DAYLIGHTING TECHNIQUES USED IN INDIGENOUS BUILDINGS IN THE UNITED ARAB EMIRATES (UAE), AN INVESTIGATIVE APPROACH

A Thesis

by

MAITHA MOHAMMED ALNUAIMI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Architecture

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Approved by:

Chair of Committee,	Liliana Beltràn
Committee Members,	Valerian Miranda
	Tazim Jamal
Head of Department,	Mark Clayton

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ABSTRACT

Daylighting Techniques Used in Indigenous Buildings in the United Arab Emirates (UAE), An Investigative Approach. (August 2007)
Maitha Mohammed AlNuaimi, B.S., United Arab Emirates University
Chair of Advisory Committee: Dr. Liliana Beltran

This study investigated the potential of the daylighting systems used in the indigenous architecture of the United Arab Emirates (UAE), located in Dubai (latitude 25° N longitude 55° E). The analysis tested the lighting performance of three daylighting systems under UAE climatic conditions.

The purpose of this research was to investigate the daylighting performance of three of the most common daylighting systems found in the indigenous buildings of the UAE, traditional windows (*Dreeshah*), gypsum decorative panels and wind tower (*Barjeel*). The lighting performance of each of the three lighting systems was examined. The lighting performance parameters examined were illuminance level, light distribution, uniformity, and glare. IESNA standards, CIBSE guidelines and LEED 2.2 daylighting credit and recommendations were used as the minimum recommended level for all analyzed variables. On-site measurements (illuminance and luminance) were conducted to compare measured versus simulated measurements inside the space. Desktop Radiance 2.0 Beta was used as the lighting performance analysis tool under clear sky conditions.

Results have shown that the gypsum decorative panel performs better than the other two systems in terms of light uniformity and distribution, regardless of a lower illuminance level. The double panel window prototype has poor lighting performance in terms of glare, light distribution and uniformity. Wind tower performed well under the area of the wind tower itself. Apart from that it also had a poor lighting performance in terms of glare, light distribution, and uniformity.

To Dad & Mom

[Mohammed Dalmouk & Moza AlFalasi],

My uncle Mohammed Bin Saifan

My brothers Mohammed and Ahmed

My sisters Eman, Rasha, Noora Fatma and Shamma

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TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

FIGURE Page

FIGURE Page

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

1.1. Background

The design of indigenous buildings in the United Arab Emirates (UAE) is not a result of chance. Rather, buildings were built in such way to reflect certain conditions, which were taken into consideration and were tested by experience acquired throughout the years. Traditions, availability of building materials and adaptations to the harsh desert climate of the region were some of these aspects [1].

The discovery of oil in the area by the end of 1950s [2] resulted in a dramatic change in all fields, specially the architectural field. These changes had a great impact upon people's culture and their life-style, which in turn had a significant effect on the region's architecture. Introduction of new building materials and techniques resulted in culture and traditions. Many projects were built without any consideration of those issues.

Catching up with modernity not only resulted in the loss of the local image and identity of the indigenous architecture of the UAE, but also had a great impact on environmental issues. To keep up with modernity, buildings were built without taking into consideration their influence on the environment. The new cultural meanings of the society sought architectural expression in buildings with facades with excessive areas of glass, giving little or no attention to the impact on the environmental issues.

This thesis follows the style and format of Energy and Buildings.

Natural lighting is one of the most important aspects which need to be studied thoroughly during the design stage of any building type. Direct sunlight, high contrast, glare discomfort, and overheating resulting from excess use of glazing can cause uncomfortable conditions for different human activities. Additionally, poor indoor quality results in the sacrifice of both visual and thermal comfort.

Below are four major perspectives held by architects toward indigenous architecture and its relevance to contemporary architecture:

1) Complete rejection of its significance to our time. Traditional buildings were products of certain historical, social, cultural, and economic circumstances. Our architecture should be the product of our time and circumstances.

2) Complete acceptance of its significance to our time. Elements and features of traditional architecture are imitated and copied in the design of new buildings. Traditional architecture is the only true architecture and architecture of our time is a cheap imitation of western architecture. This viewpoint usually holds negative judgment of modern achievements and their influence on humanity and over emphasizing the heritage as an absolute source of solutions. It also views technology and modern materials as evil to architectural heritage.

3) Use of elements of traditional architecture in the design of new buildings to follow the current fashion in architecture for commercial purposes.

4) View of contemporary architecture as a continuation of traditional architecture. This viewpoint stresses the development of a meaningful attitude towards traditional architecture as a source of inspiration for contemporary architecture. [3]

Among the previous points of view, the last opinion is the most logical. Indigenous architecture acts as the basis for contemporary architecture, for people has already experimented with different techniques and ways to make their architecture adapt to their climate, culture and surrounding environment.

On the basis of statement (4), this research will investigate its significance from the daylighting point of view through the study of the daylighting techniques used in the indigenous architecture of the UAE and examine if it can be of significant value to modern architecture.

Different daylighting techniques used in the indigenous architecture of the UAE will be explored first. Later, these techniques will be evaluated and analyzed on their ability to provide appropriate light levels and to control direct sunlight and daylighting under the UAE conditions.

1.2. Research Objectives

There are two main objectives;

1) Documentation of the available daylighting systems in the indigenous buildings.
2) Evaluation of the most common daylighting techniques incorporated in the design of the indigenous buildings from the daylighting point of view.

The following tasks for achieving these objectives have been identified:

1) Document the daylighting systems used in seven indigenous buildings in Al-Bastakia district. An inventory method is used to compile similar techniques under the same category and display them in a matrix format.

2) Use the three most common daylighting systems found in the indigenous buildings based on their occurrences in the inventory matrix.

3) Pick the spaces to be evaluated based on the presence of a single type of daylighting system to be tested.

4) Test and evaluate the lighting performance of each system using both Illuminating Engineering Society of North America (IESNA) and the Chartered Institution of Building Services Engineers (CIBSE) lighting standards and LEED 2.2 daylight credit.

1.3. Significance of the Study

This study will be useful for both designers and clients to understand how the daylighting systems in the indigenous buildings work from the daylighting point of view. It will also help designers in their decision-making process to integrate these systems in their design by modifying them, if required, based on their space need. Also, this study will broaden people’s awareness of indigenous architecture.

