set point cannot be met even after the blinds are fully opened, then electric lights are used to compensate for insufficient daylight. Similarly when task illuminance exceeds the set point, the electric lights will be dimmed first. If the set point is not reached even after the lights are turned off, then the blinds' slats are closed incrementally to reduce daylight admission until the task illuminance meets the target.

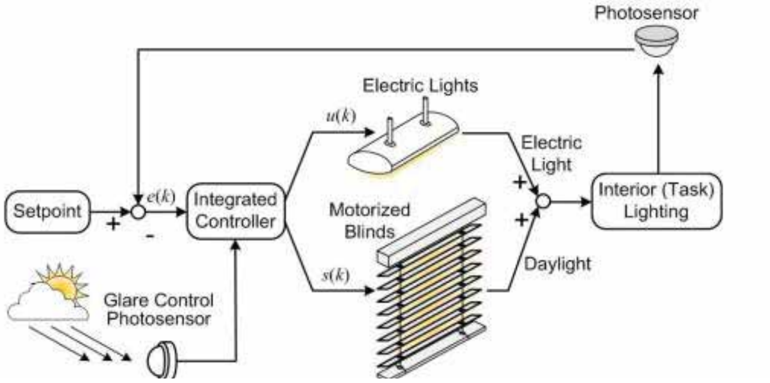


Figure 4- 33
Source: Closed Loop Integrated Lighting and Daylighting Control for Low Energy Buildings-ACEEE Summer Study on Energy Efficiency in Buildings, p. 9-256

4.3.2.2. Components of Smart Façade System

Space shell (Façade) ,which is illustrated in Figure 4-34 , is considered an energy filter that should be the starting point of the building design process. It should be smart and dynamic in order to adapt with different climate conditions. A smart façade system has possibilities for overall energy reduction for heating, cooling and lighting. Moreover, it can prevent solar heat radiation from entering the building when not needed.

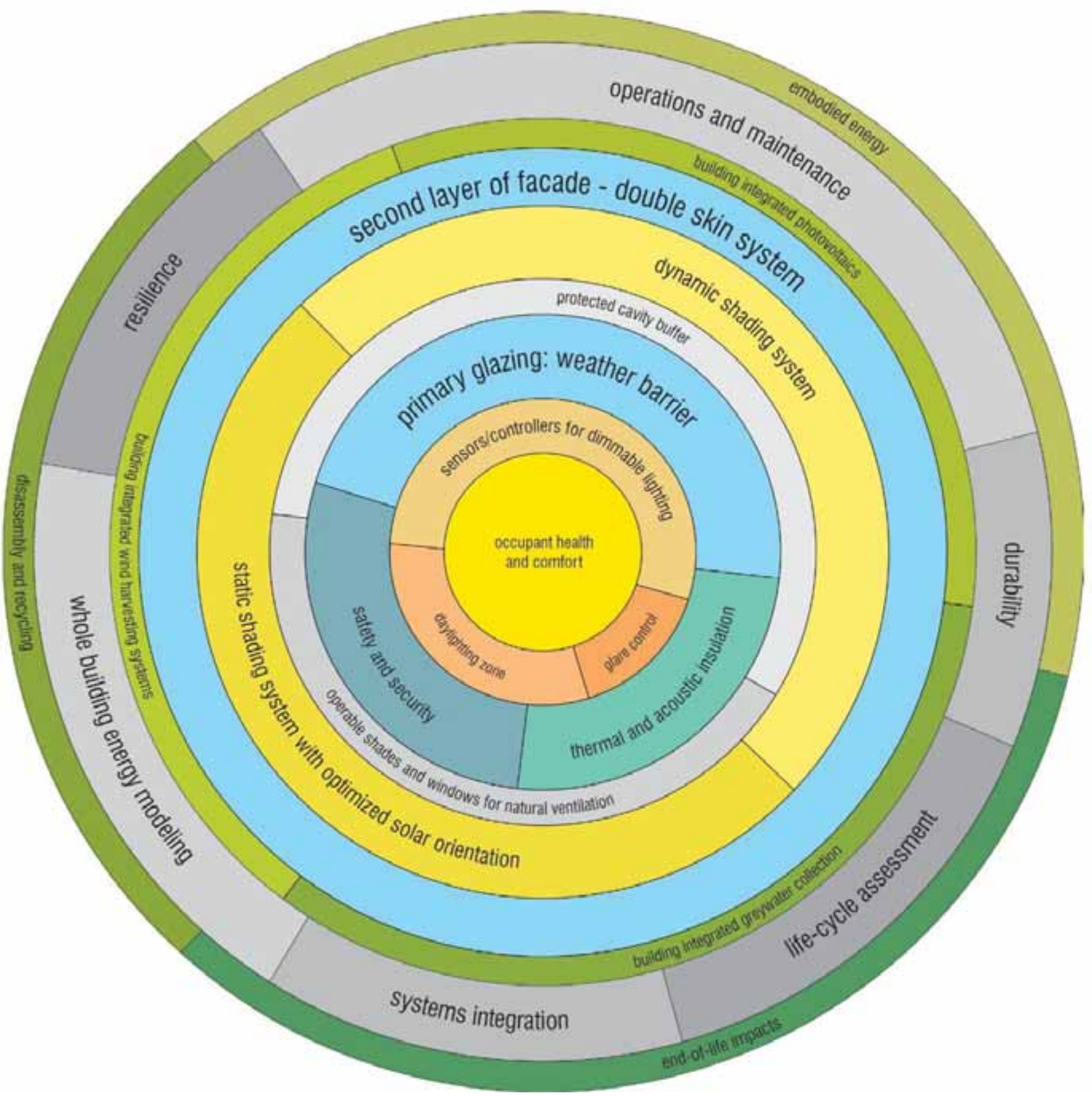


Figure 4- 34: Compnanets of smart façade system
Source: High-performance facades, p. 3

The main two components which control these issues are windows and shading devices (blinds or louvers). Therefore they will be discussed in the following section.

i. Shading Device : Automated Blind or Louvers

Shading devices have always represented the fundamental system to control the incoming of the natural light with two main purposes: improving indoor visual and thermal comfort, reducing HVACs and artificial light systems energy consumption. [1]

Automated blinds /louvers systems have been implemented in cutting-edge practices for efficient daylight harvesting and visual comfort control. They are building products which are attached to a window frame on a building façade to provide shade and control natural lighting. Automated blinds /louvers systems contain a set of sensors to detect interior and exterior light conditions as shown in Figure 4-35. Moreover they contain a set of actuators to adjust louvers for the optimum position. The actuators are either controlled automatically or manually according to the occupant's needs. [2]

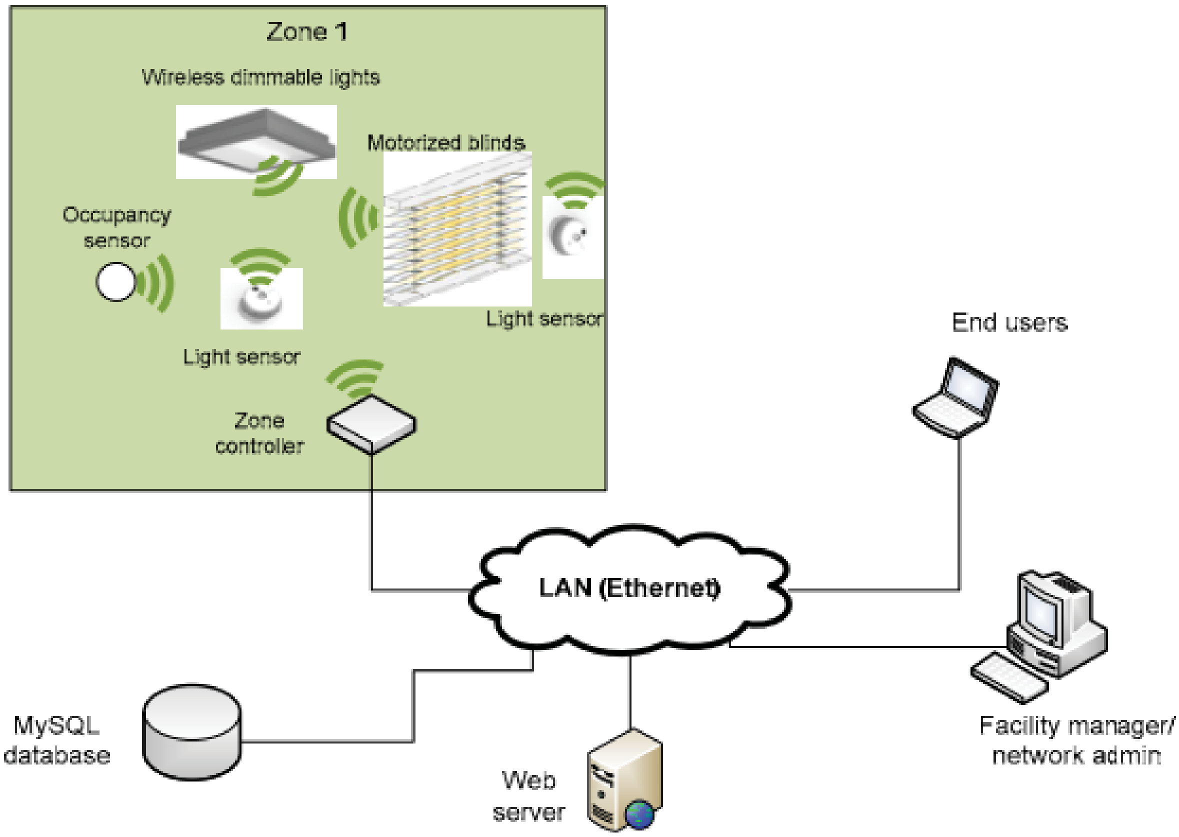


Figure 4- 35: The configuration of automated blinds system
Source: Closed Loop Integrated Lighting and Daylighting Control for Low Energy Buildings-ACEEE Summer Study on Energy Efficiency in Buildings, p. 9-258

The angle and intensity of daylight change throughout the year. A smart system manages these variations by incrementally altering the shade adjustment schedule of each façade on

[1]Gugliermetti .F.., et al, static and dynamic daylight control systems: shading devices and electrochromic windows-Ninth International IBPSA Conference, p. 357
[2]MESTEK, Solar Shading Louver Systems, p. 3

a daily basis, i.e. a blinds position in summer is different from its position in winter as illustrated in Figure 4-37. [(1)]

Figure 4- 36: Blinds position according seasonal solar variation
Source: Quantum -Total Light Management, p. 18

The following is a sample of louvers in a façade system which is used in The Berlaymont Building in Belgium. The slope of the louvers is ensured by engines which are controlled from a central processing unit. The control of the slope is set, as is illustrated in Figure 4-37, according to various parameters, such as [(2)]:

- The position of the sun (date and hour).
- The position of the louvers on the facade (orientation and height).
- The information collected by the outdoor sensors (horizontal illumination, wind speed, rain, outside temperature).

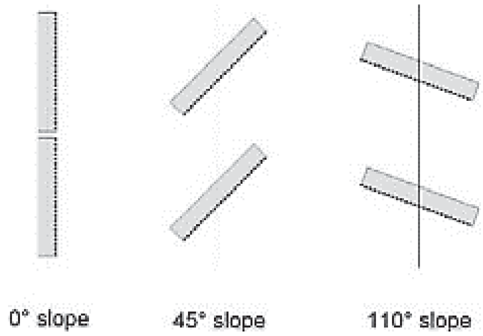


Figure 4- 37: The three sloped angles for the louvers
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 158

Figure 4-38 illustrates the control strategy for the automated louvers. When the outdoor horizontal illuminance is higher than 25000 lx, the louvers are positioned according to their position on the façade. If the louvers are located in a sunny zone, they are tilted so as to be perpendicular to the rays of the sun. Thus their slope lies thus between 0° and 80°, in order to work as solar protection. If the plates are located in a shaded zone and the external horizontal illumination is higher than 25000 lx, they are placed in a position of luminous penetration (slope of 110°). When the horizontal outdoor illuminance is lower than 25000

[1]Quantum -Total Light Management,LUTRON, p. 18
[2] IESNA, Annex 45 - Energy Efficient Electric Lighting For Buildings, p. 162

lx, all the louvers are set in to position of luminous penetration (110° slope) to allow daylight penetration to the building. Other modes are also integrated into the control algorithm, such as a maintenance mode and an alarm mode in case of fire.

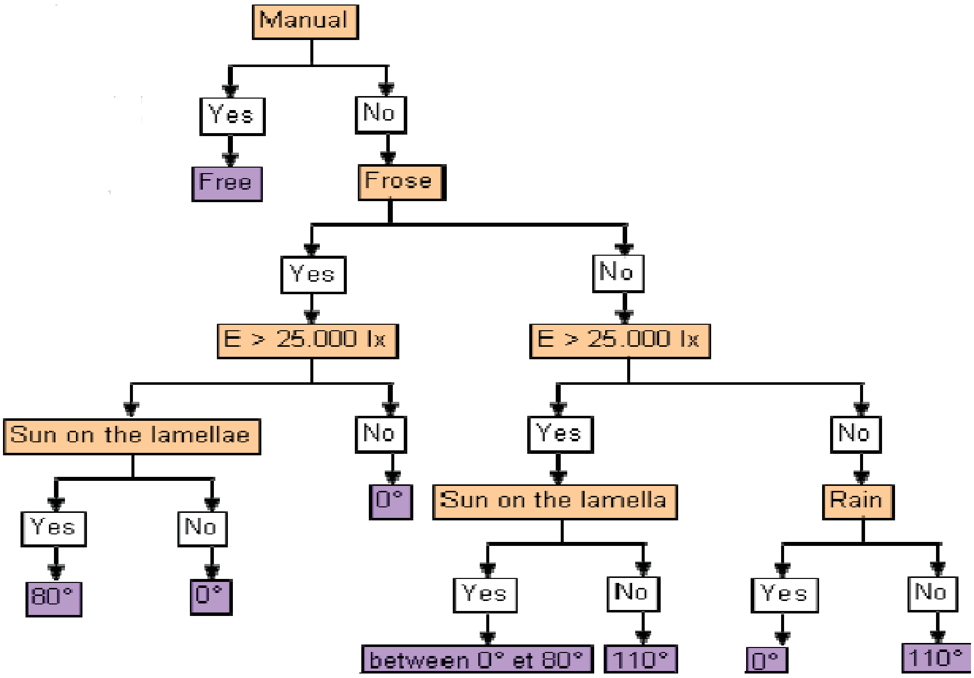


Figure 4- 38: Control strategy for automated louvers in The Berlaymont Building in Belgium
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 175

ii. Technologies of Windows Glazing

Efficient windows can be one of the best investments for a building. Different glazing and frame materials and special assemblies can provide insulation value, sun control, and daylight redirection as appropriate for a given room or building. Glass is considered a key architectural design tool and is ubiquitous in buildings today because of the design flexibility it provides and the positive impact that natural daylight and the connection with the outdoors. Figure 4-39 illustrates different technologies for window glazing which will be discussed sequentially. (1)

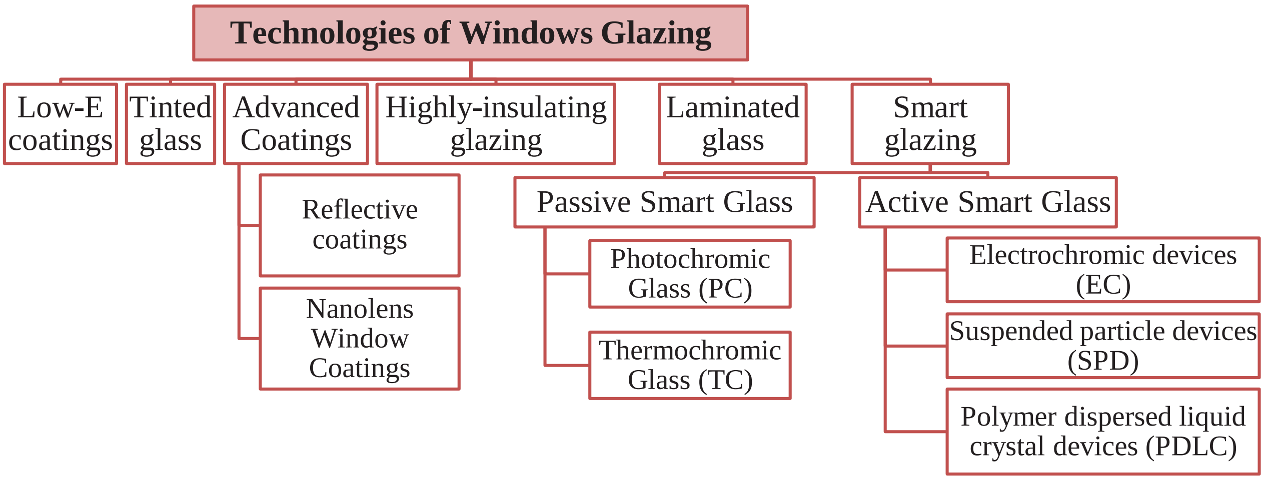


Figure 4- 39: Technologies of Windows Glazing

[1] Efficient Windows collaborative, The Efficient Windows Collaborative Tools for Schools, p. 10

A. Low-E coatings

Low-E (Low emissivity) coatings reduce radiant heat transfer through window glazing, thus improving insulating properties. In addition, the solar reflectance of low-E coatings can be manipulated so that desirable wavelengths of the solar spectrum are transmitted and others specifically reflected. Thus it prevents some solar rays from being transmitted through the glass, unlike double clear glass, as shown in Figure 4-40. Learning spaces windows are coated by spectrally selective which reflect heat from solar infrared radiation while allowing the visible light spectrum to enter. (1)

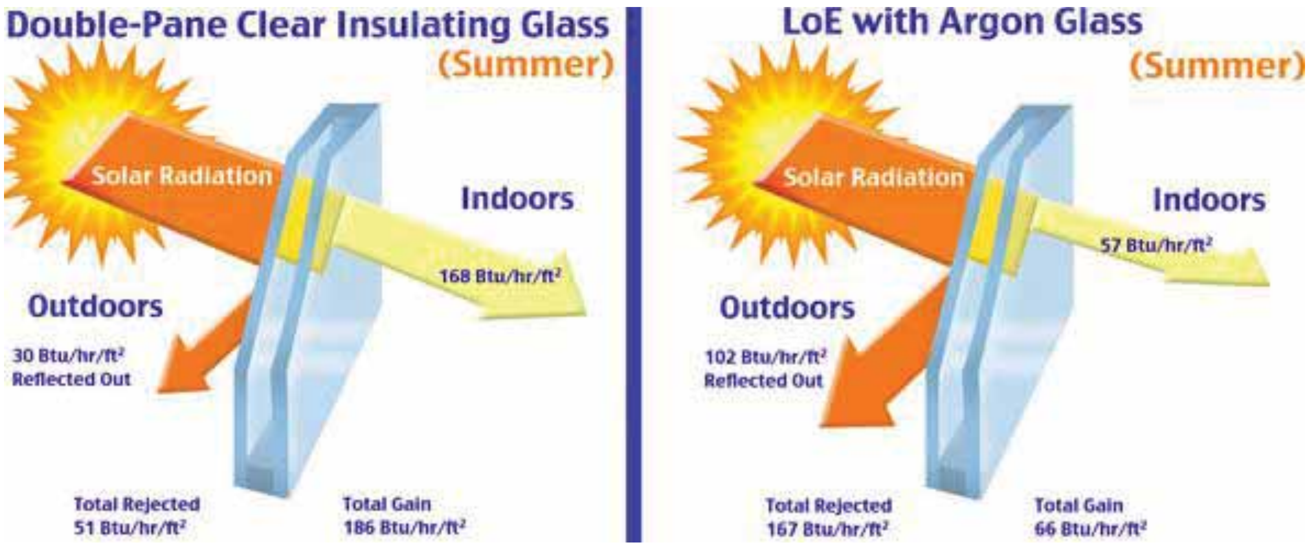


Figure 4- 40: Low E coating
Source: http://www.awwd.ca/resources_low_e.php

B. Tinted glass

The primary uses for tinted glass are reducing glare from the bright outdoors and reducing the amount of solar heat transmitted through the glass. Tinted glass retains its transparency from the inside. Although the brightness of the outward view is reduced and the color is changed, as shown in Figure 4-41, they may be controlled with switches or tinted automatically. (2)

Figure 4- 41: The change of tinted color according to outdoor sun state
Source: http://efficientdiy.com/portfolio/view-dynamic-glass-electronically-tinted-windows/

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1 http://www.awwd.ca/resources_low_e.php
2 ibid

B.1. Traditional Bronze and Gray Tinted Glass

Traditional gray tinted glass diminishes the amount of daylight entering the room more than bronze tinted glass, as shown in Figure 4-42

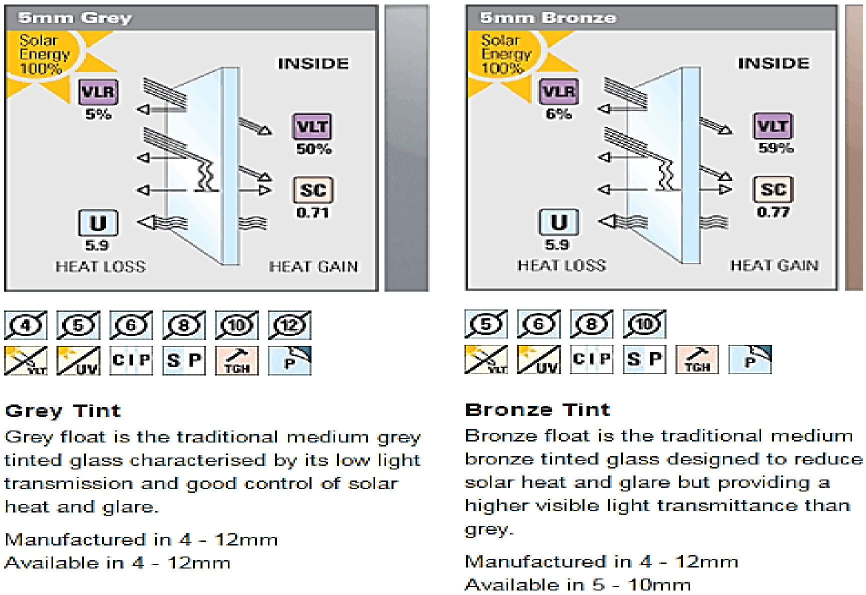


Figure 4- 42: Comparison between Traditional Bronze and Gray Tinted Glass
Source: http://efficientdiy.com/portfolio/view-dynamic-glass-electronically-tinted-windows/

B.2. High-Performance Tints

High-performance tints are light blue or light green with a relatively high visible transmittance. They can also be combined with low-E coatings to enhance their performance further and transform daylight inside the space, as shown in Figure 4-43.

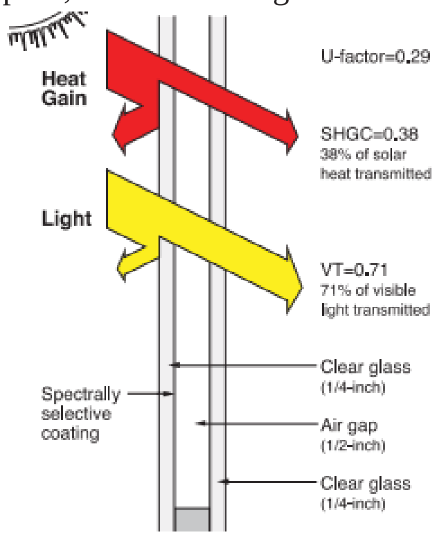


Figure 4- 43: High-Performance Tints
Source: The Efficient Windows Collaborative Tools for Schools, p. 10

In learning spaces where daylighting is desirable, it may be more satisfactory to use clear low-E coatings or high-performance tints, not traditional bronze gray, that preferentially transmit the daylight portion of the solar spectrum but absorb the near-infrared part of sunlight. (1)

[1]Efficient Windows collaborative, The Efficient Windows Collaborative Tools for Schools, p. 10

C. Advanced Coatings

C.1. Reflective coatings

Reflective coatings are used if larger reductions and solar heat gain are desired. By increasing the surface reflectivity of the glass, these coatings can reduce solar heat gain substantially, as shown in Figure 4-44, but visible transmittance usually declines even more, which is problematic if daylighting is desired. Reflective glazing is usually used for glare control or for large windows in hot climates.

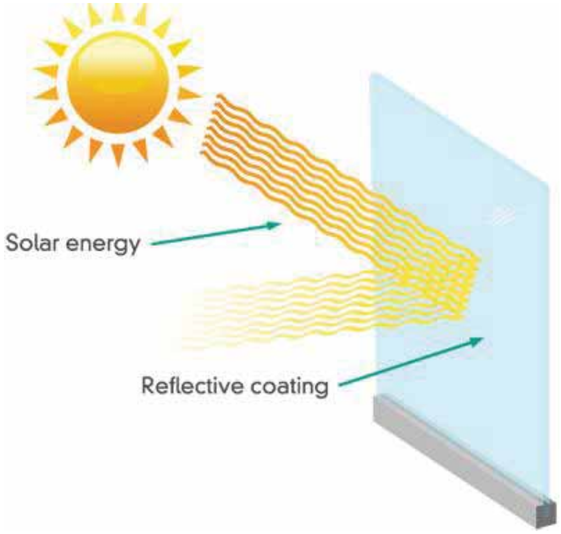


Figure 4- 44: Reflective coatings
Source: http://www.capral.com.au/High-Performance-Glass

C.2. Nanolens Window Coatings for Daylighting

Nanolens Window Coatings are advanced coatings that are being developed. They are used to redirect light deeper into building space. Figures 4-45 A and B show the daylighting schematic and figure 4-45 C shows a photograph of the effect. [1] Ball State University installed these nanolens coating glazings on Dehority Hall as shown in Figure 4-46.

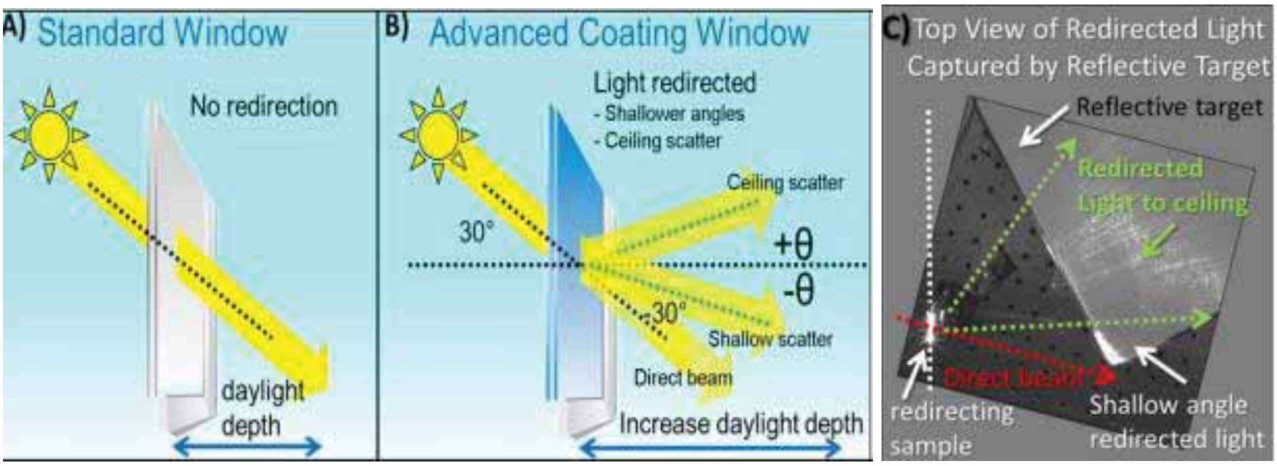


Figure 4- 45: Nanolens Window Coatings
Source: BTO Program Peer Review- http://energy.gov/sites/prod/files/2013/12/f5/emrgtech18_alvine_040413.pdf

[1]DOE, US. “Building Technologies Program, p. 23

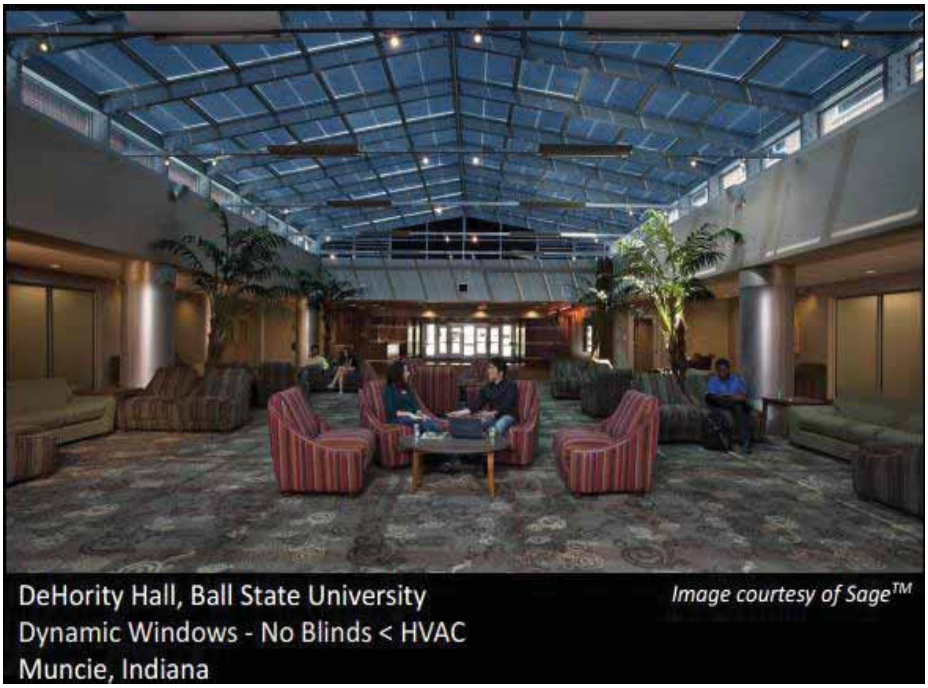


Figure 4- 46: Dehorit Hall -Ball State University- the glass is in its fully tinted state ready to provide the necessary light control for AV presentations.
Source: Building Technologies Program

D. Highly-Insulating Glazing

In addition to the insulating capabilities of double glazing and low-E coatings, gas fills (see Figure 4-47) and additional glazing layers can further improve the insulating value of glazing. Triple- and quadruple-glazed windows are available with the middle layers consisting either of glass or of suspended plastic films. These middle layers decrease the U-value of the unit by dividing the inner air space into multiple chambers, which can be filed with insulating gas.

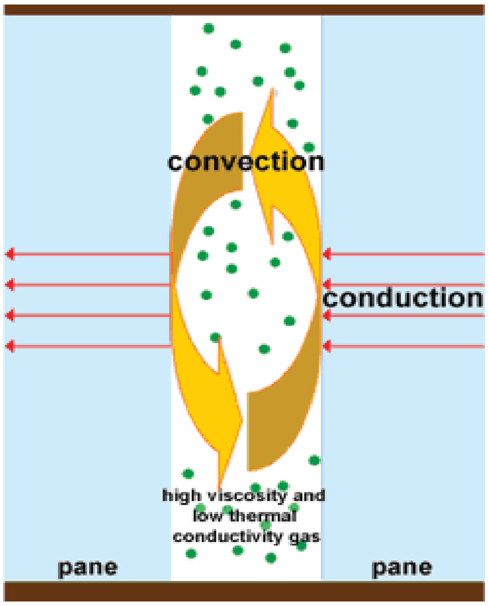


Figure 4- 47: Gas –Filled Windows
Source: https://www.e-education.psu.edu/egee102/node/2022

E. Laminated Glass

Laminated glass consists of a tough plastic interlayer made of polyvinyl butyral (PVB) bonded between two panes of glass under heat and pressure as shown in Figure 4-48. Once sealed, the glass sandwich behaves as a single unit and looks like normal glass. Laminated glass offers increased protection from the effects of disasters such as hurricanes, earthquakes, and bomb blasts. Another benefit is that laminated glass reduces noise transmission due to the PVB layer's sound-dampening characteristics. [1]

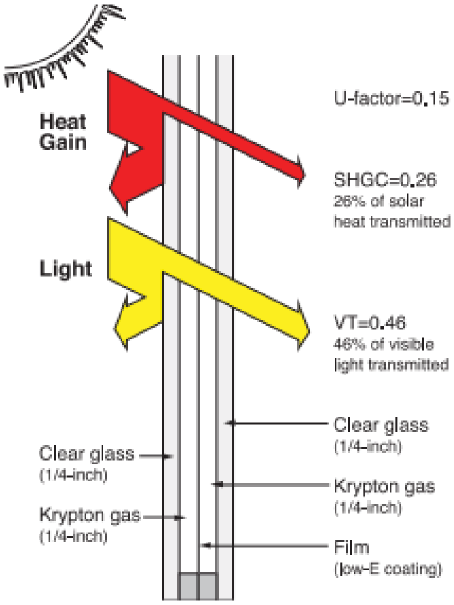


Figure 4- 48: Laminated Glass

Source: The Efficient Windows Collaborative Tools for Schools, p. 3

F. Smart Glazing[2]

Smart glazing is high technological material that can be changed from a clear to tinted state. It can change itself in response to an outside stimulus or respond to the stimulus by producing a signal of some sort for reducing solar heat gain and glare. By actively managing lighting and cooling, smart glazing could reduce peak electric loads by 20 to 30 percent in many buildings, increase daylighting benefits, and improve comfort and learning environments in learning spaces. Hence, smart glazing can be used as sensors, actuators or, in some cases, as self-sensing actuators. In general, this depends on material properties or material synthesis. Their interactions stem from physical and/or chemical influences, such as change in temperature, pressure or exposure to radiation. However, smart materials will never replace systems fully; they usually are part of some smart systems.

F.1. Passive Smart Glass

Passive smart glass does not involve an electrical stimulus. Rather, it reacts to the presence of other stimuli such as light (Photochromic Glass) (PC) or heat (Thermo-chromic Glass) (TC).

[1]Efficient Windows collaborative, The Efficient Windows Collaborative Tools for Schools, p. 11
[2]Addington, Michelle, and Daniel Schodek. Smart materials and technologies., p. 2-10

F.1.1. Photochromic Glass (PC):

Photochromic materials change color when exposed to light. They absorb radiant energy which causes a reversible change of a single chemical particles between two different energy states, both of which have different absorption spectra. Photochromic materials absorb electromagnetic energy in the ultraviolet region to produce an intrinsic property change. Depending on the incident energy, the material switches between the reflectively and absorptivity selective parts of the visible spectrum as shown in Figure 4-49.

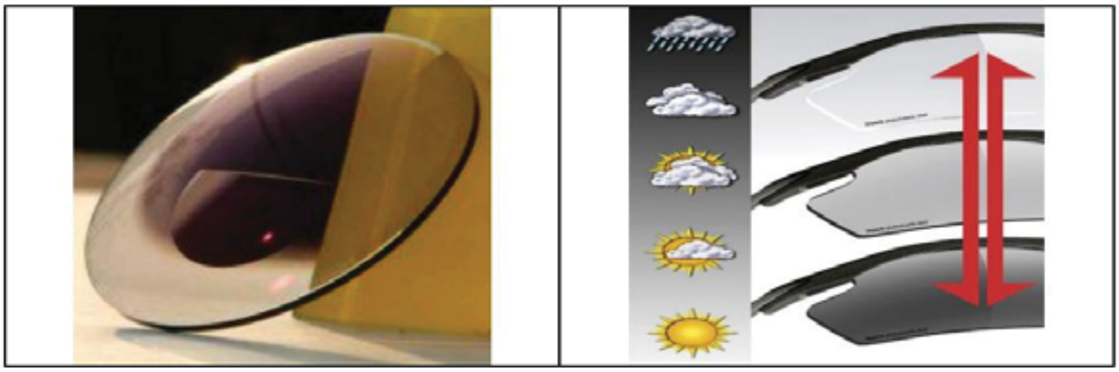


Figure 4- 49: Sample of uses of photochromic glass
Source: Smart Glass and Its Benefits on Energy Consumption in Buildings, p. 163

F.1.2. Thermo Chromic Glass (TC)

Thermo chromic glass changes color due to temperature changes as it absorbs heat, which leads to a thermally induced chemical reaction or phase transformation. It has properties that undergo reversible changes when the surrounding temperature is changed as shown in Figure 4-50.

Figure 4- 50: Thermo chromic Glass
Source: Smart Glass and Its Benefits on Energy Consumption in Buildings, p. 163

F.2. Active Smart Glass:

This type of glass is also known as switchable glass. It changes its light transmission properties when voltage is applied. Certain types of smart glass can allow users to control the amount of light and heat passing through. With the press of a button, it changes from transparent to opaque thus partially blocking light. There are three primary types of active smart glass technologies, each with its own unique chemistry, production requirements and performance characteristics; electro-chromic devices (EC), suspended particle devices (SPD), and Polymer dispersed liquid crystal devices (PDLC). The materials in each type consist of multi-layers working together.

F.2.1. Electrochromic Devices (EC)

Electrochromic windows are made by sandwiching certain materials between two panes of glass. The main middle part consists of the following layers, in order from inside to outside, conducting oxide, Electrochromic layer, Ion conductor/electrolyte, Ion storage, and a second layer of conducting oxide as shown in Figure 4-51. "Electrochromic" are the materials that can change color when energized by an electrical current. Essentially electricity kicks off a chemical reaction in this sort of material. This reaction changes the properties of the material. In this case, the reaction changes the way the material reflects and absorbs light. In some electrochromic materials, the change is between different colors. In electrochromic windows, the material changes between colored (reflecting light of some color) and transparent (not reflecting any light).

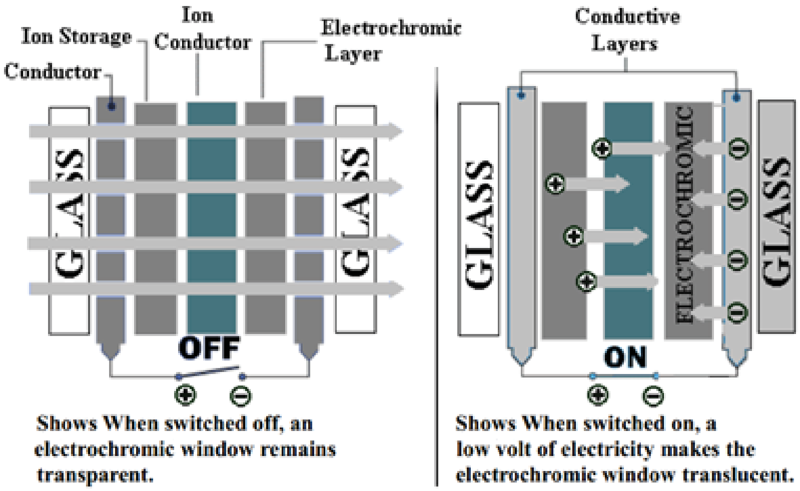


Figure 4- 51: Electrochromic devices
Source: Smart Glass and Its Benefits on Energy Consumption in Buildings, p. 165

Electrochromic windows darken when voltage is added and are transparent when voltage is taken away. Electrochromic windows can be adjusted to allow varying levels of visibility. Darkening occurs from the edges then moving inwards and is a slow process, ranging from many seconds to several minutes depending on window size. Electrochromic glass provides visibility even in the darkened state and thus preserves visible contact with the outside environment. It has been used in small-scale applications such as rearview mirrors.

F.2.2. Suspended Particle Devices (SPD):

In suspended particle devices (SPD), a thin film laminate of rod like particles, which is suspended in a fluid, is placed between two pieces of glass or plastic layers, or attached to one layer as shown in Figure 4-52. When the power supply is switched on, the rod shaped suspended particle molecules align, light passes through and the SPD Smart Glass panel clears. When the power supply is switched off, the rod shaped suspended particle molecules are randomly oriented blocking light and thus the glass panel looks dark (or opaque), blue or, in more recent developments, grey or black color.

When the SPD Smart Glass becomes dark, it can block up to 99.4% of light. SPD Smart Glass protects from the damaging effects of UV when on or off. So SPD can be dimmed and can allow for instant control of the amount of light and heat passing through.

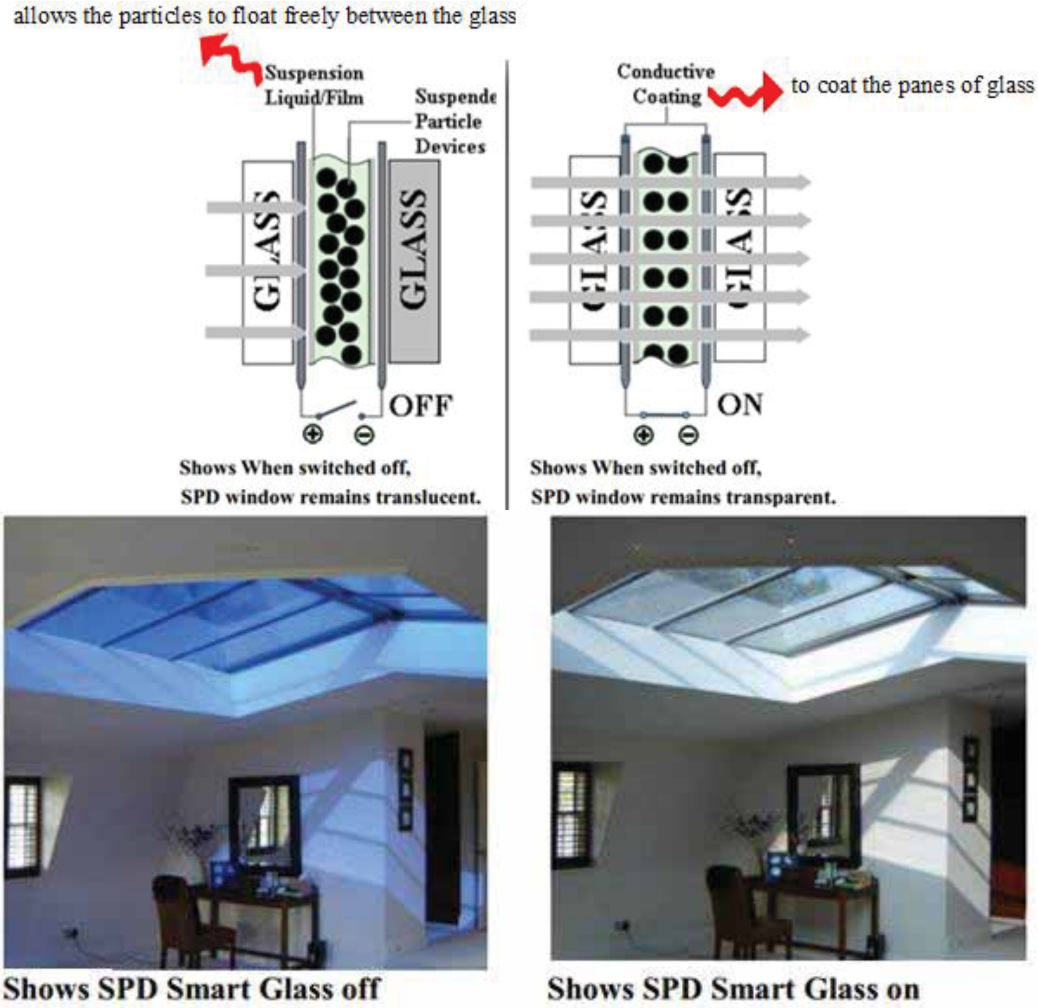


Figure 4- 52: Suspended particle devices

Source: Smart Glass and Its Benefits on Energy Consumption in Buildings, p. 167

F.2.3. Polymer Dispersed Liquid Crystal Devices (PDLC)

In polymer dispersed liquid crystal devices (PDLC), liquid crystals are dissolved or dispersed into a liquid polymer followed by solidification or curing of the polymer. Electrodes from a power supply are attached to the transparent electrodes. With no applied voltage, the liquid crystals are randomly arranged in droplets, resulting in the scattering of light as it passes through the smart window assembly. The translucent results in a "milky white" appearance. When a voltage is applied to the electrodes, the electric field formed between the two transparent electrodes on the glass cause the liquid crystals to align, thereby allowing light to pass through the droplets with very little scattering, resulting in a transparent state as shown in Figure 4-53. The degree of transparency can be controlled by the applied voltage. This technology has been used in interior and exterior settings for privacy control and as a temporary projection screen.