1.4. Characteristics of the Study

- Dubai is used as the location.
- One building in Al-Bastakia Historical District is used; Sheikh Mohamed center for cultural understanding, and from now on it will be referred to as Plot 43.
- Three spaces are chosen in that building to represent each opening prototype. Room A will represent double panel window, room B will represent gypsum decorative panel and finally room C will be for wind tower.
- IESNA standards, CIBSE guidelines and LEED 2.2 credit are used to compare the results for general, and office spaces based on the multiple functions of the current status of the space.
- This study will be limited to the study of daylight only and will not test the effects of the integration of daylight and electric lighting.

1.5. Organization of the Thesis

This thesis is comprised of six chapters. Chapter I, Introduction, provides the research background information, research objectives, characteristics, and the significance of the study.

Chapter II discusses the related literature about UAE history, UAE geography and daylighting benefits.

Chapter III provides the information on a research methodology which covers the site information, daylight opening prototypes definition and the lighting performance methodology.

Chapter IV comprises the results of the prototypes survey. It also includes the architectural characteristics of the prototypes for later evaluation.

Chapter V discusses the evaluation of the lighting performance of each case. It comprises the lighting performance of on-site measurements, comparison between on-site measurements and the windows based Desktop RADIANCE 2.0 Beta (DR) simulation and the analysis of the simulated lighting performance of double panel window, gypsum decorative panels and wind tower.

Chapter VI summarizes the results of the lighting performance. Recommendations for future studies relating to this research area are proposed.

CHAPTER II

LITERATURE REVIEW

In this section concise information regarding historical and geographical information of the UAE will be discussed, with thorough discussion about Dubai historical background. In addition to that the benefits of daylight in building will be tackled.

The objective of this section is to give the reader some idea about the location in which the buildings used in this research are. Since this information discuss why the building at that period of time where built in such way.

The literature review will examine the following areas:

1. UAE History and Geography
2. UAE Indigenous Architecture
3. Daylighting benefits

2.1. UAE History and Geography

2.1.1. Historical Background

The UAE was formed as a federation of seven emirates (Abu Dhabi, Dubai, Sharjah, Ajman, Ras Al Khaimah, Fujairah, Umm Al Quwain), which came together as one state on the 2nd of December 1971. The federal capital of the UAE is Abu Dhabi.

Dubai Emirate, located on the Arabian Gulf, consists of two parts, Deira and Bur-Dubai, separated by a creek flowing inland from the Arabian Gulf. The history of Dubai goes back several thousand years. Besides being a port where goods were imported and exported to the Gulf countries, Iran, India, and East Africa, it also was one of the towns on the caravan route from Iraq to Oman.

In 1841, smallpox broke out on Dubai side of the creek, and as a result people moved to the Deira side and started to build houses and markets. Hence Deira became larger than Dubai side. In 1894 a major fire broke out on the Deira side of the town. Since the houses were mostly constructed from fronds and trunks of palm trees, the fire spread rapidly and uncontrollably, so that the majority of houses burned down. Since that time, wealthy people started building their houses from coral stone and gypsum that could resist fire better [2].

The Maktoum family has ruled Dubai since 1833. Sheikh Maktoum bin Hasher Bin Maktoum became ruler in 1894, and is considered to be involved in making Dubai a main trading center in the Arabian Gulf. He eliminated taxes on imports and encouraged the merchants to establish their trading houses in Dubai. As a result, new markets and stores were built and the town prospered. From 1910 -1920 merchants and skilled people moved from Iran to Dubai because of political circumstances and established their own businesses. Immigrant people, with their architectural traditions such as wind towers, air-pullers and decorative gypsum panels, influenced the architectural styles in Dubai [4].

At the beginning of the twentieth century Dubai became a main trade center in the Arabian Gulf where goods were imported and exported between ports of India and East Africa by means of dhows. The main income was from pearls. However, the pearl trade started to decline after Japan produced cultured pearl in 1930 and the economy deteriorated.

1959 was a major year for Dubai; in addition to the discovery of oil offshore, the first airport was constructed to attract world airlines to use Dubai as a landing spot between Europe and Southeast Asia. In the same year, a British planning consultant was assigned to design the first city plan for Dubai. This city plan replaced the traditional fabric of the city with its narrow alleys and courtyard houses with a modern European plan [5].

2.1.2. Geographical Background

The UAE (Fig.1) is located in the Middle East at the tip of the Arabian Peninsula, with characteristic land-sea distribution of the Arabian Gulf coast, with the Tropic of Cancer passing through it and subtropical anticyclone above it. It lies between latitude 22° 50' and 26° North and longitude of 51° and 56° 25' East [6]. All provide this region a tropical desert climate with several typical climatic features. It is one of the Gulf Co-operation Council states (GCC) and has borders with Saudi Arabia, Oman and Qatar. It occupies a total of about 83,600 sq. km (32,400 sq. miles). The city of Dubai lies on latitude 25° 16' North and longitude 55° 16' East [7] overlooking the Arabian Gulf and extends for a distance of 72 km along the coastline. Dubai is considered the commercial capital of the UAE and its bustling center as well.

Fig.1 Map of the United Arab Emirates Source: http://www.persiangulfonline.org/maps.htm

The climate of the Emirates is very dry, with little rain, vegetation and animal life. Mountains only take up some percentage of the total territory. Connected to the federation are several islands outside the coast along the Persian Gulf. In the summer (April to September), temperatures in the UAE varies between 38-48°C (100-118°F) in the daytime while at night it varies between 26-30°C (79-86°F) with high humidity levels. Light rainfall and fog are characteristics of the winter season. In the winter (October to March), the days are sunny and pleasant with an average of 26°C (79°F), while nights are cool with an average of 15°C (59°F).

2.2. UAE Indigenous Architecture

2.2.1. Background on the Indigenous Architecture of the UAE

The symbiotic relationship between architecture and the environment goes deeper than climatically aware manipulation of building form and detail. Through its diurnal and seasonal course, the sun has always influenced the patterns of life, which are embedded in behavioral and cultural mores. The anatomy of the plan and section of traditional architecture often formed an integral part of the symbiotic relationship between climate, culture and behavior. The traditional vernacular architecture of the UAE reflected the traditional lifestyles and customs of the people. Resources were limited and the environment invariably harsh. Building materials were simple but were perfectly adapted to the demands of lifestyle and climate [8].

Thus the traditional architecture was a result of the mixture of three dominant factors: the climate (hot and humid), the religion and customs of its people, and the locally available building materials.

2.2.2. Factors Affecting the Indigenous Architecture of the UAE

As stated earlier, the three main factors affecting the development and the styles of the UAE's indigenous architecture are:

Climatic conditions: Arabian residential architecture has always taken procedures to protect the inhabitants from the overpowering heat of the Gulf's summer. This led to houses being built with thick walls for thermal insulation, with few windows and with devices such as the wind tower designed to take advantage of any potentially cooling breeze [9].

Culture and customs: Religion and custom have also affected the domestic architecture of the UAE. Rooms of a house generally opened into the courtyard, leaving the exterior walls with very few, if any, openings, except some ventilation holes high up in the wall, as Islamic teaching promotes privacy and modesty. Often, a wall would be placed immediately behind the entrance gate, meaning that visitors would have to take a sharp turn before continuing into the grounds and ensuring that people outside the gate could not see in, thus ensuring the privacy of the inhabitants [1].

Materials: The traditional materials of construction are coral, mud brick, dry stone and wood and thatch. Coral obtained from the coastal reefs is the prime building material on the coast. These materials have very low thermal conductivity and were therefore ideally suited for the hot and humid coastal environment [3].

2.2.3. Living Patterns and House Elements

The setting of the old UAE life was typical of the region. Houses were built along alleys. They looked inwards on to courtyards (*huwsh*) not outwards on to the street as is the usual western way. The architecture clearly reflected the basic cultural idea of the separation of the genders. Usually houses took the form of two separate areas, men's and women's. The men's area was the place of receptions and business; it is called the *majlis*.

The majlis usually fronted the street, from which it was entered by a beautifully engraved door which was often left open all day, revealing a wide passageway. The majlis room was the only part of the house which might have windows on the street. These were vertical openings with four shutters, two at the top and two below, secured with vertical iron bars. Fig. 2 shows an example of this type of window.

Fig. 2 Example of the window used in majlis.

In the past some square openings were built at the ground level. These had no shutters, but had two crossed timber joists supporting the lintel. Their position at the bottom gave cross ventilation inside the rooms and took away the humidity.

The windows in a traditional courtyard house are mostly on the inside, looking in towards the courtyard. The perimeter of the courtyard is generally cloistered and this adds to the shading effect so that direct sunlight will never penetrate the rooms. The result is that the interior of traditional homes is characterized by a subdued light level, even in the middle of the day.

The majlis was shaded by a loggia called a *lewan*. The lewan's roof was supported by a series of masonry arches, or simply decorated pillars.

The courtyard had a direct access from the street which passed through a bent entrance with no direct view, made by the adjacent rooms or by provision of a screen to prevent passers-by looking into the courtyard.

The rooms of the house were distributed around the courtyard. There was no specific room for a defined use. The furniture was very simple and flexible. Mattresses were laid on the floor. At meal times a circular palm–leaf mat was placed on the floor and removed afterwards. Seating was made of sheet bags filled with cotton leaned against the wall. The walls were decorated with gypsum panels, cut out in geometrical patterns, and with recessed niches [2].

According to Dubai Municipality [10] features of Dubai traditional architecture style can be defined as follows:

1) The diversity of nationalities of people residing in Dubai with their different cultural motivations influenced the traditional architecture. Therefore, the architectural character is distinguished by simplicity, durability, and adaptability to elements from different cultures.
2) The quoted elements that were added to the local concepts in order to define its style and character were developed to cope with the specific traditions and demands of the society under the umbrella of Islamic thoughts and philosophy.

3) The inward concept (intro-exposure) with almost regular forms was the basic design concept for all the buildings erected in a traditional way. According to that concept, the functional spaces were arranged all around a large open court with complete respect to the environmental influences.

4) The functions in all building types were clearly distributed among the plan into main and secondary items with pre-defined relations to the main court and the bent entrance. The configurations of these relations were set according to traditions and religious aspects.

5) The use of local and available materials such as coral stone, gypsum, and fresco (*sarooj*) was the main construction system for all the important buildings. The roofing materials were varied from the palm-tree fronds to the (*chandal*) wood joists according to building importance also due to the impact of the economical factor.

6) The elevations of the traditional architecture were almost plain without any projecting surfaces, with some openings arranged in a rhythm to provide a certain relation between solids and voids, especially in the absence of proportions.

7) The wind towers were the main elements that were used to overcome the negative influences of the hot humid climate. As a formalistic element, they were responsible for the staggered skyline of the old city.

2.3. Daylighting

Before electric lighting was of use it was very important to get the daylighting design correct. Many studies showed that the courtyard plan form provided a very pleasant solution, through inter-reflection of sunlight rather than directly penetrating the space. Vegetation was used in courtyard to regulate and soften the summer daylight; it also helped to control overheating [11].

Of all of the senses, vision is by far the most developed, and throughout our cultural history, light has been the main prerequisite for sensing the world. Therefore it is not surprising that the provision of light in buildings has been a fundamental concern of designers and builders.

Although daylight was the fundamental source of light, fire was present as the first source of electric lighting for millennia. It is most striking that in the last half century the majority of the population in the developed world spends most of their working day and much of their leisure time in electric light whether they are in offices, schools, factories, homes, shops, restaurants and so on. The current dependence on electric lighting has sacrificed daylighting and thus two concerns arise:

- Energy used in providing electric lighting contributes significantly to global warming and air pollution.
- Physiological and psychological effects of deprivation of daylight on occupants of the buildings.

2.3.1. Daylight Benefits

In addition to its physiological and psychological benefits, daylight has a green issue factor. By using daylight, the use of electric lighting is reduced. According to the IESNA Handbook, the use of daylight can reduce the amount of electricity used for interior lighting by 30% thus lowering the emission of CO^2 and in turn the green house effect. [11] [12].

At the present time, when energy is expensive and sustainable development is an important consideration in architectural design, daylight is once again seen as an important technique to help obtain energy savings.

Given these benefits, it is obvious that daylight should be utilized to its full potential to help create a visually pleasant environment and sustainable architecture.