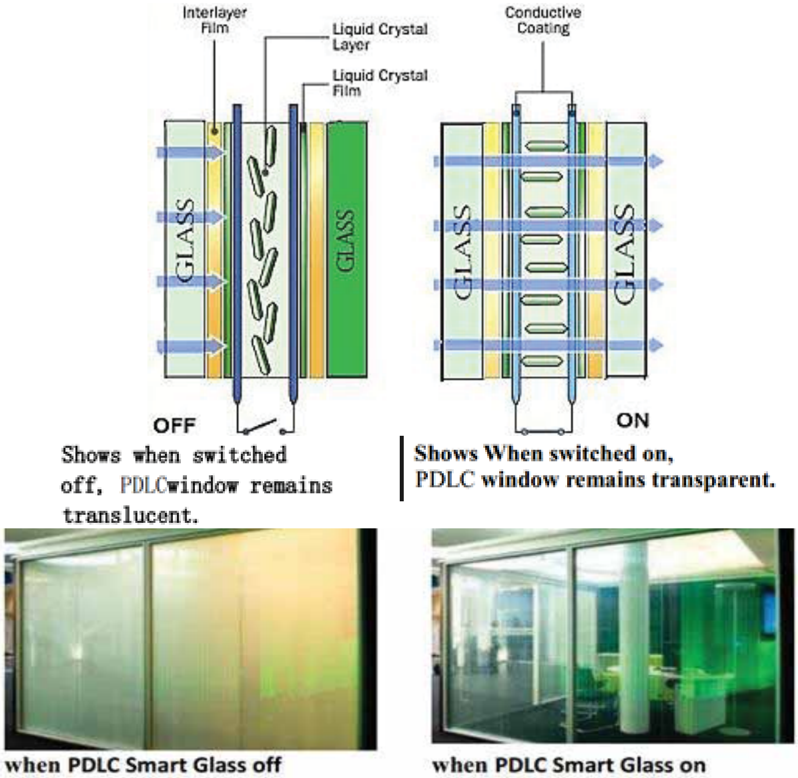


Figure 4- 53: Polymer dispersed liquid crystal devices –OFF and ON cases
Source: http://greenglasswonders.blogspot.com/2009/11/liquid-crystal-glass.html

As discussed active smart glass is classified into three specific types. Each one has its own unique chemistry, production requirements and performance characteristics. Table 4-8 shows a comparison between the three different kinds of switchable glass (EC, SPD, and PDLC) in regards to characteristics and behavior in architectural activities.

Table 4- 8 : Analysis of active smart glass types

	EC	SPD	PDLC
When is transparent?	Switched OFF	Switched ON	Switched ON
Continuous states between opaque and transparent?	Yes	Yes	No
Requires power to maintain the state?	No	Yes	Yes
Shading Benefit	Yes	Yes	Nominal (diffuses light)
Switching Speed	Varies depending upon panel size; May take many minutes for large format Panels	Several seconds regardless of panel size	Milliseconds regardless of panel size
Light-control States	Typically 2 preset levels from dark to clear	Unlimited levels from very dark to clear	2 (translucent and transparent)
Light Transmission in dark/opaque	SHADING: Yes PRIVACY: Typically some view remains	SHADING: Yes PRIVACY: Yes	SHADING: Nominal PRIVACY:
Energy Used to Operate	Very low	Very low	Very low

Source: Smart Glass and Its Benefits on Energy Consumption in Buildings, p.169

4.4. Smart Daylight Design Process

In the last decade, smart architecture techniques have changed the lighting design process completely. Nowadays by virtue of daylight simulations tools, which depend mainly on parametric design process, a lot of design concepts can be investigated in the early design phase to get the best case and optimum solution. This solution is primarily lit with natural light and combines high occupant satisfaction with the visual and thermal environment with low overall energy use for lighting, heating and cooling.

4.4.1. Parametric Environment

Parametric design is a process based on algorithmic computing that enables the expression of parameters and rules that together define, encode and clarify the relationship between design intent and design response.

Parametric simulation tools are relatively new to the architecture design process because they are based on the ideas of exploring design variations. The computer will generate many designs variation's between the predefined ranges which satisfy particular conditions. These rules and constrains usually involve numerical data and mathematical operations in order to control the properties of a generative model which could be manually or automatically made. The main benefit of using this type of software is its high ability of making modifications on any parameters such as geometry shape and size without the need to recreate the entire model for each modification. (1)

4.4.2. Measurements of Daylight Performance

Recently the measurement of spaces daylight performance has changed from a static method, which measures the performance at specific sky condition, towards a dynamic one, which depends on climate-based daylight simulations. Moreover, the new simulation tools can predict occupancy behavior models that mimic occupant use of shading devices and lighting controls. They use new methods to measure the optical properties, such as glare phenomena, of complex fenestration systems such as light redirecting devices. (2)

Nowadays the new IES quality metrics- Spatial Daylight Autonomy sDA and Annual Sunlight Exposure ASE- have been established as quality metrics (3) beside the three performance categories for daylight -daylight availability, visual comfort and thermal loads- to evaluate the space lighting behavior. (4)

[1] Wagdy, A., New parametric workflow based on validated day-lighting simulation. p. 1
[2] Reinhart, C.F., Weinhold, J., The daylighting dashboard – a simulation-based design analysis for daylit spaces-Building and Environment 46, p. 386
[3] Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), p. 1
[4] Reinhart, C.F., Weinhold, J., The daylighting dashboard – a simulation-based design analysis for daylit spaces-Building and Environment 46, p. 388

4.4.3. Daylight Simulation Software's

The development of daylighting simulation tools can be dated back to the 1970s. [1] Nowadays, commonly used programs include Lumen Micro 2000, AGI32, Diva, Ecotect, Radiance, etc. Figure 4-55 illustrates comparisons between the advantages of the most famous existing validated simulation tools. We cannot use just one type of software in order to explore and evaluate the best design solution which meets a certain environmental performance in fully automatic optimization process. Therefore in this thesis the new parametric tool which combines most of these programs will be used to investigate the daylight performance in learning spaces.

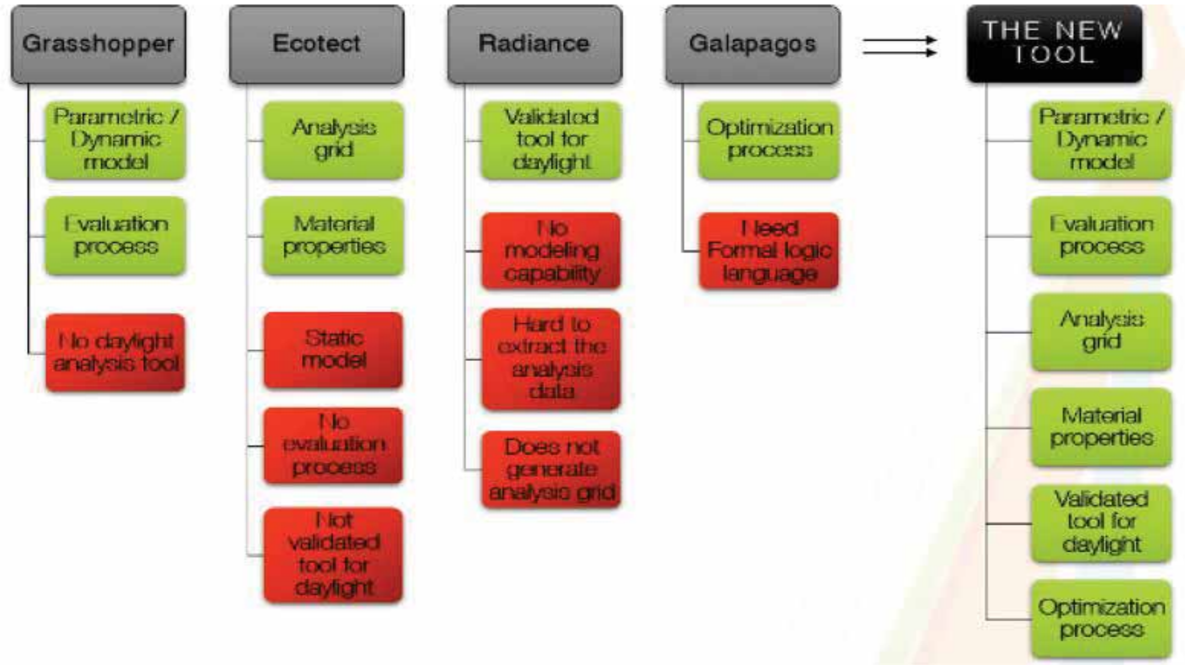


Figure 4- 54: Shows the advantages and disadvantages of each type of software such as Grasshopper, Ecotect, Radiance and Galapagos
Source: New Parametric workflow based on validated day-lighting simulation

Grasshopper, which is a plugin for Rhinoceros and parametric modeling, in cooperation with Diva [2], and Rhino, is used as the new parametric workflow. This workflow runs in automatic mode without the need to export or import the 3D modeling information between each type of software to have a totally automatic optimization process.

4.4.4. Methodology of Daylight Design Parametric Workflow

Due to the complexity and size of the simulations performed in this study, it was very important to choose tool which allowed for smooth integration between the modelling tool and the

[1] Shi, Xing, and Wenjie Yang, Performance-driven architectural design and optimization technique from a perspective of architects - Automation in Construction 32, p. 132

[2] DIVA-for-Rhino is a highly optimized daylighting and energy modeling plug-in for the Rhinoceros - NURBS modeler. The plug-in was initially developed at the Graduate School of Design at Harvard University and is now distributed and developed by Solemma LLC. DIVA-for-Rhino allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes including Radiation Maps, Photorealistic Renderings, Climate-Based Daylighting

simulation tool. The workflow, which is illustrated in Figure 4-56, describes the linking of each parametric modeler. Grasshopper plug-in for Rhinoceros and Diva -plug-in for Grasshopper depends on Radiance and Daysim engines which are suitable for the analysis and visualization of lighting in design. Radiance is the gold-standard software for daylighting and light assessment. Daysim is an associated program that enables CBDM and is employed to predict illuminance, visual quality, appearance of spaces and to evaluate new lighting and daylighting technologies. Finally, Diva plug-in for Rhinoceros, which depends on Evaglare engine, is used for glare calculations analysis. The testing process is an iterative one. Results of the simulations are used to improve the design. This process is repeated until a satisfactory outcome is achieved. (1)

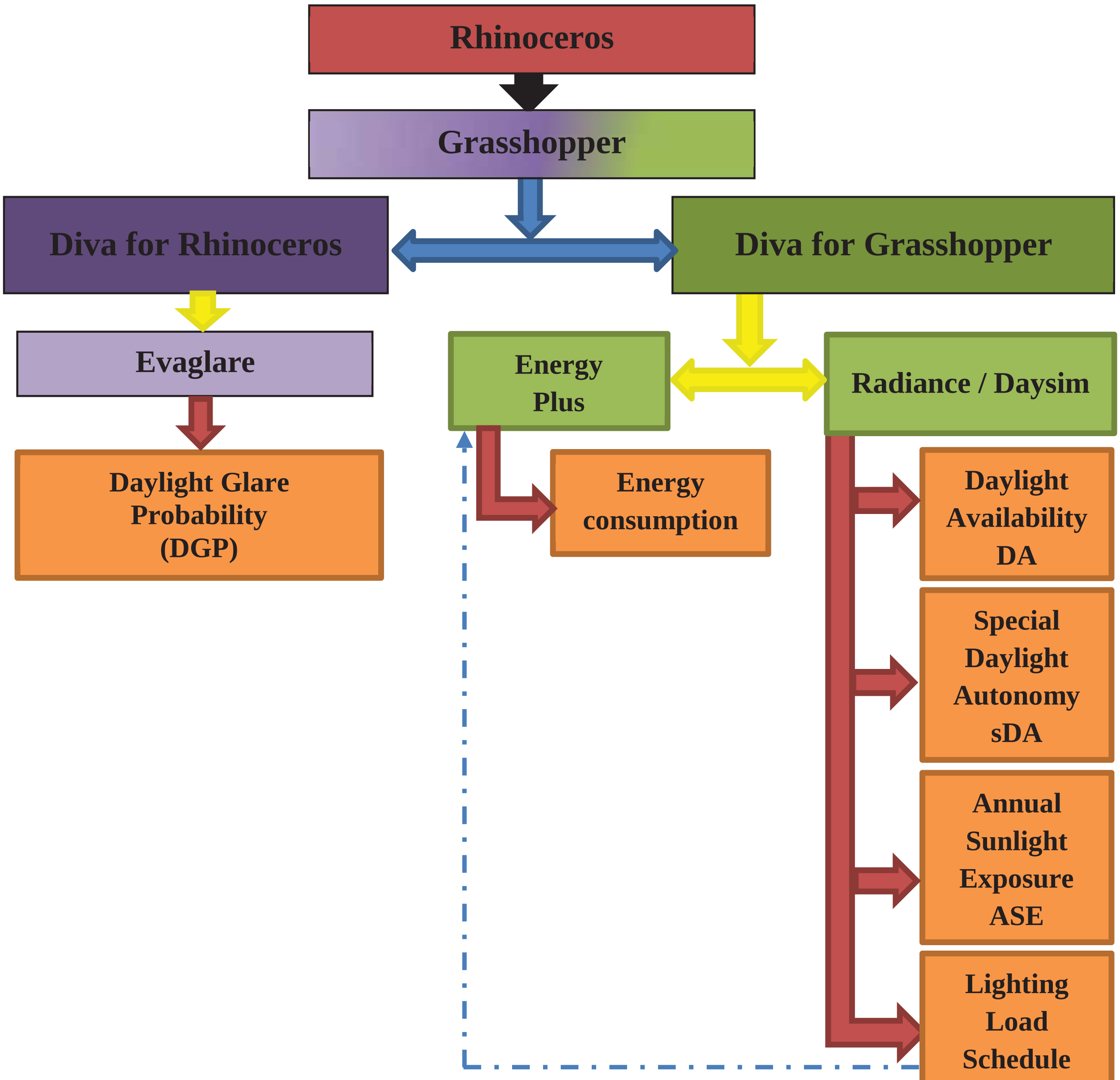


Figure 4- 55: New Tool Work flow

[1] Rahimzadeh, Shahab Din, et al. Parametric modelling for the efficient design of daylight strategies with complex geometries, p.3

This new effective workflow is done inside Grasshopper. It allows the user to work simultaneously with one platform which has the ability to export the 3D modeling information, material properties, and analysis grids into Radiance/Daysim format through the diva plug-in and calculates a series of daylight illumination analyses. Radiance is running in the background while Rhinoceros/Grasshopper is running in the foreground. After that the simulation results are automatically loaded back into the Grasshopper with the numeric values of each the analysis points as well as RGB color mappings. The results are also exported to an excel sheet by TT box plug-in which is an add-on for Grasshopper. In that case, the analysis results are evaluated within the excel sheet to get the maximum sDA and minimum ASE according to LEED V4 rating system. The best cases, which were chosen in the previous step, should be evaluated in the rhino software to investigate glare phenomena on it by Diva for rhino.

Although the methodology and techniques developed in the previous section are valuable, they have some limitations that warrant future research work:

- **Smart shading devices (Automated blinds):** However smart shading device is supported in diva for rhino, it is not included in diva for grasshopper yet. Therefore the previous parametric workflow can’t be achieved to investigate the automated louvers. Moreover, there isn’t any illuminance or glare quality metrics for the automated louvers yet.
- **Smart glazing:** It isn’t supported right now in diva for rhino or grasshopper so it can’t be investigated in the previous parametric flow.

4.5. Conclusion

Lighting and lighting control systems represent a significant contribution to the energy consumption of learning spaces and the university as well. This chapter discussed differing strategies which could be used inside learning spaces by LMS and BEMS. Table 4-10 illustrates comparative analysis for these strategies with its essential components.

All of LMS and BEMS strategies can be stand-alone systems or part of a fully interoperable lighting management system (LMS). The maximum energy consumption is achieved in the case of non-control and it can be gradually decreased by using; LMS then LMS integrated with smart façade. The maximum conservation is achieved with integration between LMS+ smart façade and HVAC.

Space shell (façade) is the energy filter that should be the starting point of the building design process. It should be smart and dynamic in order to adapt with different climate conditions. A smart façade system has possibilities for an overall energy reduction for heating, cooling and lighting. Moreover it can prevent solar heat radiation from entering the building, when it is not needed

Table 4- 9 : Components of BEMS levels

Components	*Simple strategies*				*Integrated*
	Predictable Occupancy Control Strategy	Real Occupancy Control Strategy	Constant Illuminance Control Strategy	Daylight Harvesting Control Strategy	Integration with blinds
Sensors					
Scheduler	✓		✓		✓
Clocks	✓				✓
Illuminance sensor			✓	✓	✓
Presence sensor		✓			✓
Temperature sensor					
Wind sensor					✓
Actuators					
Switch	✓	✓		✓	✓
Dimmer			✓	✓	✓
Others					
Skywells				✓	✓
Smart windows					✓
Automatic blinds					✓
Networks					
Proprietary	✓	✓	✓	✓	✓
Open	✓	✓	✓	✓	✓

Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 169

Learning spaces, which may be new or refurbish spaces, should be supported with smart fixtures and systems with low energy consumption. Figure 4- 57 illustrates the work flow for designing the control lighting steps in two types of learning spaces.

Smart architecture techniques changed the lighting design process completely. Nowadays by virtue of daylight simulations tools, which depend mainly on parametric design processes, a lot of design concepts can be investigated early in the design phase to get the best case and optimum solution. Therefore the next chapter will investigate daylight performance for smart learning spaces case studies.

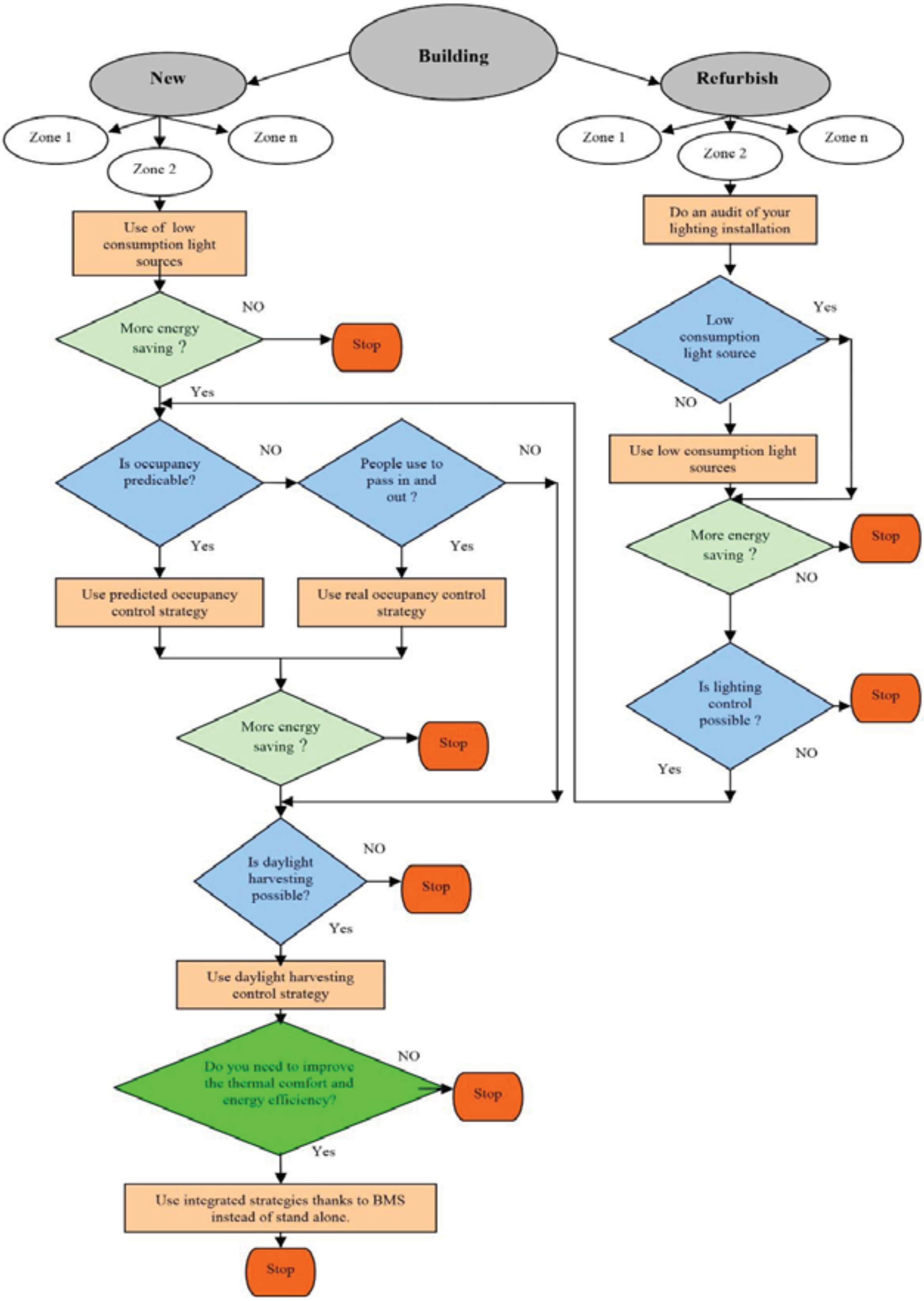


Figure 4- 56: General scheme for energy efficient design of lighting control
Source: IES Annex 45 - Energy Efficient Electric Lighting for Buildings, p. 171

5.1. Introduction

This chapter investigates daylighting performance in a large lecture hall as a sample for group learning and teaching spaces in a university. The hall was chosen to be located in Cairo, Egypt. Figure 5-1 illustrates the steps of the hall's lighting design process. The spatial environment was designed according to halls standard in chapter two as a parametric hall model to accommodate various students' capacities. In this chapter, it was chosen to accommodate 120 students, with an area of 225m^2, as a base case in order to start daylight performance analysis. The simulation analyses were made at two consecutive stages. The objective of the first stage was set to find the optimum window to wall ratios, WWR, based on annual simulation runs at the four orientations. Stage two investigated the possible variation in count and tilting angles of the horizontal, vertical and aligned louvers devices for the cases which achieved acceptable performance in stage one. Stage two mainly focuses on South, East and West orientations as these were found the most problematic orientations according to the stage one analysis.

The new IES quality metrics (sDA and ASE) and LEED v4 are the main two evaluation criteria used for the investigative techniques in this chapter. If the technique had a lot of successful alternatives, another evaluation steps was also used such as daylight availability glare analysis and total energy consumption to get the most efficient alternative.

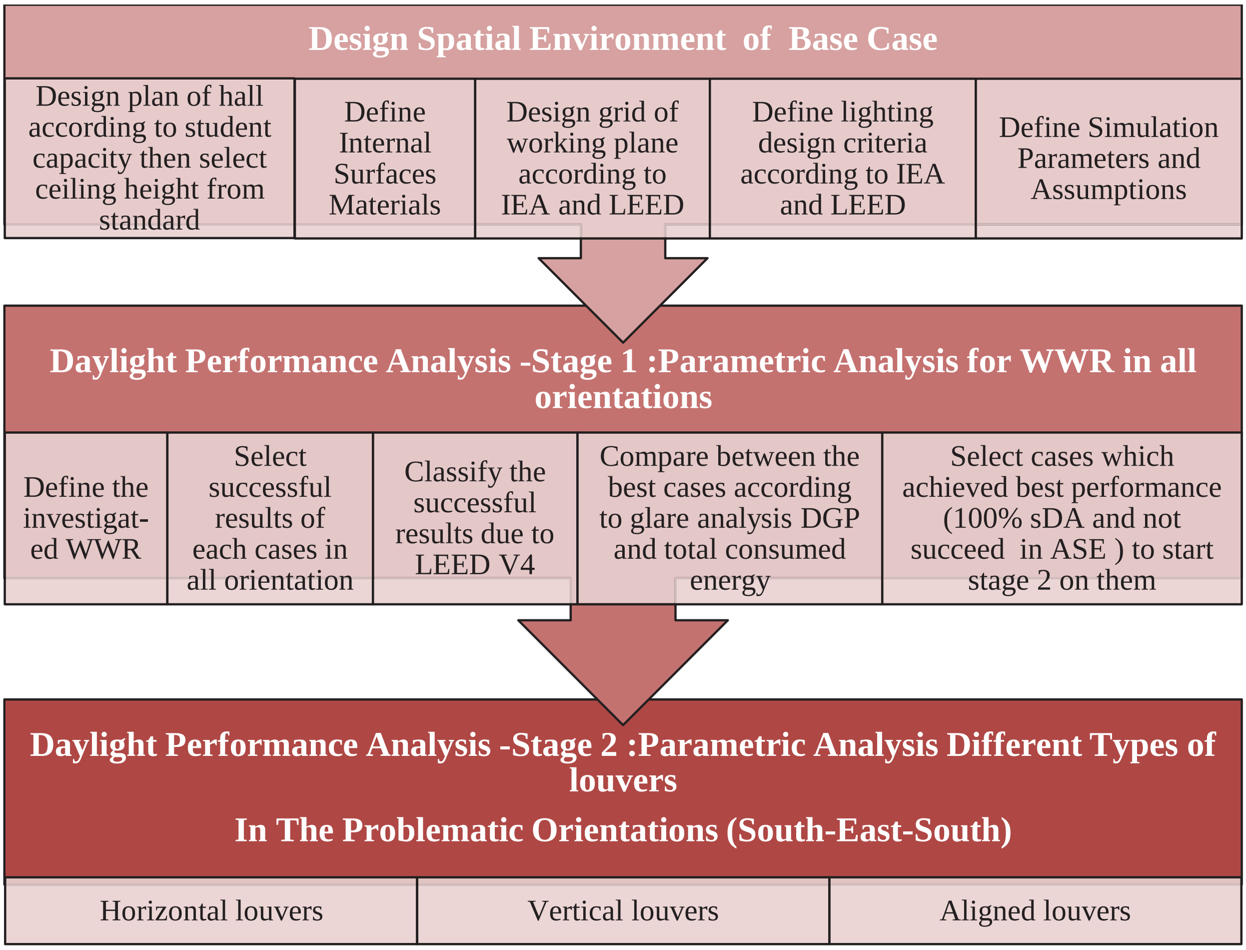


Figure 5- 1: Steps of lighting design process for the lecture hall

5.2. Base Case Parameters

5.2.1. Site Analysis of Lecture Hall

5.2.1.1. Location and sky type

The case study was chosen to be located in the city of Cairo, Egypt (30° N- 31° E). Cairo, the capital of Egypt, is considered as one of the world's 15 largest cities in urban and population growth. As the capital and primary city of Egypt, the government is heavily concentrated in the capital. Cairo also contains most of the higher-order private sector services and education buildings. According to the previous studies which are illustrated in Table 5-1, Cairo is endowed with a clear sunny sky for almost all the year. Most of the year's days are sunny with only a few cloudy and partial cloudy days.

Table 5-1: The monthly, seasonal and annual mean number of days of the sky-cover occurrence over Cairo during the period of (1992–2003)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Clear sky	22	21	26	28	29	30	31	31	30	29	26	25	27
Cloudy sky	2	1	0	0	0	0	0	0	0	0	0	1	0
Partial cloud sky	7	6	5	2	2	0	0	0	0	2	4	5	3

Season	Winter	Spring	Summer	Autumn
Clear sky	23	28	31	28
Cloudy sky	1	0	0	0
Partial cloud sky	6	3	0	2

Source: "A Study of Solar Radiation Climate at Cairo Urban Area, Egypt and its Environs" International Journal of Climatology, Vol. 26. P. 1913-1928

5.2.1.2. Weather Data

Annual daylighting simulations use weather files to retrieve hourly solar radiation data for a specific location. Simulation was conducted using the IWEC weather file of Cairo.(1)

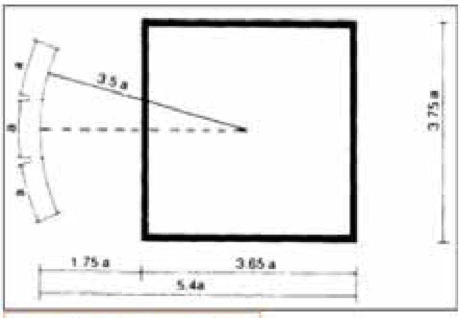
5.2.2. Spatial Environment Design for The Lecture Hall

According to the previous studies in chapter two, a parametric model for the hall was designed to be used later for different student capacities. Following are the main steps used in the spatial environment design process.

5.2.2.1. Base Case Size and Proportions

Spaces which are too wide make it hard for instructors to maintain eye contact and typically have poor sightlines. Deeper spaces make it hard for students in rear rows to interact with instructors and other students. Figure 5-2 illustrates the preferred proportions for large lecture halls according to the standard as discussed before in chapter 2. Large lecture halls must be sloped or tiered to provide good sight lines. The slope of the floor in a large room or lecture hall should be no more than 1:12 to provide good sight lines and acoustics.

[1]http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=1_africa_wmo_region_1/country=EGY/cname=Egypt



Source: Neufert, P 316

	Group Teaching /Learning space type		Students Capacity	Square meter	Clear Ceiling height (m) Rear	Clear Ceiling height (m) Front	Furnishings	Display modes
Halls	Lecture Hall	Small lecture hall	48-70	Till120 m²	2.5m	3.6m	• Fixed writing surfaces & movable chairs • Instructor desk • Guest table for	1 projector-2 screens 1 Overhead Projectors or 1 Document camera 3 whiteboards 1 voice amplification
Halls	Lecture Hall	Large lecture hall	70-120	120-250 m²	2.5m	4.6m	• Fixed writing surfaces & movable chairs • Instructor desk • Guest table for three speaker	2 projectors 1 w/screen – 2 s/screens 1 Overhead Projectors or 1 Document camera 1 whiteboards 1 voice amplification
Halls	Auditorium	Small Auditorium	120-300	250-450 m²	2.5m	4.6m	• Fixed writing surfaces & movable chairs • Instructor desk • Guest table for three speaker	3 projectors 1 w/screen – 2 s/screens 1 Overhead Projectors or 1 Document camera 1 whiteboards 1 voice amplification
Halls	Auditorium	Medium Auditorium	300-400	400-500 m²	2.5m	5.4m	• Fixed writing surfaces & movable chairs • Instructor desk • Guest table for three speaker	3 projectors 1 w/screen – 2 s/screens 1 Overhead Projectors or 1 Document camera 1 whiteboards 1 voice amplification
Halls	Auditorium	Large Auditorium	400-650	500-850 m²	2.5m	5.4m	• Auditorium seats with tablet arms • Instructor desk • Guest table for three speaker	3 projectors 1 w/screen – 2 s/screens 1 Overhead Projectors or 1 Document camera 1 voice amplification

Figure 5- 2 : Large hall size according to standard and guidelines

5.2.2.2. Parametric Proportions Based on Standard

According to the pervious figure, the following definition is generated for the lecture hall plan. The definition is depending on (a) parameter as shown in following figures to shape each of followings:

i. Student area rectangle with width (3.75 a) and depth (3.65 a) as shown in Figure 5-3.
ii. The main wall for screens and white board with minimum rib width (a) as shown in Figure 5-4.

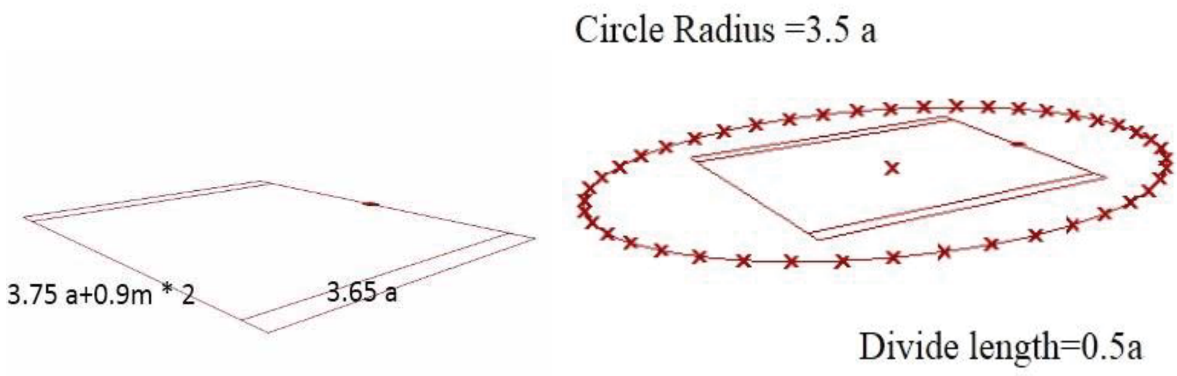


Figure 5- 3: Parametric Proportions of the Base Case –Define a parameter

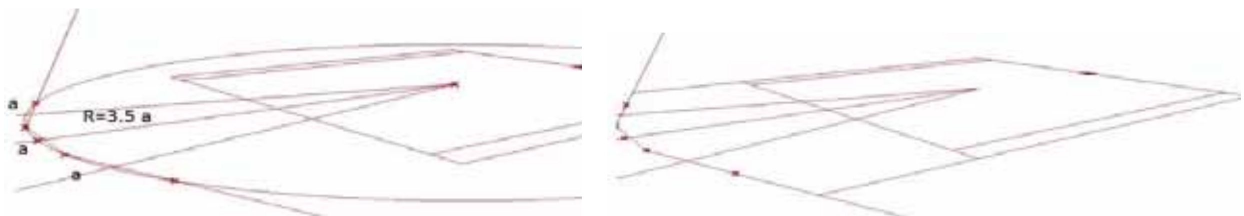


Figure 5- 4: Parametric Proportions of the Base Case- main wall outline

5.2.2.3. Lecture Hall for 120 Student

The case study was chosen to accomdate 120 students in a large lecture hall with 225 m^2 according to the pervious standard. So (a) parameter was modified to be 3.2 m as shown in Figure 5-5. The lecture hall consists of two main zones; the first one is the student zone which is represented in nearly square proportions with a 12m (3.75a=3.75*3.2) width and 11.7m (3.65a=3.65*3.2) depth. The second one is the instructor zone with 12.00m width and 5.25m depth. The main wall is the important component in the instructor zone. It contains three ribs with minimum length a (3.2m). Figure 5-6 illustrates the final plan for the hall.

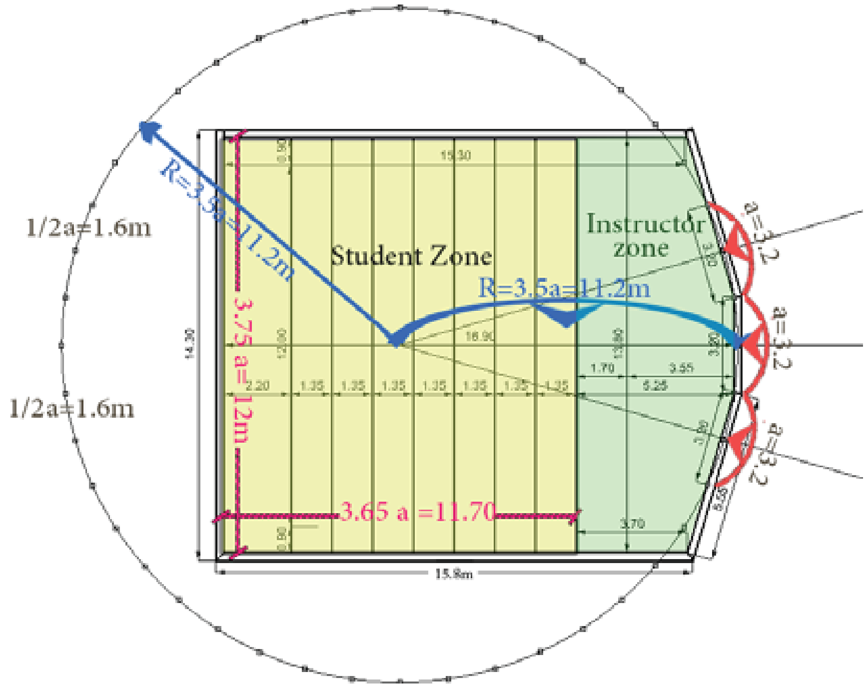


Figure 5- 5: Outline of lecture hall plan according to standard

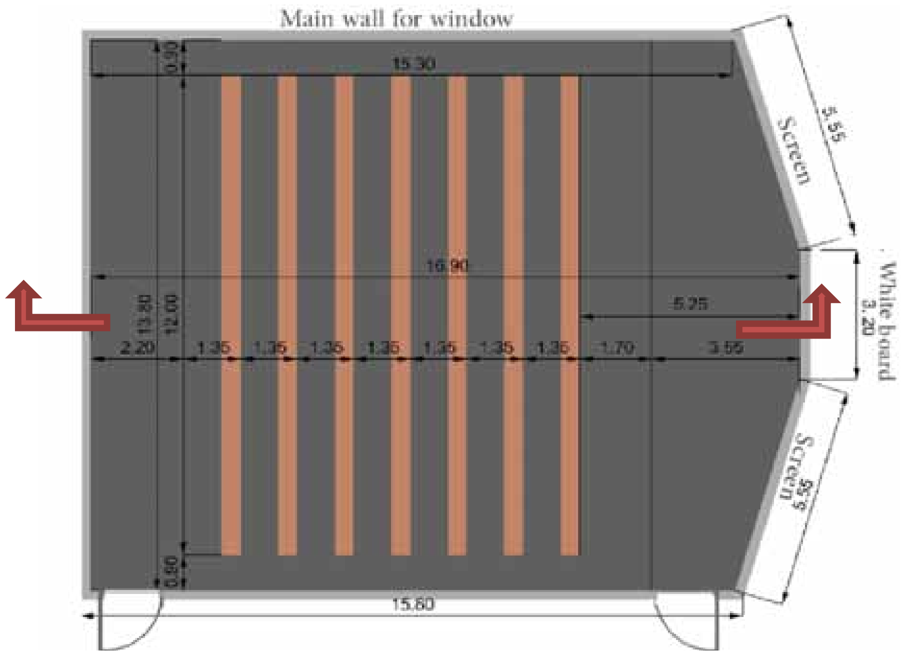


Figure 5- 6: Lecture hall plan

The hall's clear height at the entrance is 4.6 m and it decreases in each step to reach a minimum of 3.55 m at the back as shown in Figure 5-7. The lecture hall's space was assumed to have a 6 mm double glazed window on the left side wall in order to avoid shadow phenomena for the students when taking notes. The window sill height is 1.05m as shown in Figure 5-8 and its width and height will be investigated in the first parametric analysis stage to choose the size which best achieves sufficient daylight in each orientation.

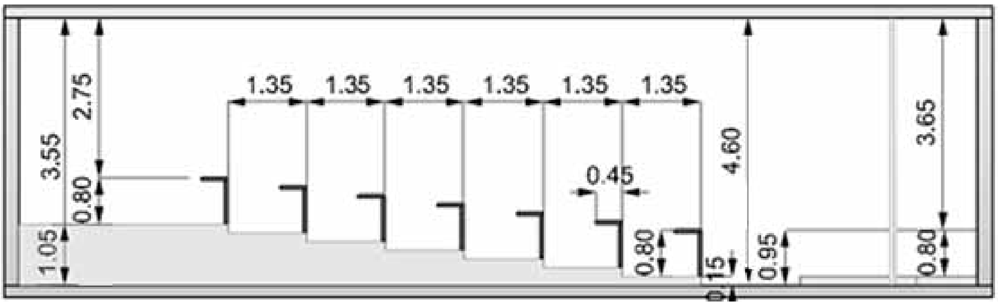


Figure 5- 7: Lecture hall section

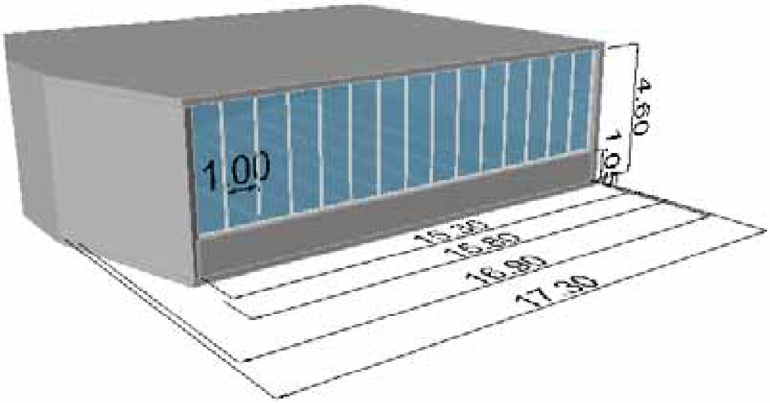


Figure 5- 8: Lecture hall 3D

5.2.2.4. Location of Lecture Hall in the Building

In order to neutralize the effect of the context and surroundings on daylighting performance, the lecture hall was assumed to have an open horizon and no obstructions. The external ground reflectance of 20% was assumed. The investigated hall was located on the second floor and surrounded be two similar halls in the same building as shown in Figure 5-10.Table 5-1 illustrates conclusion for hall case study main parameters.

Figure 5- 9: Location of base case in the building

Table 5- 1: Conclusion for base case parameters

Large Lecture Hall Parameters	
Site Analysis	
Location	Cairo, Egypt
Sky Type	Clear Sunny Sky
Climate Weather File	Cairo IWEC weather file (U.S Department of Energy)
Occupancy Schedule	
Working Hours	8:00 AM till 6:00 PM.
Spatial Environment	
Type Of Learning Space	Group Teaching/Learning
Students Number	100-120
Hall Area	225 m^2
Type Of Furniture	Fixed writing surfaces with width 0.45 m& movable chairs
Space Between Movable Seats	0.70 m
Grade Of Technology	Base
Display Modes	2 projectors -3/screens 1 Overhead Projectors or 1 Document camera 1 whiteboard -1 voice amplification
Main Floor Level	5.00 m on second floor - figure (5-10)
Hall Height	4.60 m (3.65m minimum on the hall back)
Internal Surfaces Materials	
Internal walls	Generic internal wall 50 % (Light color)
Ceiling	Generic ceiling 80% (white color)
Floor	Generic floor 20%
Fenestration Type :Window with Sill Height 1.05 m	
Frame and mullions	Metal diffuse
Glass	Glazing double pane clear 80

5.3. Simulation Parameters and Assumptions

5.3.1. Methodology of Evaluating Steps Simulation Analysis [(1)]

The following simulations analysis were made at four levels of evaluation. The first three evaluations were done as daylight simulation analysis (with lighting criteria illustrated in table 5-2) and the last one investigated the total energy consumption for the hall with highest daylight performance by running a thermal simulation.

Table 5- 2: Conclusion for lighting criteria used in evaluation of simulations results

Lighting Criteria	
Target Illuminance	300 lux
ASE	Must be less than 10 preferred ratio less than 7 and the best case less than 3
sDA	>55 – 2 points on LEED >75 – 3 points on LEED
DGP	<35 imperceptible glare- 35>DGP<45-perceptible glare

[1] Check Appendix D for more information about Simulation settings

1. sDA and ASE Analysis was done for the tested parameters to get the cases which achieve sufficient daylight and get the points on the LEED rating system as illustrated in Table 5-3:

Table 5- 3 : The key legend for cases classification according to LEED rating system

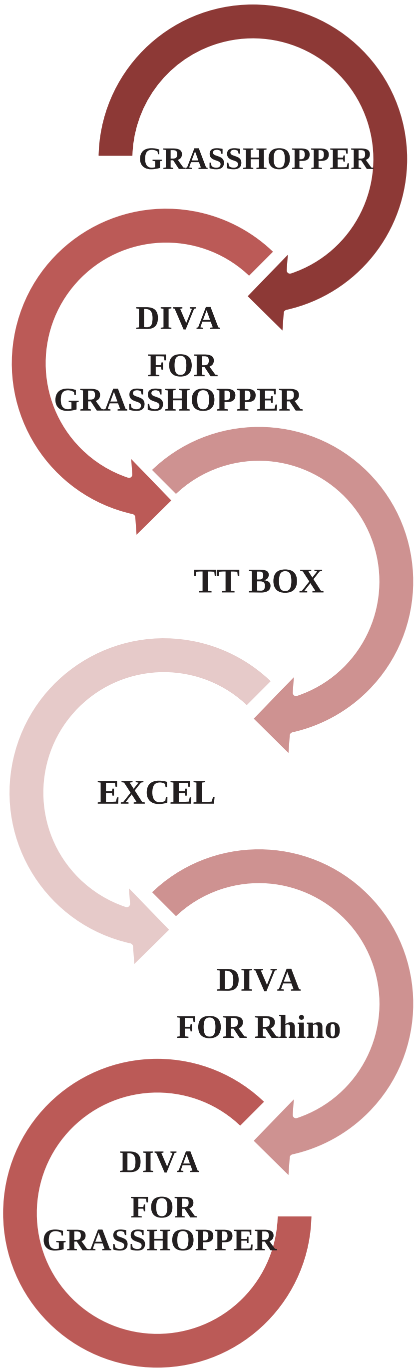
Classification according LEED V4	Refused		Accepted			
	Due to ASE	Due to sDA	2 points on LEED	3 points on LEED		
			ASE < 10	ASE < 10	ASE ≤ 7	ASE ≤ 3
Color legend						
Classification criteria	ASE > 10	sDA < 55	55 < sDA ≤ 75	sDA ≥ 75		

2. Daylight availability was analyzed for the successful cases at the previous step, and then the best performance cases which achieved the maximum daylit and minimum partially daylit were chosen from the following performance to continue with other evaluations steps:
   - **"Low Performance":** daylit area percentage is equal to or more than half of the space area and less than two-thirds (50%≤ daylit area <65%).
   - "**Medium Performance**": daylit area percentage is equal to or more than two-thirds of the space area and less than three-quarters (65%≤ daylit area <75%).
   - "**High Performance**": daylit area percentage is equal to or more than three-quarters of the space (75%≤ daylit area) with minimum partial daylit area.
3. Glare analysis at 9:00 am and 12:00 pm in the different seasons of summer/winter solstices and autumn equinox (21 of June, 21 of December and 21 of September) was done to the high performance cases from the previous steps and the best cases which achieved minimum imperceptible glare were chosen for the last evaluation step. In this method, glare was divided into four categories: intolerable glare (DGP ≥ 45%), disturbing glare (45% > DGP ≥ 40%), perceptible glare (40% > DGP ≥ 35%), and imperceptible glare (DGP < 35%). In the analysis of this research, the camera was located at a student's eye level in the last row level (2.3 m) and looking towards the whiteboard and screens in front of him. Results were compared to evaluate visual comfort. The cases that were subject to disturbing and intolerable glares were considered unacceptable.
4. Thermal simulation analysis were done for the high performance cases which achieved minimum glare to get the minimum total energy for cooling, heating and electricity loads in order to find the best case which documents most energy consumption.