CHAPTER III

RESEARCH METHODOLOGY

Site information, daylight opening prototype definition and its architectural characteristic as well as the lighting performance methodology used in the current research study will be presented in this chapter. Fig. 3 summarizes the methodology followed in this study.

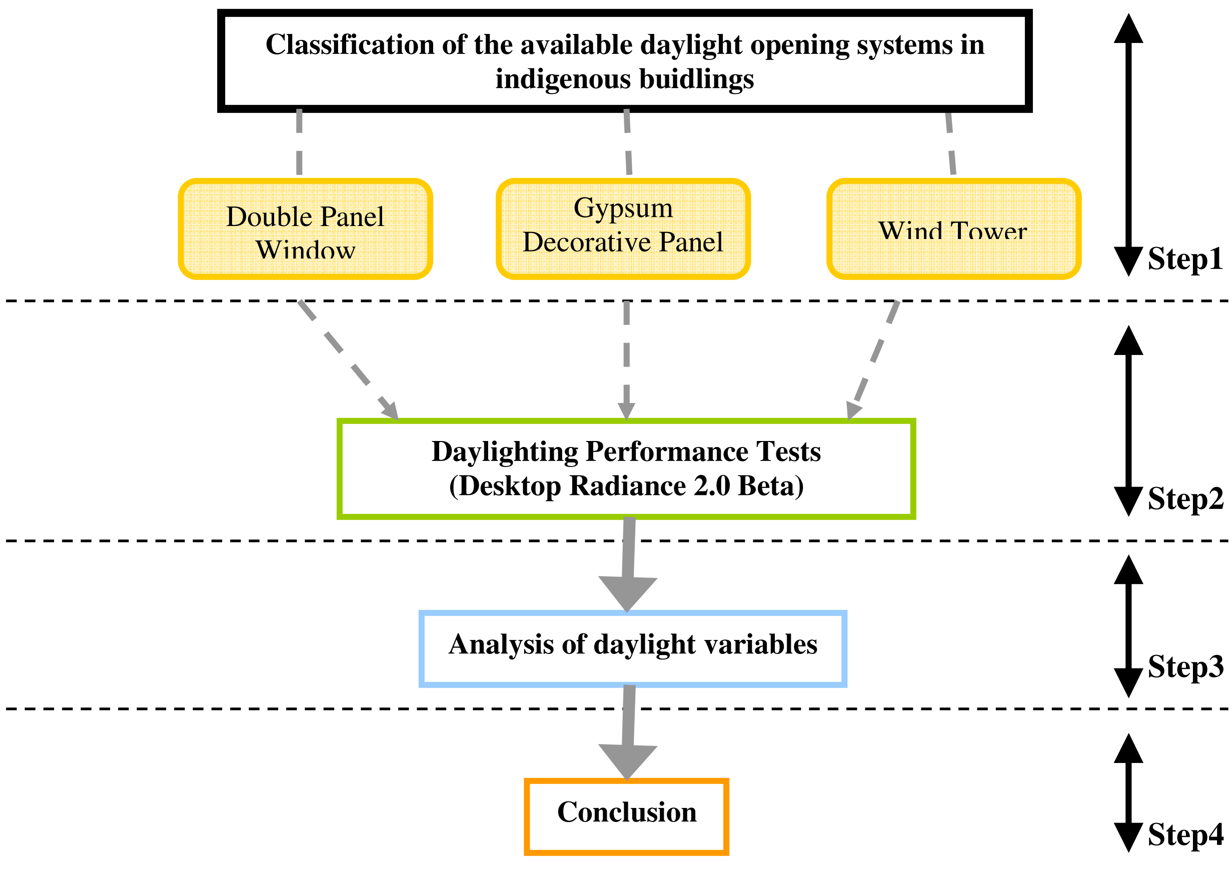


Fig. 3 Research methodology

3.1. Site Information

3.1.1. Background on Al-Bastakia District

Total area: 1.5 hectares

No. of historical buildings: 58 buildings

Major land-use: Residential

Proposed land-use: cultural and tourist

Main character: Traditional Urban and Architecture

Average height: one and two floors

Conservation strategy: conservation and rehabilitation [10]

Al-Bastakia is located on the Bur-Dubai side. It represents one of the historic landmarks of Dubai. Its construction dates back to around 1890. It extends along the creek for a distance of three hundred meters, with the width of nearly two hundred meters to the south. Its represented area is 38,000 m^2 [10] and includes traditional residential buildings of one or two floors with historical value, rich with traditional architectural elements such as wind-towers, air-pullers, columns, and beautiful wooden and gypsum ornaments. These create its unique architectural and urban formation. Rehabilitation work started on 1996, in line with a well-studied plan to rehabilitate the whole area due to its special urban and architectural values. It was decided to turn the area into a major tourist attraction consisting of museums, art centers, a boutique, hotels and traditional markets [10].

Location of the Al-Bastakia area in the aerial view map of Dubai city is shown on Fig.4. This area represents the location of the old city of Dubai. Fig.5 shows an image of Al-Bastakia area, and as can been seen from the picture wind towers dominates the skyline in that district.

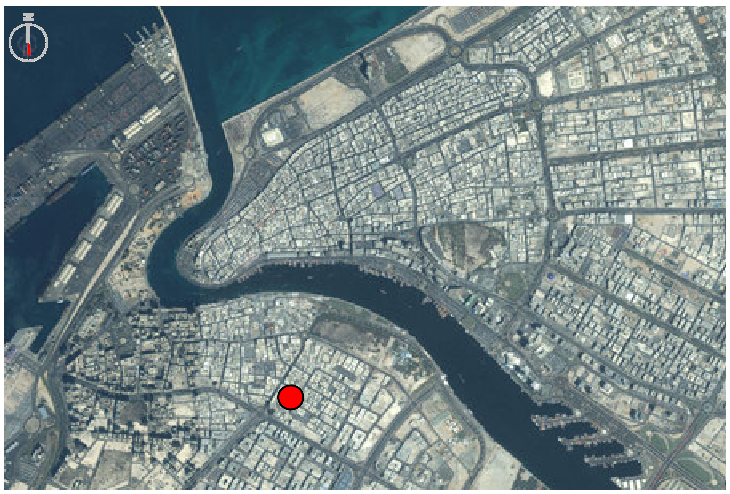


Fig. 4 Aerial view of Dubai Creek

Fig. 5 Al-Bastakia District; Dubai

3.1.2. Background on Plot 143

Sheikh Mohammed Centre for Cultural Understanding is located in one of the restored historical buildings in Al-Bastakia District, sometimes referred to as Plot number 143. It dates back to early 1920s. It is a two-story residential building, with a central courtyard with a lewan overlooking it from two sides, several rooms and a majlis with its separate entry. It is used as a Centre for Cultural Understanding, to give more ideas about the way people in UAE live. [10] This house was chosen because it had all the defined prototypes to be studied separately, without the influence of the others, namely a wind tower, double panel windows and gypsum decorations. Three different spaces were chosen as depicted in Fig.6.

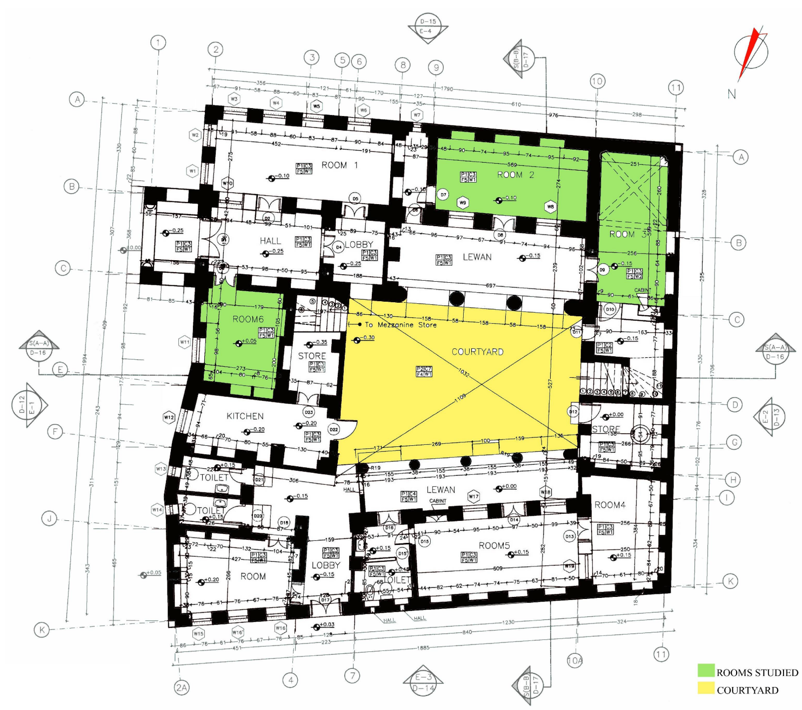


Fig. 6 First Floor Plan of Plot 143

3.1.3. Dubai Weather Detail

As discussed earlier in Chapter II, Dubai, UAE is located in a hot and humid climate.

Fig. 7 presents mean, mean maximum, mean minimum and extreme temperatures for the period of 1984-2001. This information was obtained from the Department of Civil Aviation (DCA), Dubai International Airport (DIA). The blue stripped band represents the thermal temperature comfort zone which is between 24 and 27°C. The red dashed line is the mean maximum, the green dashed line is the mean minimum, and the orange line is the average temperature range of each month.

Fig. 8 presents annual mean temperatures for the same time period. The blue straight band represents the thermal temperature comfort zone which is at about 24-27°C. The orange line is the average temperature range of each month. The green dashed line represents the linear mean temperature.

Fig. 9 represents mean, mean maximum, mean minimum and extreme humidity for the same period of time. The red dashed line is the mean maximum, and as shown in the graph it falls out of the comfort zone. The green dashed line is the mean minimum, and the orange line is the average humidity range of each month.