   For the thermal simulations it was assumed that the space is bordered on five sides by similar spaces as shown in Figure 5-9. As a consequence, interior walls, floor and ceilings were modeled adiabatically. The exterior wall has an R value of 13. The space is conditioned with a fan coil unit. Coefficients of performance are 0.80 for heating and 3 for cooling. Heating and cooling set points and setbacks are 22 C/14 C and 26 C/30 C, respectively. All thermal simulations were set up in Grasshopper and run using EnergyPlusV7-0-0. Annual hourly schedules for occupancy, electric lighting were generated in Daysim and read as simulation input into EnergyPlus and Grasshopper respectively.

5.3.2. Simulation Software

Nowadays by virtue of simulations tools a lot of design concepts can be investigated to find the best case and optimum solution for a lecture hall. Figure 5-11 illustrates the workflow of programs and plugins that will be used in the upcoming work flow to define the best solutions for each orientation.



Model: Grasshopper () which is a plug-in for Rhinoceros modeling software was used to create a parametric model for the lecture hall. The model was created where selected parameters were chosen to be altered in the simulation each model was based on the standard model

Daylight Simulation: A dynamic daylight simulation was carried out to test the effect of chosen parameters. Simulations were conducted using Diva-for-Rhino (V. 3.0.0.6) [(2)] a plug-in for both Rhino and Grasshopper. Diva is used to interface Radiance and Daysim for annual simulation and illuminance computation.

Collect: The simulation results were collected for evaluation. TT box which is plugin for Grasshopper contains a lightning fast Excel Writer which can transform results' numbers into excel with many options such as file creation, work sheet creation, conditional formatting that matches GH coloring and more.

Analysis + Get the best Cases: Sorting the results according to LEED V4 to get the best cases which achieve sufficient daylight with ASE less than 10 and rating sDA values as following:

2 points: for showing 55% $sDA_{300/50\%}$

3 points: for showing 75% $sDA_{300/50\%}$

Glare Analysis: Diva for Rhino was used to interface Evalglare for calculating the Daylight Glare Probability (DGP) for the second phase to compare between best cases beside energy consumption.

Thermal Simulation: Total energy consumption, which is used by the hall, was calculated by using Diva for Grasshopper again. Simulations were conducted using Diva-for-Rhino (V. 3.0.0.6) [(2)] a plug-in for both Rhino and Grasshopper.

Figure 5- 10: Simulation Programs and plugins which were used in model and analysis

[1] Robert McNeel & Associates (2007) "Grasshopper 3d". www.grasshopper3d.com

[2] Solemma "Diva-for-Rhino" www.diva4rhino.com

5.3.3. Grid of Working Plane

The working plane is the surface grid on which daylighting performance was simulated as shown in Figure 5-11. The whole grid has 786 measuring points. It was divided into two groups; the first one was for the instructor area which is illustrated with a blue border in Figure 5-12 and consists of grid points that are divided in 0.6 m intervals (0.6m * 0.6m) with a height of 0.8 m. The second group was for the student area which is represented with a yellow border in figure 5-12 and is separated into six slices, five of them with dimensions of 1.35*13.6m and the last one with dimensions of 3.35*13.6m. These slices were ranged in vertical series with step height 0.15m. These slices consist of grid points that are divided into spaces of 0.6m * 0.45m with 0.8m height. (Table 5-4)

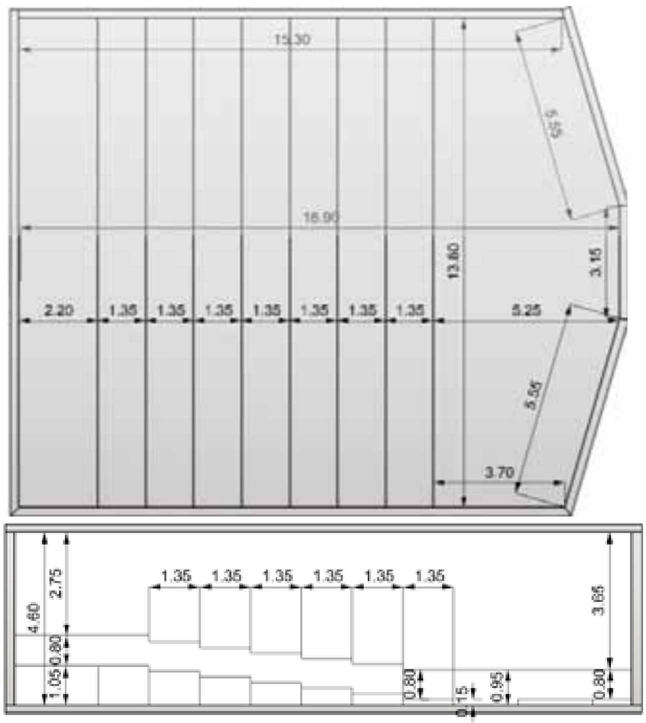


Figure 5- 11: Work surface grid dimension

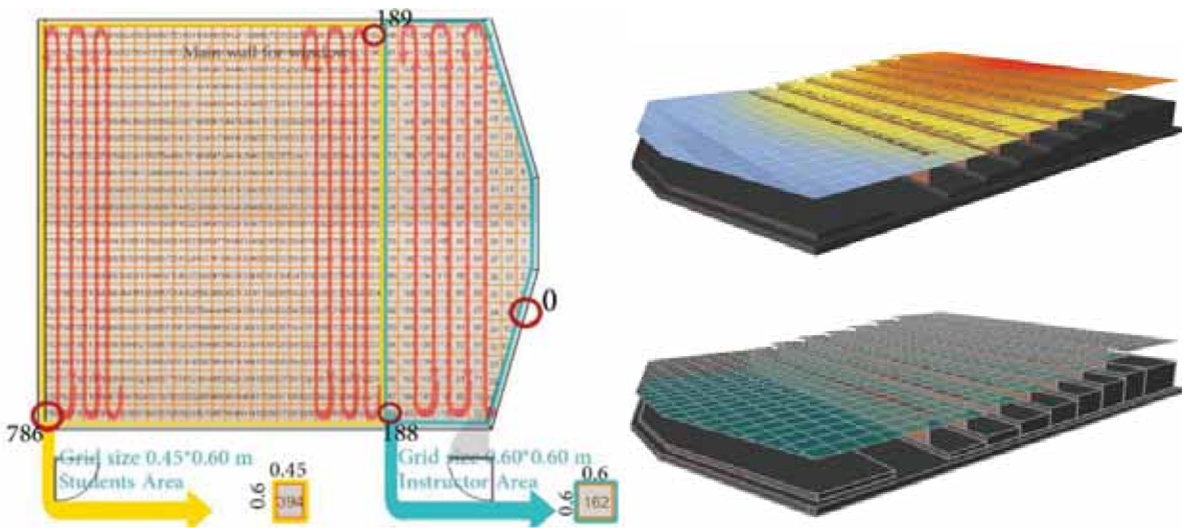


Figure 5- 12: Work surface grid points

Table 5- 4: Conclusion for work surface grid

Work Surface Grid		
Instructor and First row Yellow border at Figure (5-12)	Width Figure (5-12)	0.60*0.60 m
	Height Figure (5-11)	0.95 m above level of 5.00m 0.80 m above level of 5.15 m
Students and Hall Back Red border Figure (5-12_	Width Figure (5-12)	0.45*0.60 m
	Height Figure (5-11)	Ranged from 1.10 till 1.85 above level of 5.00m (Steps of 0.15 m)

5.3.4. Lighting Control Strategy

According to the New Buildings Institute (NBI 2003), daylight harvesting systems are generally used in spaces that have relatively wide areas of windows or skylights such as learning spaces. The savings potential varies from 20% (daylight-harvesting alone) to more than 50% . [1] Therefore daylight harvesting will be used as a lighting control strategy (Table 5-4).

Table 5- 5: Conclusion for light control strategy

Light control Strategy	
Daylight Harvesting strategy	Photo sensor controlled Dimming

5.3.5. Methodology of Parametric Analysis Simulation

The simulations and analysis were made at two consecutive stages as shown in Figure 5-14; the objective of the first stage was set to find the optimum window to wall ratios, WWR, based on annual simulation runs at the four orientations. Stage two investigated the possible variation in count and tilting angles of the horizontal, vertical and angled louvers for the cases which achieved acceptable performance in stage one. Stage two mainly focuses on the most problematic orientations according to stage one analysis.

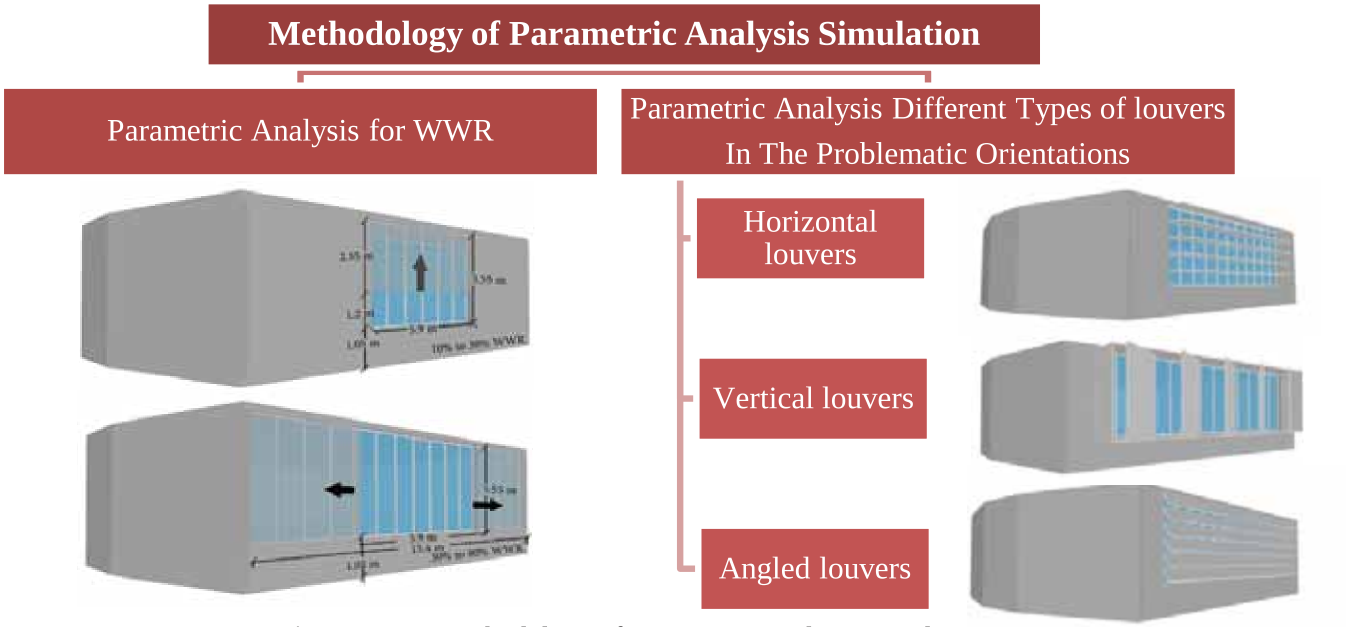


Figure 5- 13: Methodology of Parametric Analysis Simulation

[1] NBI. "Advanced Lighting Guidelines 2003", Table 8.4.http://www.newbuildings.org.

5.4. Stage one :Parametric Analysis for WWRs

Windows are the most critical component of the lecture hall outdoor facade. Their shape, size and optical properties determines the indoor daylighting conditions and visual comfort. Therefore computational models that consider comprehensive building simulation are needed for the prediction of illuminance on the interior surfaces of the hall as well as on the work plane level.

5.4.1. The Investigated WWRs

Fifteen values of window sizes, expressed as Window-to-Wall Ratio (WWR) ,were analyzed for each design. These values started from 10% until they reached 80 % at 5% increments. The window started from the middle of the wall with fixed sill height 1.05 m. Window height and width are considered the two variable parameters. Figure 5-15 illustrates the increase in window height in the first five investigated WWRs from 10% to 30%. Figure 5-16 illustrates the increase in window width in the rest of the investigated WWR from 30% to 80%. The alternatives for the two studied parameters in the investigated WWR are illustrated thoroughly in Table 5-6.

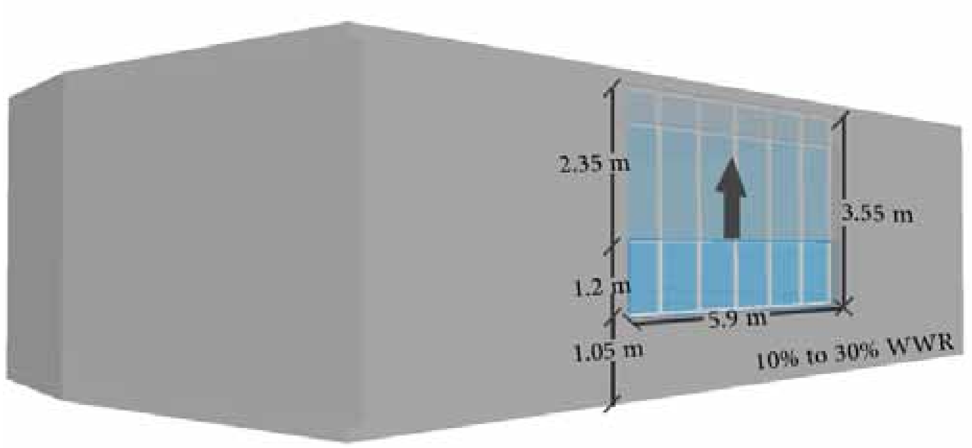


Figure 5- 14: Vertical Extend for Window to achieve WWR from 10 to 30% at lecture hall parametric model

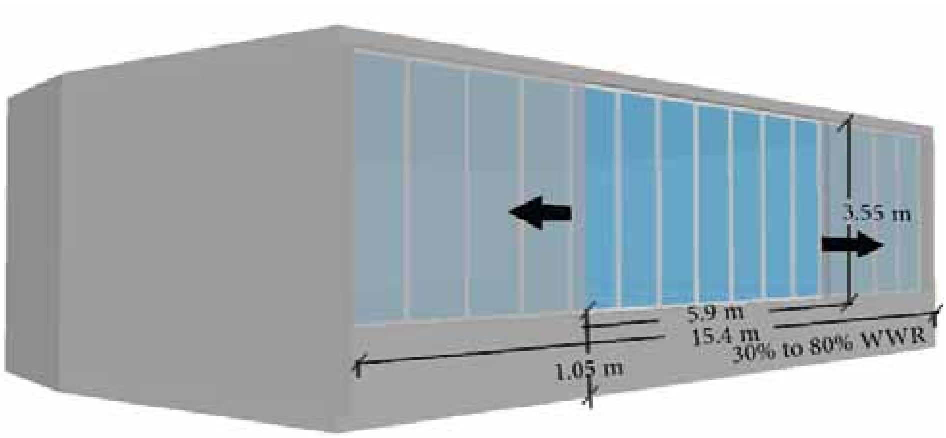
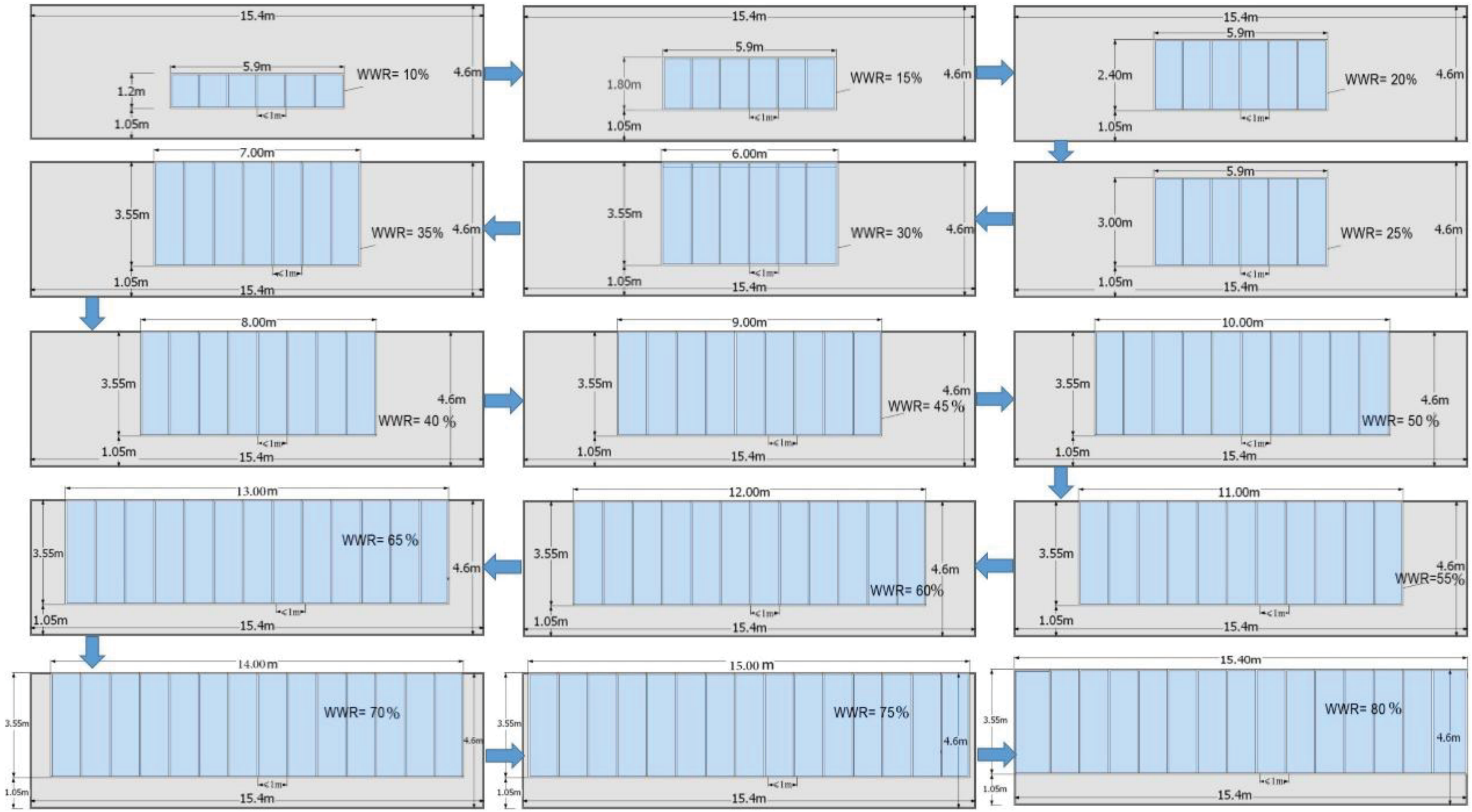


Figure 5- 15: Horizontal Extend for Window to achieve WWR from 30 to 80% at lecture hall parametric model

Table 5- 6: Size and Dimension for examined WWR models



WWR %	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Area m2	7.10	10.60	14.15	17.70	21.20	24.75	28.30	31.80	35.35	38.90	42.40	45.95	49.50	53.00	54.55
WIDTH m	5.9	5.9	5.9	5.9	6.0	7.0	8.0	9.0	10.0	11.0	12.0	12.9	13.9	14.9	15.4
Height m	1.2	1.8	2.4	3	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55	3.55

5.4.2. WWR Simulation Results at North Direction

5.4.2.1. sDA and ASE Analysis of Investigated WWR

Simulation results revealed that sDA and ASE are directly proportional with the increase of WWR's values as illustrated in Figure 5-16. The first threshold for successful cases lies on the 55% sDA. All cases with a larger than 35% WWR reached or exceeded this threshold. In contrast, cases with small windows with a WWR of less than 35 %, didn't achieve sufficient daylight performance. The second threshold for successful cases lies on the 10% ASE. All cases achieved acceptable ASE performance and didn't override the limit.

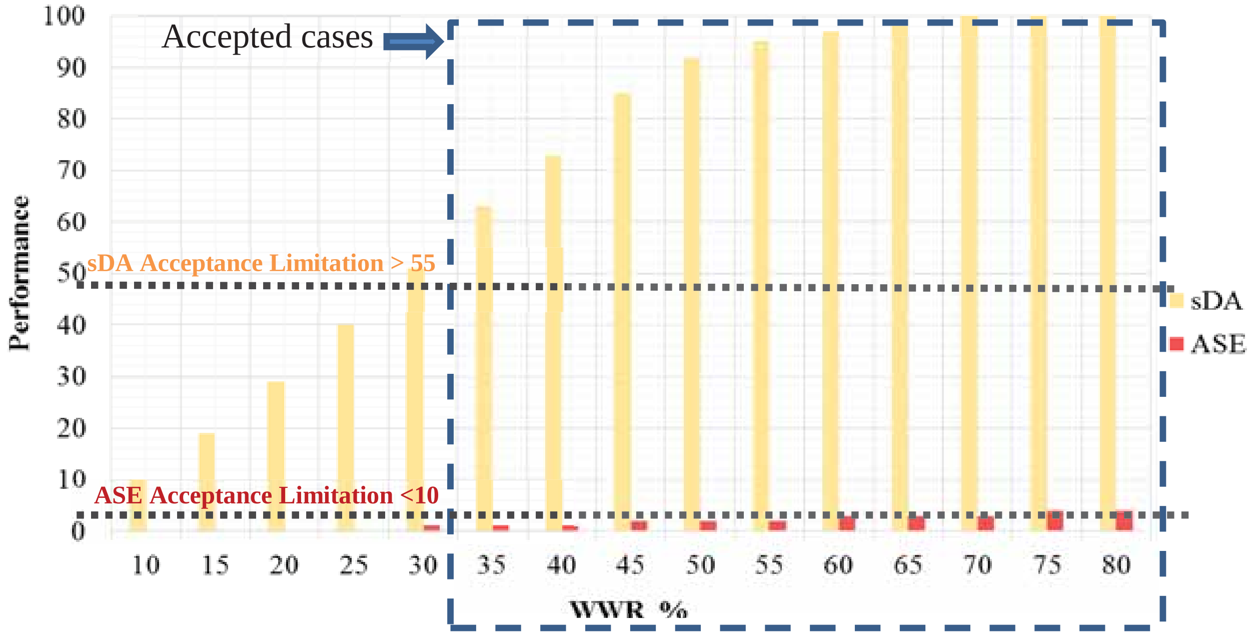


Figure 5- 16 : sDA and ASE performance results for the investigated WWR at north orientation (15 cases)

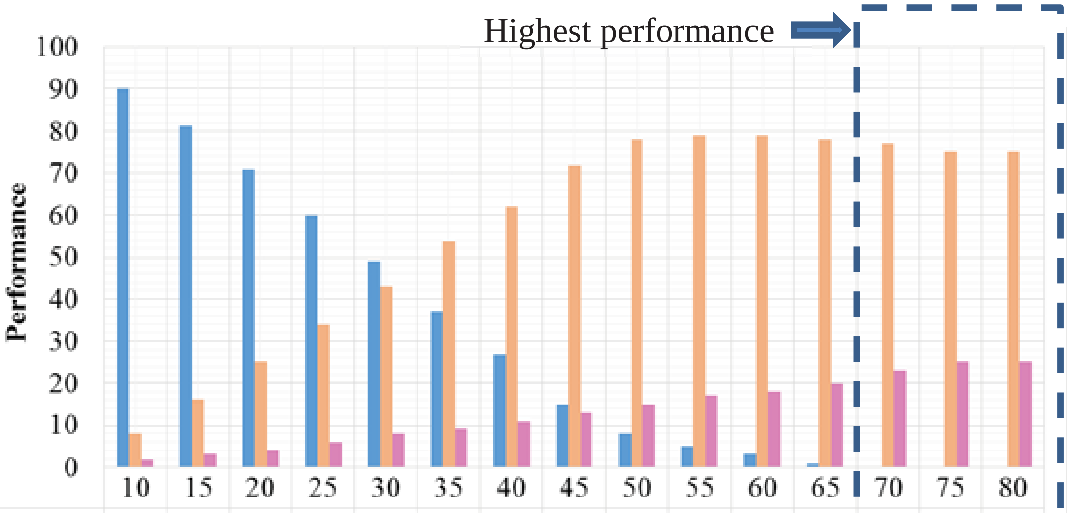
The results of the 15 cases are classified according to LEED v4 rating system in Table 5-7 to choose the best WWRs. The blue rectangle colors represent the non-acceptable results due to low daylight performance (for WWR 10, 15, 20, 25 and 30%), while the others represent the accepted cases in regards to daylight performance. The green rectangle colors represent the accepted cases with two points on LEED v4 (WWR 30 and 35%), while the yellow and orange represent the accepted cases with three points on LEED v4. The yellow represents ASE performance less than 3 (WWR 45, 50, 55, 60, 65 and 70 %) which is the most preferred ASE performance. The orange represents ASE larger than three and less than 7 (WWR 75 and 80%).

Table 5- 7: Analysis of Investigated WWR according LEED V4 in north direction

Performance	WWR %														
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
sDA	10	19	29	40	51	63	73	85	92	95	97	99	100	100	100
ASE	0	0	0	0	1	1	1	2	2	2	3	3	3	4	4
LEED V4 Classification															

5.4.2.2. Daylight Availability Analysis of Investigated WWR

Simulation results revealed that in the cases starting from 35% WWR till 80% the “daylit” area reached more than 50% of the space area, especially in cases starting from 50% WWR it reached more than 75%. “Partially daylit” dominated the space area from 10% WWR until 35%, where it reached 80-90% of the space as an average at the lower values of WWRs (10% to 25%). However it decreased gradually until it faded at 70% WWR. In contrast the overall lit area was almost negligible at the lower values of WWR (10% to 35%), as it increased slightly and remained constant as shown in Figure 5-17.



	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
PARTIALY DAYLIT	90	81	71	60	49	37	27	15	8	5	3	1	0	0	0
DAYLIT	8	16	25	34	43	54	62	72	78	79	79	78	77	75	75
OVERLIT	2	3	4	6	8	9	11	13	15	17	18	20	23	25	25

WWR %

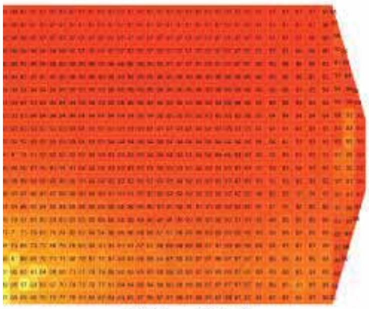
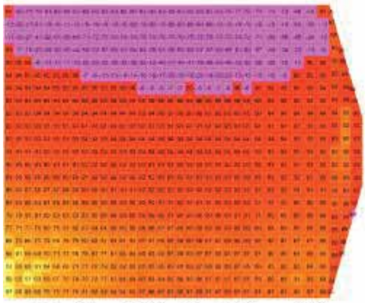
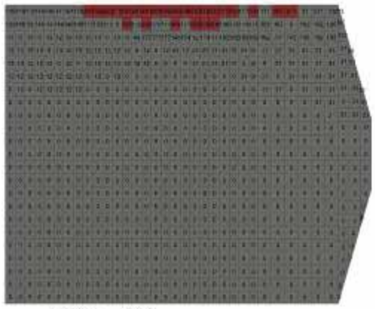
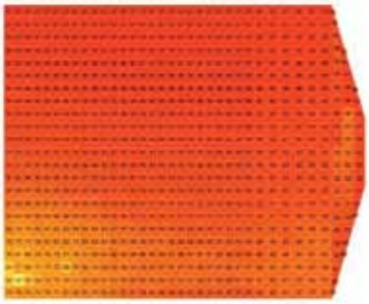
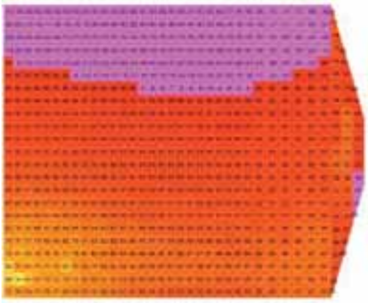
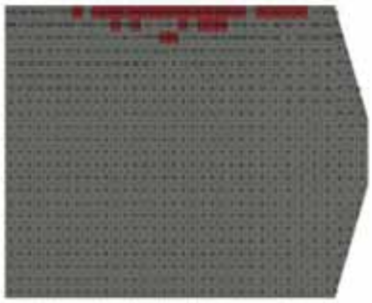
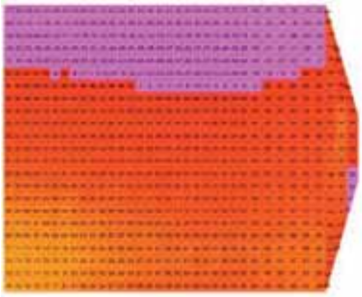
Figure 5- 17: Daylight Availability performance results for the investigated WWR at north orientation (15 case)

The cases are classified into the following performances:

- **"Low Performance ":** The cases with minimum windows size achieved low daylit performances which are 10%, 15%, 20%, 25% and 30% WWR.
- "**Medium Performance “:** The cases with medium windows size achieved medium daylit performances which are 35%, 40%, and 45% WWR.
- "**High Performance “:** The cases with large windows size achieved high daylit performances which are 50%, 55%, 60%, 65%, 70% ,75% and 80% WWR.

The highest daylight performances are achieved with the disappearance of partially daylit areas. The cases with 70, 75 and 80 % WWRs achieved the highest performances in this orientation and get sufficient daylight as well (Table 5-8), but they also have a large over lit area. Therefore they need to be checked with the glare analysis on the next step

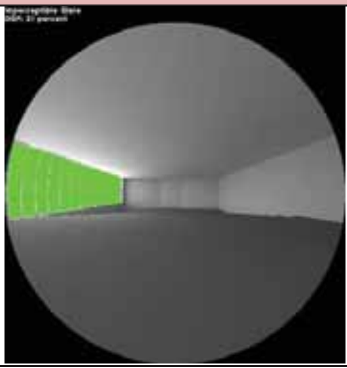
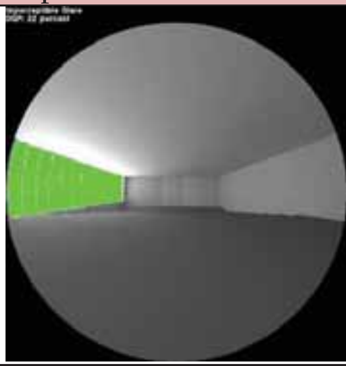
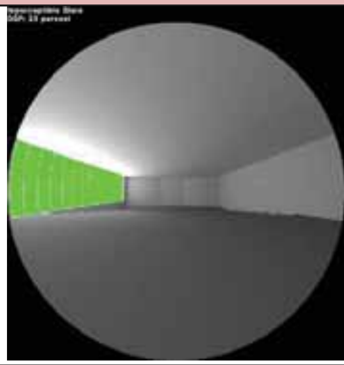
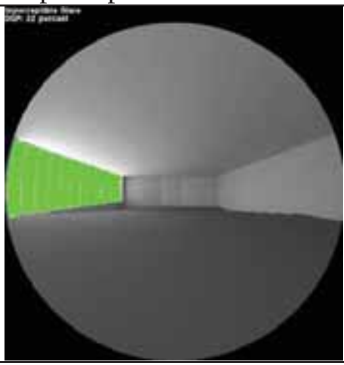
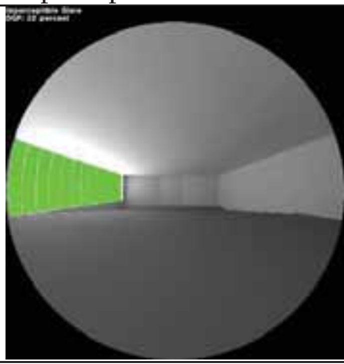
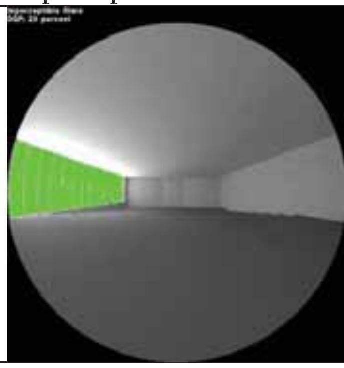
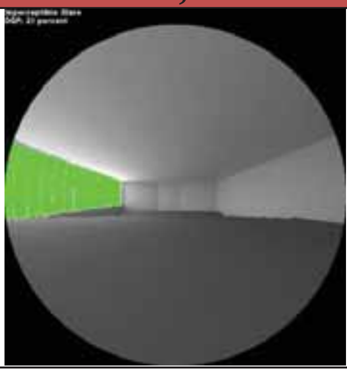
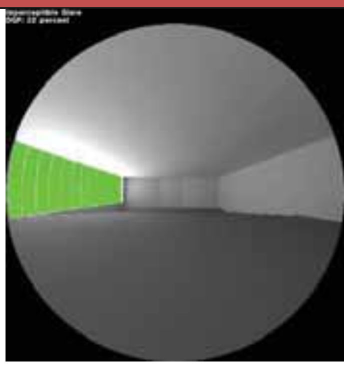
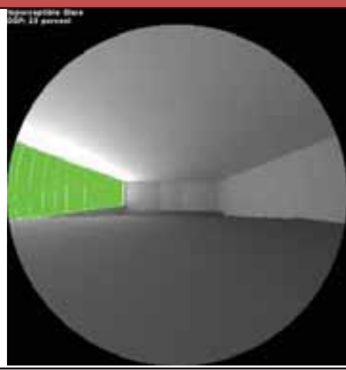
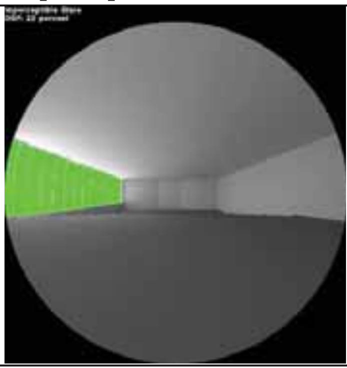
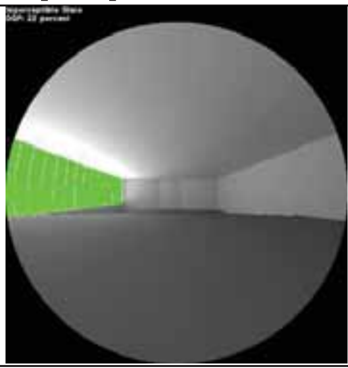
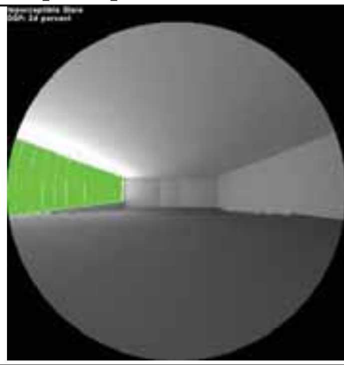
Table 5- 8: Daylight analysis for the highest performance cases at north direction

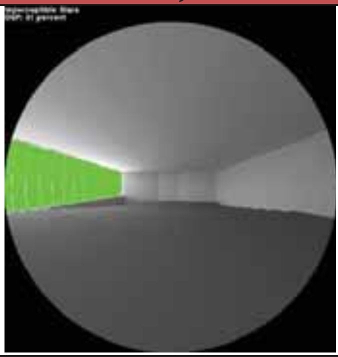
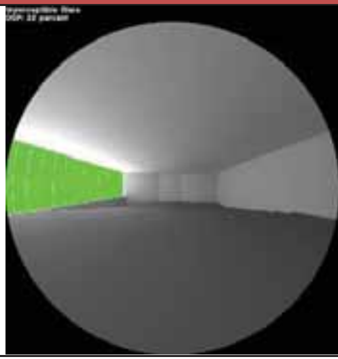
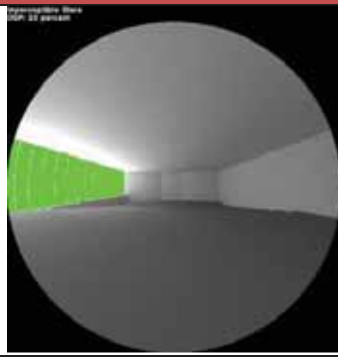
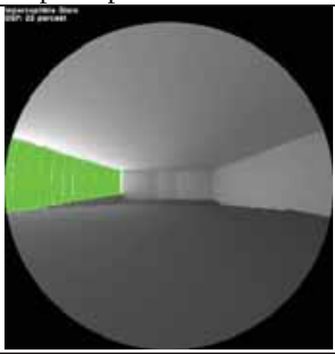
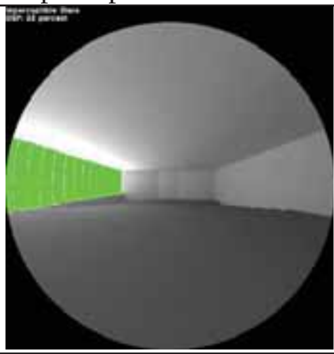
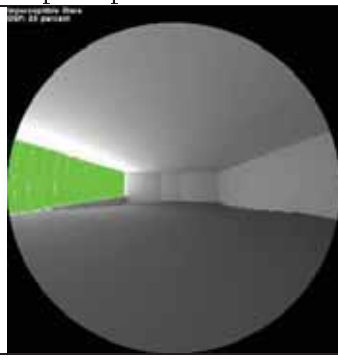
Daylight analysis for the high performance cases at north direction			
WWR	**sDA**	**Daylight Availability**	**ASE**
70 %	 sDA = 100%	 Daylit = 77% Partially = 0% Over lit = 23%	 ASE = 3%
75 %	 sDA = 100%	 Daylit = 75% Partially = 0% Over lit = 25%	 ASE = 4%
80%	 sDA = 100%	 Daylit = 74% Partially = 0% Over lit = 26%	 ASE = 4%
KEY	100% Daylit 50% Partially – daylit 0%	Over lit	ASE > 250 Hours ASE < 250 Hours

5.4.2.3. Glare Analysis for The Top Performance Cases

Analysis for visual comfort was carried out for cases that obtained best daylight availability performance. In north orientation, the top performance achieved was in cases with WWRs 70%, 75% and 80 %. Therefore the Daylight Glare Probability (DGP) was calculated for each of these cases to check their visual comfort. The three cases had imperceptible glare at 9:00 and 12:00 in the different season's as shown in Table 5-9.Although there were minor differences in their performance, the three cases were all acceptable. Therefore their energy consumption will be calculated in the next step to identify the efficient WWR case.

Table 5- 9: Glare analysis for the three best cases

North Direction , CASE 12 :WWR=70%			
	December 21	September 21	June 21
9:00 AM	 Imperceptible DGP 21%	 Imperceptible DGP 22%	 Imperceptible DGP 23%
12.00 PM	 Imperceptible DGP 22%	 Imperceptible DGP 22%	 Imperceptible DGP 25%
North Direction , CASE 13 :WWR=75%			
9:00 AM	 Imperceptible DGP 21%	 Imperceptible DGP 22%	 Imperceptible DGP 23%
12.00 PM	 Imperceptible DGP 22%	 Imperceptible DGP 22%	 Imperceptible DGP 24%

North Direction , CASE 14 :WWR=80%			
9:00 AM			
	Imperceptible DGP 21%	Imperceptible DGP 22%	Imperceptible DGP 23%
12.00 PM			
	Imperceptible DGP 22%	Imperceptible DGP 22%	Imperceptible DGP 25%

5.4.2.4. Energy Consumption for The Top Performance Cases

The analysis of energy consumption provides valuable insight into the energy expenditures of the hall and university as well. Therefore a total energy consumption analysis was carried out per year for the three successful cases which obtained the best daylight performance without any discomfort glare in order to get the most efficient WWR at the north facing direction. The thermal simulation analysis assists with obtaining a detailed view of how energy consumption occurs in the three investigated cases. It used the artificial lighting scheduled which is calculated in the previous daylight simulation for each WWR and began the calculation of lighting, cooling and heating loads per hour for each WWR. Hence the consumption per year for each load was calculated to get the total energy used in each WWR as shown in Table 5-10.

Table 5- 10: Energy consumption For Best cases

WWR	Electric consumption per year- KW/h	Cooling consumption per year- KW/h	Heating consumption per year- KW/h	Total Energy consumption per year- KW/h
70%	3.80	83.73	9.14	96.66
75%	2.78	86.84	9.29	98.91
80%	3.05	88.77	9.34	101.16

The results of thermal analysis, which are shown in the previous table, revealed that the case with 70 % WWR is the most efficient one for saving energy. Its total energy consumption per year is 96.66 KW/H while the other cases at 75% and 80 % are 98.91 and 101.16 KW/h.

5.4.3. WWR Simulation Results at West Direction

5.4.3.1. sDA and ASE Analysis of Investigated WWR

As the north direction simulation result show, the sDA and ASE are directly proportional with the increase of WWRs values as illustrated in Figure 5-18 but with a huge increase in ASE values. The first threshold for successful cases lies on the 55% sDA. All cases larger than 30% WWR reached or exceeded the threshold. In contrast cases with small windows and with a WWR less than 25 % didn't achieved sufficient daylight performance. The second threshold for successful cases lies on the 10% ASE. All cases, except WWR of 10%, achieved a non-acceptable ASE performance as they overrode the limit. Therefore they needed to be treated by shading devices to avoid glare phenomena and achieve sufficient daylight for the lecture hall.

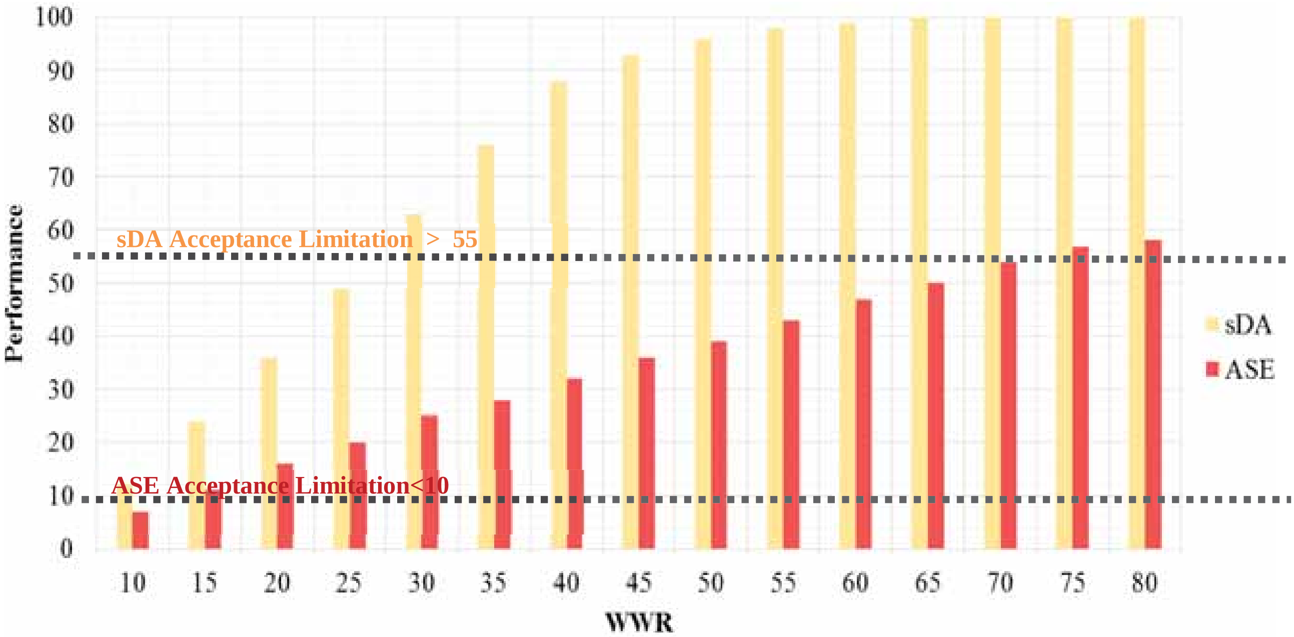


Figure 5- 18: sDA and ASE performance results for the investigated WWR at West orientation (15 cases)

The results of the 15 cases at west orientation are classified according to LEED v4 rating system in Table 5-11. All cases in this orientation didn't get any points in LEED. The blue rectangle colors represent the results which were unacceptable due to low daylight performance (10% WWR). The dark gray represents the results which were unacceptable due to high ASE values (from 30% WWR till 80%) and the brown represents the unacceptable results due to both low daylight performance and ASE (from 15%.WWR till 25 %).

Table 5- 11: Analysis of Investigated WWR according LEED V4 in west direction

Performance	WWR %														
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
sDA	12	24	36	49	63	76	88	93	96	98	99	100	100	100	100
ASE	7	11	16	20	25	28	32	36	39	43	47	50	54	57	58
LEED V4 Classification															

5.4.4. WWR Simulation Results at South Direction

5.4.4.1. sDA and ASE Analysis of Investigated WWR

As west direction simulation results show, the sDA and ASE are directly proportional with the increase of WWRs values but the ASE increment here is less than west orientation, as illustrated in Figure 5-20. The first threshold for successful cases lies on the 55% sDA. All cases with a WWR larger than 25% reached or exceeded the threshold. In contrast, cases with small windows and a WWR less than 20 % didn’t achieve sufficient daylight performance. The second threshold for successful cases lies on the 10% ASE. All cases, except WWR of 10% and 15 %, achieved unacceptable ASE performances and they overrode the limit. Therefore they also need to be treated with shading devices in the west direction to avoid glare phenomena and achieve sufficient daylight for the lecture hall.