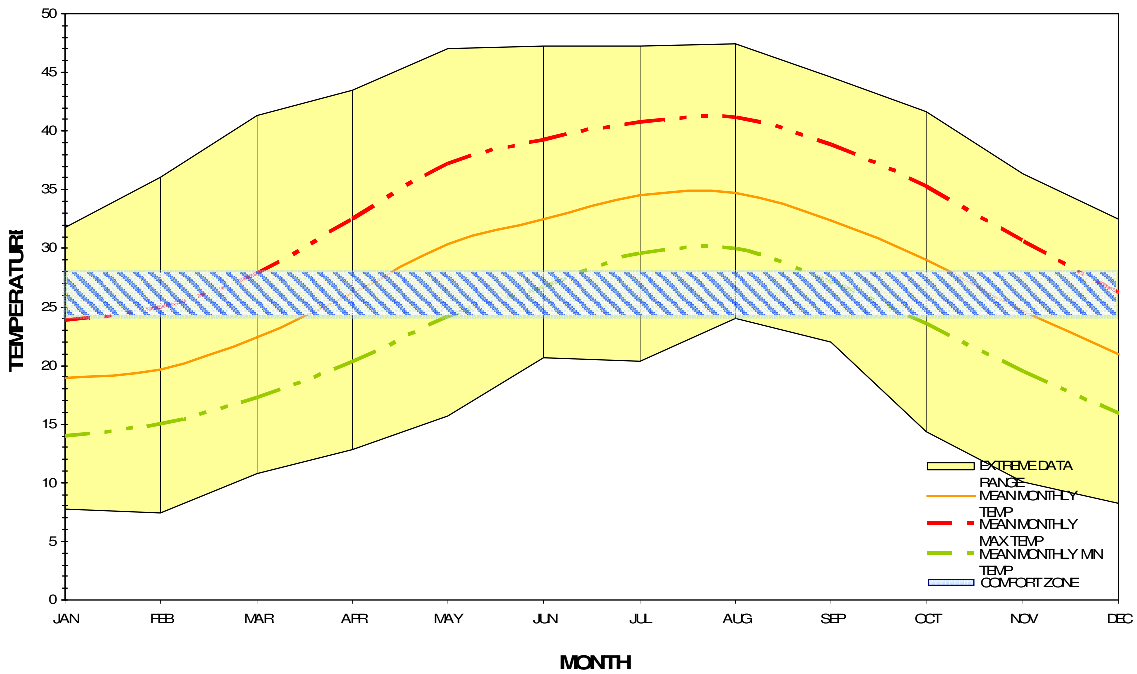


Fig. 7 Mean, mean max., mean min. and extreme temperatures 1984-2001

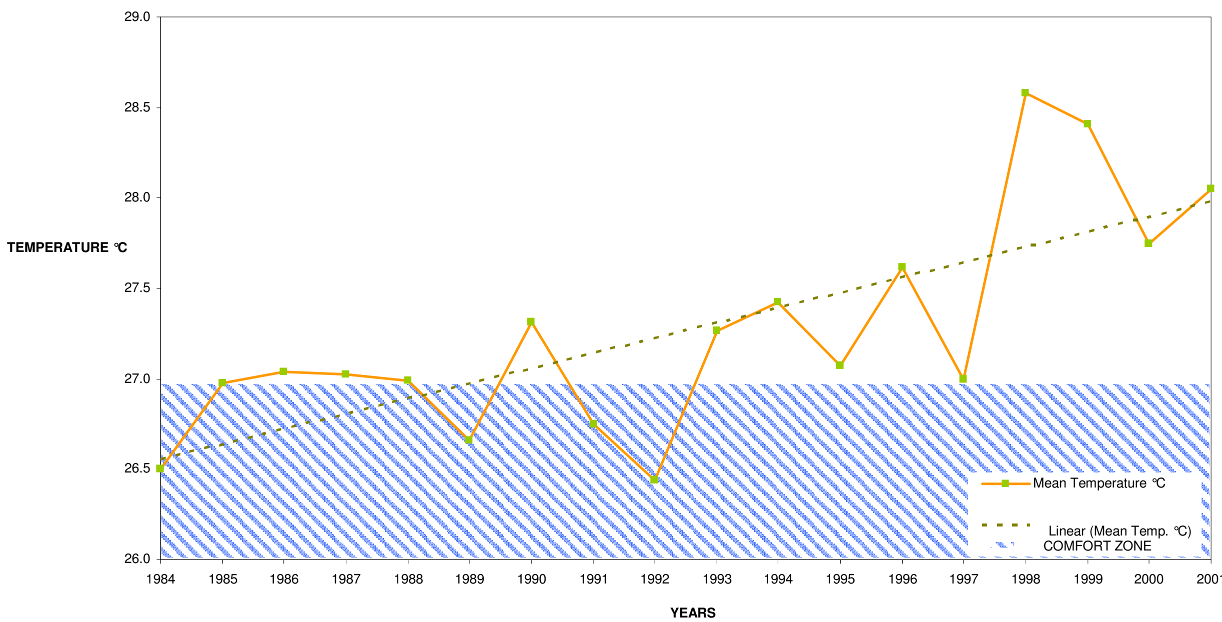


Fig. 8 Annual mean temperatures 1984-2001

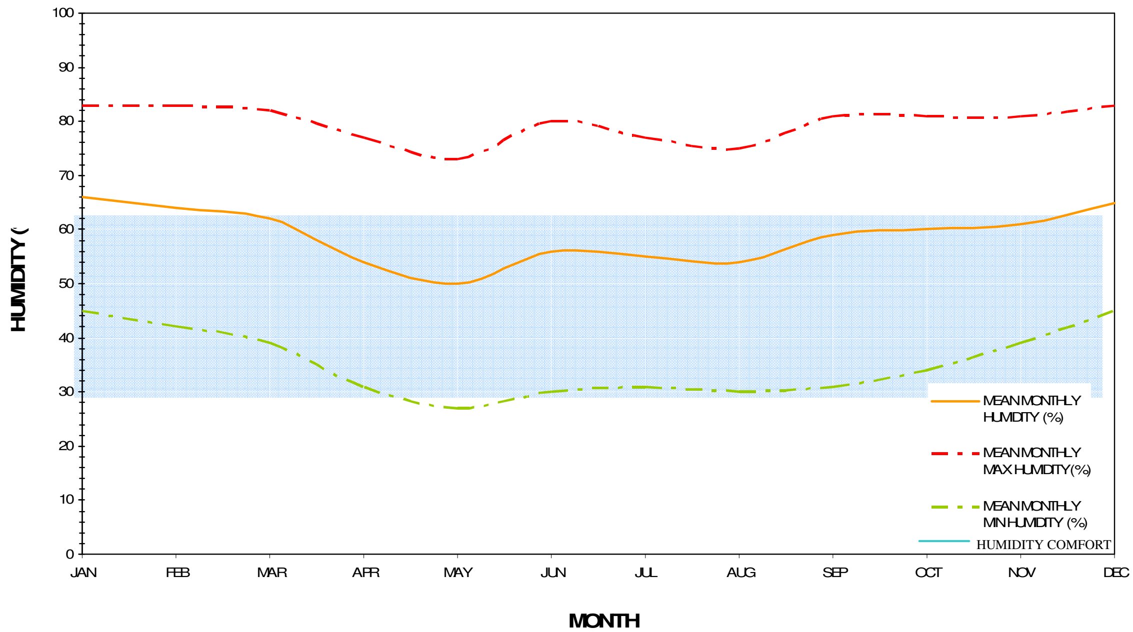


Fig. 9 Mean, mean max., mean min. and extreme humidity 1984-2001

<u>Dubai Sky Type</u>

As explained in Chapter II, from the information that was obtained from the DCA, DIA, the sky type of Dubai [13], UAE has predominantly clear sky conditions year-round. Fig. 10 graphically summarizes the average monthly sunshine hours from the period from 1974-2001. From the graph the average sunshine ranges from 7 to 11 hours a day. The maximum sunshine hour is 12 hours per day while the minimum recorded number is 5 hours per day which was recorded in the month of December.

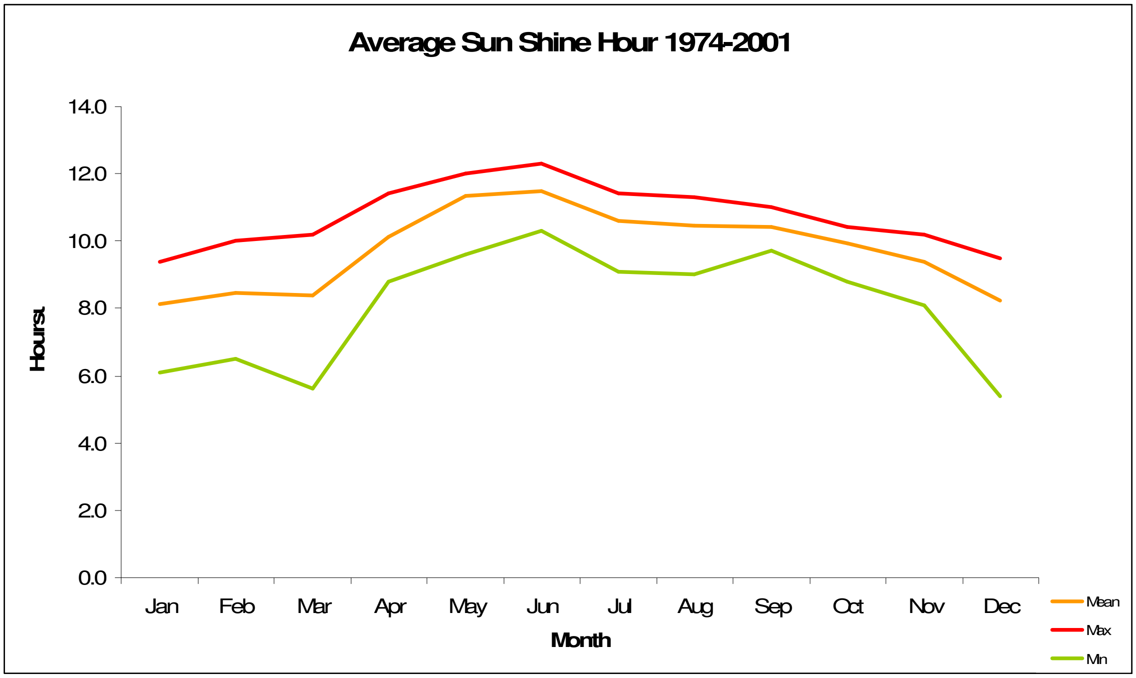


Fig. 10 Average sunshine hours 1974-2001

3.2. Daylight Opening Prototypes Definition

3.2.1. Case Studies Surveyed

To define the daylighting prototypes to analyze, seven buildings in Dubai historical district were surveyed. The number of opening in each building was documented and later categorized. The buildings are:

1. Historical building section
2. Dar Al-Nadwa
3. Sheikh Mohammed Centre for Cultural Understanding
4. Society for Architectural Conservation UAE
5. Dar Al-Khat Al-Arab
6. House of Sheikh Obaid Bin Thani
7. House of Sheikh Saeed Al-Maktoum

Since the area is still undergoing restoration, renovation and reconstruction, the selected case studies were chosen because of their complete status and public access. Architectural drawings and historical information of the case studies were provided by the Dubai Municipality; Historical Building Section. A brief original status description of each case study is presented below.

1. Historical Building Section: It is a two-story residential building; consists of a central courtyard with veranda (lewan) overlooking it from two sides, several rooms and a majlis with its separate entry. Currently used as offices for the Historical Building Section in Dubai municipality.
2. Dar Al-Nadwa: It is also a two-story residential building; consisting of a central courtyard with a veranda (lewan) overlooking it from three sides, several rooms, a majlis and two entries. A full transparent covering was made for the whole inside court so it can be used as an important center to deliver lectures, organize exhibitions, seminars and press conferences.
3. Sheikh Mohammed Centre for Cultural Understanding: It is a two-story residential building, with a central courtyard, veranda (lewan) overlooking it from two sides, several rooms and a majlis with its separate entry. It is used as a Centre for Cultural Understanding, to give more idea about the way people in the UAE live.
4. Society for Architectural Conservation UAE: It is similar to the previous prototypes, with a central courtyard, a single veranda (lewan), a couple of rooms

and a majlis with its separate entry. It is used to accommodate the offices of the society.

5. Dar Al-Khat Al-Arabi: It is similar to the previous prototypes, with a central courtyard, two sided veranda "lewan", a couple of rooms and a majlis. This house is used these days as a calligraphy gallery.
6. House of Sheikh Obaid Bin Thani: The construction of this building dates back to 1916. It is considered as one of the first residential buildings in the area. Its importance lies in its excellent location at the middle of the district, in addition to its large area measuring 39 x 35 m. The building has a great historic and artistic value, as it contains a large number of architectural and traditional elements of different formations showing the aesthetic values in the building facades, particularly after the completion of its rehabilitation in 1999.
7. House of Sheikh Saeed Al-Maktoum: It is one of the most important landmarks of traditional heritage architecture. This is due to its historic value, as it was the residence of the ruler since 1896. The house is distinguished by its wind towers (Barjeel), and its aesthetic ornamentation which highlight the heritage and historic authenticity of the building. It measures 54 x 48 m, and heights vary between one and two floors. Presently it is being used as a museum for historic pictures and documents of the emirate of Dubai.

3.2.2. Assortment of Daylight Opening Prototypes

There are diverse types of daylight openings found in the indigenous buildings of the UAE. A regular window is by far the most common one, while the wind tower (*barjeel*) and air pullers (*masgat*) are another category of daylight opening.

Windows in the indigenous buildings of the UAE differs from contemporary windows in they do not have glazing; but are always open to the exterior environment. Due to the high temperature of the region this characteristic served well in promoting natural ventilation through the space. Therefore all openings in the indigenous buildings had a dual function of both ventilating and daylighting the space. Instead of the glazing people used iron bars, gypsum ornaments and wooden shutters to cover the window, for privacy, security as well as to reduce the amount of daylight entering the space. Glass was introduced later, when oil was discovered, and when sea trips were increased to nearby countries for trading purposes. Mainly colored glass was brought back and that was mostly used for decorative purposes because of its high cost [14]. Windows can be classified into four main groups, referring to the architectural drawings of the seven case studies and the pictures taken from the site

1. Window type A; referred to as *dreeshah* in the local UAE dialect. See Fig.11. This type is mostly used for the majlis; or male gathering space. Usually it is bigger than the normal window size. It is covered by iron rails from the outside for security purposes, and closes from the inside with wooden shutters. These shutters divide the window into half, allowing some flexibility to either have it completely open or partly closed. They can be found in both outer walls and inner walls opening into the courtyard.