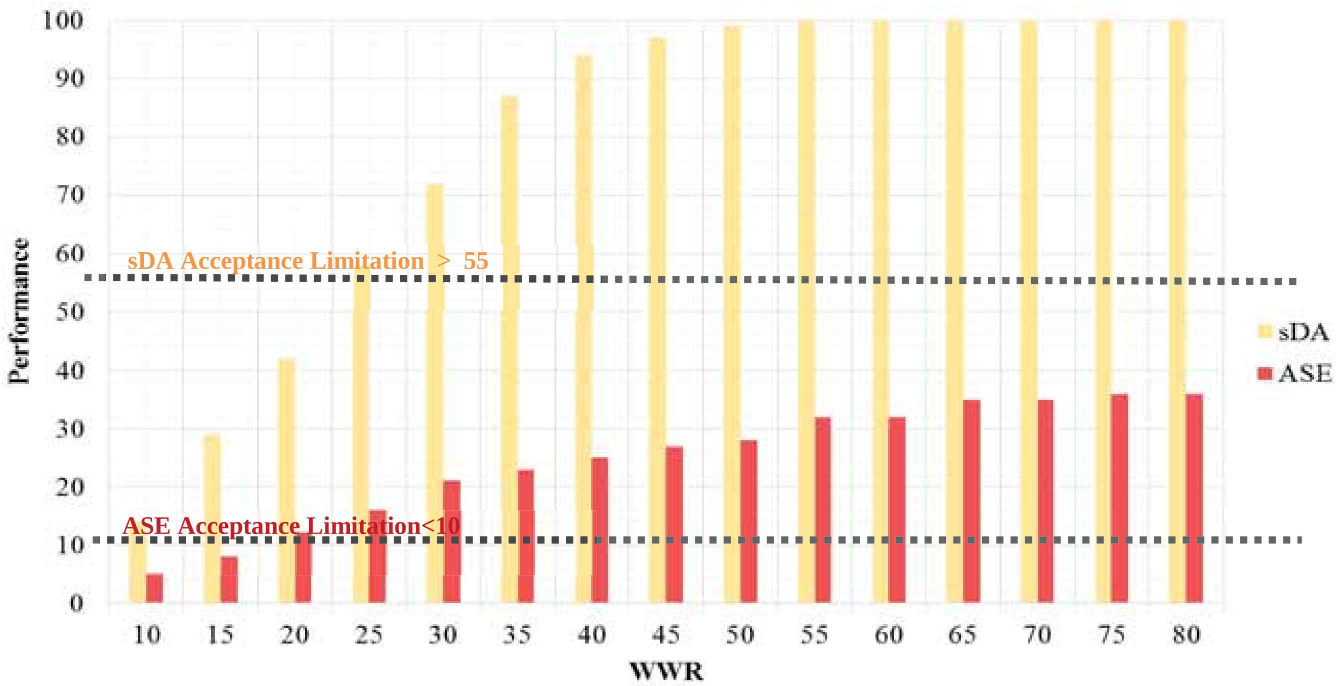


Figure 5- 19: sDA and ASE performance results for the investigated WWR at South orientation (15 cases)

The results of the 15 cases at south orientation are classified according to LEED v4 rating system in Table 5-12. All cases in this orientation didn’t get any points in LEED. The blue rectangle colors represent the results which are refused due to low daylight performance (10% and 15 %WWR), while the dark gray represent the results which are refused due to high ASE values (from 25% WWR till 80%) and the brown represent the non-acceptable results due to low daylight performance and ASE as well (20%.WWR).

Table 5- 12: Analysis of Investigated WWR according LEED V4 in south direction

Performance	WWR %														
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
sDA	14	29	42	58	72	87	94	97	99	100	100	100	100	100	100
ASE	5	8	12	16	21	23	25	27	28	32	32	35	35	36	36
LEED V4 Classification															

5.4.5. WWR Simulation Results at East Direction

5.4.5.1. sDA and ASE Analysis of Investigated WWR

The Simulation results of east orientation is similar to west orientation results the sDA and ASE are directly proportional with the increase of WWRs values as illustrated in figure 5-22 but with huge increase in ASE values. The first cutting edge for the successful cases lies on the 55% sDA. All cases larger than 30% WWR reached or exceeded the threshold. In contrary, cases with small windows with WWR less than 25 %, they didn't achieved sufficient daylight performance. The second cutting edge for the successful cases lies on the 10% ASE. All cases - except WWR of 10% and 15% - achieved non-acceptable ASE performance and they override the limit. Therefore they need also to be treated by shading devices to avoid glare phenomena and achieve sufficient daylight for the lecture hall.

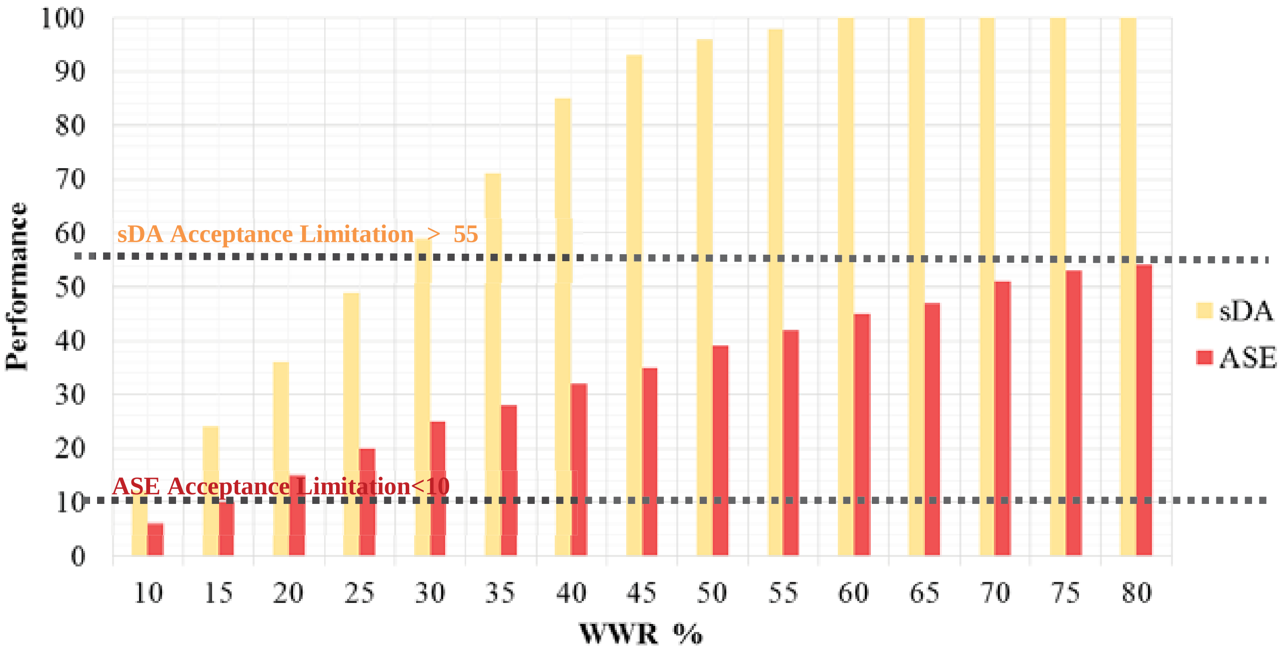


Figure 5- 20: sDA and ASE performance results for the investigated WWR at East orientation (15 case)

The results of the 15 cases at west orientation are classified according to LEED v4 rating system in table 5-13 .All cases in this orientation didn't get any points in LEED. The blue rectangle colors represent the results which are unacceptable due to low daylight performance (10% WWR). The dark gray represent the results which are refused due to high ASE values (from 30% WWR till 80%) and the brown represents the unacceptable results due to both low daylight performance and ASE (from 15%.WWR till 25 %).

Table 5- 13: Analysis of Investigated WWR according LEED V4 in the east direction

Performance	WWR %														
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
sDA	12	24	36	49	59	71	85	93	96	98	100	100	100	100	100
ASE	6	10	15	20	25	28	32	35	39	42	45	47	51	53	54
LEED V4 Classification															

5.5. Stage 2: Parametric Analysis for Various Louvers Types

The simulation results in the previous stage revealed that west, south and east are the problematic orientations. They didn't achieve any sufficient daylight due to the high values in ASE. Therefore they need to be treated with shading devices to avoid glare phenomena and achieve sufficient daylight.

As discussed in chapter three, universities prefer to install horizontal blinds or louvers in learning spaces' windows because they can controlled glare, redirect daylight and guide lighting into the space. Therefore louvers were chosen as the shading device for the investigated lecture hall. Louvers are composed of multiple horizontal, vertical, or sloping slats and different surface finishes. In this stage three louvers techniques were chosen to study their effect on daylighting performance in the three problematic orientations. Following are the techniques which are investigated with their variants (Figure 5-21):

- **Horizontal louvers:** In this technique the successful WWR, which achieved 100% sDA in step one, are investigated with the louvers slates count.
- **Vertical louvers:** In this technique the WWR is fixed at 65% with changing each of louvers count and tilting angle of the louvers.
- **Aligned louvers:** In this technique the WWR is also fixed at 65% with changing each of louvers width, which equal the distance between them, louvers tilting angle and the aligned fixation angle.

The aim of using louver techniques in this stage varies according to its surface finishes. It may be used to block direct sun beams only or to redirect the beams inside the space as well. The first and second techniques were used as sun breakers with reflectivity of 30% while the third one was used as a redirective device with reflectivity of 50%.

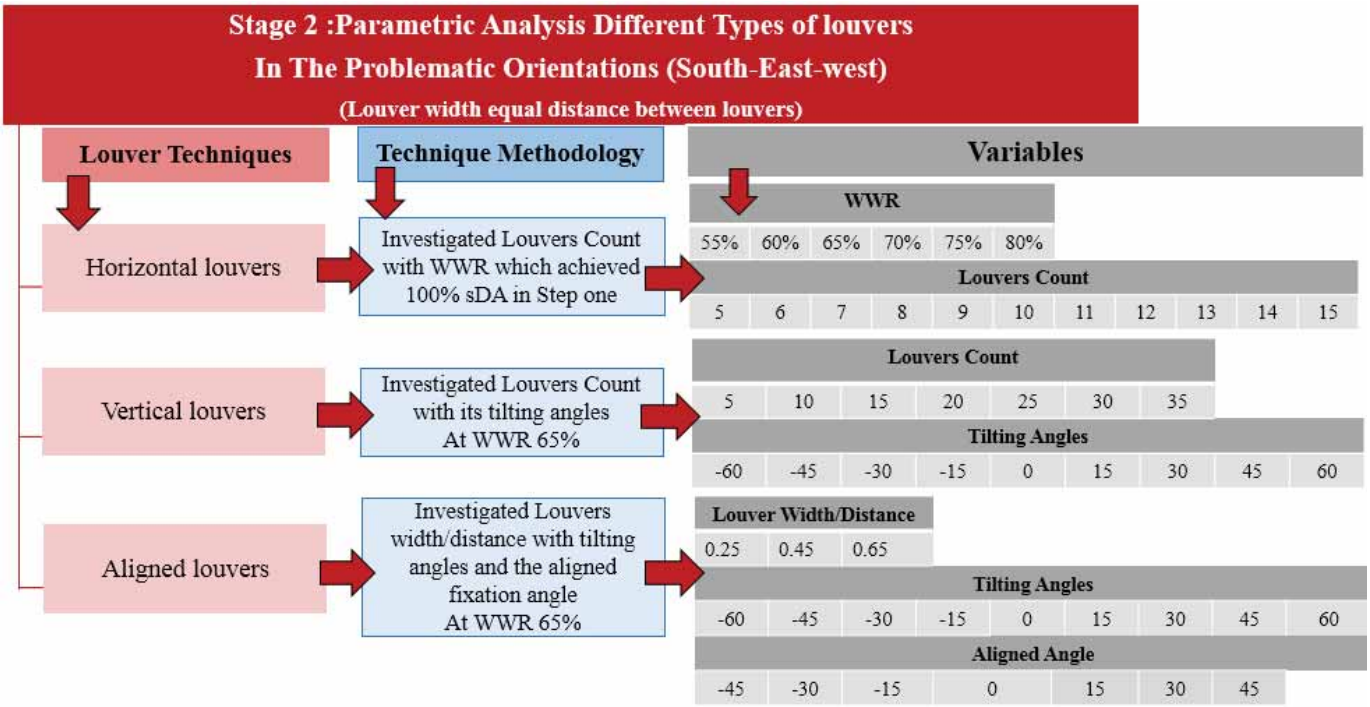


Figure 5- 21: The Methodology of stage two

5.5.1. Horizontal louvers: Investigated Louvers Count with Succeed WWR.

Horizontal louvers with 30% reflectivity and 0.05m thickness were added to the south and east and west oriented facades. Sixty six cases were investigated in this step with changing the two main variables as follow:

- **The first variable:** is changing window to wall ratio. The cases which achieved 100% sDA in stage one were chosen to investigate its WWR with the second variable. These WWR ranged from 55% till 80% as shown in Table 5-14.
- **The second variable:** is changing the horizontal louvers slats number. Slats are spaced at a distance that is equal to the slat width so that the slats could be fully closed. Louvers counts are ranged from 5 to 15 slat as shown in Table 5-15.

Parametric iterations took place representing all possible combinations of the previous variables resulting in 66 different alternatives. These alternatives were investigated in parametric simulation analysis like in the first stage in order to reach efficient alternatives which achieve sufficient daylight performance.

Table 5- 14: Analysis for the investigated WWR parameters

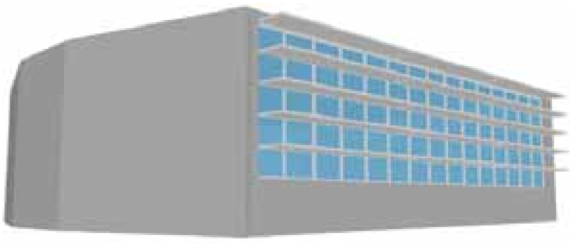
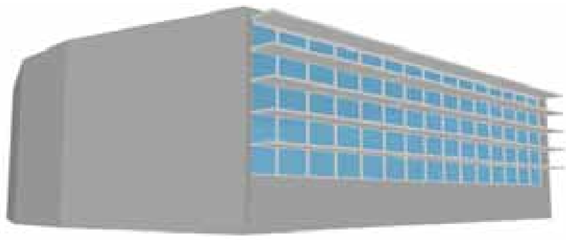
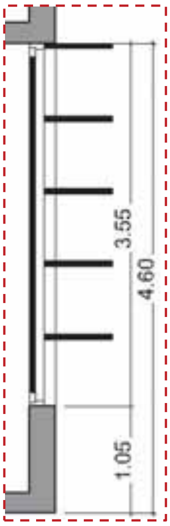
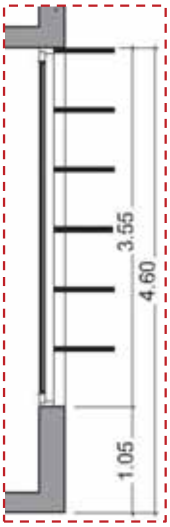
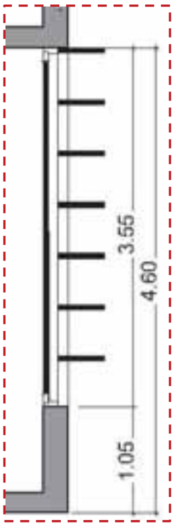
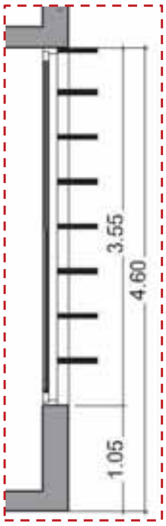
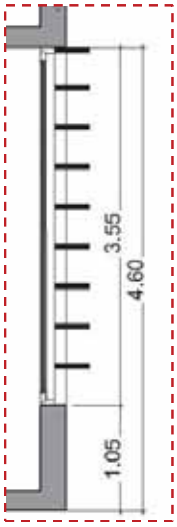
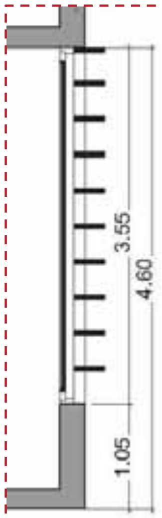
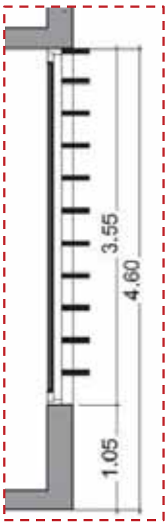
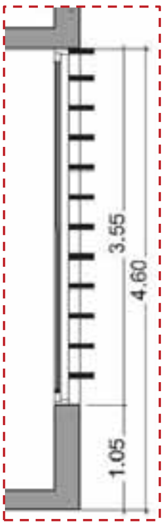
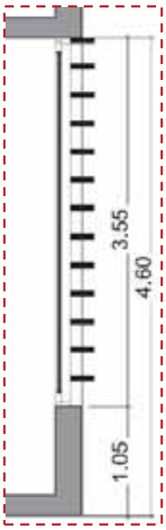
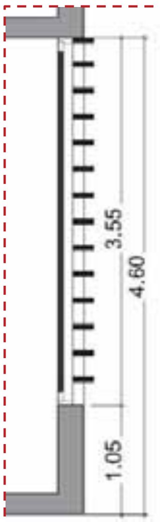
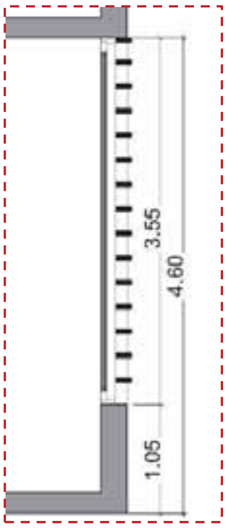
The first variable : The investigated WWR (sample for the investigated WWR with 5 louvers)	
WWR:55%	**WWR:60%**
	
Window size :W=11m H=3.55m	Window size :W=12m H=3.55m
WWR:65%	**WWR:70%**
	
Window size :W=13m H=3.55m	Window size :W=14m H=3.55m
WWR:75%	**WWR:80%**
	
Window size :W=15m H=3.55m	Window size :W=15.4m H=3.55m

Table 5- 15: Analysis for the investigated horizontal louvers count parameters

The second variable : louvers count The following sections for different louvers count are used for each investigated WWR						
Louvers count	**5**	**6**	**7**	**8**	**9**	**10**
Section						
Louvers Width / Distance	0.65 m	0.55 m	0.45 m	0.40 m	0.33 m	0.30 m
Louvers count	**11**	**12**	**13**	**14**	**15**	
Section						
Louvers Width / Distance	0.27 m	0.25 m	0.22 m	0.20 m	0.19 m	

5.5.1.1. Simulation Results of Horizontal Louvers at South Direction

i. sDA and ASE Analysis of Investigated WWRs

Simulation results revealed that sDA and ASE are reversely proportional to the increase of louvers slates number in each WWR while they are directly proportional with the increase of WWR in each louver count as illustrated in Figure 5-16. The first threshold for successful cases lies on the 55% sDA. All cases, except one case with 55% WWR and 15 slate, reached or exceeded the threshold. The second threshold for successful cases lies on the 10% ASE. The cases which have a large louver count (from 10 to 15 louvers) achieved acceptable ASE performance and didn't override the limit. In contrast, the cases with few louver counts, less than 10 slates, are unacceptable except the cases with small WWR (from 55%WWR till 65%) which were acceptable but with high ASE values.

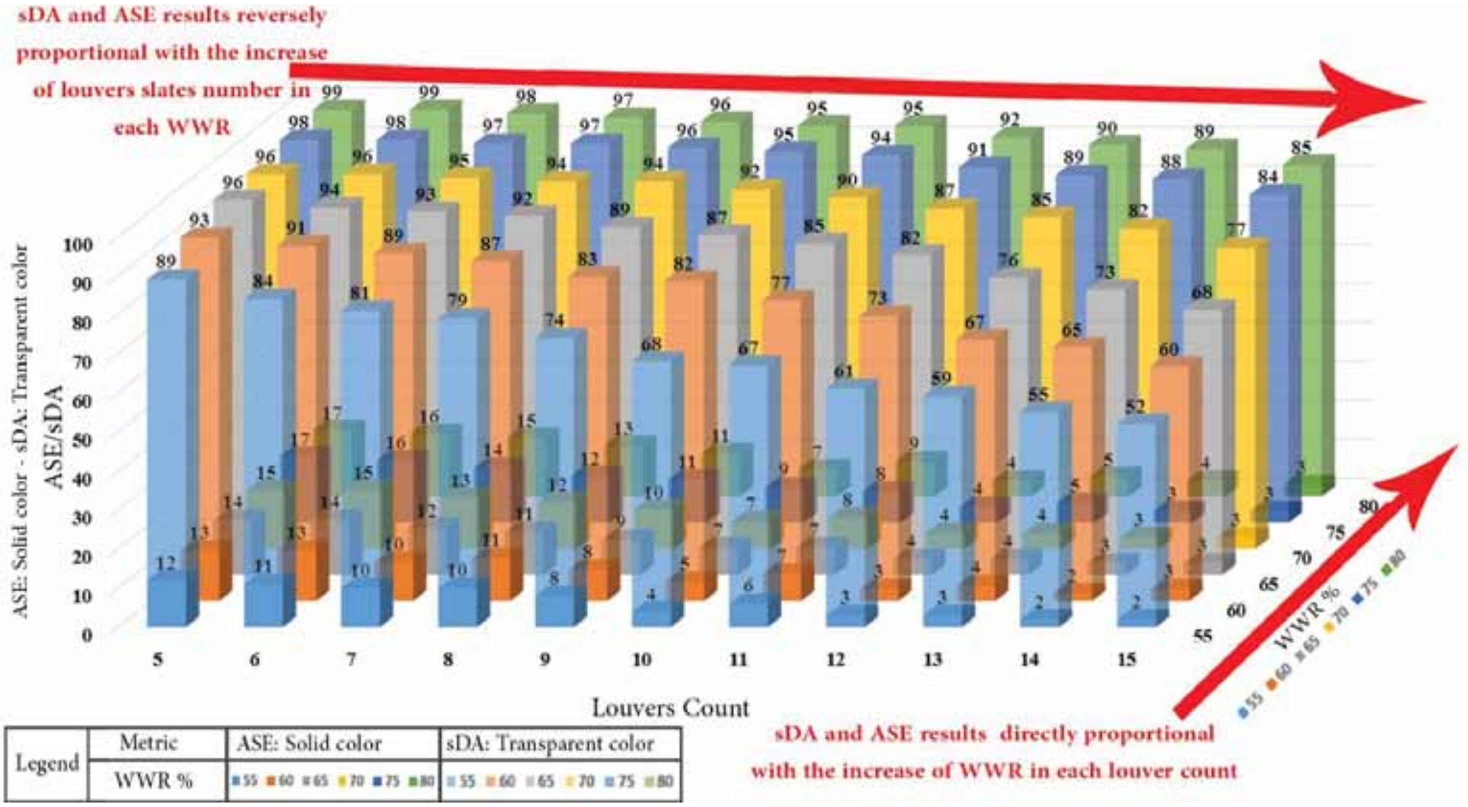


Figure 5- 22: South orientation ASE and sDA results for Investigated Louvers Count and WWRs

The results of sDA and ASE values are compiled into Table 5-16 and Table 5-17 sequentially to make it easier to check them and classify their performance. Then these results of the 66 cases are classified according to LEED v4 rating system in Table 5-18 to choose the best WWRs. The dark gray rectangles represent the results which are unacceptable due to high ASE values. The blue colors represent the unacceptable results due to low daylight performance .The others represent the accepted cases based on daylight performance. The green rectangle colors represent the accepted cases with two points on LEED v4, while the yellow, orange and red represent the accepted cases with three points on LEED v4. The yellow represents ASE performance less than 3 which are the most preferred ASE performance. But the orange represents ASE larger than three and less than 7 which is neutral, and the red represent ASE larger than 7 and less 10 which is critical and a non-preferred performance. (Figure 5-23).

Table 5- 16: sDA results for the investigated cases – Horizontal louvers –south orientation

sDA												
Louvers Count		5	6	7	8	9	10	11	12	13	14	15
WWR	55%	89	84	81	79	74	68	67	61	59	55	52
	60%	93	91	89	87	83	82	77	73	67	65	60
	65%	96	94	93	92	89	87	85	82	76	73	68
	70%	96	96	95	94	94	92	90	87	85	82	77
	75%	98	98	97	97	96	95	94	91	89	88	84
	80%	99	99	98	97	96	95	95	92	90	89	85

Table 5- 17: ASE results for the investigated cases –Horizontal louvers –south orientation

ASE												
Louvers Count		5	6	7	8	9	10	11	12	13	14	15
WWR	55	12	11	10	10	8	4	6	3	3	2	2
	60	13	13	10	11	8	5	7	3	4	2	3
	65	14	14	12	11	9	7	7	4	4	3	3
	70	15	15	13	12	10	7	8	4	4	3	3
	75	17	16	14	12	11	9	8	4	5	3	3
	80	17	16	15	13	11	7	9	4	5	4	3

Table 5- 18 : Acceptance according LEED

Louvers count		5	6	7	8	9	10	11	12	13	14	15
WWR	55%											
	60%											
	65%											
	70%											
	75%											
	80%											

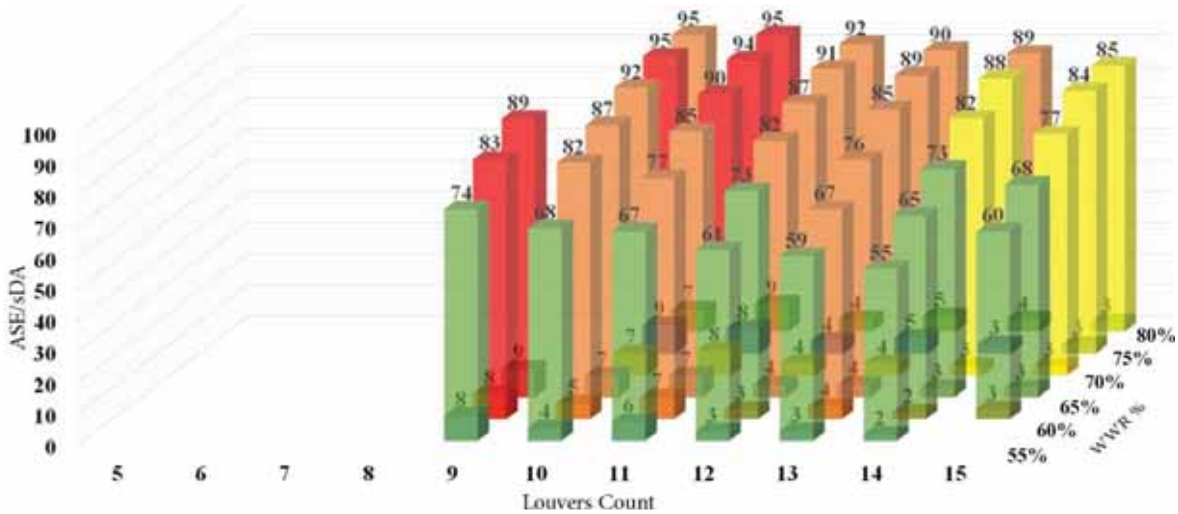


Figure 5- 23: Acceptance according LEED

ii. Daylight Availability Analysis of Investigated Accepted Cases

Simulation results, which are illustrated in Figure 5-24, revealed that the small windows with WWR 55% and 60% achieved low and medium daylight performance sequentially regardless of the increase or decrease of louvers slates. Starting from WWR 65 %, daylight performance begins to override the limit of 75% of the daylit area, which represents the high daylight performance, till they reach the best performance at 75% WWR as shown in Table 5-19. "Partially daylit" area decreased gradually with the increase of window size. However its values are directly proportional to the increase of the number of slates in each WWR % as shown in Table 5-20. In contrast the over lit area was almost negligible with the large slates count as shown in Table 5-21. It is also noted that the best louver slat count is 12 slates as it represents the highest performance in all WWR.

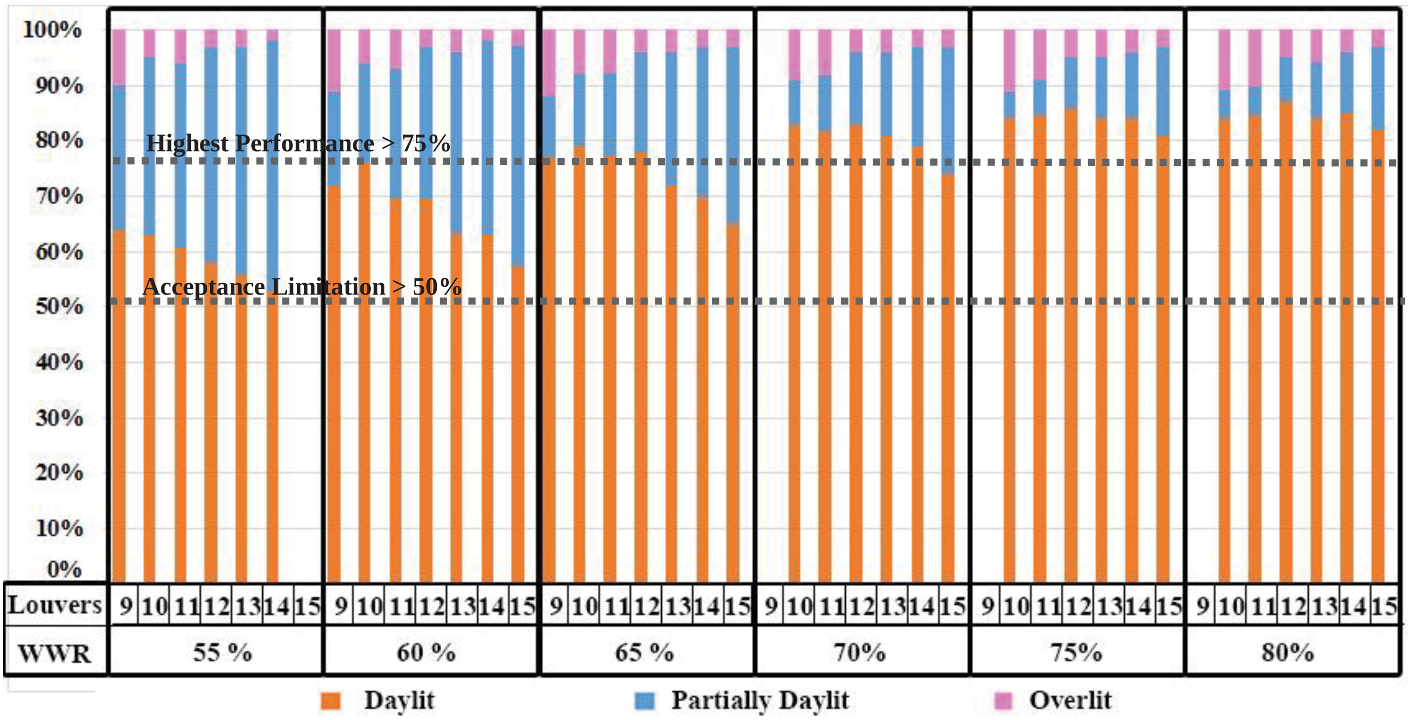


Figure 5- 24: Daylight Availability performance results for the investigated horizontal louvers at south orientation

Table 5- 19: Colored analysis for the ratio of daylit area by using horizontal louvers at south direction

Daylight Availability		Daylit						
Louvers count		9	10	11	12	13	14	15
WWR	55%	64	63	60	58	56	53	
	60%	72	76	69	69	64	63	58
	65%	77	78	78	78	72	70	65
	70%		83	81	83	80	79	74
	75%		84	84	86	84	84	80
	80%		85	84	87	85	85	82

Table 5- 20: Colored analysis for the ratio of Partially Daylit area by using horizontal louvers at south direction

Daylight Availability		Partially Daylit						
Louvers count		9	10	11	12	13	14	15
WWR	55%	26	32	33	39	41	45	
	60%	17	18	23	27	33	35	40
	65%	11	14	15	18	24	27	32
	70%		8	10	13	15	18	23
	75%		5	6	9	11	12	16
	80%		5	5	8	10	11	15

Table 5- 21 : Colored analysis for the ratio of overlit area by using horizontal louvers at south direction

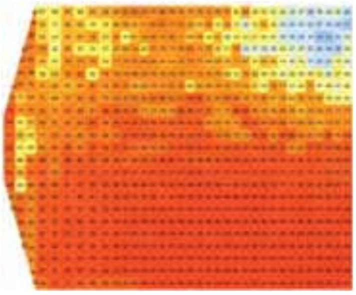
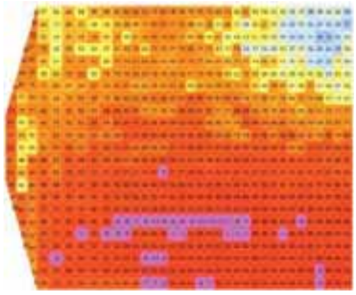
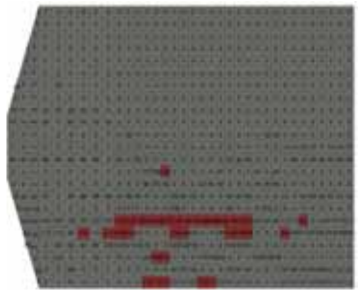
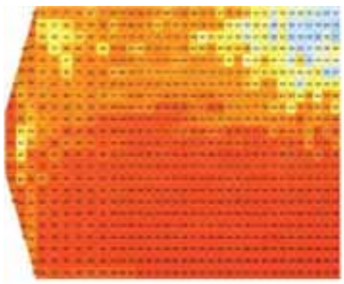
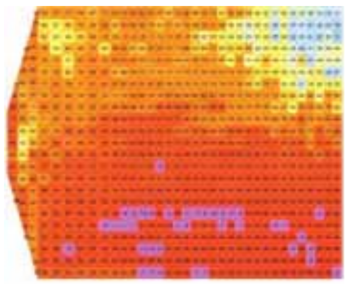
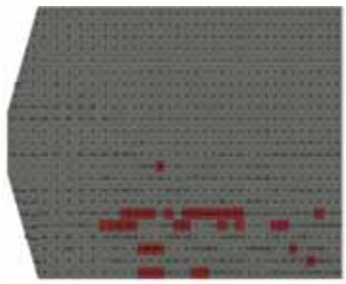
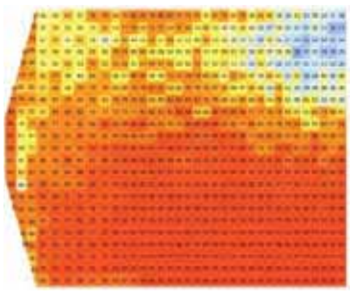
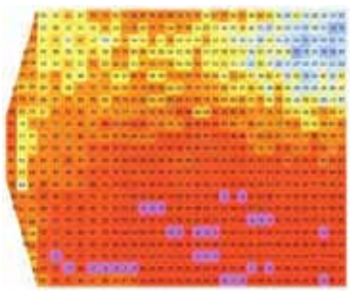
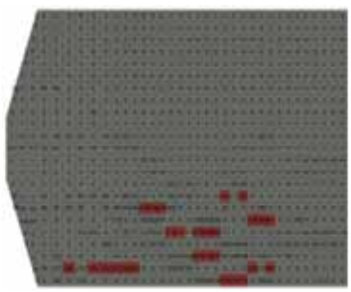
Daylight Availability		Overlit						
Louvers count		9	10	11	12	13	14	15
WWR	55%	10	5	6	3	3	2	
	60%	11	6	7	3	4	2	3
	65%	12	8	8	4	4	3	3
	70%		9	8	4	4	3	3
	75%		11	9	5	5	4	3
	80%		11	10	5	6	4	3

Even though in several cases the daylight reached the depth of the room, these cases were entitled to higher percentages of overlit areas near the glazing. It's also observed that cases that achieved better performance were the cases that had the least overlit areas near the glazing. The highest daylight performances, which are colored with yellow on Table 5-22, are achieved with high daylit performance and the minimum values of overlit and partially daylit areas. The cases 46, 47 and 53, which are colored with the purple color on Table 5-22, achieved the highest performances at this orientation and achieved sufficient daylight as well. But they need to be checked with glare analysis in the next step. Table 5-23 illustrates detailed analysis for the three best cases.

Table 5- 22: Evaluation for Daylight Availability performance for using horizontal louvers at south direction

Louvers count		9			10			11			12			13			14			15		
Daylight Availability		P	D	O	P	D	O	P	D	O	P	D	O	P	D	O	P	D	O	P	D	O
WWR	55%	26	64	10	32	63	5	33	60	6	39	58	3	41	56	3	45	53	2			
	60%	17	72	11	18	76	6	23	69	7	27	69	3	33	64	4	35	63	2	40	58	3
	65%	11	77	12	14	78	8	15	78	8	18	78	4	24	72	4	27	70	3	32	65	3
	70%				8	83	9	10	81	8	13	83	4	15	80	4	18	79	3	23	74	3
	75%				5	84	11	6	84	9	9	86	5	11	84	5	12	84	4	16	80	3
	80%				5	85	11	5	84	10	8	87	5	10	85	6	11	85	4	15	82	3

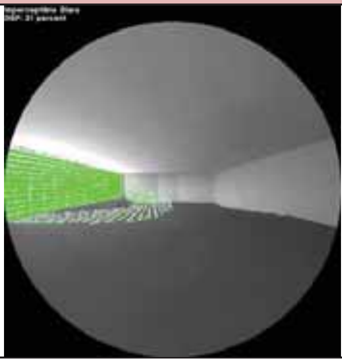
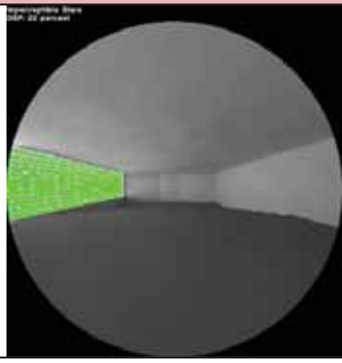
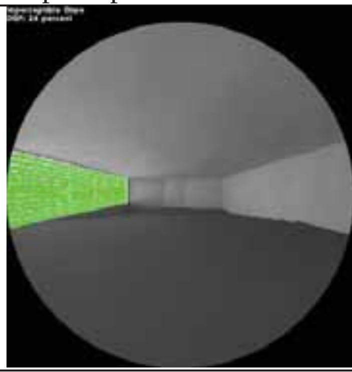
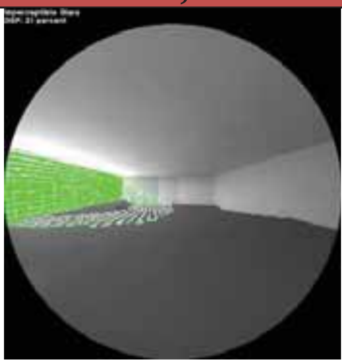
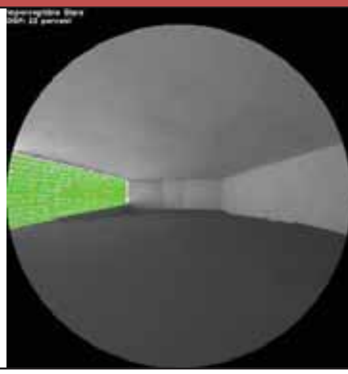
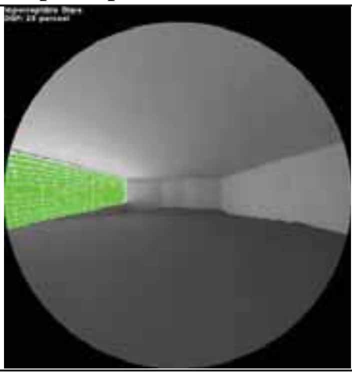
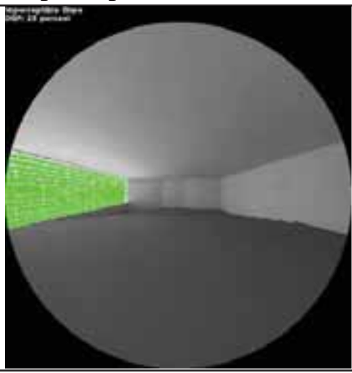
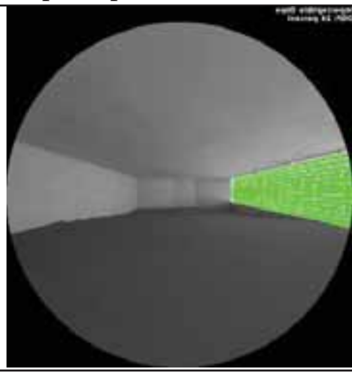
Table 5- 23: Daylight analysis for the highest performance cases at south direction

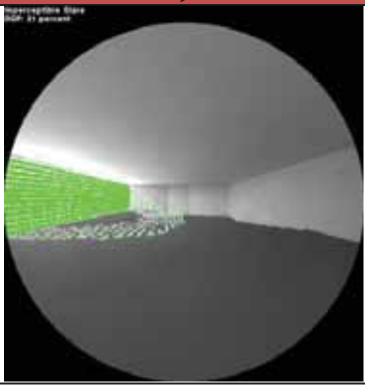
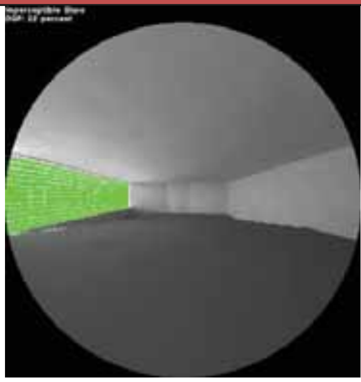
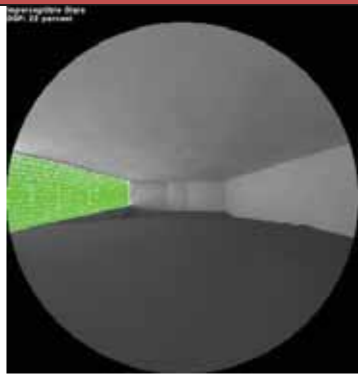
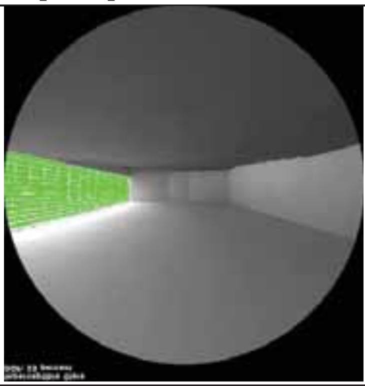
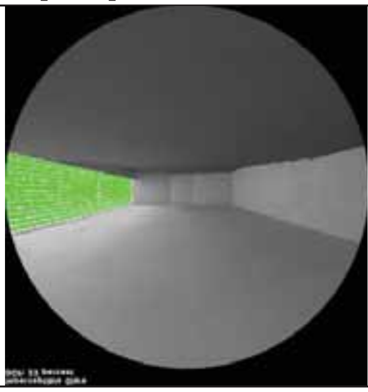
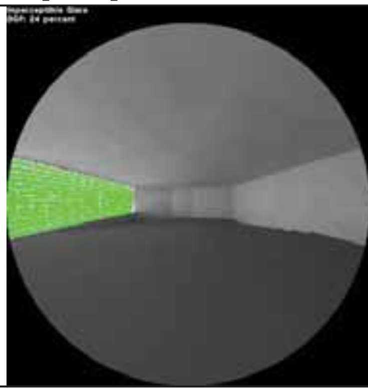
Daylight analysis for the high performance cases at north direction						
case	**variable**	**sDA**	**Daylight Availability**			**ASE**
Case 46	**75 %WWR 12 louver slat**					
		sDA= 91 %	Partially =9	Daylit=86	Overlit=5	ASE= 4
Case 47	**80 %WWR 12 louver slat**					
		sDA = 92 %	Partially=8	Daylit=87	Overlit=5	ASE= 4
Case 58	**80 %WWR 13 louver slat**					
		sDA = 90 %	Partially=10	Daylit=85	Overlit=6	ASE= 5
KEY						

iii. Glare Analysis for The Top Performance Cases

Analysis for visual comfort was carried out for cases that obtained best daylight availability performance. In the south orientation, the top performances achieved were in cases 46, 47 and 53. Therefore the Daylight Glare Probability (DGP) was calculated for each case to check their visual comfort. The three cases had imperceptible glare at 9:00 and 12:00 in the different season's as shown in Table 5-24. Although there were minor differences in their performance, the three cases were acceptable. Therefore their energy consumption will be calculated in the next step to identify the most efficient WWR case.

Table 5- 24: Glare analysis for the three best cases (46, 47 and 53)

	December 21	September 21	June 21
South Direction , CASE 46 :WWR=75% - Louvers =12 slats			
9:00 AM			
	Imperceptible DGP 21%	Imperceptible DGP 22%	Imperceptible DGP 22%
12.00 PM			
	Imperceptible DGP 23%	Imperceptible DGP 23%	Imperceptible DGP 24%
South Direction , CASE 47 :WWR=80% - Louvers =12 slats			
9:00 AM			
	Imperceptible DGP 21%	Imperceptible DGP 22%	Imperceptible DGP 22%
12.00 PM			
	Imperceptible DGP 23%	Imperceptible DGP 23%	Imperceptible DGP 24%

South Direction , CASE 53 :WWR=80% - Louvers =13 slats			
9:00 AM			
	Imperceptible DGP 21%	Imperceptible DGP 23%	Imperceptible DGP 24%
12.00 PM			
	Imperceptible DGP 23%	Imperceptible DGP 23%	Imperceptible DGP 24%

iv. Energy Consumption for The Top Performance Cases

The total energy consumption analysis was carried out per year for the three successful cases; 46, 47 and 53, which obtained the best daylight performance without any discomfort glare, in order to get the most efficient alternative in a southern direction. The thermal simulation analysis assists with obtaining a detailed view of how energy consumption occurs in the three investigated cases. It used the artificial lighting scheduled, which is calculated in the previous daylight simulation for each case and began to calculate lighting, cooling and heating loads per hour for each case. Hence, the consumption per year for each load is calculated to get the total energy used in each case as shown in Table 5-25.

Table 5- 25: Energy consumption For Best cases

Case	Electric consumption per year- KW/h	Cooling consumption per year- KW/h	Heating consumption per year- KW/h	Total Energy consumption per year- KW/h
46	6.44	174.3	6.84	187.58
47	6.60	178.5	6.86	191.96
58	7	179	6.85	192.85

The results of thermal analysis, which are shown in the previous table, revealed that the case 46, with 75 % WWR and 12 slate, is the most efficient one in regards to saving energy. Its total energy consumption per year is 187.58 KW/H while the others 47 and 53 are 191.96 and 192.85 KW/h.

5.5.1.2. Simulation Results of Horizontal Louvers at West Direction

As with the south orientation, simulation results revealed that sDA and ASE are reversely proportional with the increase of louver's slates number in each WWR while they are directly proportional with the increase of WWR in each louver count as illustrated in Figure 5-16. The first threshold for successful cases lies on the 55% sDA. All cases reached or exceeded the threshold (Table 5-26). The second threshold for successful cases lies on the 10% ASE. All cases achieved unacceptable ASE performance and they overrode the limit (Table 5-26). Therefore they need to also be treated by another louver technique, such as vertical or tilted louvers, to avoid glare phenomena and achieve sufficient daylight for the lecture hall.

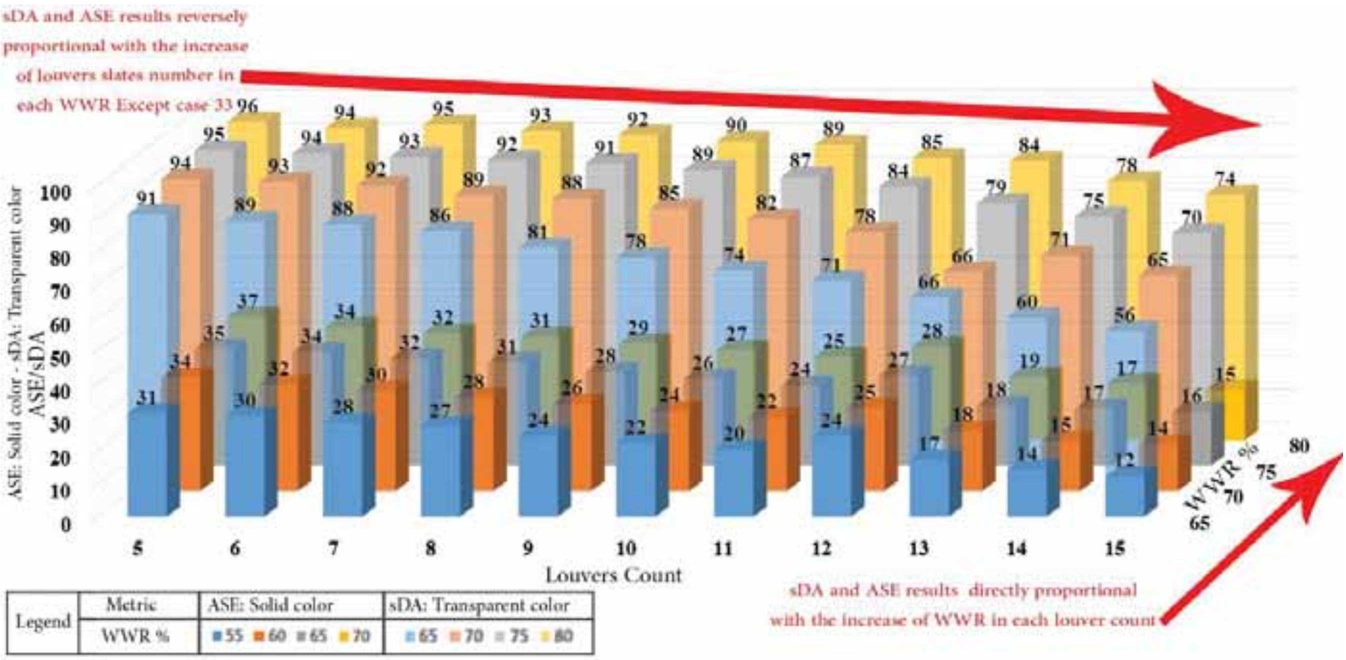


Figure 5- 25: West orientation ASE and sDA results for Investigated Louvers Count and WWRs

Table 5- 26 : sDA results for the investigated cases –Horizontal louvers –West orientation

sDA												
Louvers Count		5	6	7	8	9	10	11	12	13	14	15
WWR	65%	91	89	88	86	81	78	74	71	66	60	56
	70%	94	93	92	89	88	85	82	78	66	71	65
	75%	95	94	93	92	91	89	87	84	79	75	70
	80%	96	94	95	93	92	90	89	85	84	78	74

Table 5- 27 : ASE results for the investigated cases – Horizontal louvers –West orientation

ASE												
Louvers Count		5	6	7	8	9	10	11	12	13	14	15
WWR	65%	31	30	28	27	24	22	20	24	17	14	12
	70%	34	32	30	28	26	24	22	25	18	15	14
	75%	35	34	32	31	28	26	24	27	18	17	16
	80%	37	34	32	31	29	27	25	28	19	17	15

5.5.1.3. Simulation Results of Horizontal Louvers at East Direction

The simulation results in east orientation are similar to the results from the west orientation. sDA and ASE values are reversely proportional with the increase of louvers slates number in each WWR while they are directly proportional with the increase of WWR in each louver count as illustrated in Figure 5-25. However all cases reached or exceeded the sDA limit of 55% as shown in Table 5-28. None of them achieved less than 10 ASE as shown in Table 5-29. Therefore they need also to be treated by another louver technique, such as vertical or tilted louvers, to avoid glare phenomena and achieve sufficient daylight for the lecture hall.

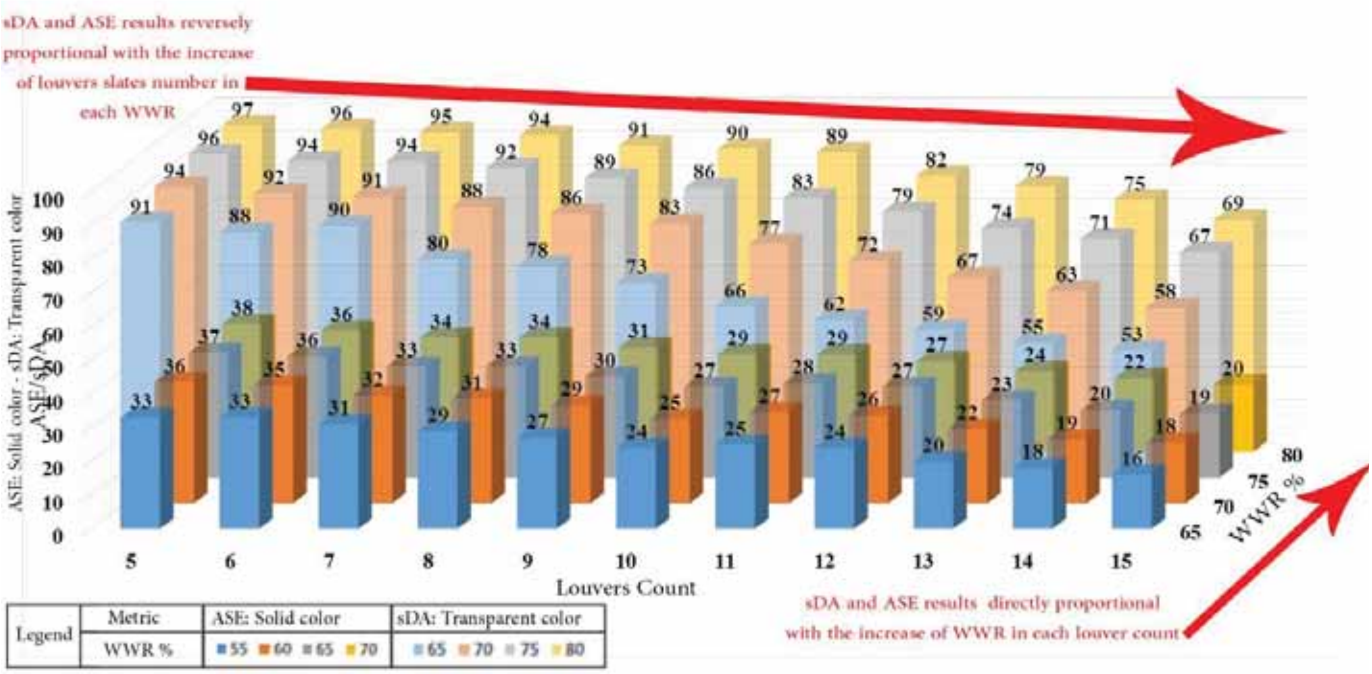


Figure 5- 26: East orientation ASE and sDA results for Investigated Louvers Count and WWRs

Table 5- 28 : sDA results for the investigated cases – Horizontal louvers –East orientation

sDA												
Louvers Count		5	6	7	8	9	10	11	12	13	14	15
WWR	65%	18	27	32	32	32	28	21	12	5	18	27
	70%	19	29	35	36	35	32	24	13	3	19	29
	75%	17	27	34	36	36	30	22	14	3	17	27
	80%	20	29	36	38	36	32	24	13	3	20	29

Table 5- 29 : ASE results for the investigated cases – Horizontal louvers –East orientation

ASE												
Louvers Count		5	6	7	8	9	10	11	12	13	14	15
WWR	65%	33	33	31	29	27	24	25	24	20	18	16
	70%	36	35	32	31	29	25	27	26	22	19	18
	75%	37	36	33	33	30	27	28	27	23	20	19
	80%	38	36	34	34	31	29	29	27	24	22	20

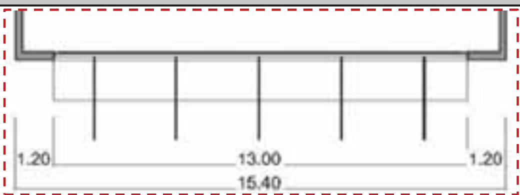
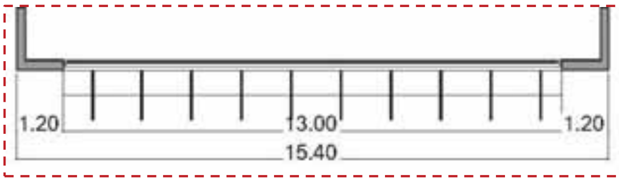
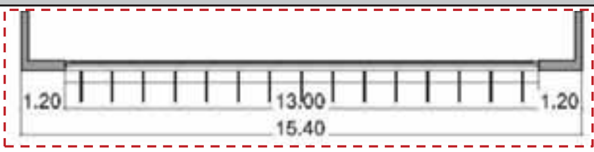
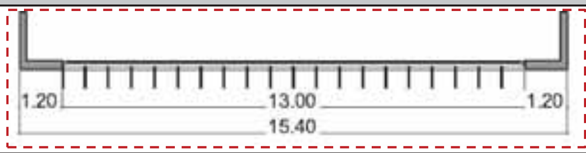
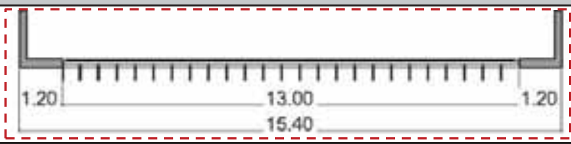
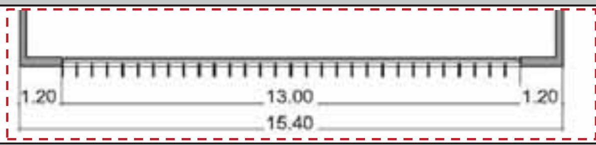
5.5.2. Vertical louvers : Investigated Louvers Count with Tilting Angles

Similar to horizontal louvers, vertical louvers are widely used to provide protection from direct sun. Vertical louvers are more popular in east and west orientations. In south orientation, vertical shading can also be used to prevent the low angle sun beams. In this section, vertical louvers with 30% reflectivity and 0.05 m thickness were added to the three critical orientations of south, east and west. The effect of changing the vertical louvers count and rotation angle was studied. Sixty three cases were investigated in this step with changing of the two main variables as follow:

- **The first variable:** is changing the number of vertical louvers slats. Slats are spaced at a distance that is equal the slat width so that the slats can be fully closed. Louver counts ranged from 5 to 35 slats at 5 slat increments as shown in Table 5-30.
- **The second variable:** is changing the vertical louvers slats tilting angles. Slats rotation angles ranged from -60° to 60° angle degree at 15° increments as shown in Table 5-31.

Parametric iterations took place representing all possible combinations of the previous variables resulting 63 different alternatives. These alternatives are investigated in a parametric simulation analysis like the first stage in order to reach the most efficient alternatives in regards to sufficient daylight performance.

Table 5- 30 : Analysis for the investigated vertical louvers slates count parameters

The first variable : The investigated Louvers Slates Count (sample for the investigated count with 0° tilting angle)		
Louver count	5	10
Plan		
Louvers Width	2.55m	1.25 m
Louver count	15	20
Plan		
Louvers Width	0.82 m	0.60 m
Louver count	25	30
Plan		
Louvers Width	0.47 m	0.38 m

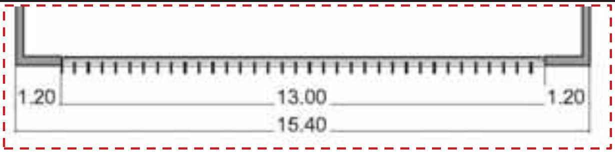
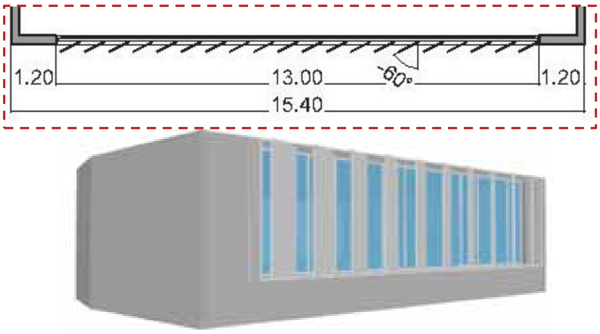
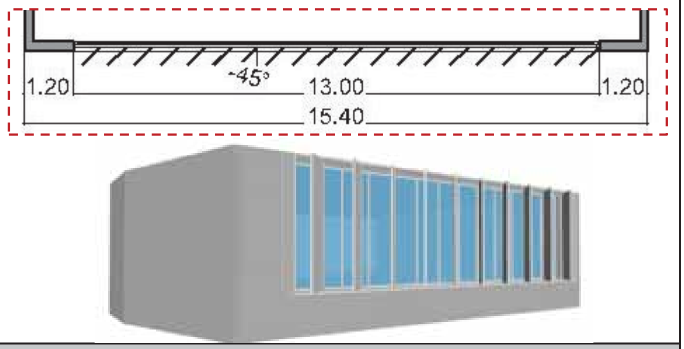
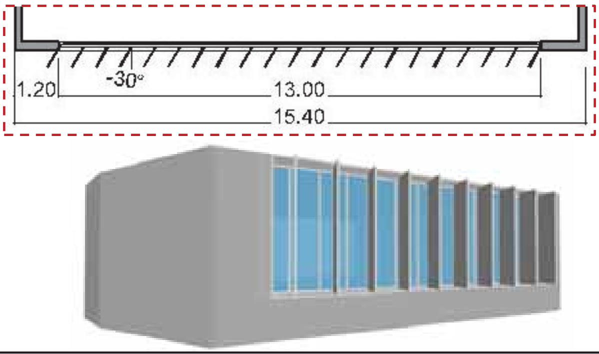
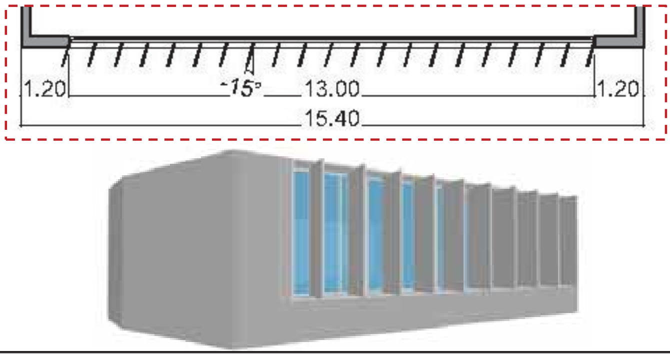
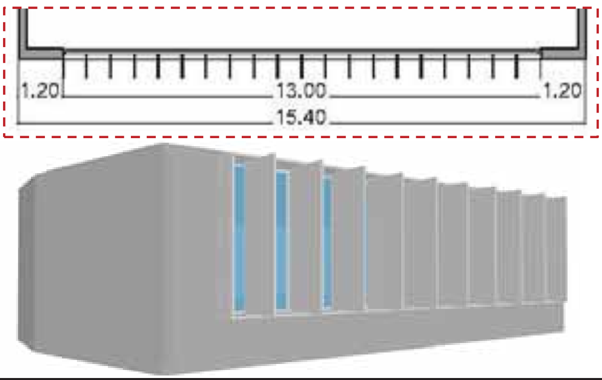
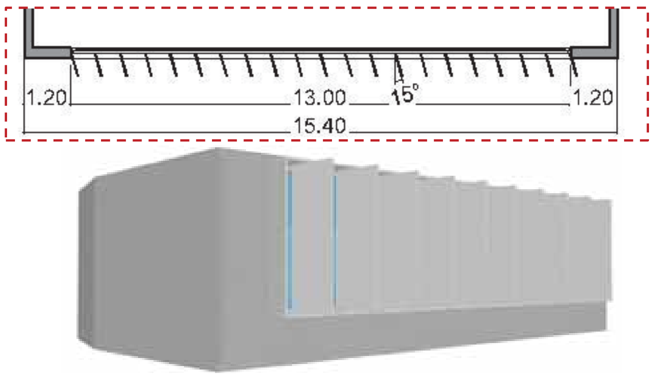
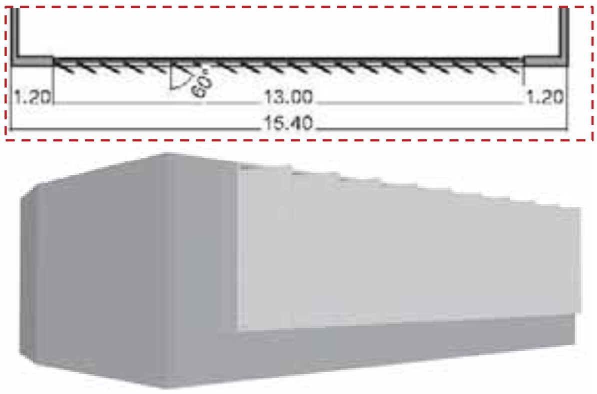
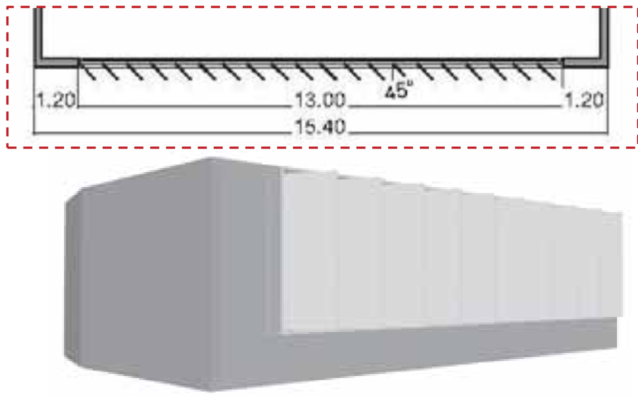
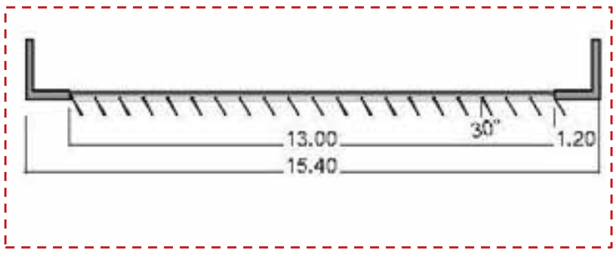
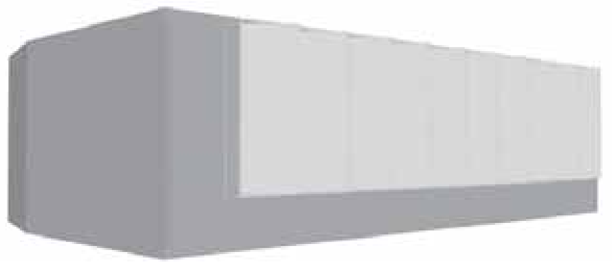
Louver count	35
Plan	
Louvers Width	0.32 m

Table 5- 31: Analysis for the investigated vertical louvers tilting angle parameters

The second variable : The investigated Louvers Tilting Angle The illustrated plan: sample for the investigated tilting angle with 20 louvers The illustrated 3d: sample for the investigated tilting angle with 10 louvers		
Tilting Angles	-60°	-45°
		
Tilting Angles	-30°	-15°
		
Tilting Angles	0°	15°
		

Tilting Angles	30°	45°
		
Tilting Angles	60°	
		

5.5.2.1.Simulation Results of Vertical Louvers

The vertical louvers didn't enhance the overall performance in regards to the increase in ASE values in all critical orientations. All cases with vertical louvers were found unacceptable and had poor performances. Following are the results analysis in each direction:

i. **The results of south direction**: Figure 5-27 and Table 5-33 illustrate the results of ASE in south direction with a minimum ASE value on 12 which is unacceptable. Although sDA results rarely exceeded the high performance limit as shown in table 5-32.

ii. **The results of west direction:** Figure 5-28 and Table 5-35 illustrate the results of ASE in west direction. When ASE values are accepted they are accompanied with low values on sDA as shown in Table 5-34 which is not acceptable. The rest of the ASE values overrode the limit of 10 which is larger than south and surely unacceptable. The values of sDA, which are illustrated in Table 5-34, are lower than the sDA in the south direction and most of them didn't override the limit of 55%.

iii. **The results of east direction:** Figure 5-29 and Table 5-37 illustrate the results of ASE in east direction which is a mirror of west direction results. The ASE decreased with a positive 60° tilting angle with low sDA values as shown in Table 5-36.

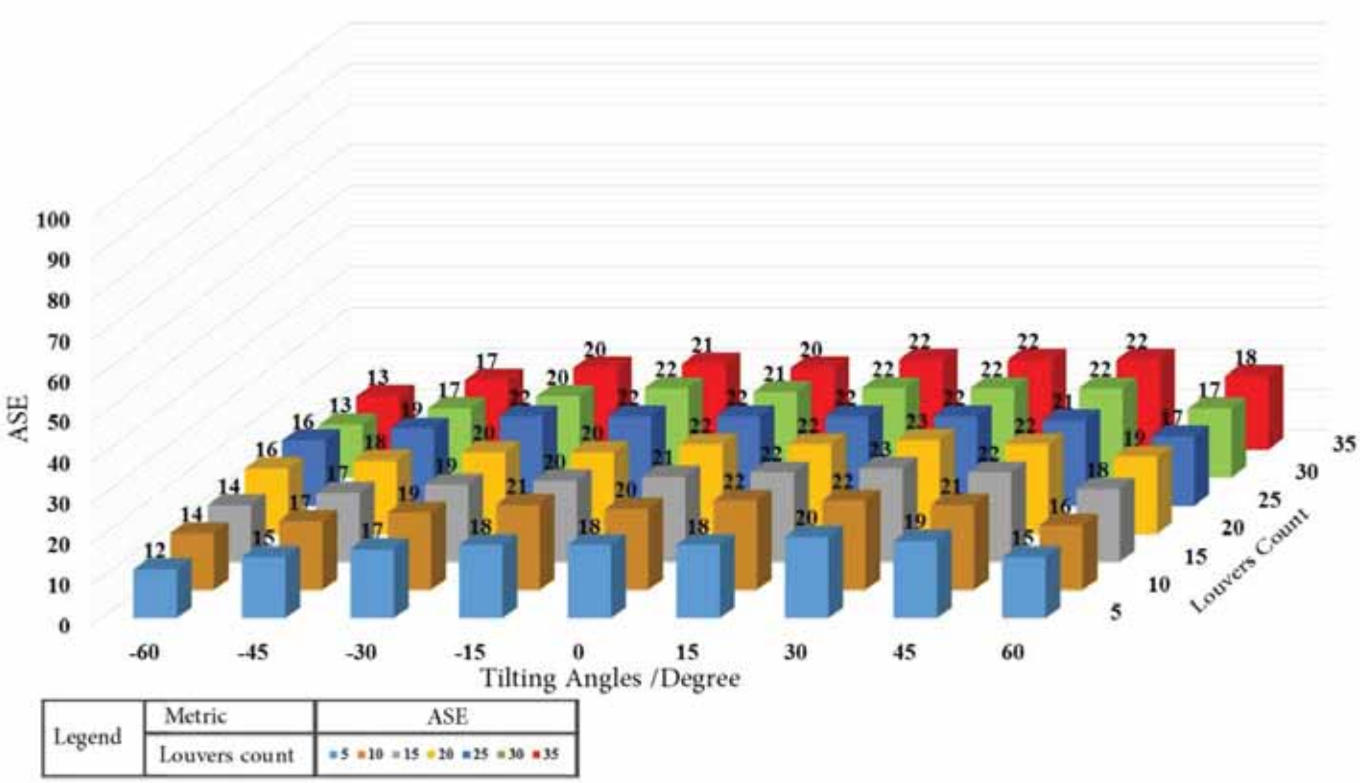


Figure 5- 27: South orientation ASE and sDA results for Investigated Vertical Louvers Count with Tilting Angles

Table 5- 32 : sDA results for the investigated cases –Vertical louvers –South orientation

sDA										
Tilting Angles		-60	-45	-30	-15	0	15	30	45	60
Louvers Count	5	34	47	60	72	82	81	68	51	36
	10	34	49	62	76	85	84	71	54	35
	15	33	47	61	74	83	82	70	52	35
	20	33	46	60	73	81	81	68	51	34
	25	32	45	58	70	79	78	63	49	32
	30	28	43	56	66	76	75	63	48	29
	35	26	43	55	65	73	71	60	45	28

Table 5- 33 : sDA results for the investigated cases –Vertical louvers –South orientation

ASE										
Tilting Angles		-60	-45	-30	-15	0	15	30	45	60
Louvers Count	5	12	15	17	18	18	18	20	19	15
	10	14	17	19	21	20	22	22	21	16
	15	14	17	19	20	21	22	23	22	18
	20	16	18	20	20	22	22	23	22	19
	25	16	19	22	22	22	22	22	21	17
	30	13	17	20	22	21	22	22	22	17
	35	13	17	20	21	20	22	22	22	18

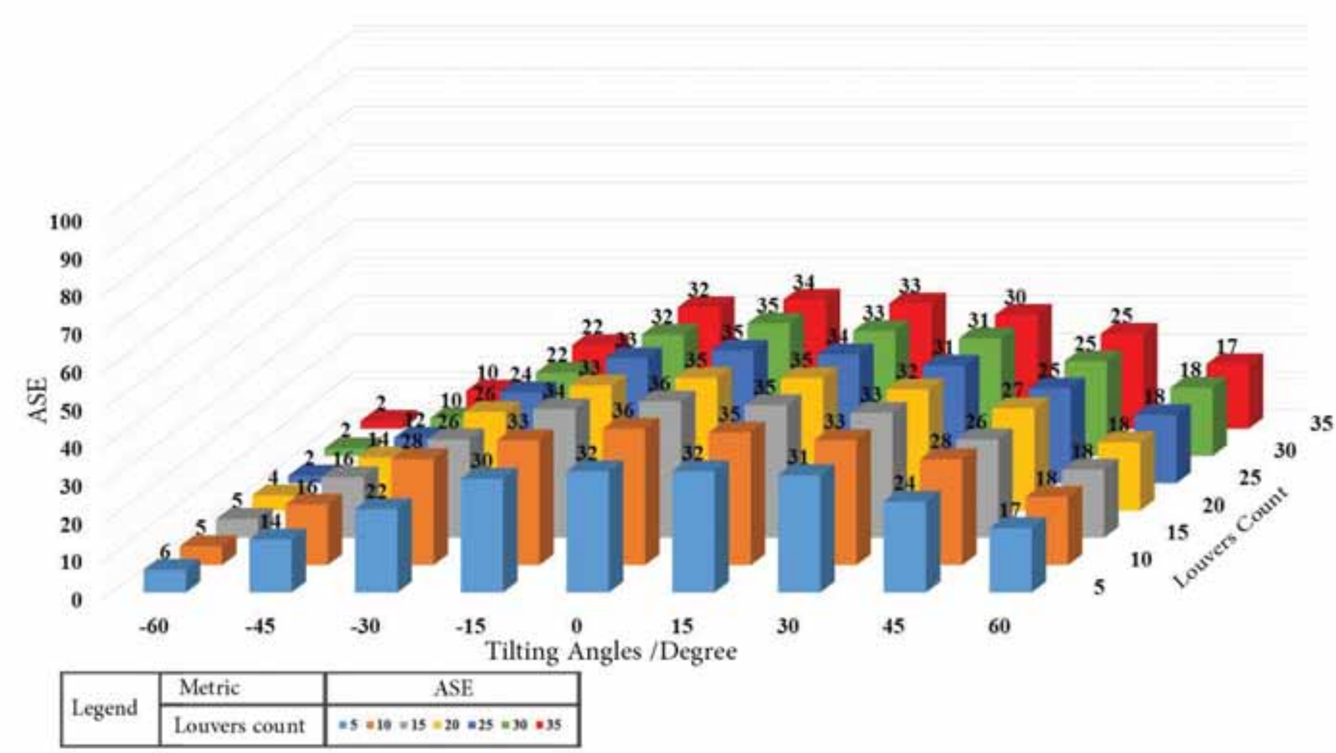


Figure 5- 28: West orientation ASE and sDA results for Investigated Vertical Louvers Count with Tilting Angles

Table 5- 34 : sDA results for the investigated cases –Vertical louvers –West orientation

sDA										
Tilting Angles		-60	-45	-30	-15	0	15	30	45	60
Louvers Count	5	25	38	49	57	65	70	62	51	35
	10	26	39	50	61	71	73	65	53	35
	15	26	39	51	60	70	73	64	50	34
	20	31	41	52	61	73	75	67	52	35
	25	26	40	53	61	71	73	63	49	32
	30	25	40	49	60	66	69	61	48	31
	35	23	37	48	58	64	66	58	46	29

Table 5- 35 : sDA results for the investigated cases –Vertical louvers –West orientation

ASE										
Tilting Angles		-60	-45	-30	-15	0	15	30	45	60
Louvers Count	5	6	14	22	30	32	32	31	24	17
	10	5	16	28	33	36	35	33	28	18
	15	5	16	26	34	36	35	33	26	18
	20	4	14	26	33	35	35	32	27	18
	25	2	12	24	33	35	34	31	25	18
	30	2	10	22	32	35	33	31	25	18
	35	2	10	22	32	34	33	30	25	17

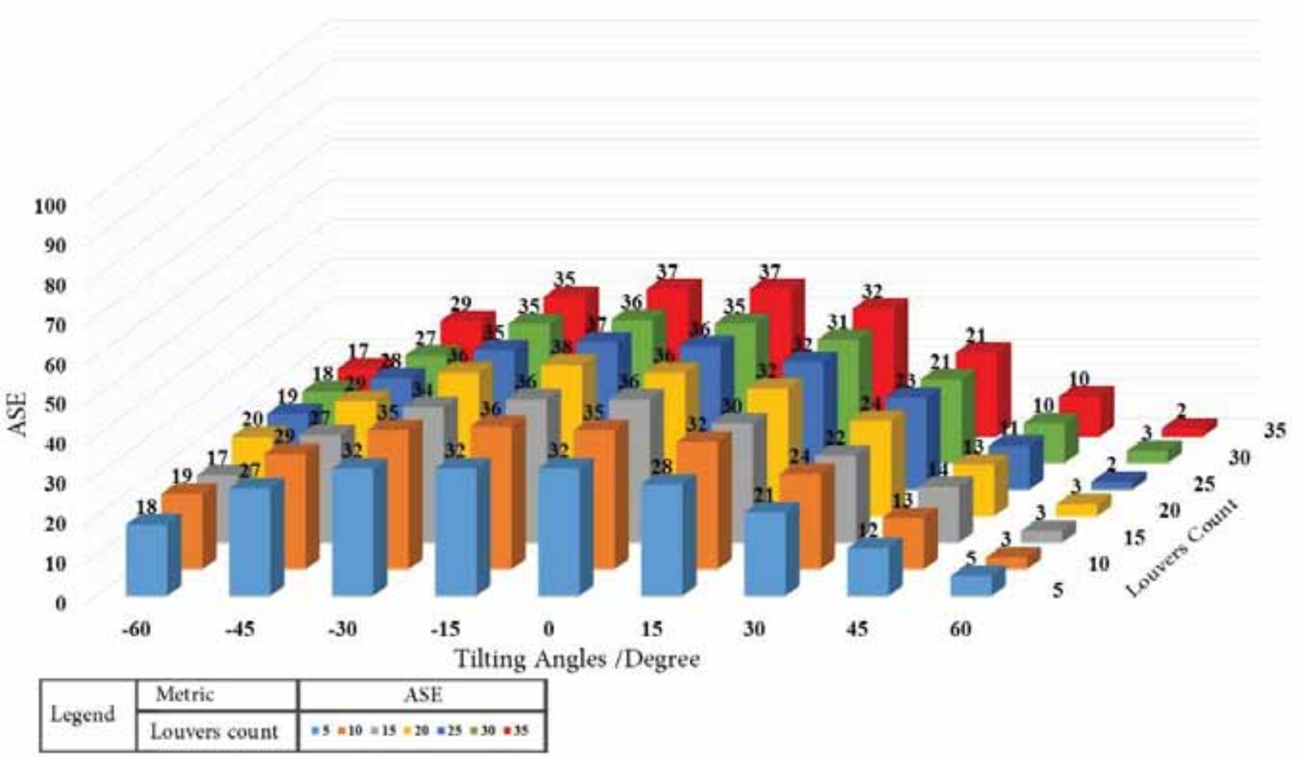


Figure 5- 29: East orientation ASE and sDA results for Investigated Vertical Louvers Count with Tilting Angles

Table 5- 36 : sDA results for the investigated cases –Vertical louvers –East orientation

sDA										
Tilting Angles		-60	-45	-30	-15	0	15	30	45	60
Louvers Count	5	32	44	53	59	61	59	51	38	24
	10	32	45	55	61	66	63	53	39	25
	15	29	44	53	61	64	62	52	40	24
	20	34	48	58	69	74	70	59	44	29
	25	32	46	57	67	73	67	57	44	27
	30	30	44	55	63	69	65	56	42	26
	35	29	43	53	60	65	62	54	40	23

Table 5- 37 : sDA results for the investigated cases –Vertical louvers –East orientation

ASE										
Tilting Angles		-60	-45	-30	-15	0	15	30	45	60
Louvers Count	5	18	27	32	32	32	28	21	12	5
	10	19	29	35	36	35	32	24	13	3
	15	17	27	34	36	36	30	22	14	3
	20	20	29	36	38	36	32	24	13	3
	25	19	28	35	37	36	32	23	11	2
	30	18	27	35	36	35	31	21	10	3
	35	17	29	35	37	37	32	21	10	2

5.5.3. Aligned louvers : Investigated Louvers Aligned Angle with Tilting Angles and Louver Width

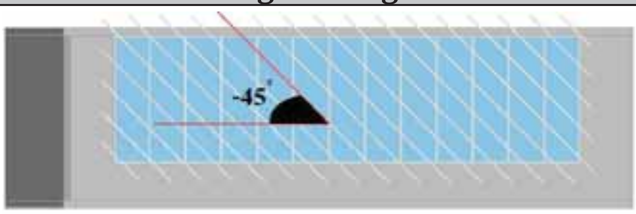
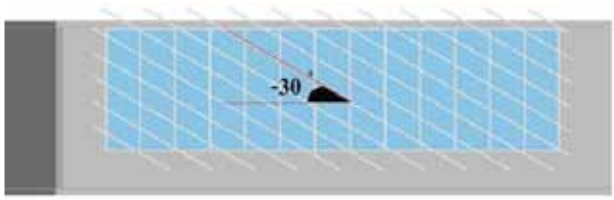
The simulation results of the two previous louver techniques revealed that neither the straight horizontal nor tilting vertical louver can be fixed alone in east and west direction. They did not achieve sufficient daylight inside the hall. Therefore combinations between them may allow for more sufficient daylight and reduce the values of ASE. The Aligned Louvers, which are rotated on YZ or XZ plane with different fixation angles, can get the sunbeams' advantages and avoid glare phenomena as well.

Redirecting daylight to the depth of the room provides better lighting distribution and can protect from glare and high illuminance near the window. Redirecting systems usually consists of a high reflecting surface to reflect and guide the natural light to the ceiling and the depth of the room. Several parameters affect the performance of such systems and as the sunrays' angle is not constant, it's beneficial to allow a simple control method in order to move it. In this section Aligned Louvers with 50% reflectivity were added to the three critical orientations of south, east and west at WWR 65%. The effect of changing the Aligned Louvers fixation angle, in addition to their tilting rotation angle and the spacing between them, was studied. One hundred and eighty nine cases were investigated in each orientation in this step with changing of the three main variables as follows:

- **The first variable:** is changing the aligned fixation angle of the louvers. The louvers are rotated in XZ or YZ depending on the hall orientation. Louver aligned fixation angles are from -45° to 45° degree at 15◦ increments as shown in Table 5-38.
- **The second variable:** is changing the aligned louvers slats' tilting angles. Slats' rotation angles ranged from a -60° to 60° angle degree at 15° increments as shown in Table 5-39.
- **The third variable:** is changing the space between louvers' slats. Slats are spaced at a distance that is equal the slat width so that the slats can be fully closed. The investigated louver space distance / width are 0.25, 0.45, and 0.65 as shown in Table 5-40.

Parametric iterations took place representing all possible combinations of the previous variables resulting in 189 different alternatives. These alternatives were investigated in a parametric simulation analysis like the first stage in order to reach the most efficient alternatives in regards to sufficient daylight performance.

Table 5- 38: Analysis for the investigated aligned louvers aligned angle parameters

The first variable : The investigated Aligned fixation angle (Sample for the investigated Aligned fixation angle with 0 tilting angle and 0.6 m slats spacing)	
Aligned Angle -45 °	**Aligned Angle -30 °**
	

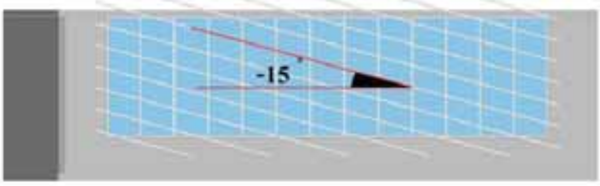
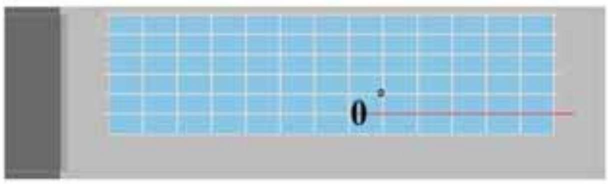
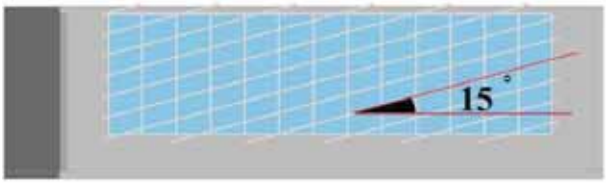
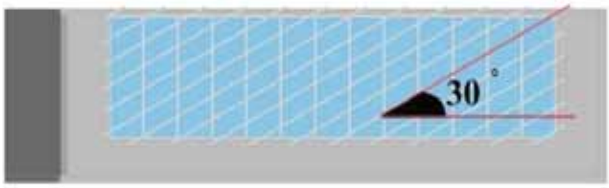
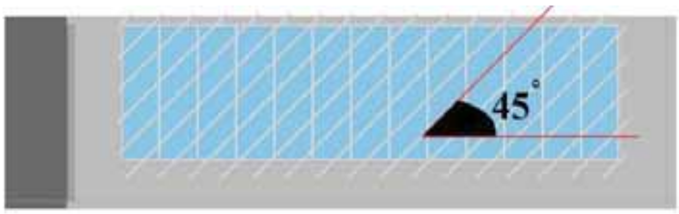
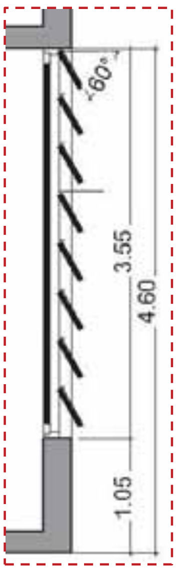
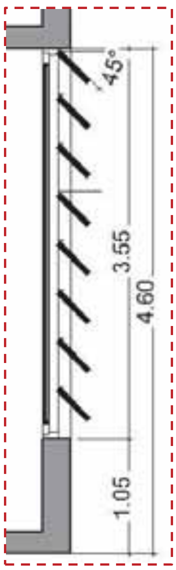
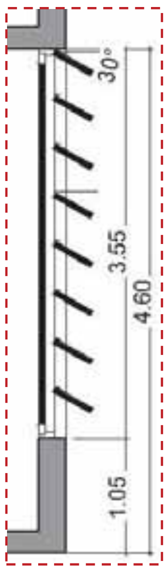
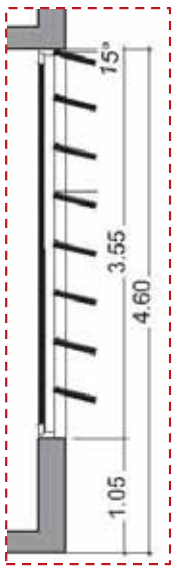
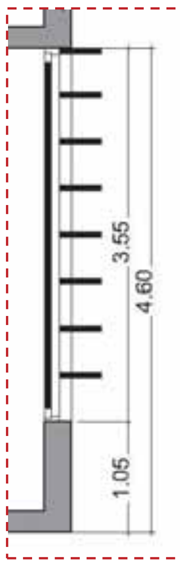
Aligned Angle -15 °	Aligned Angle 0 °
	
Aligned Angle 15 °	**Aligned Angle 30 °**
	
Aligned Angle 45 °	
	

Table 5- 39: Analysis for the investigated Aligned louvers tilting angles

The second variable : louvers tilting angles (Sample for the investigated tilting angle in case of fixed the other parameters ;0 aligned angle and 0.6 m slats spacing)					
Louvers Count	-60°	-45°	-30°	-15°	0°
					

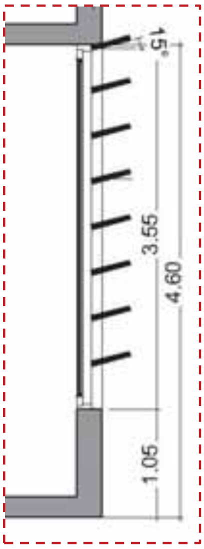
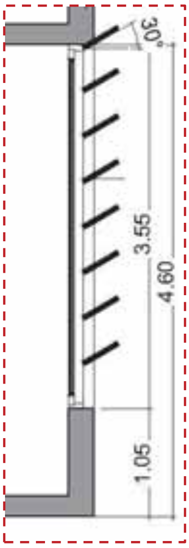
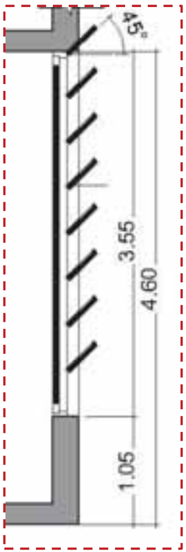
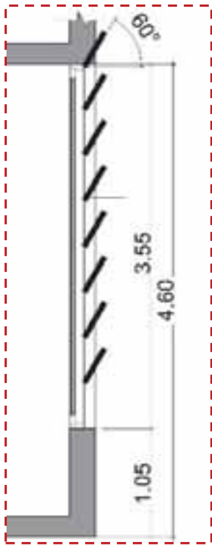
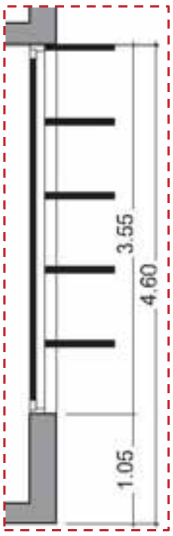
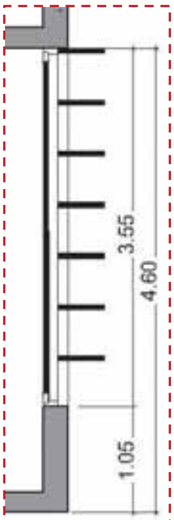
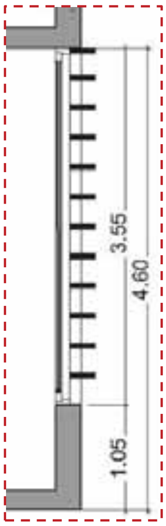
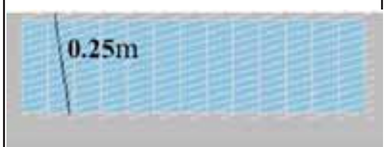
Louvers count	15°	30°	45°	60°
Section				

Table 5- 40: Analysis for the investigated horizontal louvers count parameters

The second variable : louvers spacing distance / louver width **The following sections for different louvers spacing distances in case of fixed the other parameter** Louvers count is directly proportional to increasing aligned angle ,i.e. number of slats in the following section ,which represent 0 ° aligned angled, is less than the slats in following elevation ,which represent 15 ° aligned angle, in order to cover all of the window in case of closing .			
Section For 0 ° Aligned angle			
Elevation For 15 ° Aligned angle			
Louvers Width / Distance	0.65 m	0.45 m	0.25 m

5.5.3.1.Simulation Results of Aligned Louvers at West Direction

i. sDA and ASE Analysis of Investigated Aligned Louvers

Simulation results, which are illustrated in Figure 5-30, revealed that 60% of the cases reached or exceeded the successful threshold of sDA which lies at 55% sDA. But unfortunately 85% of these successful cases are unacceptable due to high ASE values. Around 70% of all the cases override the ASE limit, which lies on the 10% ASE. Following is the detailed explanation for the effect of changing each variable on daylight performance.

A. <u>The Effect of changing Aligned angles</u>

Simulation results revealed that the positive aligned fixation angles allow more sunbeams to reach the inside of the space which increases both the sDA and ASE. Sometimes these high values of sDA enhance the daylight performance especially when these positive angles are used with negative tilting angles which control ASE values. In contrast when these positive aligned angles are used with positive tilting angles, they reduce the performance by increasing ASE values more than 10 which is unacceptable. The negative aligned angles control ASE values but with low sDA. The aligned angles 0 ° and – 15° were found to be the best aligned angles to use in this direction respectively.

B. <u>The Effect of changing Tilting angles</u>

Simulation results revealed that in each aligned angle the sDA and ASE values are directly proportional to the increase of negative tilting angles until they reach to their maximum value in 15 ◦ tilting angle and then they start to decrease gradually. Although the negative tilting angles always have low ASE values, the positive tilting angles have high ASE values. In contrast sDA values are almost the same in each angle and its negative (opposite). Therefore the positive tilting angle should be avoided in this direction. The tilting angle -30 ◦ has a good daylight performance with different aligned angles especially with 0.60m slats space distance.

C. <u>The effect of Changing Louvers Spacing Distance</u>

Simulation results revealed that the sDA and ASE values are reversely proportional to the decrease of louvers' width, which equals the spacing between the slats, in each tilting angle. The large slat has a better performance than the small one especially at the 0◦, 15 ◦ tilting angle.

The results of sDA and ASE values are compiled into three tables to make it easier to check them and classify their performance. Table 5-41 illustrates the analysis of negative aligned angles and Table 5-42 illustrates zero aligned angle, while Table 5-43 illustrates the analysis of positive aligned angles. These tables contain the classification of the 189 cases are according to the LEED v4 rating system in order to choose the best cases. The dark gray rectangles represent the results which are unacceptable due to high ASE values while the blue color represents the unacceptable results due to low daylight performance and the brown represents the unacceptable results due to both low daylight performance and ASE. The others represent the accepted cases based on daylight performance, which were a total of16 cases in this stage. The green rectangle colors represent the accepted cases with two points on the LEED v4 (cases: 6, 33, 60, 63, 64, 65, 81, 84, 87, 88, 89, 92, 114, 11, and 148). The red represents the accepted case with three points on the LEED v4 (case 90). But its ASE value is larger than 7 and less 10 which is critical and a non-preferred performance.

ii. Daylight Availability Analysis of Investigated Accepted Cases

The daylight availability results for the sixteen accepted cases from the previous simulation, which are illustrated in Figure 5-31, revealed that although these cases have points on the LEED rating system, they achieved low or medium performance in daylight availability. None of them exceed 65% daylit area. The best daylight availability performance achieved is in the case of 0° aligned angle with -15° tilting angle and louver width of 0.65m. It achieved 65% daylit, 10% partially daylit and 25 % overlit.

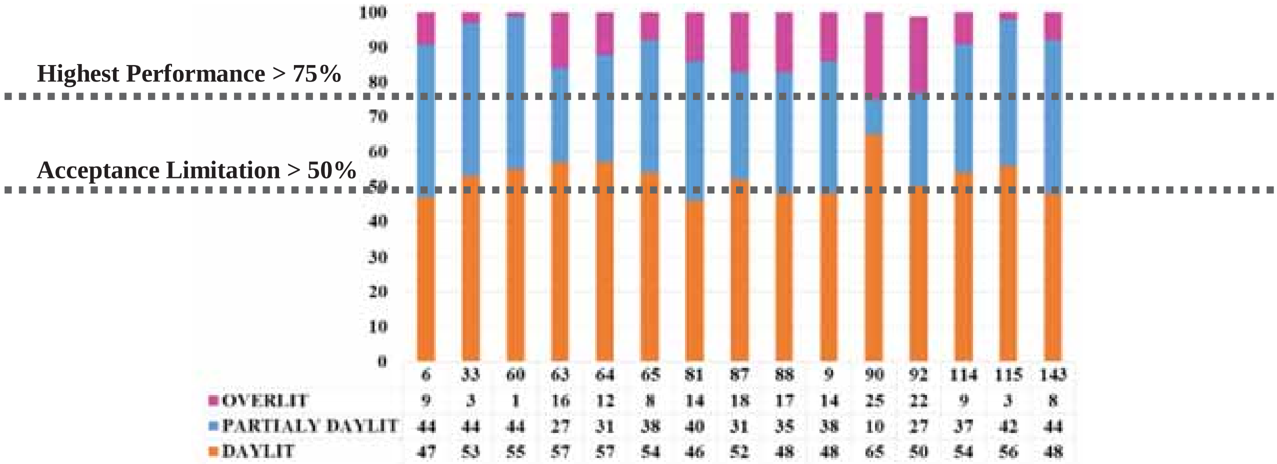


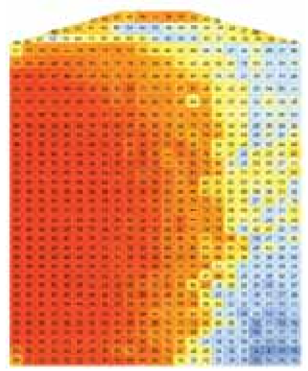
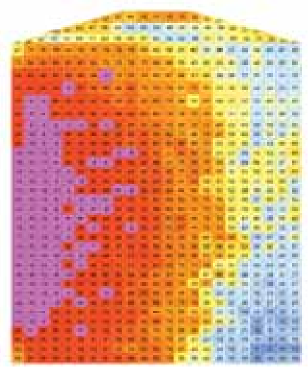
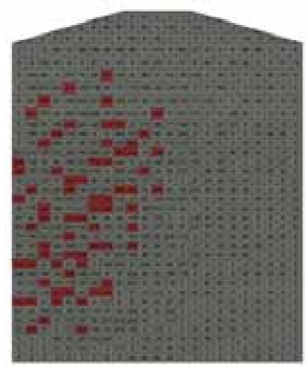
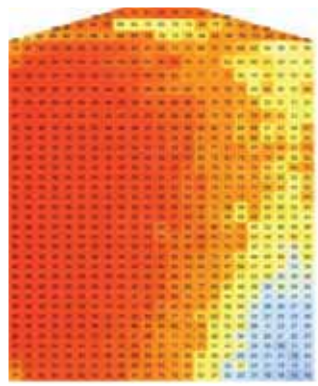
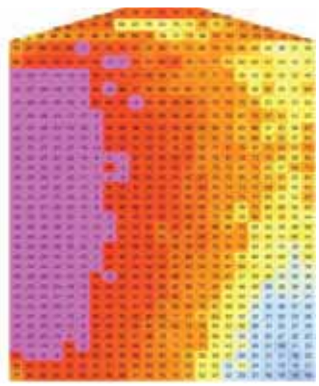
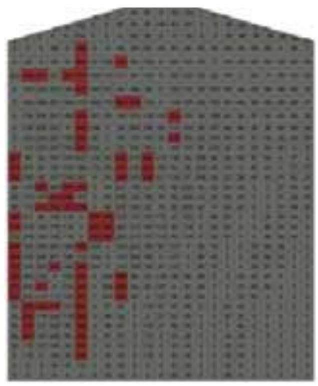
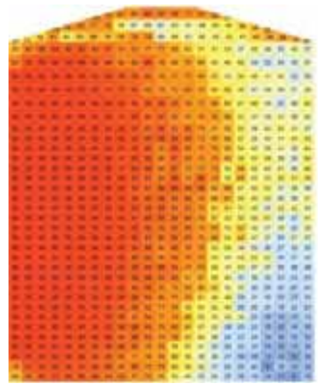
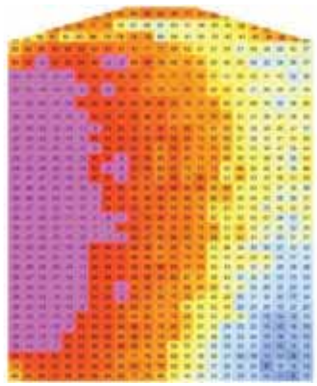
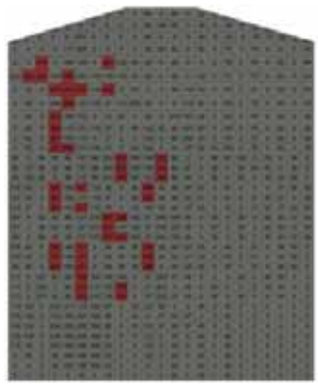
Figure 5- 31: Daylight Availability performance results for the accepted cases -Aligned louvers at west orientation

Even though in several cases the daylight reached the depth of the room, these cases were enabled higher percentages of overlit areas near the glazing. It's also observed that cases that achieved better performance were the cases that had the least overlit areas near the glazing. Table 5-44 illustrates the colored ranged analysis for the daylight availability results of the accepted cases according to the LEED V4 and the main parameters of them. The cases 63, 90, and 92 achieved the best performances of sDA, ASE and also daylight availability at this orientation. Table 5-45 illustrates their colored grids analyses which show that they have large overlit values so glare check will be carried out in the next.

Table 5- 44: Colored analysis for the daylight availability results - Aligned louvers at west direction

Case Number	Width	Aligned Angle	Tilting Angle	Daylight Availability			QUALITY	
				PARTIALY DAYLIT	DAYLIT	OVERLIT	sDA	ASE
6	0.65	-45	-30	44	47	9	56	3
33	0.65	-30	-30	44	53	3	56	6
60	0.65	-15	-30	44	55	1	56	0
63	0.65	-15	-15	27	57	16	73	9
64	0.45	-15	-15	31	57	12	69	7
65	0.25	-15	-15	38	54	8	62	5
81	0.65	0	-60	40	46	14	60	1
87	0.65	0	-30	31	52	18	69	1
88	0.45	0	-30	35	48	17	65	1
89	0.65	0	-30	38	48	14	62	1
90	0.65	0	-15	10	65	25	88	9
92	0.25	0	-15	27	50	22	73	6
114	0.65	15	-30	37	54	9	63	6
115	0.45	15	-30	42	56	3	58	3
143	0.25	30	-30	44	48	8	56	7

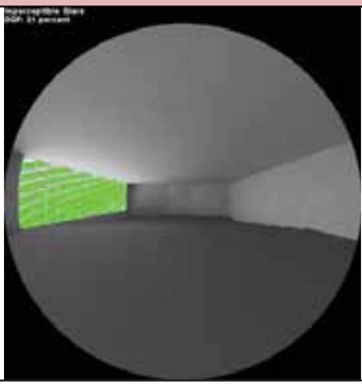
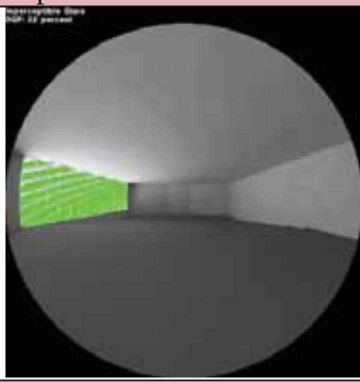
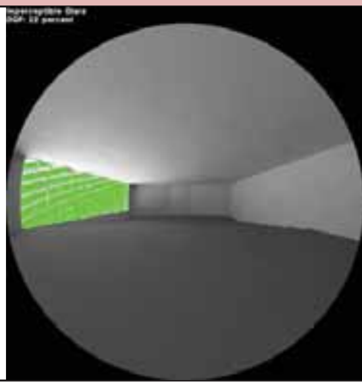
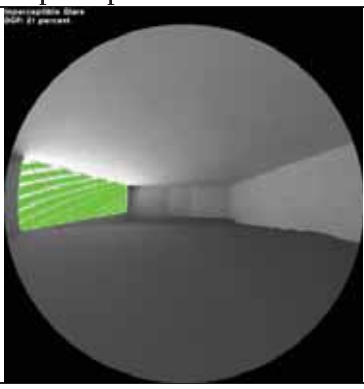
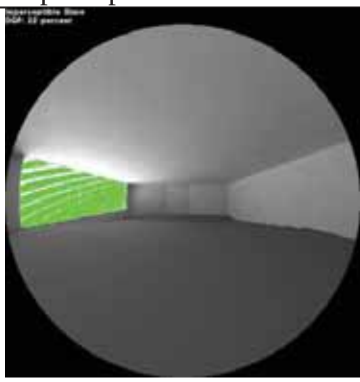
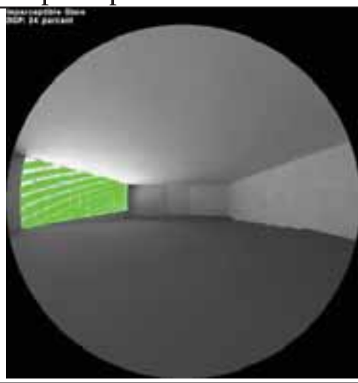
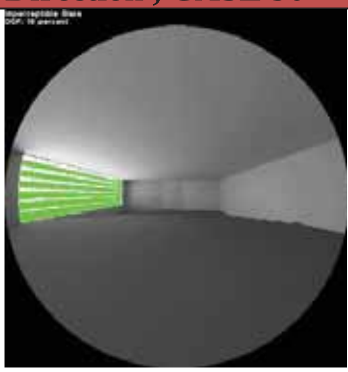
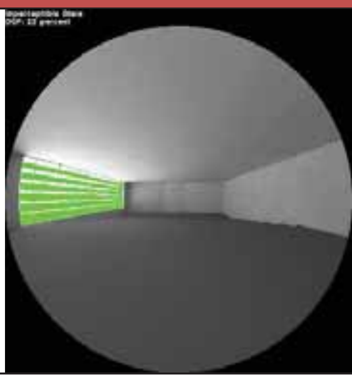
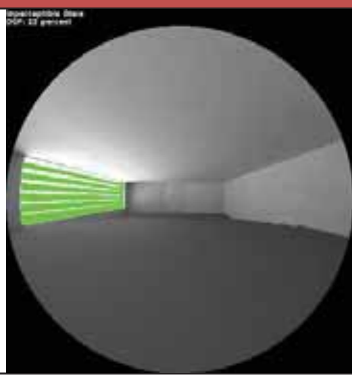
Table 5- 45: Daylight analysis for the highest performance cases at west direction –Aligned louvers

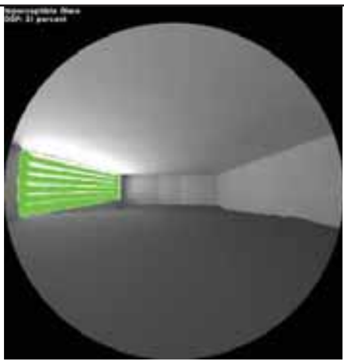
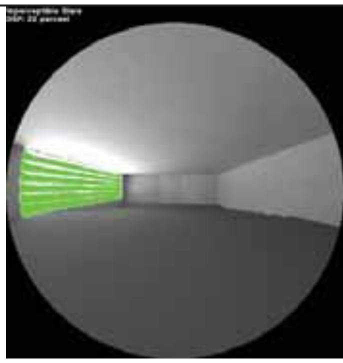
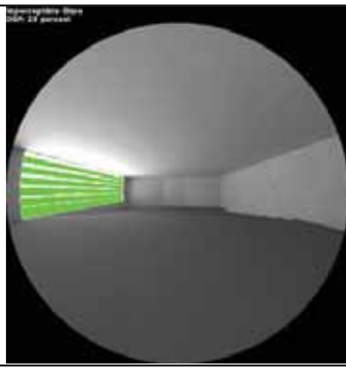
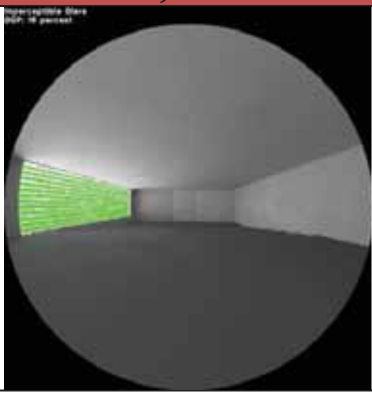
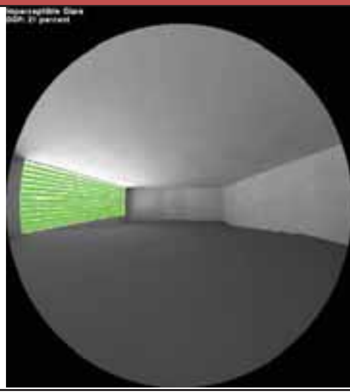
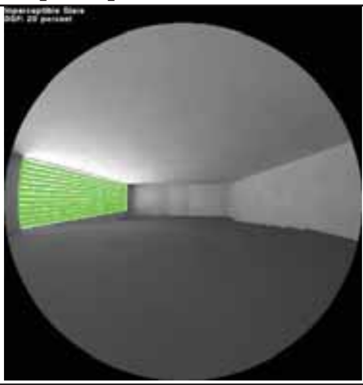
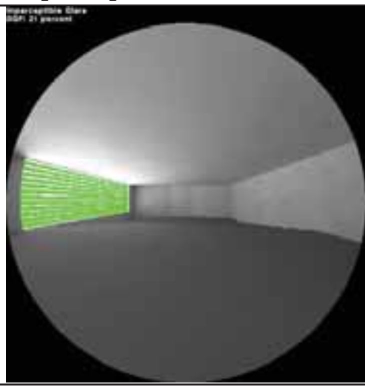
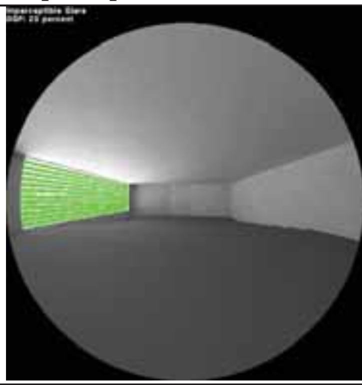
Daylight analysis for the high performance cases at west direction (WWR=65%)					
Case	**sDA**	**Daylight Availability**			**ASE**
Case 63					
	sDA= 73%	Partially =27	Daylit=57	Overlit=16	ASE=9
Case 90					
	sDA = 88%	Partially=10	Daylit=65	Overlit=25	ASE=9
Case 92					
	sDA = 73%	Partially=22	Daylit=50	Overlit=22	ASE=6
KEY					

iii. Glare Analysis for The Top Performance Cases

Analysis for visual comfort was carried out for cases that obtained best daylight availability performance. In the west orientation, the best performance achieved were in cases 63, 90 and 92. Therefore the Daylight Glare Probability (DGP) was calculated for each case to check their visual comfort. The three cases all had imperceptible glare at 9:00 and 12:00 in the different seasons as shown in Table 5-46. Although there were minor differences in their performance, the three cases were acceptable. Therefore their energy consumption will be calculated in the next step to identify the most efficient case.

Table 5- 46: Glare analysis for the three top cases (63, 90 and 92)

West Direction , CASE 63			
	December 21	September 21	June 21
9:00 AM			
	Imperceptible DGP 21%	Imperceptible DGP 22%	Imperceptible DGP 22%
12.00 PM			
	Imperceptible DGP 21%	Imperceptible DGP 22%	Imperceptible DGP 24%
West Direction , CASE 90			
9:00 AM			
	Imperceptible DGP 19%	Imperceptible DGP 22%	Imperceptible DGP 22%

12.00 PM			
	Imperceptible DGP 21%	Imperceptible DGP 22%	Imperceptible DGP 23%
West Direction , CASE 92			
9:00 AM			
	Imperceptible DGP 16%	Imperceptible DGP 23%	Imperceptible DGP 21%
12.00 PM			
	Imperceptible DGP 20%	Imperceptible DGP 21%	Imperceptible DGP 23%

iv. Energy Consumption for The Top Performance Cases

The thermal simulation was carried out to get the total energy consumption per year for the three top cases. It used the artificial lighting scheduled, which was calculated in the previous daylight simulation for each case and began to calculate lighting, cooling and heating loads per hour for each case. Hence the consumption per year for each load was calculated to get the total energy used in each case as shown in Table 5-47.

The results of thermal analysis revealed that case 63 and 90 have almost the same consumption and they are more efficient than case 92. But case 90 has better daylight performance as discussed before. Therefore it was found to be the most efficient one. Its total energy consumption per year is 187.24 KW/H while case 63 and 92 are 187.13 and 191.03 KW/h respectively.

Table 5- 47: Energy consumption for top cases - (63, 90 and 92)

Case	Electric consumption per year- KW/h	Cooling consumption per year- KW/h	Heating consumption per year- KW/h	Total Energy consumption per year- KW/h
63	10.98	168.7	7.45	187.13
90	11.00	168.8	7.44	187.24
92	13.03	170.66	7.4	191.03

5.5.3.2.Simulation Results of Aligned Louvers at South Direction

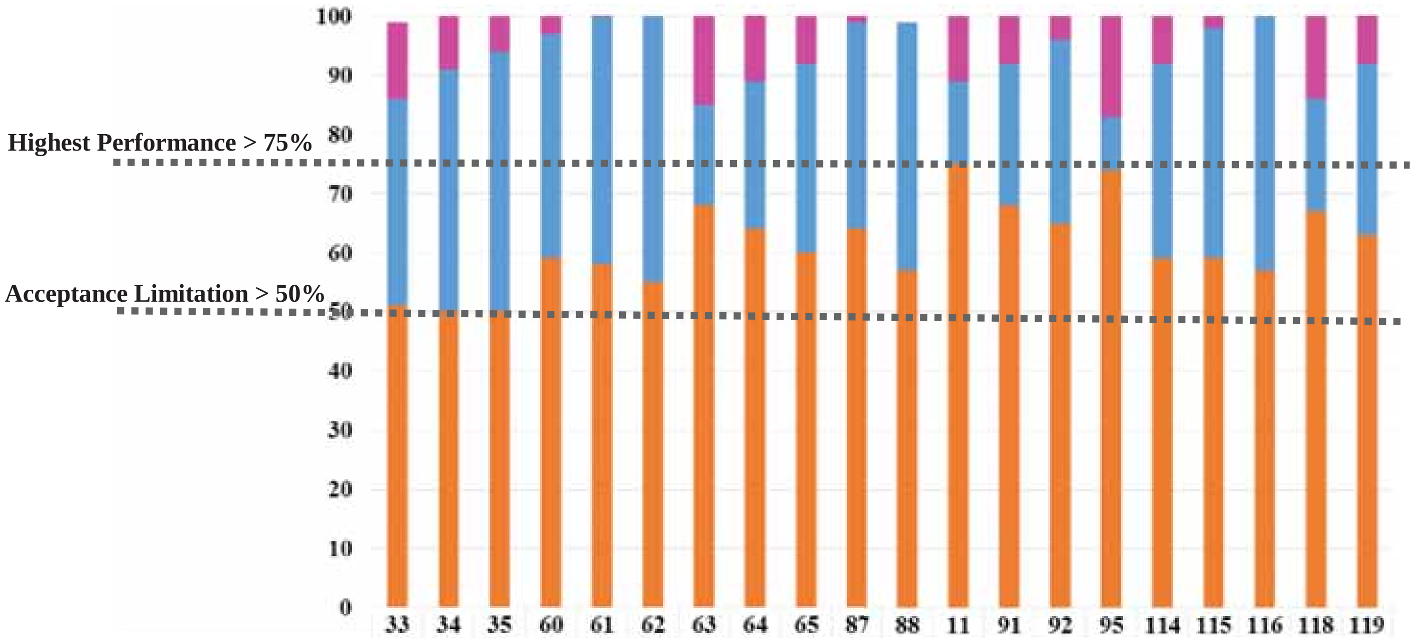
i. sDA and ASE Analysis of Investigated WWRs

Simulation results, which are illustrated in Figure 5-32, revealed that 70% of the cases reached or exceeded the successful threshold of sDA which lies at 55% sDA. But unfortunately 85% of these successful cases are unacceptable due to high ASE values. Around 70% from the all cases override the ASE limit, which lies at 10% ASE. The effect of changing each variable on daylight performance is similar to west direction except with the aligned angle variable. The negative aligned angles have more sDA values than the positive one. The aligned angles 0°, 15° and -15 ° are the best three aligned angles in this orientation respectively. The tilting angles -15 ° and -30° have good daylight performance in different aligned angles except 30° and 45 ° which didn't achieve any accepted cases. Similar to west direction, the sDA and ASE values are reversely proportional to the decrease of louvers width, which equals the spacing between the slats in each tilting angle. The large slat has a better performance than the small one especially at a 0°, - 15 ° and 15° tilting angle.

The results of sDA and ASE values are compiled into three tables to make it easier to check them and classify their performance. Table 5.48 illustrates the analysis of negative aligned angles and Table 5-49 illustrates zero aligned angle, while Table 5-50 illustrates the analysis of positive aligned angles. These tables contain the classification of the 189 cases according to the LEED v4 rating system in order to choose the best cases. The dark gray rectangles represent the results which are unacceptable due to high ASE values while the blue color represents the unacceptable results due to low daylight performance and the brown represents the unacceptable results due to both low daylight performance and ASE. The others represent the accepted cases based on daylight performance which are a total of 20 cases in this stage. The green rectangles represent the accepted cases with two points on the LEED v4 (cases; 33, 34, 35, 60, 61, 62, 65, 87, 88, 92, 114, 115, 116, and119), while the yellow, orange and red represent the accepted cases with three points on the LEED v4. The yellow represents ASE performance less than 3 which are the most preferred ASE performance (cases; 63, 64, and 91). But the orange rectangles represent ASE values larger than three and less than 7 which is neutral (Case; 90, 95, and118).

ii. Daylight Availability Analysis of Investigated Accepted Cases

The daylight availability results for the 20 accepted cases, which are illustrated in Figure 5-33, revealed that the positive aligned angles in addition to 0° aligned angle have more daylit areas than the negative aligned angles. In contrast "Partially daylit" dominated the space area in negative aligned angles and it decreased gradually with the increase of the aligned angles. This performance reaches its maximum when it is complied with negative tilting angles. The best daylight availability performance achieved in case of -0° aligned angle with -15° tilting angle and louver width of 0.65m.



	33	34	35	60	61	62	63	64	65	87	88	11	91	92	95	114	115	116	118	119
OVERLIT	13	9	6	3	1	0	15	12	8	1	0	11	8	4	17	8	2	0	14	9
PARTIALY DAYLIT	35	41	44	38	42	45	17	25	32	35	42	14	24	31	9	33	39	43	19	29
DAYLIT	51	50	50	59	58	55	68	64	60	64	57	75	68	65	74	59	59	57	67	63

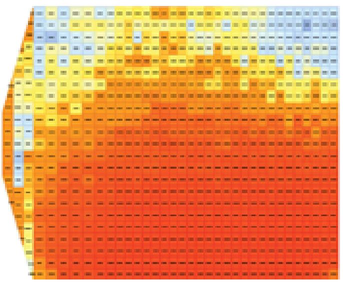
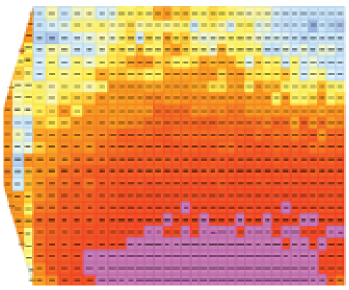
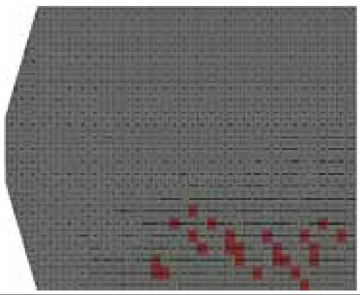
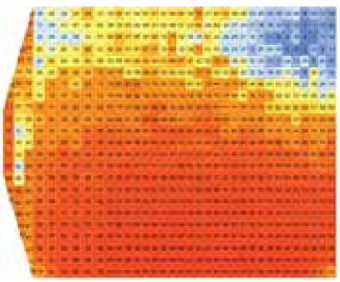
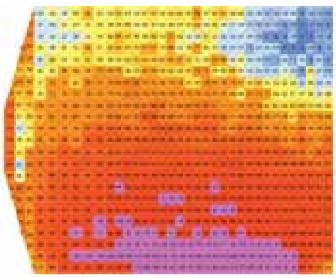
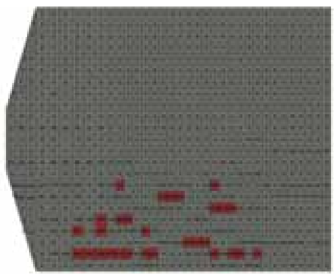
Figure 5- 33: Daylight Availability performance results for the accepted cases -Aligned louvers at south orientation

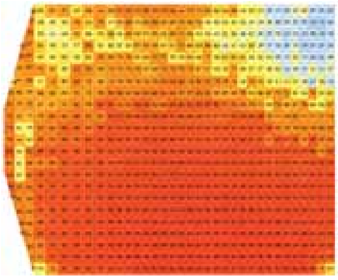
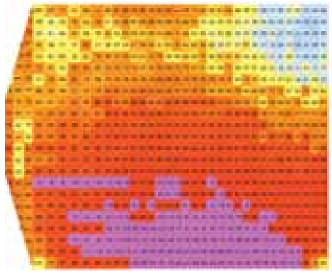
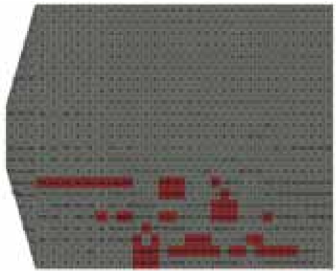
Table 5-51 illustrates the colored ranged analysis for the daylight availability results in the accepted cases according to the LEED V4 with their main parameters; aligned angle, titling angle and spacing distance/width of louvers' slats. The cases 63, 90, and 95 achieved the best performances of sDA, ASE and also daylight availability at this orientation. Case 90 had the highest performance as it achieved 75% daylit area followed by case 95 which achieved 74% then case 63 and 91 with 68%. Although each of the cases 63 and 91 had the same daylit area 68%, case 63 had less partially daylit area than case 90. Table 5-52 illustrates their colored grids analyses which show that they have large overlit values so glare check will be carried out in the next.

Table 5- 51: Colored analysis for the daylight availability results by using Aligned louvers at south direction

Case Number	Width	Aligned Angle	Tilting Angle	Daylight Availability			QUALITY	
				PARTIALY DAYLIT	DAYLIT	OVERLIT	sDA	ASE
33	0.65	-30	-30	35	51	13	65	6
34	0.45	-30	-30	41	50	9	59	3
35	0.25	-30	-30	44	50	6	56	3
60	0.65	-15	-30	38	59	3	62	0
61	0.45	-15	-30	42	58	1	58	0
62	0.25	-15	-30	45	55	0	55	0
63	0.65	-15	-15	17	68	15	83	3
64	0.45	-15	-15	25	64	12	75	2
65	0.25	-15	-15	32	60	8	68	3
87	0.65	0	-30	35	64	1	65	0
88	0.45	0	-30	42	57	0	58	0
90	0.65	0	-15	14	75	11	86	4
91	0.45	0	-15	24	68	8	76	2
92	0.25	0	-15	31	65	4	69	1
95	0.25	0	10	9	74	17	91	7
114	0.65	15	-30	33	59	8	67	5
115	0.45	15	-30	39	59	2	61	2
116	0.25	15	-30	43	57	0	57	0
118	0.45	15	-15	19	67	14	81	7
119	0.25	15	-15	29	63	9	71	3

Table 5- 52: Daylight analysis for the highest performance cases at south direction

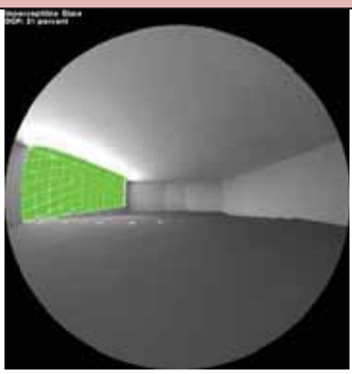
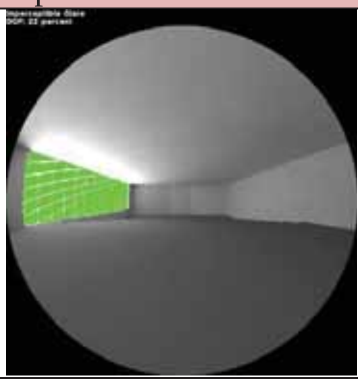
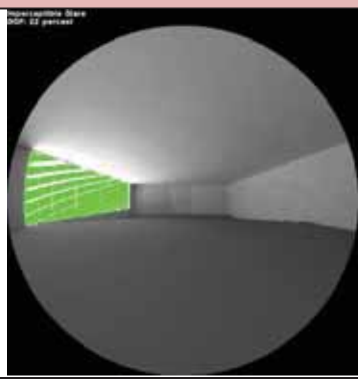
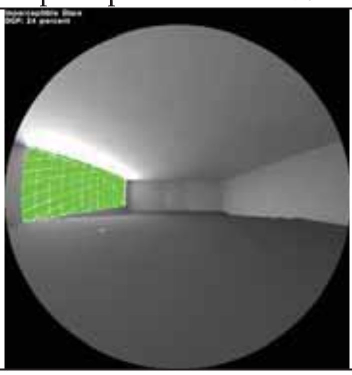
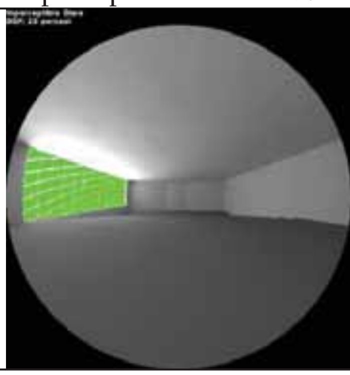
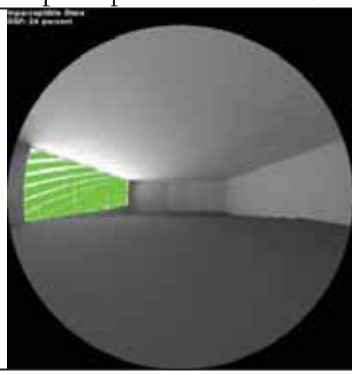
Daylight analysis for the high performance cases at south direction (WWR=65%)					
Case	**sDA**	**Daylight Availability**			**ASE**
Case 63					
	sDA= 83%	Partially =17	Daylit=68	Overlit=15	ASE= 3
Case 90					
	sDA = 86%	Partially=14	Daylit=75	Overlit=11	ASE= 4

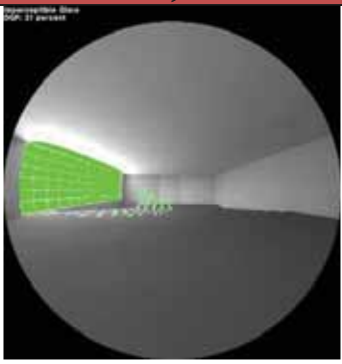
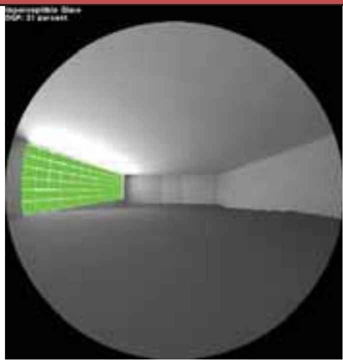
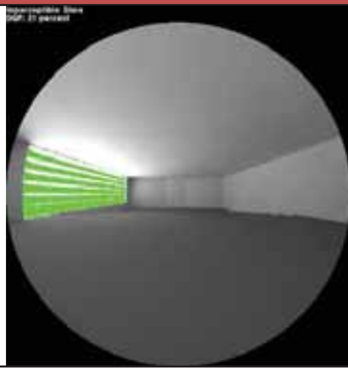
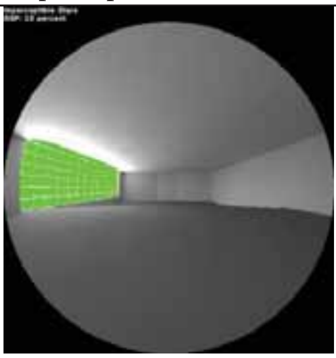
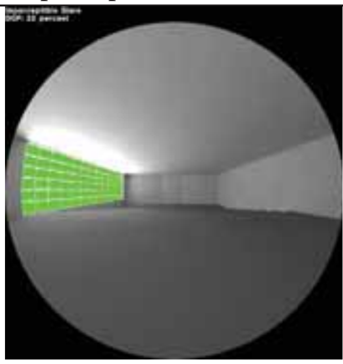
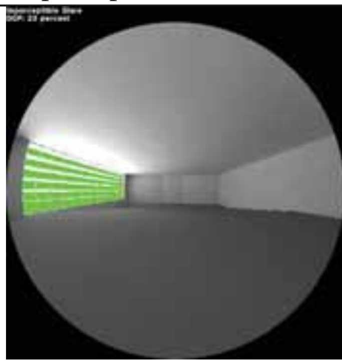
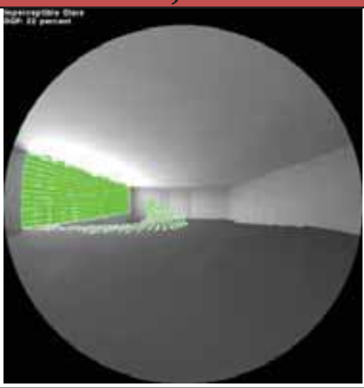
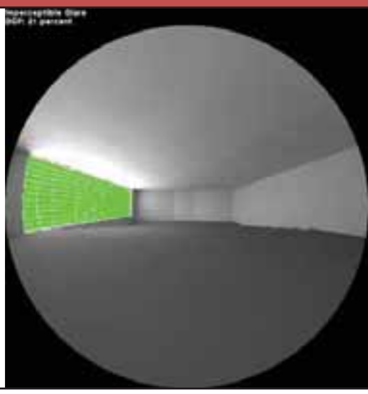
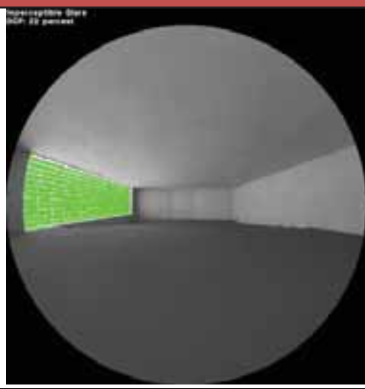
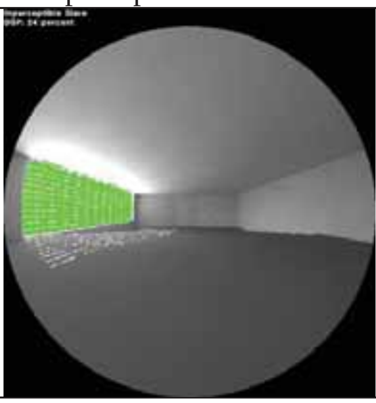
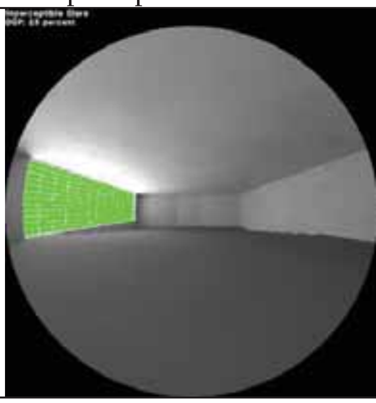
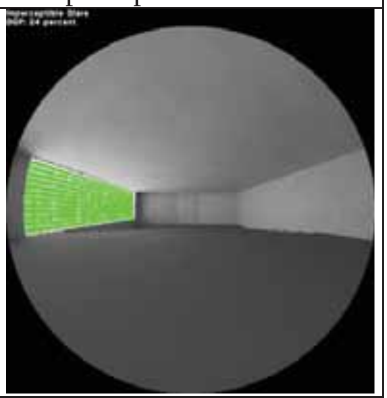
Case 95					
	sDA = 91 %	Partially=9	Daylit=74	Overlit=17	ASE= 7
KEY	100% Daylit 50% Partially – daylit 0%	Over lit	ASE > 250 Hours	ASE < 250 Hours	

iii. Glare Analysis for The Top Performance Cases

Analysis for visual comfort was carried out for the cases that obtained top daylight availability performance. In the south orientation, the top performance achieved were in cases 63, 90 and 95. Therefore the Daylight Glare Probability (DGP) was calculated for each case to check their visual comfort. The three cases had imperceptible glare at 9:00 and 12:00 in the different seasons as shown in Table 5-53. Although there were minor differences in their performance, the three cases were all acceptable. Therefore their energy consumption will be calculated in the next step to identify the most efficient case.

Table 5- 53: Glare analysis for the three top cases (63, 90 and 95)

South Direction , CASE 63			
	December 21	September 21	June 21
9:00 AM			
	Imperceptible DGP 21%	Imperceptible DGP 22%	Imperceptible DGP 22%
12.00 PM			
	Imperceptible DGP 24%	Imperceptible DGP 23%	Imperceptible DGP 24%

South Direction , CASE 90			
9:00 AM			
	Imperceptible DGP 21%	Imperceptible DGP 21%	Imperceptible DGP 21%
12.00 PM			
	Imperceptible DGP 23%	Imperceptible DGP 22%	Imperceptible DGP 23%
South Direction , CASE 95			
9:00 AM			
	Imperceptible DGP 22%	Imperceptible DGP 21%	Imperceptible DGP 22%
12.00 PM			
	Imperceptible DGP 24%	Imperceptible DGP 23%	Imperceptible DGP 24%

i. Energy Consumption for The Top Performance Cases

The thermal simulation was carried out in order to get the total energy consumption per year for the three successful cases. It used the artificial lighting scheduled, which was calculated in the previous daylight simulation for each case and began to calculate lighting, cooling and heating loads per hour for each case. Hence the consumption per year for each load is calculated to get the total energy used in each case as shown in Table 5-54.

Table 5- 54: Energy consumption for top cases- (63, 90 and 95)

Case	Electric consumption per year- KW/h	Cooling consumption per year- KW/h	Heating consumption per year- KW/h	Total Energy consumption per year- KW/h
63	8.3	156.6	6.5	171.4
90	11.78	159.5	6.4	177.68
95	7.52	156	6.53	170.05

The results of the thermal analysis, which are shown in the previous table, revealed that case 95 is the most efficient one in regards to energy savings. Its total energy consumption per year is 170.05 KW/H while the others 63 and 90 are 171.4 and 177.68 KW/h respectively.

5.5.3.3. Simulation Results of Horizontal Louvers at East Direction

i. sDA and ASE Analysis of Investigated WWRs

Simulation results, which are illustrated in Figure 5-32, revealed that 50% of the cases reached or exceeded the successful threshold of sDA which lies at 55% sDA and this ratio is the smallest one of the three investigated orientations. But unfortunately 89% of these successful cases are unacceptable due to high ASE values. Around 64% of all the cases override the ASE limit, which lies at 10% ASE. Unlike west orientation, the negative aligned angles didn’t achieve good performance due to high ASE values while the positive aligned angles had some accepted cases with -30 and -15 tilting angles. The cases with 0 aligned angles in this orientation weren’t efficient compared with the other orientations. Similar to west and south directions, the large slats have better performance than the small ones.

The results of sDA and ASE values are compiled into three tables to make it easier to check them and classify their performance. Table 5-55 illustrates the analysis of negative aligned angles and Table 5-56 illustrates zero aligned angle, while Table 5-57 illustrates the analysis of positive aligned angles. These tables contain the classification of the 189 cases according to the LEED v4 rating system to choose the best cases. The dark gray rectangles represent the results which are unacceptable due to high ASE values while the blue color represents the unacceptable results due to low daylight performance and the brown represents the unacceptable results due to both low daylight performance and ASE. The green rectangle colors represent the accepted cases with two points on the LEED v4, which total 11 cases in this stage. (Cases; 61, 61, 87, 114, 115, 118, 119, 141, 142, 168, and 169). There isn’t any case that achieved three points on the LEED at this stage.

ii. Daylight Availability Analysis of Investigated Accepted Cases

The daylight availability results for the 20 accepted cases from the previous simulation results, which are illustrated in Figure 5-35, revealed that the cases with positive aligned angles in addition to 15° and - 15° aligned angle are the only accepted aligned angles which achieve daylit areas more than 50%. Although the cases had a rating of two points on the LEED, the “Partially daylit” dominated the spaces in this orientation. The partially daylit areas represent around 50% of the spaces. The best daylight availability performance achieved was in the case of 15° aligned angle with -15° tilting angle and louver width of 0.45m.

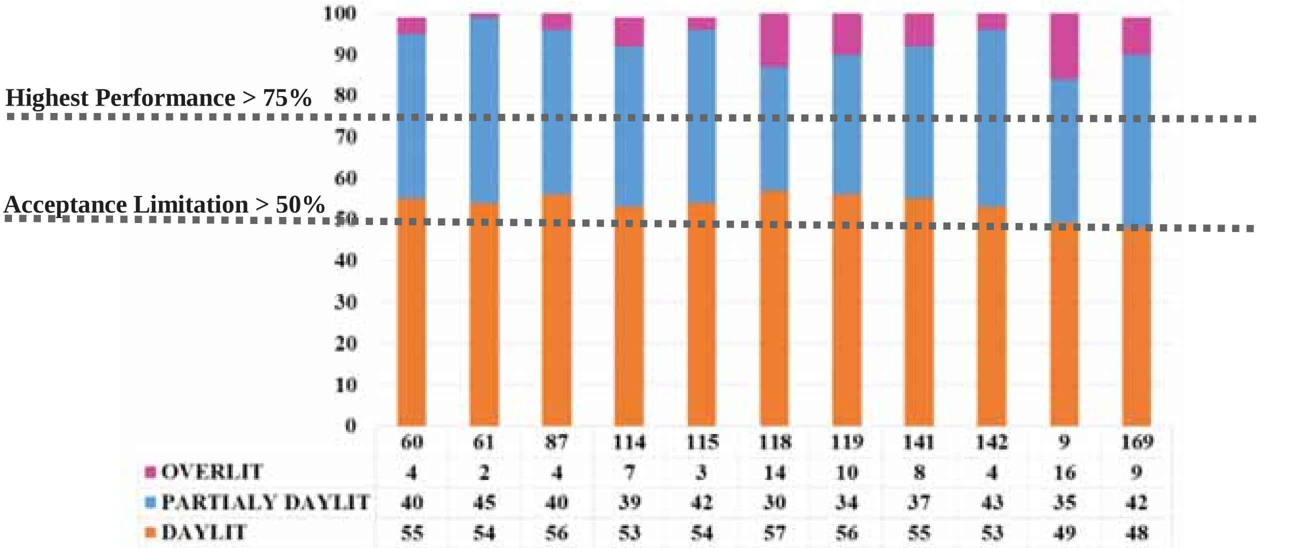


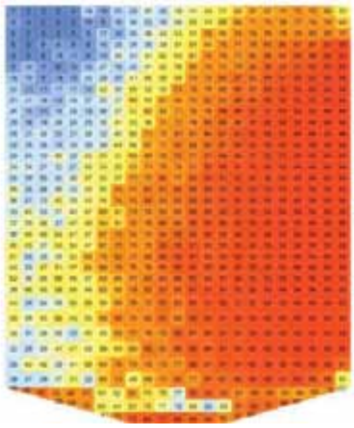
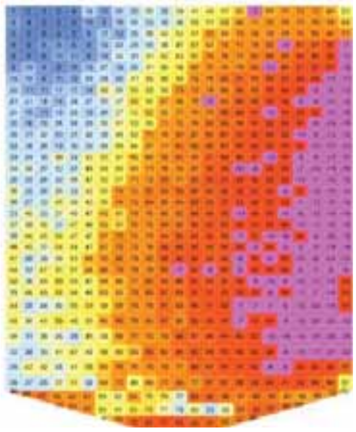
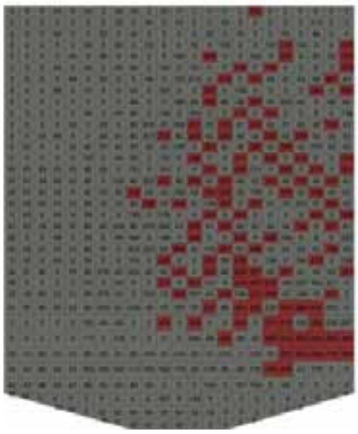
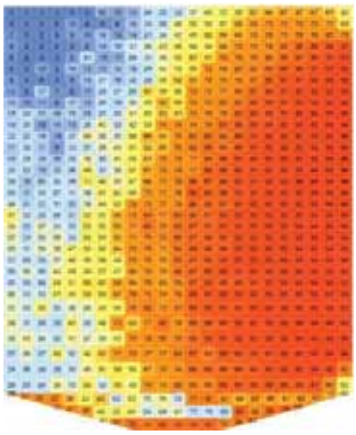
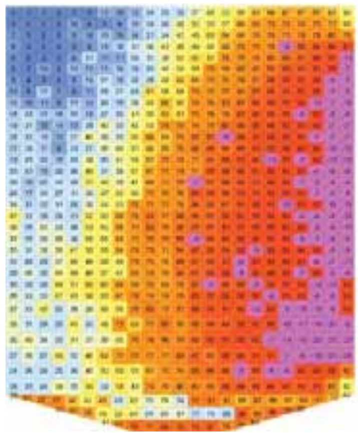
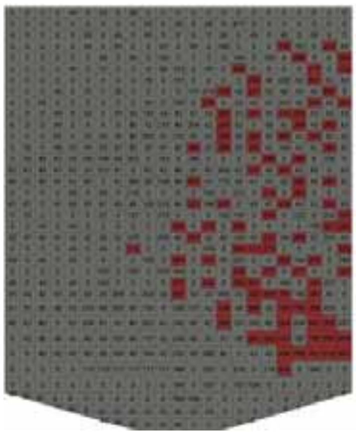
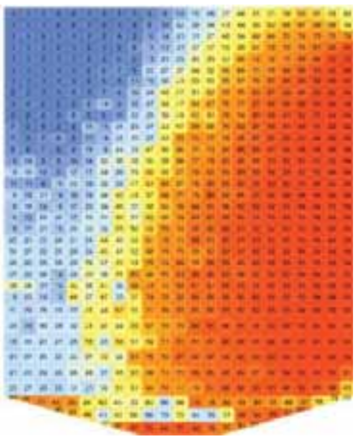
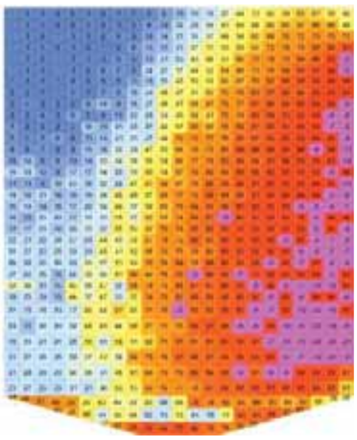
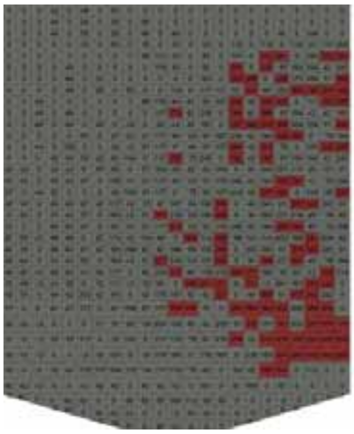
Figure 5- 35: Daylight Availability performance results for the accepted cases -Aligned louvers at east orientation

Table 5-58 illustrates the colored ranged analysis for the daylight availability results of the accepted cases according to the LEED V4 with their main parameters; aligned angle, titling angle and spacing distance/width of louvers’ slats. The cases 118, 119, and 141 achieved the best performances of sDA, ASE and also daylight availability at this orientation. Table 5-59 illustrates their colored grids analysis which shows that they have large overlit values so glare check will be carried out in the next.

Table 5- 58 : Colored analysis for the daylight availability results by using Aligned louvers at east direction

Case Number	Width	Aligned Angle	Tilting Angle	Daylight Availability			QUALITY	
				PARTIALY DAYLIT	DAYLIT	OVERLIT	sDA	ASE
60	0.65	-15	-30	40	55	4	60	4
61	0.45	-15	-30	45	54	2	55	3
87	0.65	0	-30	40	56	4	60	5
114	0.65	15	-30	39	53	7	61	6
115	0.45	15	-30	42	54	3	58	3
118	0.45	15	-15	30	57	14	70	9
119	0.3	15	-15	34	56	10	66	7
141	0.6	30	-30	37	55	8	63	9
142	0.45	30	-30	43	53	4	57	8
168	0.65	45	-30	35	49	16	65	8
169	0.45	45	-30	42	48	9	58	6

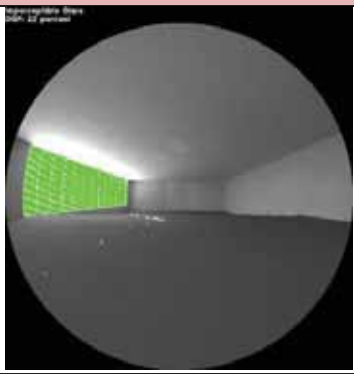
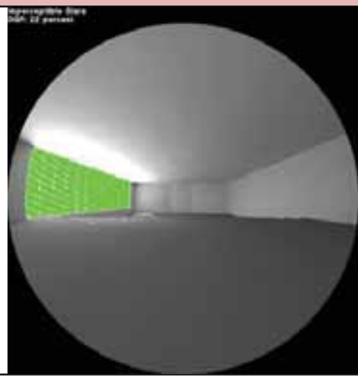
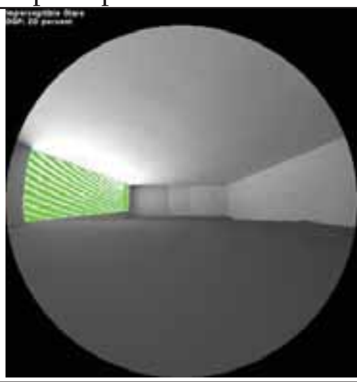
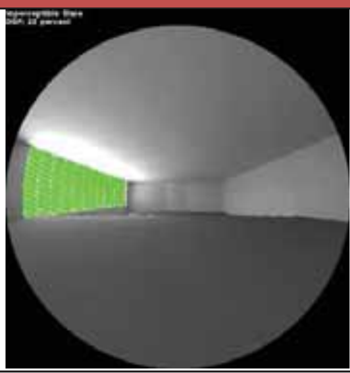
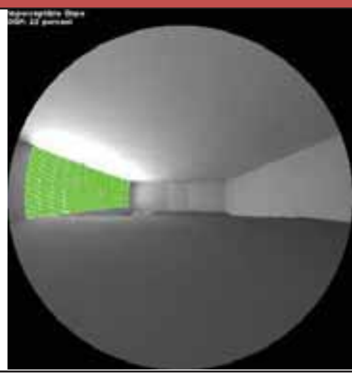
Table 5- 59: Daylight analysis for the highest performance cases at east direction

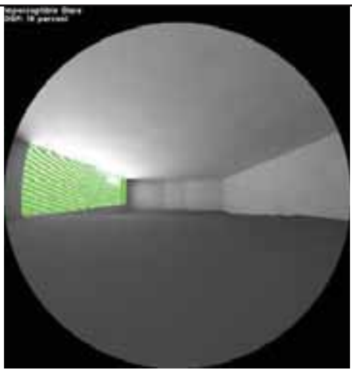
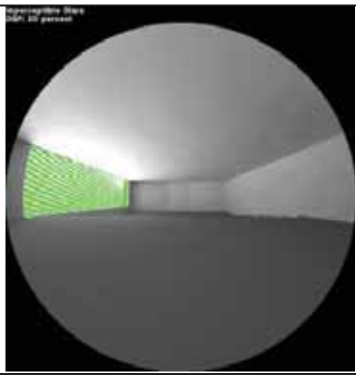
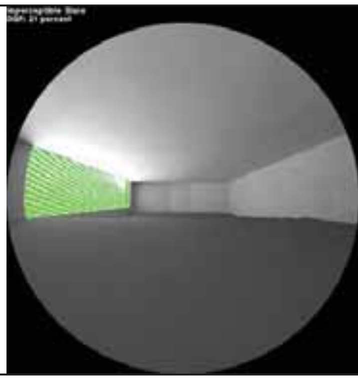
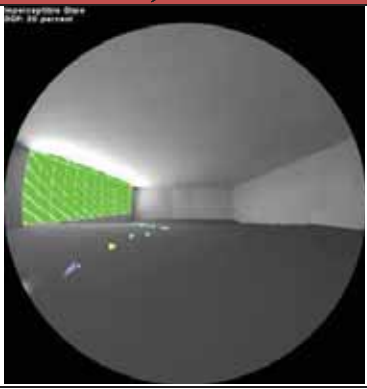
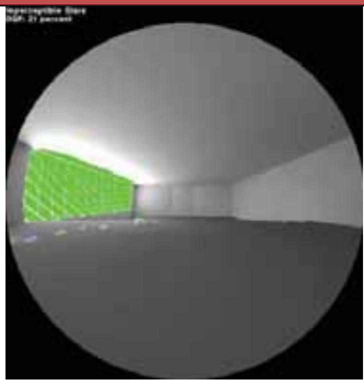
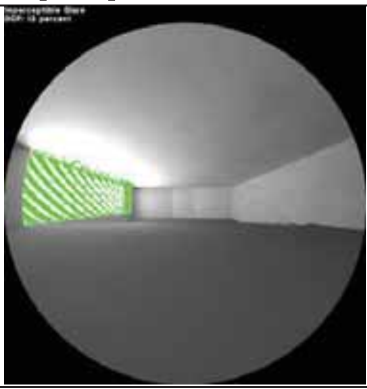
Daylight analysis for the high performance cases at east direction (WWR=65%)					
case	**sDA**	**Daylight Availability**			**ASE**
Case 118					
	sDA= 70%	Partially =30	Daylit=57	Overlit=14	ASE= 9
Case 119					
	sDA = 66%	Partially=34	Daylit=56	Overlit=10	ASE= 7
Case 141					
	sDA = 63 %	Partially=37	Daylit=55	Overlit=8	ASE= 9
KEY					

iii. Glare Analysis for The Top Performance Cases

Analysis for visual comfort was carried out for cases that obtained top daylight availability performance. In the south orientation, the best performance achieved were in cases 118, 119 and 141. Therefore the Daylight Glare Probability (DGP) was calculated for each case to check their visual comfort. The three cases had imperceptible glare at 9:00 and 12:00 in the different seasons as shown in Table 5-60. Although there were minor differences in their performance, all three cases were acceptable. Therefore their energy consumption will be calculated in the next step to identify the most efficient WWR case.

Table 5- 60: Glare analysis for the three top cases (118, 119 and 141)

East Direction , CASE 118			
	December 21	September 21	June 21
9:00 AM			
	Imperceptible DGP 22%	Imperceptible DGP 23%	Imperceptible DGP 22%
12.00 PM			
	Imperceptible DGP 20%	Imperceptible DGP 20%	Imperceptible DGP 22%
East Direction , CASE 119			
9:00 AM			
	Imperceptible DGP 22%	Imperceptible DGP 22%	Imperceptible DGP 22%

12.00 PM			
	Imperceptible DGP 19%	Imperceptible DGP 20%	Imperceptible DGP 21%
East Direction , CASE 141			
9:00 AM			
	Imperceptible DGP 20%	Imperceptible DGP 21%	Imperceptible DGP 21%
12.00 PM			
	Imperceptible DGP 13%	Imperceptible DGP 17%	Imperceptible DGP 19%

ii. Energy Consumption for The Top Performance Cases

The thermal simulation was carried out to get the total energy consumption per year for the three top cases. It used the artificial lighting scheduled, which was calculated in the previous daylight simulation for each case and began to calculate lighting, cooling and heating loads per hour for each case. Hence the consumption per year for each load is calculated to get the total energy used in each case as shown in Table 5-61.

The results of thermal analysis revealed that case 118 is the most efficient one in regards to saving energy and also it has the best daylight performance. Its total energy consumption per year is 142.38 KW/H while cases 119 and 141 are 145.11 and 150 KW/h respectively.

Table 5- 61: Energy consumption for top cases-(118, 119 and 141)

Case	Electric consumption per year- KW/h	Cooling consumption per year- KW/h	Heating consumption per year- KW/h	Total Energy consumption per year- KW/h
118	7.7	128.27	6.41	142.38
119	9.2	129.5	6.41	145.11
141	12	131.7	6.3	150

5.6. Conclusion

Grasshopper which is a plugin for Rhinoceros and a parametric modeling and optimization tool was used in this chapter to create a parametric lecture hall model and also to automate the simulation process. Besides using DIVA, which is a plugin for Rhino, to perform both daylighting and thermal simulations. These tools allow for annual simulation and point in time illuminance computation as well as measurement of glare probabilities based on the new IES daylighting standard (sDA, ASE and DGP). The first stage of the simulation concluded that north direction had high daylight performance with low ASE values and it didn't need any shading techniques. In contrast south, west and east orientations didn't reach any successful WWR and they need to be treated in order to control ASE. A lot of alternatives of three louver techniques (horizontal, vertical and aligned) were investigated to find the best cases for daylight performance in the three problematic orientations. Then a comparative analysis for daylighting and thermal simulation results was done for the three best cases in each technique to find the optimum solution of daylighting and energy consumption of the lecture hall. Following are the conclusions for the daylight performance of each orientation.

5.6.1. North Direction

The investigated hall got sufficient daylight at this orientation without need for any shading devices. The daylighting performance was enhanced gradually by increasing WWR to reach the acceptable limit on cases with WWR 30%. The high performance level started to be achieved from the case with WWR 45 %. Comparative analysis was done for the highest performing cases to get the best case for daylight performance and energy consumption which was found to be case 12 with WWR 70%. It achieved 100% sDA with 3% ASE and it consumed 96.66 KW/h as total energy consumption per year.

5.6.2. South Direction

The investigated hall didn't get any sufficient daylight at this orientation in the first stage. Therefore it was treated in the second stage by using three louver types to find the most efficient technique. Aligned redirected louvers and horizontal louvers were found to be the most effective shading systems of the three investigated systems for the south direction. Aligned redirected louvers enhanced the daylight performance and reach almost to the horizontal louver results but with small WWR which reduced the total energy consumption. In contrast using vertical louvers at this orientation was not effective.

5.6.2.1. Horizontal Louvers

Horizontal louvers enhanced the daylighting performance significantly in 38 cases from the investigated 66 cases. Especially by using large windows (from WWR 65% to 80%) with large louver count (from 10 to 15 louvers) because this configuration achieved high sDA with acceptable ASE performance and didn't override the ASE threshold limit. Case 46, with 75 % WWR and 12 slats, was found to be the most efficient case. It achieved 91% sDA with 4% ASE and it consumed 187.58 KW/H as total energy consumption per year.

5.6.2.2. Aligned Redirected Louvers

Aligned Redirected Louvers, which were used at WWR 65% with slats reflectance 50%, enhanced the daylighting performance in 20 cases from the 189 investigated cases. The aligned angles 0◦, 15◦ and -15 ◦ are the best three aligned angles at this orientation respectively. The tilting angles -15 ◦ and -30◦ have a good daylight performance in different aligned angles except 30◦ and 45 ◦ which they didn't achieve any accepted case. sDA and ASE values are reversely proportional to the decrease of louvers width in each tilting angle. Case 95, with slat width 0.25m, aligned angle 0 °, and tilting angle 0°, was found to be the most efficient one. It achieved 91% sDA and 7% ASE and it consumed 170.05 KW/H as total energy consumption per year.

5.6.3. West Direction

Similar to the south orientation, the investigated hall didn't get sufficient daylight at the west orientation in the first stage. Therefore it was treated in the second stage by using three louver types to get the sufficient technique. Simulation results revealed that horizontal and vertical louvers were not efficient at this orientation. They didn't succeed in getting sufficient daylight and there wasn't any accepted case with the LEED rating. Aligned Redirected Louvers, which were used at WWR 65% with slats reflectance 50%, enhanced the daylighting performance in 16 cases from the 189 investigated cases. The acceptable configurations were achieved when the positive aligned angles were used with negative tilting angles and large slats width. In contrast the worst performance achieved when positive aligned angles were used with positive tilting angles because they increased ASE values more than 10 which is not acceptable. Case 90, with slat width 0.65m, aligned angle 0 °, and tilting angle -15°, was found to be the most efficient one. It achieved 88% sDA and 9% ASE and it consumed 187.24 KW/H for total energy consumption per year.

5.6.4. East Direction

Similar to south and west orientations, the investigated hall didn't get sufficient daylight in this orientation in the first stage. Therefore it was treated in the second stage by using three louver types to get the sufficient technique. Similar to the east direction, horizontal and vertical louvers didn't succeed in getting sufficient daylight and there wasn't any accepted case on the LEED rating. Aligned Redirected Louvers, which were used at WWR 65% with slats reflectance 50%, enhanced the daylighting performance in 11 cases from the 189 investigated cases. The negative aligned angles didn't achieve good performance due to high ASE values, while the positive aligned angles had some accepted cases on -30 and -15 tilting angles. Case 118, with slat width 0.45m, aligned angle 15°, and tilting angle 0-15°, was found to be the most efficient one. It achieved 70% sDA and 9% ASE and it consumed 142.38 KW/H for total energy consumption per year.

1. Conclusion

This thesis discussed the role of smart architecture techniques in improving the optical environment in learning spacing in university. Therefore a brief study for intelligent buildings and systems were discussed to study its effect on both universities environment and lighting design process. Intelligent and smart buildings became a turning point in architecture and construction fields, parallel to advancements in envelope engineering, building science , and Information and communications technology (ICT).Therefore various intelligent buildings have been developed with most advanced technologies and techniques to develop high performing buildings in Smart cities. AT the same time, concept of traditional classrooms at universities has been changed nowadays to be ‘smart’ Learning spaces which correspond to the needs of our smart building era. Nowadays, students prefer to interact with information and receive near-instantaneous responses, so they need different learning environment which engages them in active learning and collaboration. Lately, learning process may be occurred in different physical environment whether classroom spaces as formal learning or by serendipitous interactions among individuals as informal learning. Smart university is a new trend nowadays to accommodate these students’ needs. It should be created in order to maintain the highest value and comfort at the lowest environmental cost with implementation of intelligent technologies and processes, as well as the “green” results, able to accommodate some level of adaptation and reconfiguration without exorbitant expense or structural modification. Whenever possible it could accommodate an addition or additions over time.

Different classifications of university learning spaces had been illustrated with their significant requirements of size, furniture and also the type of technology that should be used in each one. According to that Group Teaching/Learning spaces, which consist basically of classrooms and teaching halls, were found to be the main spaces for formal learning process at the university. It represents around 10-25% from total university space and more than 40% of learning spaces areas, so it had been chosen to study its visual environment requirements and investigate lighting performance. The critical factors affecting lighting system design in the three different types of university Group Teaching/Learning spaces are explained and followings are the main criteria for each type:

(a) Small Classrooms

They usually have a simple lighting system with movable seats and tables oriented so that students and instructors can easily interact with each other. They do not have special-purpose equipment and power socket points for student use that would make the room unsuitable for multiple disciplines. Because the room size is small, lighting zoning may not be ideal. But the projection image and light switches can be managed quite easily.

(b) Medium-size Lecture Rooms

These rooms typically have a multi-media AV system, with movable seats oriented towards the front of the room, and writing surfaces for each student. They do not have special-purpose equipment for student use. Because they are larger in size, it is easier to define the zoning for the lighting system. These rooms require a good design in lighting control and viewing positions since there would be a few door entrances and the back of the classroom may be quite far away from the board or projection screen.

(c) Auditoriums

They usually have fixed seating, work surfaces and tilted floor, with seats normally arranged in a gentle arc to enhance the viewing angles. A lecture theatre or auditorium is often equipped with sophisticated multi-media AV system (such as the room CYC-A in our study).Because of the size and shape, the lighting zones and controls will be more complicated. Lighting controls is often located to the instructor station and have few options: full-on, 2 or 3 projection settings, and full-off. Dimmable directional down lights are used to allow adjustment of the lighting level for the work surface.

Smart systems enhance lighting environment inside learning space. BEMS, which is a sub system of Environmental Control Systems, and Lighting Management Systems (LMS), are the two main systems which are responsible for efficient and smart lighting design process at Building Management System. Several lighting control strategies were studied besides the smart shading strategies to get the efficient strategy to be used inside group learning teaching spaces. Daylight harvesting strategy, which is one from LMS strategies , was found the best control system could be used in learning spaces, its savings potential varies from 20% (daylight-harvesting alone) to more than 50% (daylight harvesting plus real occupancy).

Smart Architecture techniques changed lighting design process completely. The research explored a methodology for integrating computational methods and performance simulation tools to ensure its ability to provide performativity solutions at the early design stages. The presented methodology can be applied in other cases with different characteristics to obtain high daylighting performance on learning spaces .The simulation results revealed that the investigated hall got sufficient daylight in north orientation without needing for any shading devices. The daylighting performance was enhanced gradually by increasing WWR to reach the acceptance limit on case with WWR 30%.In contrast the other orientation didn't get sufficient daylight and they need to be treated with shading devices . In universities it is preferable to install blinds or louvers in learning spaces' windows because they can control glare, redirect daylight and guide lighting into the space. Therefore three louvers types were studied as sun breaker and redirecting system to provide guidelines and recommendations for using fixed daylighting systems in learning spaces. Though the research was limited to a specific climate zone, space type and dimensions, some of the results could be generalized in the design of similar spaces and context like classrooms or auditoriums.

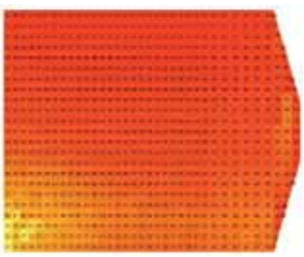
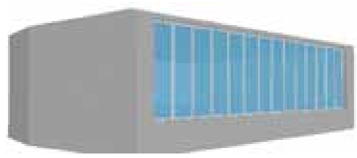
2. Shading Systems Guidelines

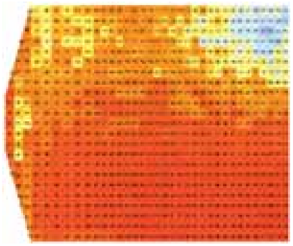
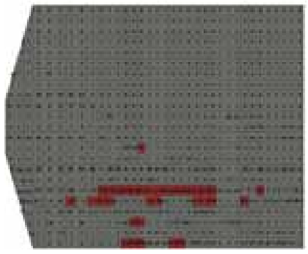
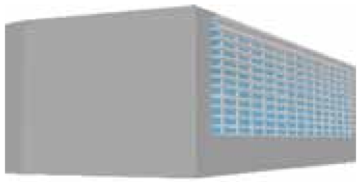
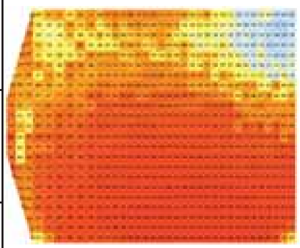
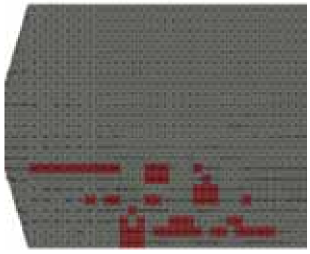
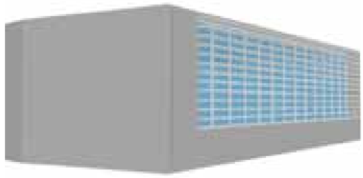
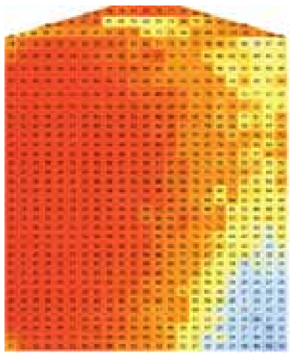
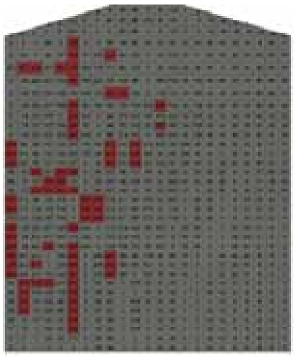
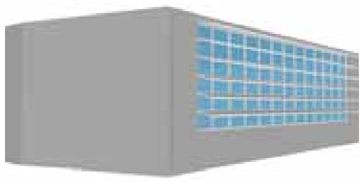
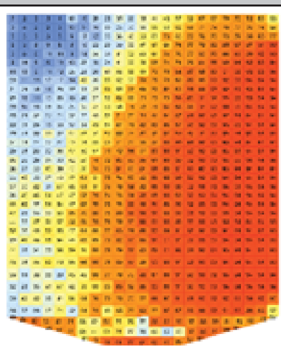
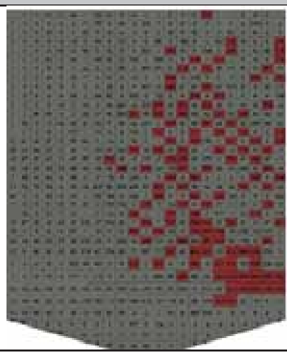
Horizontal louvers were used as sun breakers shading system in the three problematic orientations. They were effective in only in South orientation. The large windows (from WWR 65% to 80%) had better daylight performance when large louver count (from 10 to 15 louvers) was used and provided visual comfort as well. The best performance achieved in South orientation was a "high" daylighting performance .It achieved 91% sDA with 4% ASE and it consumed 187.58 KW/H as total energy consumption per year. Table 1 illustrates recommended settings for the use of Horizontal louvers on south orientation with analysis for its daylight and energy performance.

Using vertical louvers weren’t effective on the three problematic orientations. Regardless, increasing the number of slates or rotating them with different tilting angles. The ASE values were very high and almost all of them override the threshold limit of 10 ASE. Therefore, it is not recommended to use vertical louvers in that case. Moreover, despite the common belief in the effectiveness of vertical louvers in East/West orientation, it failed in preventing the high intense rays of Cairo's sun for the case tested in this thesis. Vertical louvers were unable to reduce the ASE values.

Aligned redirected louvers proved to be very useful in the three problematic orientations. Several configurations achieved acceptable performance in each direction. The daylighting performance was enhanced significantly in several cases and reached three points on LEED V4 rating system in South and West orientations and acceptable but with only two points on LEED v4 in East. Reflecting louvers were found to be more effective when the louvers were tilted downwards at this position louvers had similar shading effect to the horizontal sun breakers. Table 1 illustrates recommended configuration for the use of aligned reflected louvers in the three orientations with analysis for its daylight and energy performance.

Table 1: Best cases by using horizontal, vertical and aligned louvers in all directions

North Direction					
The investigated hall got sufficient daylight in large WWR and it didn’t need any shading devices					
T/Case	**V**	**P**	**Grid**		**3D**
WWR Investigation Case 12 Rate:3 points on LEED	**WWR :70 %** W=14m-H=3.55m	sDA 100%			
		ASE 3%			
		Energy 96.66			
South Direction					
The investigated hall had successful cases, which get sufficient daylight according IES and LEED V4, by using each of horizontal and aligned louvers and didn’t get any accepted case by using vertical louvers					

Horizontal louvers Case 46 Rate:3 points on LEED	**WWR:70%** Louver Reflectance: 30% 12 louver slat –slat w=0.25	sDA 91% ASE 4% Energy 187.58			
Aligned Louvers Case 95 Rate:3 points on LEED	**WWR:65%** Louver Reflectance 50% slat w=0.25 -Aligned angle 0- tilting angle 0	sDA 91% ASE 7% Energy 170.05			
West Direction					
The investigated hall had successful cases, which get sufficient daylight according IES and LEED V4, by using aligned redirected louvers and didn't get any accepted case by using horizontal or vertical louvers					
Aligned Louvers Case 90 Rate:3 points on LEED	**WWR:65%** Louver Reflectance 50% slat w=0.65-Aligned angle 0 tilting angle -15	sDA 88% ASE 9% Energy 187.24			
East Direction					
The investigated hall had successful cases, which get sufficient daylight according IES and LEED V4, by using aligned redirected louvers and didn't get accepted case by using horizontal or vertical louvers					
Aligned Louvers Case 118 Rate:2 points on LEED	**WWR:65%** Louver Reflectance 50% slat w=0.45-Aligned angle 15 tilting angle -15	sDA 70% ASE 9% Energy 142.38			
Key	Colors				
	Abbreviations	**T**:Technique **V**:variables **P:**performance			

3. Recommendations

The findings of this thesis highlight the importance of studying general lighting design criteria which are used inside smart learning spaces. For new classrooms, it is necessary to coordinate the architectural and interior designs with daylighting and artificial lighting so that optimal performance can be achieved. For existing classrooms, there is a need to re-examine their lighting systems to identify energy saving measures and promote good practices in lighting control and operation. It is believed that better lighting can be obtained by considering the needs of end-users and development of teaching pedagogy.

The main key aspects for designing efficient lighting environment for learning spaces are:

- Design daylighting into all occupied zones adjacent to an exterior wall.
- Provide for integral glare mitigation techniques in the initial design.
- Provide automatic, continuously dimming, daylighting controls for all daylit zones.
- Design interiors to maximize daylighting distribution.
- Integrate the electric lights with the daylighting system.
- Commission and verify post occupancy energy savings.

Summary of recommendations to resolve some common problems for learning space lighting is given below:

1. **Avoid light that creates glare or reflections on screens:**
   - Use indirect natural and artificial lighting.
   - Use indirect or parabolic fluorescent lights that can reduce the risk of glare.
   - Avoid placing lights behind instructor workstations.
2. **Enhance the ability to see projected images and read lecture notes:**
   - Lighting configuration and control optimized to suit presentation and projection needs.
   - Light levels at the front of the room require special attention to avoid washing out projected images.
   - Task light for instructor workstations that avoid light spillover to screens/monitors.
   - Lights focused on marker boards that do not wash out screen images.
3. **Increase energy efficiency by using:**
   - Lighting controls that automatically turn off lights in vacant rooms.
   - Energy-efficient dimmable lighting for seating areas.
   - Lighting zones and levels appropriate for the classroom.
   - Daylighting harvesting strategies as far as possible.

This thesis also highlights the importance of using smart systems and parametric simulation tools in design as each technique was found to perform differently according to its parameters. Considering and testing these parameters makes a real difference in the overall performance. The thesis also provides a comparison between the different techniques and the usability of each of them. Finally, the results show the promising future of using computational methods along with simulation tools. It paves the way for more research in the area of building performance and its relation with the design of the building.

4. Future Work

The research can be extended in several ways.

- Other university spaces can be studied to define its visual environment needs.
- Acoustics and thermal environment can be studied in university spaces.
- The results of this research can be investigated and compare its performance for other environmental aspects such as: Thermal comfort, Natural ventilation, Structure aspects and Life cycle cost.
- Moreover, investigating the use of dynamic and kinetic systems for more adaptive solutions and comparing the feasibility of dynamic systems and fixed systems may give a better guide for designing even more performativity facades.
- Finally, verification of the results of this study by real life measurements can strengthen the thesis recommendations.

➢ Appendix A : The Smart City Outline

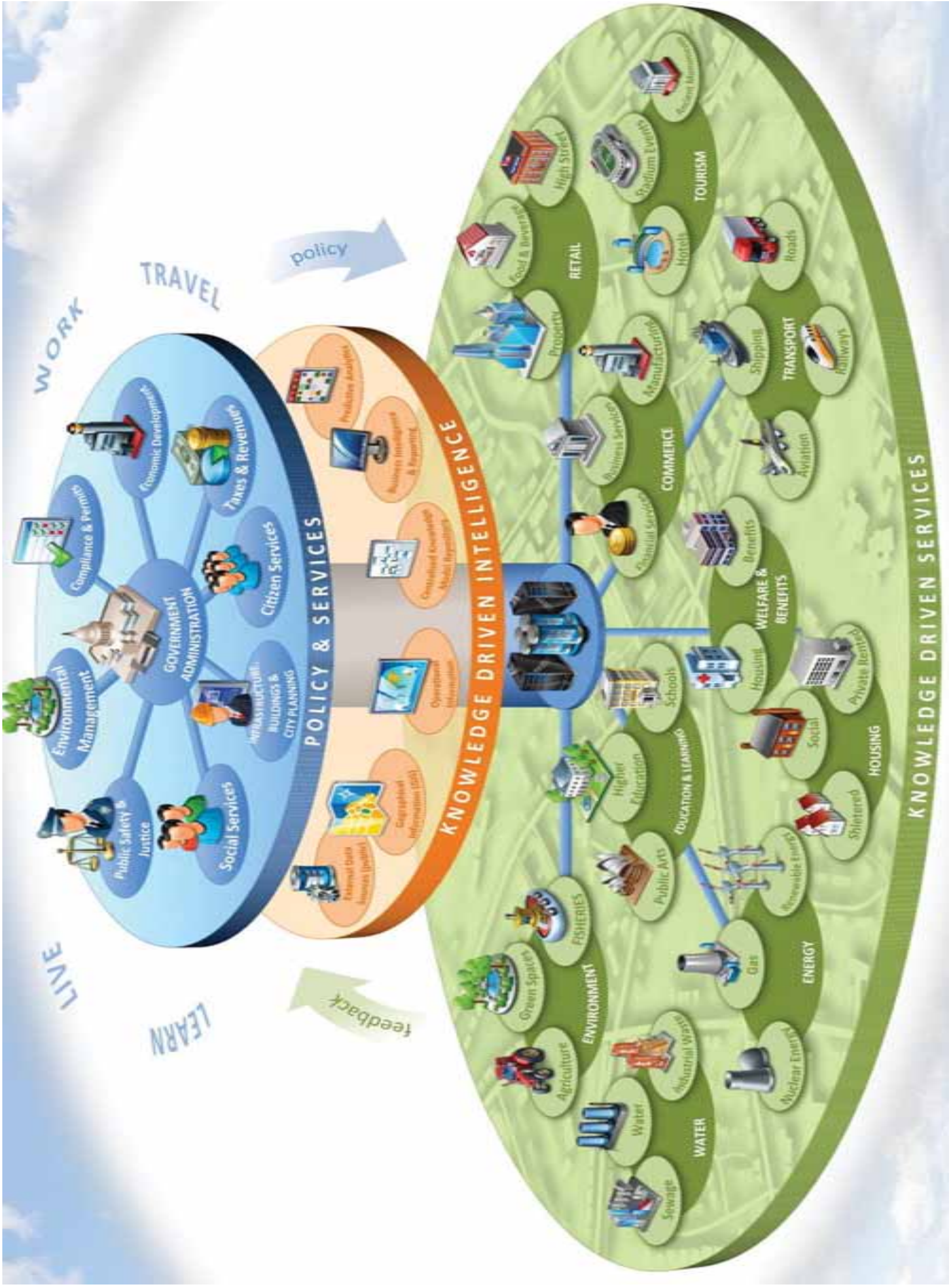


Figure A- 1: The outline for Intelligent City of the Future
Source: http://www.beinformed.com/BeInformed/website/en/EN/IntelligentCities?init=true

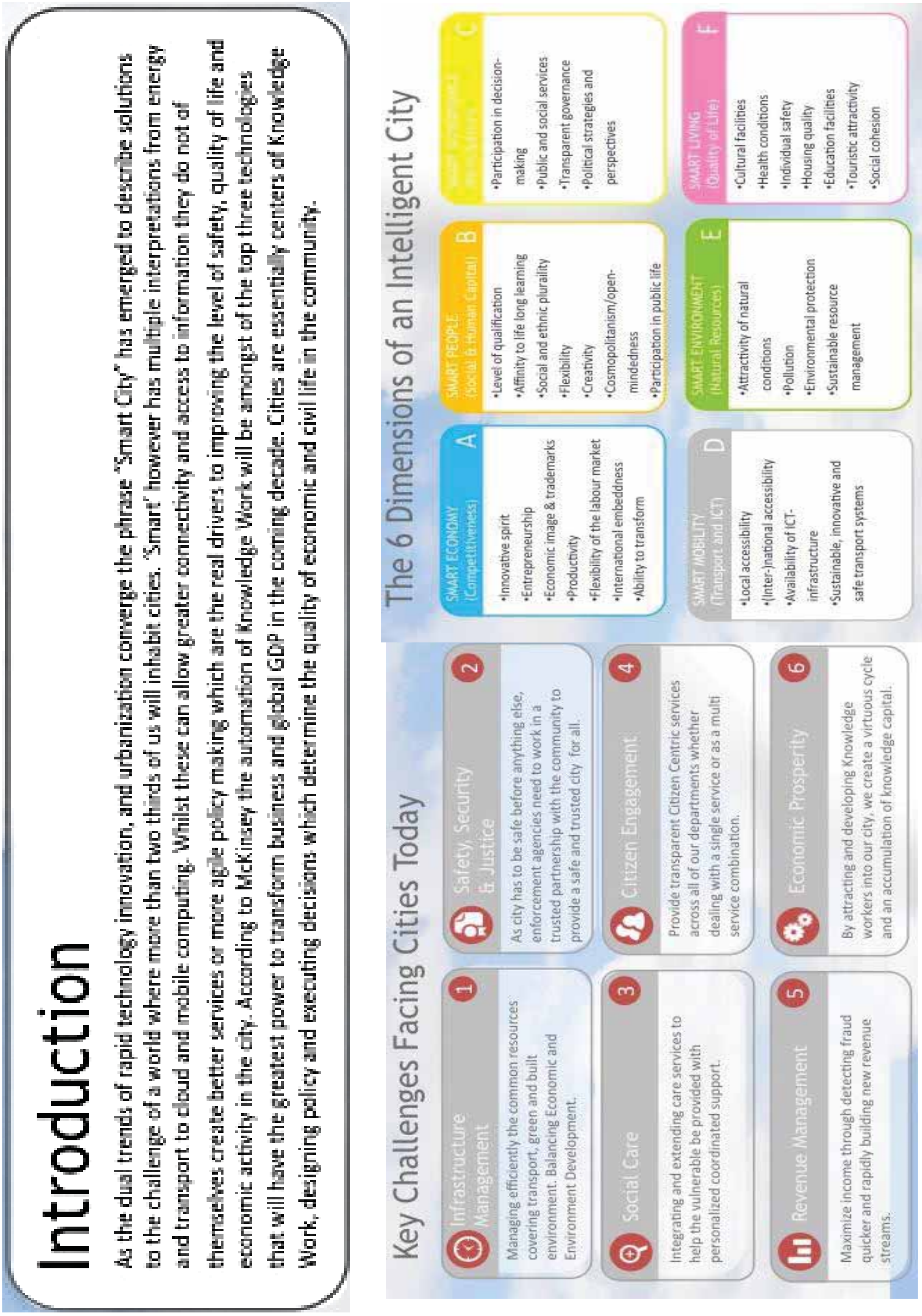


Figure A- 2 : The Main creiteria for Intelligent City of the Future
Source: http://www.beinformed.com/BeInformed/website/en/EN/IntelligentCities?init=true

➢ Appendix C: The Main Issues for Learning Spaces Lamps Type

Lamp type		Designations and dimensions	Efficacy (lumens/ lamp watt)	Lamp life (hours)	Control gear required	Colour rendering Ra/colour temperature (K)/colour appearance	Lamp start-up/ lamp re-strike	Dimming possible	Linking with lighting control
Tubular fluorescent	Linear	T5 (Ø16mm)  288mm-1449mm	88-104	10000-15000	Yes	50-98/ 2700-6000/ warm to cold	1-3 seconds	Yes	Yes
Tubular fluorescent	Linear	T8 (Ø26mm)  590mm-1764mm	88-100	10000-15000	Yes	50-98/ 2700-6000/ warm to cold	1-3 seconds	Yes	Yes
Tubular fluorescent	Circular	T5C (Ø16mm)  Ø225mm-Ø375mm	60-80	5000-8000	Yes	50-98/ 2700-6000/ warm to cold	1-3 seconds	Yes	Yes
Compact fluorescent	External control gear Internal control gear	 Various	50-85	10000	Yes No	82-98/ 2700-4000/ warm to intermediate-cold	1-3 seconds	Yes	Yes
Metal Halide	Various shapes	 Various	70-100	6000-20000	Yes	60-93/ 3000-10000/ warm to cold	3-6 minutes	No	No
High pressure sodium	Various shapes	 Various	65-140	9000-28500	Yes	25-80/ 2000-3000/ warm	3-6 minutes	No	No

Figure C- 1: The Main Issues for Learning Spaces Lamps Type
Source: Standard Specifications Layouts and Dimensions- Lighting in Schools, p. 15

➢ Appendix D: The Simulation Software Settings and Inputs

1. Materials Selection on Diva Rhino (the same for Diva Grasshopper)

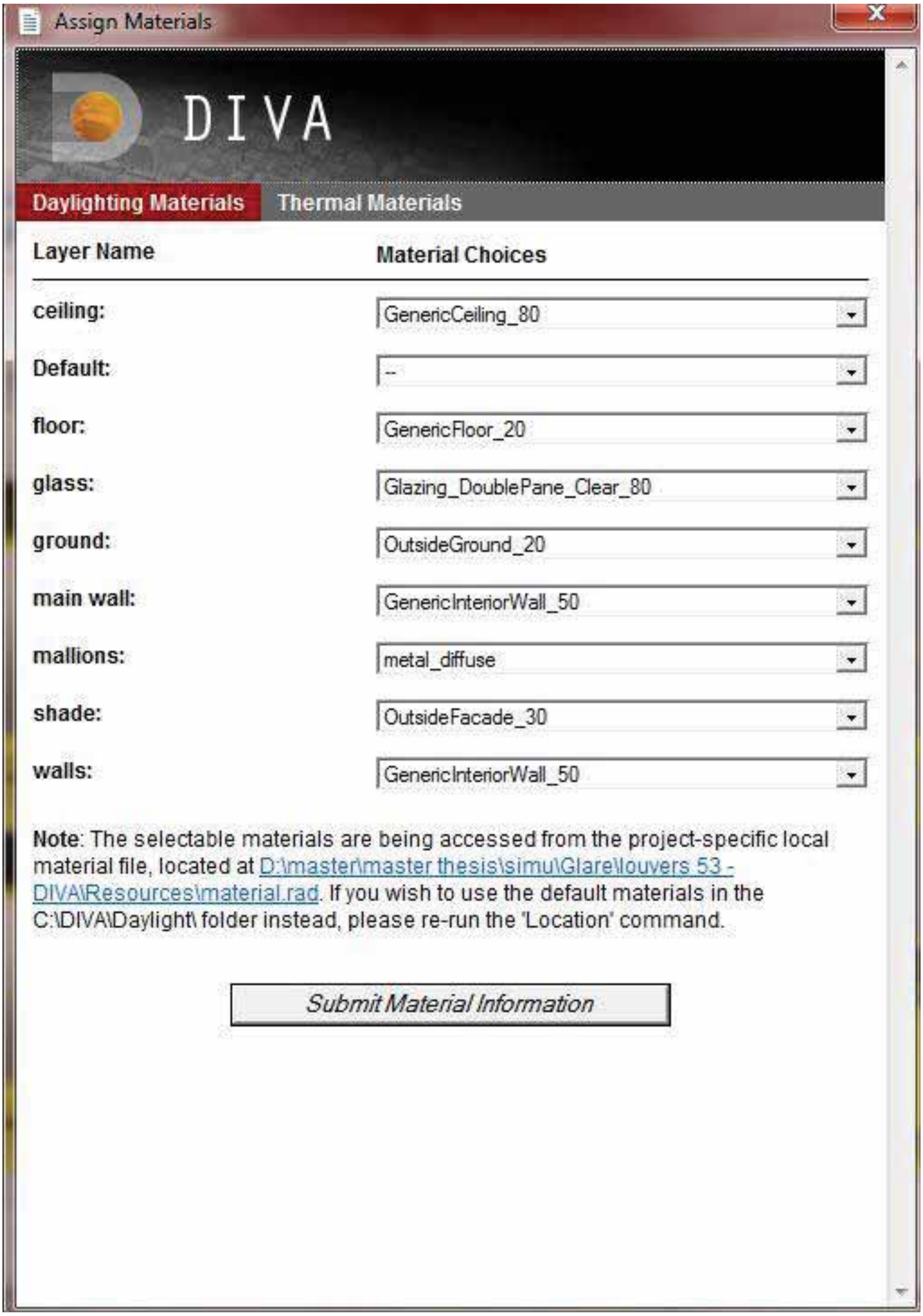


Figure D- 1: Materials selection interface showing the selected materials

2. Daylight Analysis on Diva Grasshopper

2.1. Diva Component for CBDM (used for sDA Calculation)

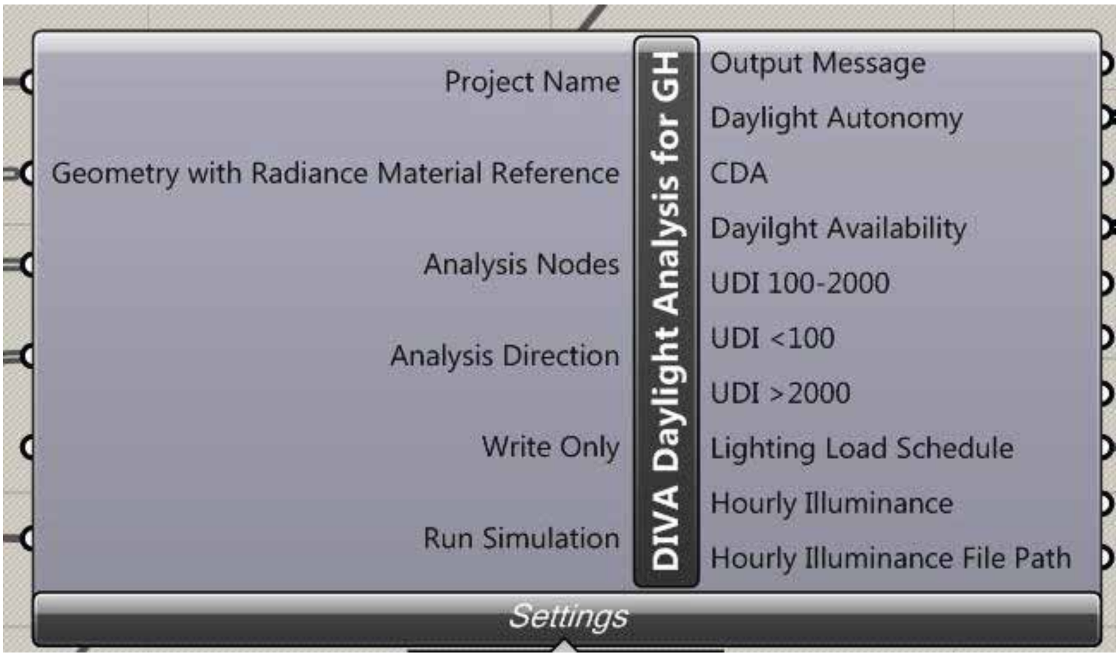


Figure D- 2: Interface of Diva for grasshopper component for CBDM and sDA Calculations

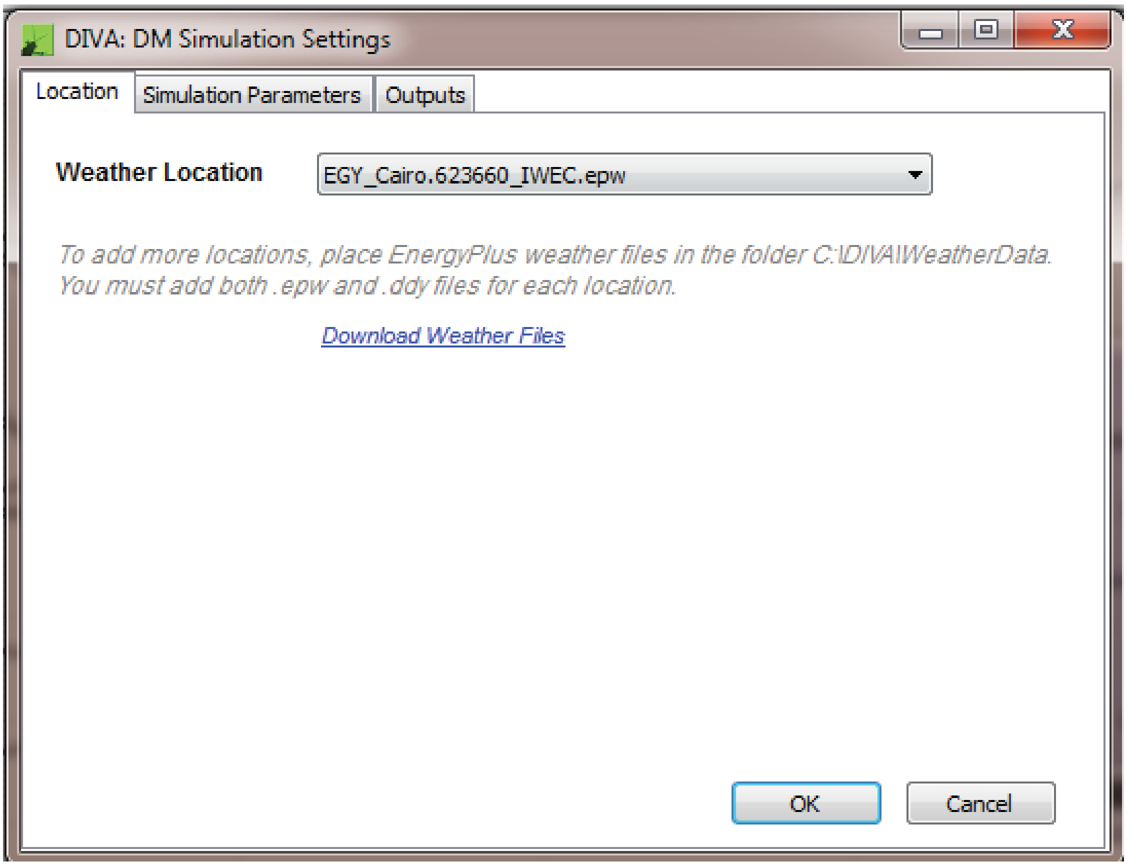


Figure D- 3: Diva for Grasshopper location settings-Cairo Egypt

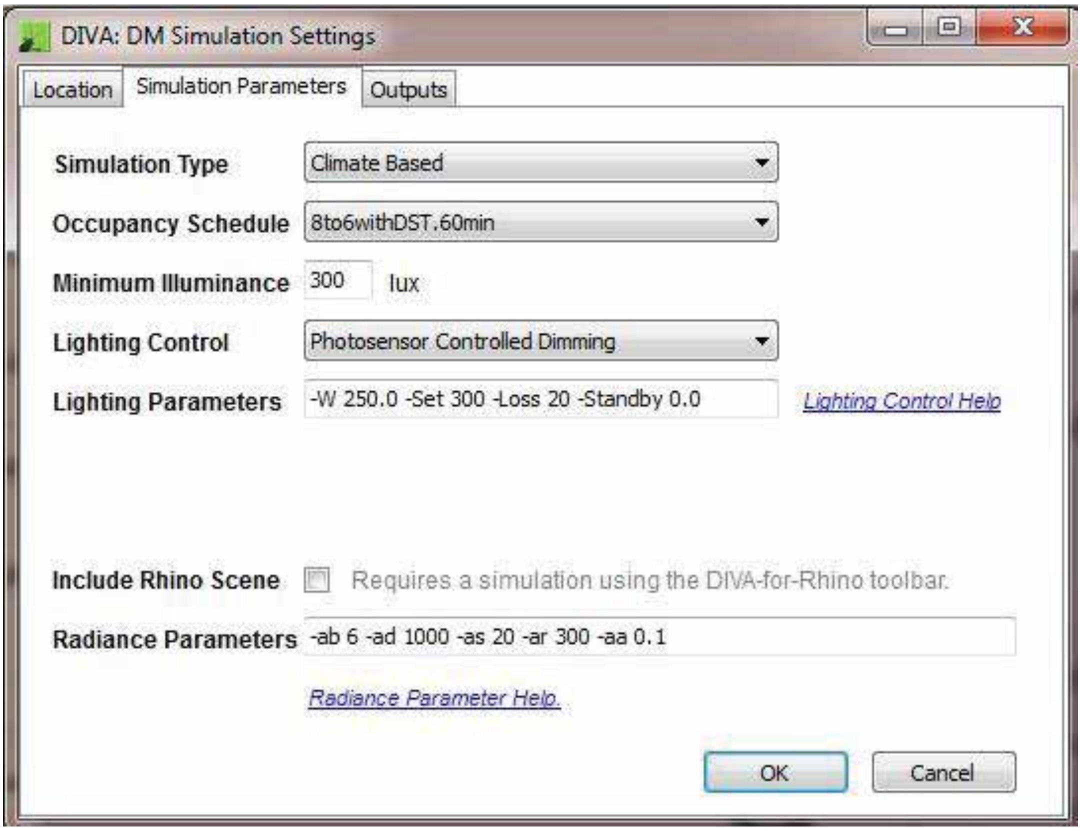


Figure D- 4: Diva for Grasshopper simulation parameters settings-CBDM component

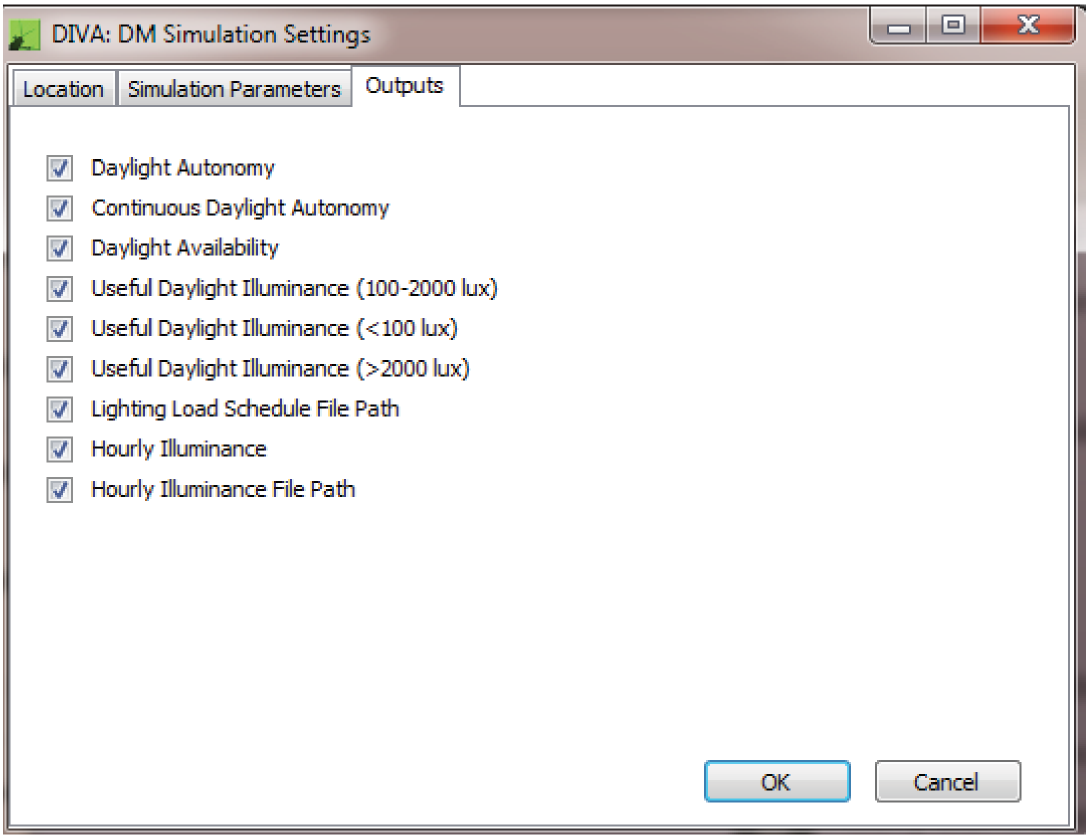


Figure D- 5: Diva for Grasshopper simulation outputs - CBDM component

2.2.Diva Component for SPT and ASE Calculations

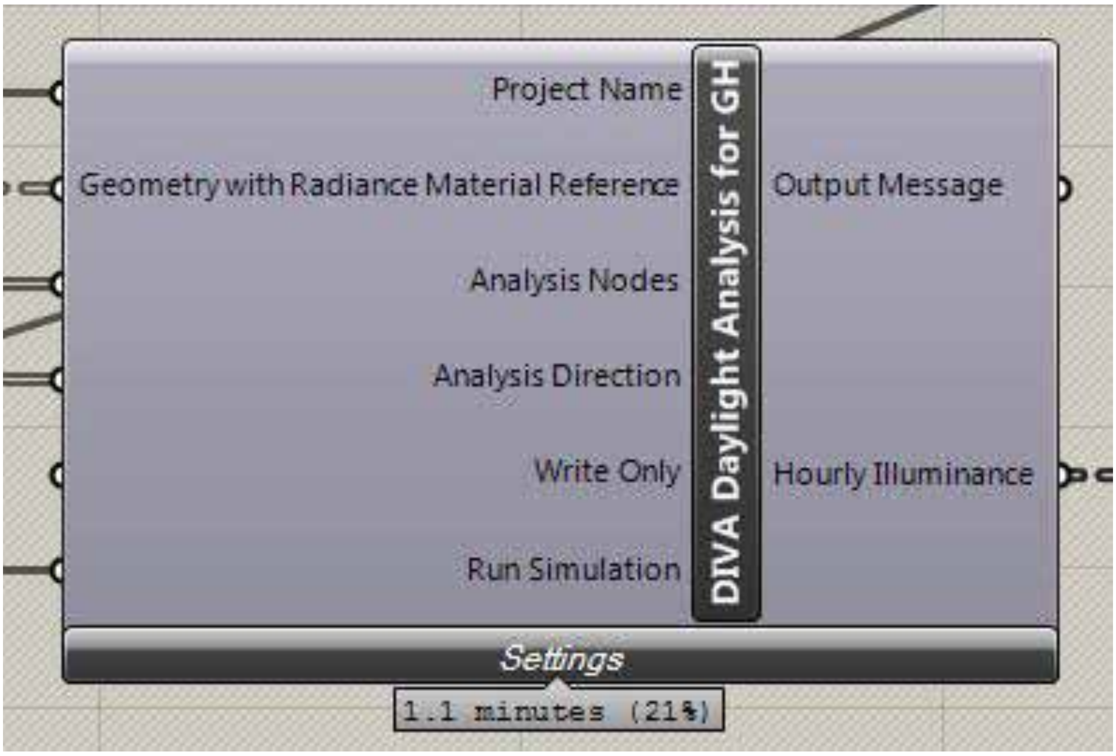


Figure D- 6: Interface of Diva for grasshopper component for SPT and ASE calculations

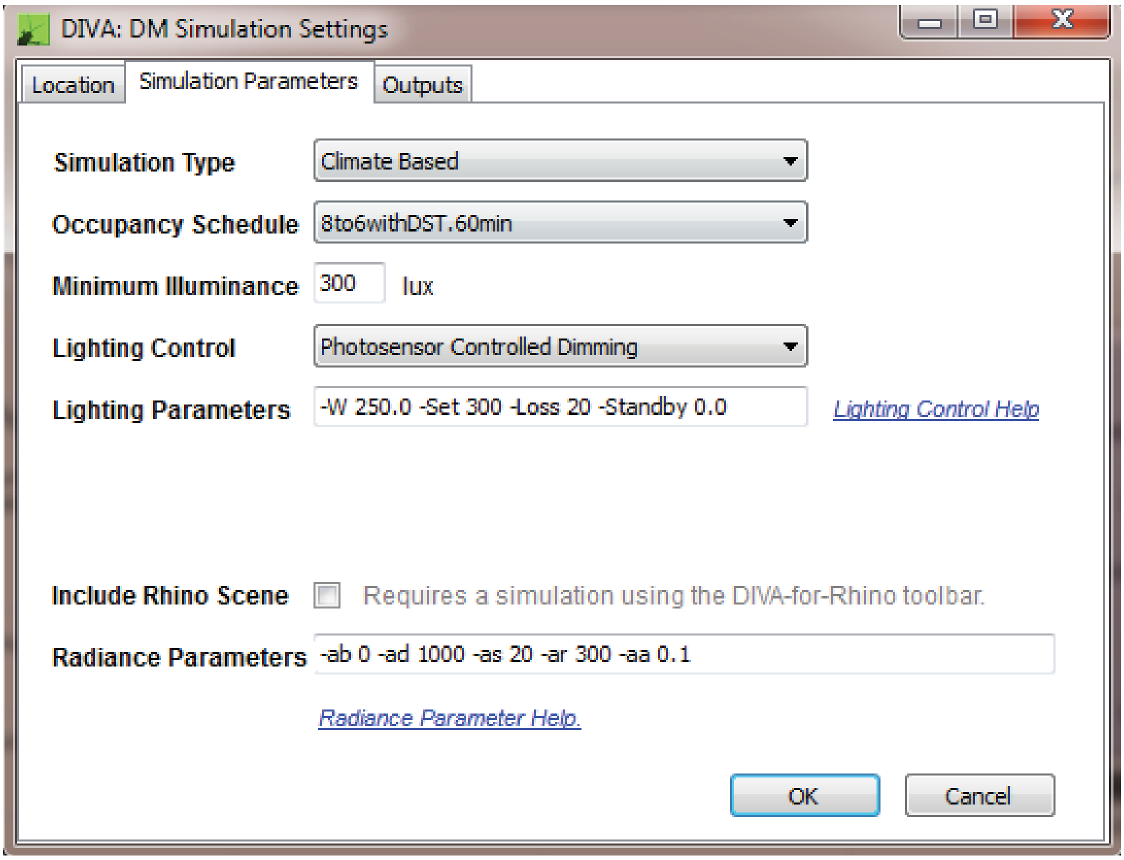


Figure D- 7: Diva for Grasshopper simulation parameters settings-ASE component

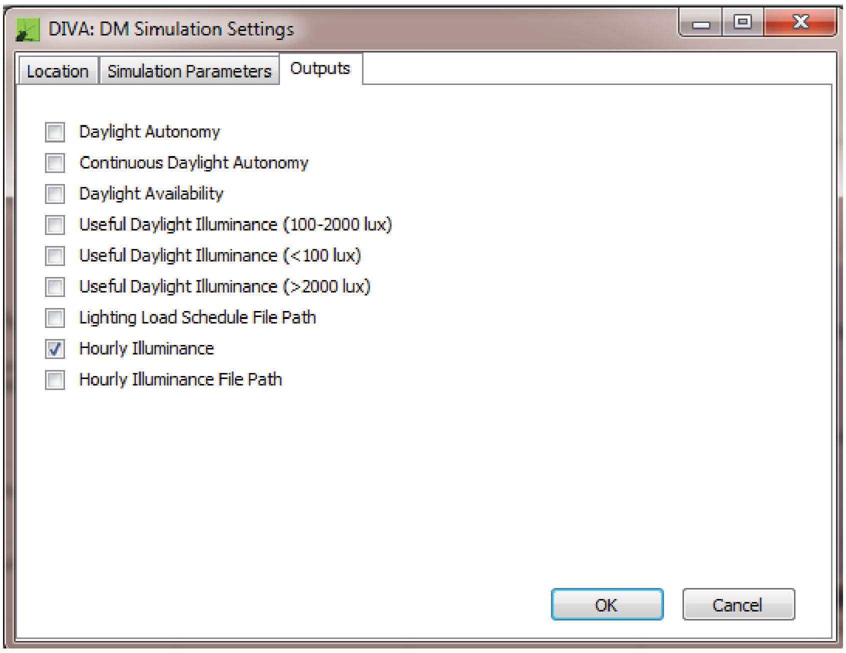


Figure D- 8: Diva for Grasshopper simulation outputs - ASE component

2.3.Diva for Rhino Glare component – DGP calculations

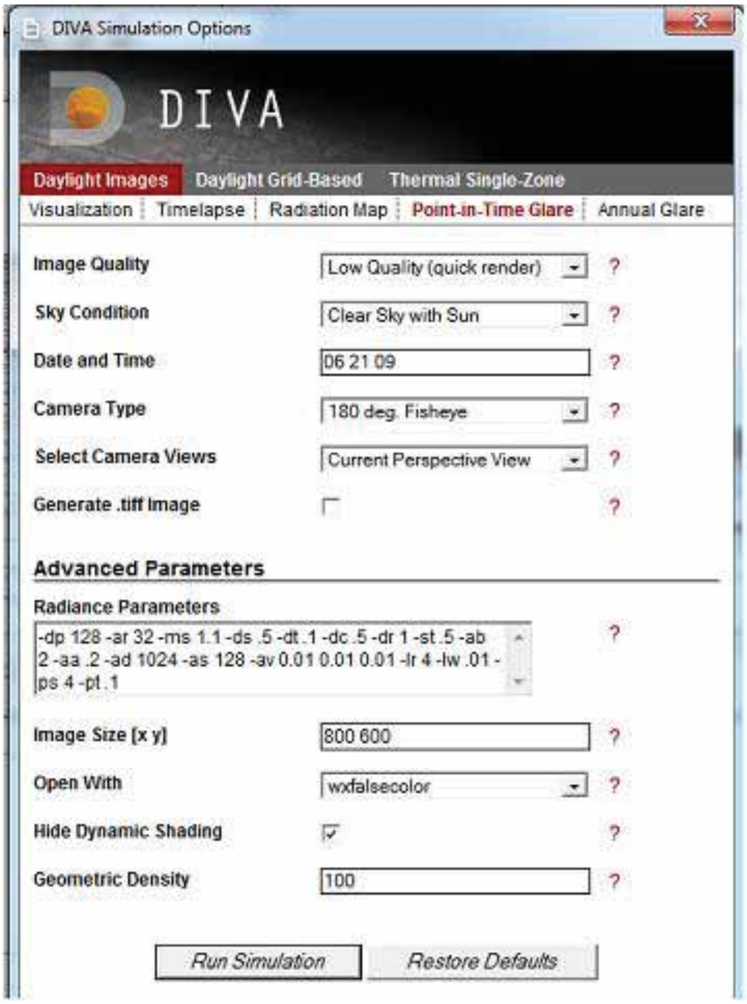


Figure D- 9: Diva for Rhino simulation –Point in time glare simulation parameters

3. Thermal Analysis on Diva Grasshopper

Figure D- 10: Interface of Diva for grasshopper component for Thermal Analysis

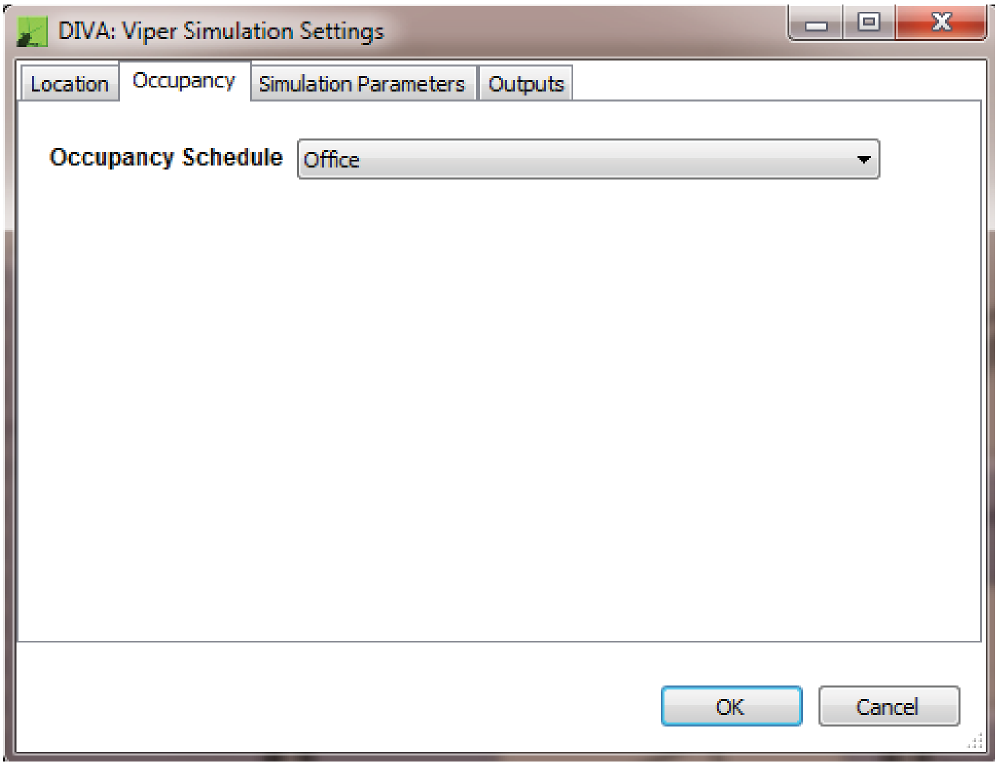


Figure D- 11: Diva for grasshopper thermal component occupancy settings

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تقنيات العمارة الذكية
فى معالجة البيئة الضوئية
بالفراغات الجامعية

رسالة مقدمة من
م/ نوران عادل عوض الكيكى
بكالوريوس الهندسة المعمارية – جامعة عين شمس 2010

كجزء من متطلبات الحصول على درجة
ماجيستير العلوم في الهندسة المعمارية

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جامعة عين شمس
القاهرة - مصر
2015

إقرار

هذه الرسالة مقدمة فى جامعة عين شمس للحصول على درجة الماجستير فى الهندسة المعمارية بقسم العمارة .

إن العمل الذى تحتويه هذه الرسالة تم إنجازهبمعرفة الباحثة فى قسنم العمارة بكلية الهندسة جامعة عين شمس فى الفترة الواقعه بين 2010 – 2015 م.

هذا ولم يتقدم بأى جزء من هذا البحث لنيل أى مؤهل أو درجة علمية لأى كلية أو معهد علمى أخر .

وهذا إقرار من بذلك....

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عنوان الرسالة : **"تقنيات العمارة الذكية فى معالجة البيئة الضوئية بالفراغات الجامعية"**
الدرجه العلمية :**ماجستير العلوم الهندسية**

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موافقة مجلس الكلية: / / موافقة مجلس الجامعة: / /

بسم الله الرحمن الرحيم

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ ﴿1﴾ خَلَقَ الْإِنسَانَ مِنْ عَلَقٍ ﴿2﴾ اقْرَأْ وَرَبُّكَ الْأَكْرَمُ ﴿3﴾ الَّذِي عَلَّمَ بِالْقَلَمِ ﴿4﴾ عَلَّمَ الْإِنسَانَ مَا لَمْ يَعْلَمْ﴿5﴾

عَنْ كَثِيرِ بْنِ قَيْسٍ قَالَ: " كُنْتُ جَالِسًا مَعَ أَبِى الدَّرْدَاءِ فِى مَسْجِدِ دِمَشْقَ فَجَاءَهُ رَجُلٌ فَقَالَ يَا أَبَا الدَّرْدَاءِ إِنِّى جِئْتُكَ مِنْ مَدِينَةِ الرَّسُولِ صلى الله عليه وسلم لِحَدِيثٍ بَلَغَنِى أَنَّكَ تُحَدِّثُهُ عَنْ رَسُولِ اللَّهِ صلى الله عليه وسلم مَا جِئْتُ لِحَاجَةٍ. قَالَ فَإِنِّى سَمِعْتُ رَسُولَ اللَّهِ صلى الله عليه وسلم يَقُولُ :

"مَنْ سَلَكَ طَرِيقًا يَطْلُبُ فِيهِ عِلْمًا سَلَكَ اللَّهُ بِهِ طَرِيقًا مِنْ طُرُقِ الْجَنَّةِ وَإِنَّ الْمَلاَئِكَةَ لَتَضَعُ أَجْنِحَتَهَا رِضًا لِطَالِبِ الْعِلْمِ وَإِنَّ الْعَالِمَ لَيَسْتَغْفِرُ لَهُ مَنْ فِى السَّمَوَاتِ وَمَنْ فِى الأَرْضِ وَالْحِيتَانُ فِى جَوْفِ الْمَاءِ وَإِنَّ فَضْلَ الْعَالِمِ عَلَى الْعَابِدِ كَفَضْلِ الْقَمَرِ لَيْلَةَ الْبَدْرِ عَلَى سَائِرِ الْكَوَاكِبِ وَإِنَّ الْعُلَمَاءَ وَرَثَةُ الأَنْبِيَاءِ وَإِنَّ الأَنْبِيَاءَ لَمْ يُوَرِّثُوا دِينَارًا وَلاَ دِرْهَمًا وَرَّثُوا الْعِلْمَ فَمَنْ أَخَذَهُ أَخَذَ بِحَظٍّ وَافِرٍ."

رواه الترمذي (2682) واللفظ له وعزاه في التحفة لأحمد (2/ 252، 325) من حديث أبي هريرة، والدارمي (3/ 381) النسـخة الهندية ، وأبو داود (3641). وذكره الألباني في صـحيح أبي داود: (2/ 694) برقم (096- 3) وقال: صحيح. وقال محقق «جامع الأصول» (8/ 6): إسناده حسن.

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الملخص

شهدت الأونة الأخيرة تطور غير مسبوق فى وسائل التكنولوجيا والعمارة الحديثة أدت إالى تحول العالم إلى عالم ذكى إفتراضى مكون من مبانى إدارية وتعليمية وخدمية ذكية متكاملة ، لذا أصبح من اللازم إنشاء جامعات ذكية كنموذجاً حديثاً للمؤسسات التعليمية المترابطة. و من المعروف أن التعليم هو النشاط الرئيسي في الجامعات لذلك ينبغى التركيز على إنشاء فصول دراسية تتوافق مع المتطلبات التكنولوجية الحديثة. و نتيجه لذلك تم تغيير مفهوم الفصول الدراسية التقليدية بالجامعات الآن لتصبح فراغات تعليمية ذكية متلائمة مع إحتياجات عصرنا الذكى. هذه الفراغات الذكية لا تحتوي على مقاعد وطاولات وسبورات فحسب، ولكنها أيضا تحتوى على العديد من المعدات ووسائل العرض السمعية والبصرية . بالتالى أثر هذا التطور التكنولوجى على الإحتياجات البصرية فى الفراغات التعليمية ، وبما أن الهدف الرئيسي من تصميم الفراغات التعليمية ليس فقط التعليم بل ايضاً توفير بيئة بصرية جيدة لجميع المستخدمين بما في ذلك الطلاب والمعلمين. لذا فإن جودة البيئة البصرية ومكافحة مشاكل الإضاءة و السطوع خاصة للطلاب عندما ينظروا إلي شاشات العرض أصبحت قضية حرجة الآن. ومنذ ذلك الوقت اصبح التصميم الذكي للفراغات التعليمية له تأثيراً كبيراً على نظام الإضاءة والبيئة البصرية بداخلها من أجل استيعاب التوجهات المستقبلية لفراغات التعليم الجامعي.

أثبتت العديد من الدراسات الأثر الإيجابي للضوء الطبيعى ومدى تأثيره على جودة البيئة التعليمية وتحسين أداء الطالب وإدارة الطاقة بها. و من ثم أصبح توفير الإضاءة الطبيعية في الفراغات التعليمية أمراً حاسماً ليس فقط للجامعة ولكن ايضاً لجميع المؤسسات التعليمية الأخرى. لذلك يتم إستخدام التقنيات الذكية ونظام الإضاءة المتكامل الذى يدعم دمج الإضاءة الطبيعية مع الإضاءة الصناعية ليساهم بشكل إيجابي في تحقيق فراغات تعليمية جيدة وفعالة. في الوقت الحاضر و بفضل العمارة الذكية تغيرت تقنيات تصميم الإضاءة نتيجة ظهورالكثير من أدوات المحاكاة اصبح من السهل التحقق من البدائل التصميمية المختلفة من أجل الحصول على أفضل بديل والوصول للحل الأمثل.

تتناول هذه الأطروحة أثر استخدام التقنيات الذكية للعمارة فى تحسين ومعالجة البيئة البصرية للفراغات التعليمية بالجامعات وتتكون الرسالة من أربعة أجزاء وتنتهي إلى الاستنتاجات والتوصيات. الجزء الأول (الفصل الأول والثاني) يناقش تطور التكنولوجيا والتقنيات الذكية، ومدى تأثيرها على مفاهيم المباني وخاصة الجامعات والفراغات التعليمية وتغييرها من فراغات ومبانى تقليدية إلى فراغات ومباني ذكية مع أنظمة متكاملة، كما يتناول أيضا هذا الجزء تصنيف الفراغات التعليمية الحديثة وتوضيح لتحديد اكثرهم شيوعا وتأثيرا على العملية التعليمية وهو فراغات التدريس / التعلم للمجموعات التى تتكون بشكل رئيسى من الفصول والقاعات الدراسية وتمثل تقريباً 10-25٪ من مساحة الجامعة الكلية وأكثر من 40٪ من اجمالى مساحة الفراغات التعليمية. يناقش الجزء الثانى مكونات البيئة البصرية ومدى تأثيرها على الطالب والعملية التعليمية كما يستعرض ايضا إستراتيجية لتصميم البيئة البصرية لفراغات التدريس / التعلم للمجموعات والتى تشمل تحديد المعايير الرئيسية للإضاءة المطلوبة داخل الفراغات التعليمية بالجامعات وفقا لمنظمات الإضاء والطاقة العالمية (الفصل الثالث). ينااقش الجزء الثالث (الفصل الرابع) كيفية استخدام النظم والتقنيات الذكية لتحسين البيئة البصرية في االفراغات التعليمية ويستعرض أنظمة التحكم فى الإضاءة وما تحتويه من إستراتيجيات مختلفة من اجل الحفاظ على الطاقة وتوفير بيئة بصرية عالية الجودة تتمشا مع الفراغ التعليمى الذكى كما يناقش ايضاً أثر إستخدام برامج المحاكاة على عملية التصميم المعمارى من أجل الوصول للحل الأمثل . الجزء الرابع والأخير(الفصل الخامس) يقدم نموذج تصميمى لقاعة محاضرات في القاهرة كدراسة حالة ويحلل أداء الضوء الطبيعى بها من خلال التحقق من افضل نسب فتحة نافذة للجدار WWR في التوجيهات

الملخص

الأربعة الرئيسية. ثم اختبار اعداد وزوايا مختلفة للكاسرات الشمسية_(louvers) الأفقية والرأسية والمائلة للحالات التي حققت أداء مقبول في المرحلة الأولى .

تهدف هذه الأطروحة إلى اقتراح نموذج تصميمى مرن لفراغات التعلم / التعليم للمجموعات وخاصة قاعات المحاضرات مع مقترح لنظام الإضاءة المتكامل الذى يمكن أن يعزز أداء الضوء الطبيعى بها مع استخدام وسائل التظليل و كاسرات شمسية المختلفة بالإتجاهات الأربعة الرئيسية.

المشكلة البحثية

لقد تغير مفهوم الفصول الدراسية التقليدية الأن لتصبح فراغات تعليمية ذكية، هذه الفراغات تتطلب نظام إضاءة يتكيف مع الأنشطة التعليمية المختلفة، من المحاضرات والعمل الجماعي والعروض السمعية والبصرية. لسوء الحظ، العديد من أنظمة إضاءة الفراغات التعليمية لا تزال تسيطر عليها تقنية التحكم التقليدية عن طريق الفتح والغلق التي تستهلك الكثير من الطاقة. تستهلك الإضاءة بالجامعات حوالي 30٪ من تكاليف الطاقة لذلك يجب إنشاء نظام إضاءة متكامل للفراغات التعليمية للسماح للمعلمين بالسيطرة على الإضاءة داخل الفراغات وتخفيض الإضاءة عند الحاجة اثناء العرض لدعم قدرتها على الحفاظ على بيئة بصرية مريحة، من أجل توفير بيئة تعليمية فعالة تحافظ على استدامة الطاقة وتقلل من تكاليف التشغيل الكلية.

أهداف البحث

<u>الأهداف الرئيسية:</u>

- تحديد نموذج تصميمى للبيئة البصرية بالفراغات التعليمية باستخدام تقنيات ذكية لمساعدة المصممين في تحقيق فراغات تعليمية عالية الأداء.
- استكشاف فعالية التقنيات الذكية للحصول على دمج الضوء الطبيعي والضوء الاصطناعي بواسطة أدوات المحاكاة الحاسوبية.

<u>الأهداف الإجرائية :</u>

1. دراسة ظاهرة الجامعات الذكية ، مهمتها، وفوائدها مع تحديد الخطوط العريضة لمكوناتها الرئيسية.
2. تحديد تصنيف الفراغات التعليمية الذكية وتحديد النوع الأكثر شيوعا لدراسة البيئة البصرية بداخله.
3. دراسة البيئة المكانية لفراغات التدريس / التعليم للمجموعات وجوانب التصميم العام لها.
4. دراسة تأثير نظم التظليل الذكية على أداء الإضاءة الطبيعية وكفاءة الإضاءة داخل الفراغ التعليمي .
5. دراسة استخدام مصابيح الإضاءة الذكية ومدى تأثيرهاعلى كفاءة الفراغ التعليمي .
6. استكشاف فعالية استخدام طرق المحاكاة الحاسوبية والخوارزميات في تحليل البدائل التصميمية المختلفة والتوصل إلى الحلول المثلى.

الملخص

المنهجية البحثية

للوصول إلى أهداف هذه الأطروحة، تطور البحث من خلال مراحل متتالية من الدراسة:

الدراسة النظرية

- دراسة تطوير المباني والأنظمة الذكية وخاصة نظام التحكم فى الإضاءة. (الفصل الأول)
- دراسة الجامعات الذكية وأنواع الفراغات التعليمية. (الفصل الثاني)

الدراسة التحليلية

- تحديد معاييرتصميم البيئة المكانية لفراغات التدريس / التعليم للمجموعات. (الفصل الثاني)
- تحديد استراتيجية لتصميم البيئة البصرية لفراغات التدريس / التعليم للمجموعات. (الفصل الثالث)

الدراسة التطبيقية

- دراسة تأثير النظم والتقنيات الذكية لتحسين البيئة البصرية في الفراغات التعليمية. (الفصل الرابع)
- دراسة تطبيقية باستخدام وسائل المحاكاة لقاعة محاضرات بمحافظة القاهرة. من أجل الوصول إلى تحليل مقارن للإضاءة الطبيعية المتكاملة مع الضوء الإصطناعى لأنواع مختلفة من الكاسرات (louvers) عن طريق استخدام قياسات المناخ السنوى (CBDM). (الفصل الخامس)

هيكل البحث

الفصل الأول: نظرة عامة عن المبانى الذكية

الفصل الأول من هذه الأطروحة يناقش تطورتقنيات التكنولوجيا الحديثة ومدى تأثيرها على العملية التصميمية لتحولها من المبانى تقليدية إلى مبانى ذكية متكيفة وفعالة. كما استعرض ايضاً النظم الذكية المتكاملة التي تتحكم في إدارة المباني خصوصا الإضاءة وكيفية استغلالها لتوفير الطاقة الكلية للمبنى.

الفصل الثانى: الجامعة الذكية

استعرض هذا الفصل مفهوم الجامعة الذكية، مهمتها، وفوائدها مع تحديد الخطوط العريضة لمكوناتها الرئيسية. بالإضافة لذلك، تم دراسة أنواع الفراغات التعليمية الذكية وتحديد الفراغ التعليمى الأكثر أهمية وشيوعاً لدراسة بيئته المكانية والبصرية بدقة فى الأجزاء التالية.

الفصل الثالث: البيئة البصرية فى الفراغات التعليمية

في هذا الفصل تم دراسة مكونات البيئة البصرية و مدى تأثير جودتها على أداء الطلاب. إلى جانب ذلك، تم تحديد إستراتيجية لتصميم البيئة البصرية في فراغات التدريس / التعليم للمجموعات .مع توضيح وسائل التقييم الحديثة لكفاءة وجودة هذه البيئة البصرية وفقاً للمنظمات العالمية للإضاءة و المبانى البيئية (IES-LEED).

الفصل الرابع: تصميم إضاءة ذكية للفراغات التعليمية

يتناول هذا الفصل تأثيراستخدام النظم والتقنيات الذكية لتحسين البيئة البصرية في الفراغات التعليمية. فإنه يوضح دور نظام إدارة الإضاءة وكيف يمكن أن يتكامل مع التقنيات الذكية الحديثة لتعزيز أداء الإضاءة والفراغات بشكل عام.

الملخص

الفصل الخامس: نموذج تصميم لقاعة المحاضرات (دراسة حالة)

يختبر هذا الفصل أداء الإضاءة من خلال دراسة نموذج لقاعة محاضرات بالقاهرة، مصر. تم إجراء الدراسة التحليلية باستخدام برامج المحاكاة على مرحلتين متتاليتين. الهدف من المرحلة الأولى العثور على افضل نسب فتحة نافذة للجدار WWR في التوجيهات الأربعة الرئيسية. المرحلة الثانية تم اختبار اعداد وزوايا مختلفة للكاسرات(louvers)الأفقية والرأسية والمائلة للحالات التي حققت أداء مقبول في المرحلة الأولى. المرحلة الثانية تركز بشكل رئيسي على التوجيه الجنوبى والشرقى والغربى لأنها الأكثر إشكالية ويصعب السيطرة على جودة الأضاءة بها وفقا لنتائج المرحلة الأولى.

النتائج والتوصيات:

قدمت الدراسة توصيات ومبادئ تصميمية للفراغات التعليمية الذكية الفعالة مع مقترح لنظام الإضاءة المتكامل الذى يمكن أن يعزز أداء الضوء الطبيعى بها مع استخدام وسائل التظليل والكاسرات المختلفة.