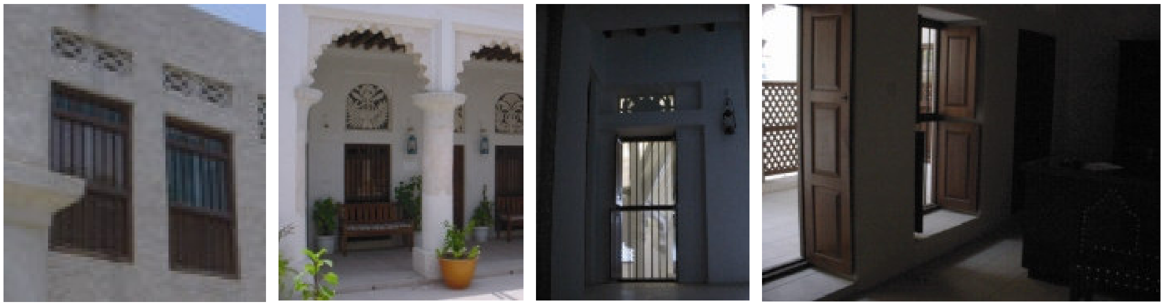


Fig. 11 Window type A; *Dreeshah*

2. Window type B; *or mesbah* is used for both common rooms and bedrooms. Mainly they are located on the upper part of the wall, and they are smaller than the usual size of window. This type of window opening is either covered by gypsum ornamentation or iron bars as can be seen in Fig.12. The size varies depending on the room area and location.

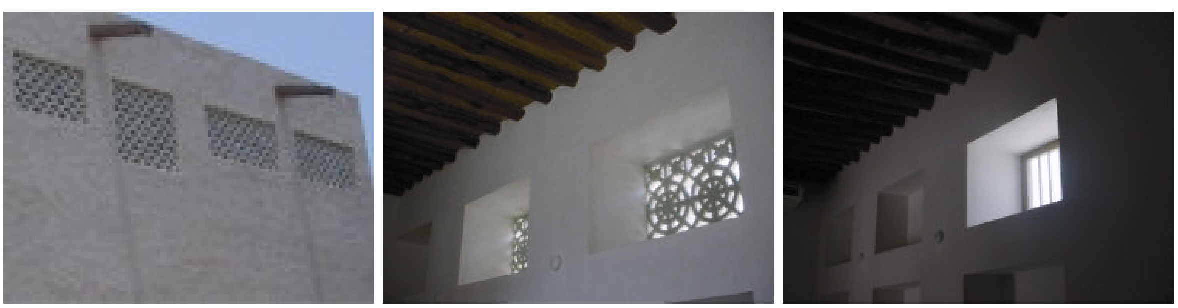


Fig. 12 Window type B *Mesbah*

3. The wind tower; referred to as *barjeel* is the most distinctive architectural element. It consists of four open sides, each of which is hollowed into a concave V-shape that deflects the wind down, cooling the rooms below. Water thrown on the floor

beneath the tower cools the house as the water evaporates. When cool air is not necessary, the vents can be closed. In addition to its ventilation purpose, the barjeel acts as a skylight in bedroom spaces. Mostly for privacy purposes bedrooms tend to have a minimal number of windows. Light is admitted through the barjeel and the windows located at the upper level of the room (Fig.13).

Fig. 13 Wind tower; *Barjeel*

4. The air puller (*masgat*) Shown in Fig.14 is a type of opening primarily used for circulation zones as well as common rooms; the majlis, and family gathering area. It is recessed into the wall from outside, so that shadows are cast into the recessed part, causing a reduction in the temperature nearby, hence causing a wind draft into the room. Some times they are referred to as “breathing walls as well as air puller.” A similar treatment can be found in bedrooms but with some alterations. The decorative part will be on the upper portion for privacy’s sake, and it will have a small opening on the top for ventilation purposes. This is used mainly in bedrooms on the second floor of houses.

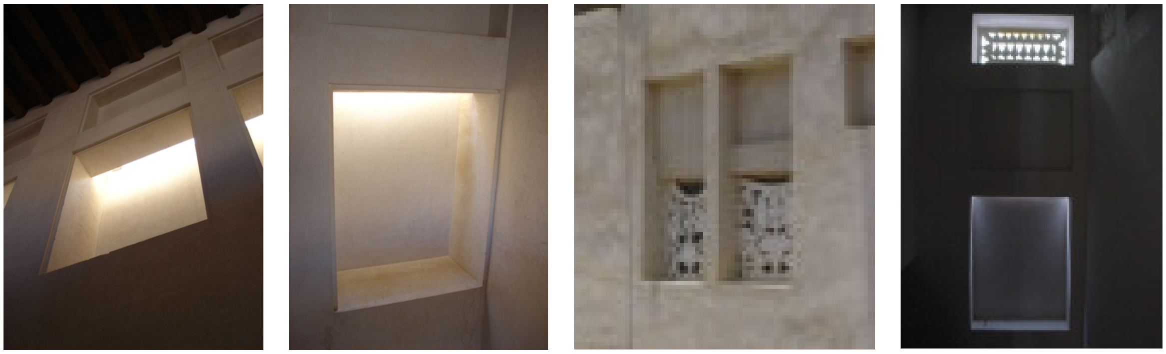


Fig. 14 Air pullers; *Masgat*

3.3. Lighting Performance Methodology

The lighting performance tests were done using on-site measurements and the lighting program Desktop Radiance 2.0 Beta (DR). The on-site measurements tests were done to verify the results with the outputs from DR and to estimate the difference with the DR simulations. DR is used for detailed lighting calculations and scene renderings.

The prototypes tested using on-site measurements and DR are traditional window, gypsum decoration panels and wind tower, with no glazing (using a special illum material in DR which has 100 % visible transmittance). See appendix B for material details.

3.3.1. Clear Sky Test Conditions

The tests of on-site measurements and DR were done under clear sky conditions; that is, the sky type found in Dubai, UAE.

For clear sky conditions in DR, the tested dates and times were summer solstice (June 21), equinoxes (March 21/September 21), and winter solstice (December 21) at 9:00am, 12:00pm, and 3:00pm. The dates were chosen to see the variation of the lighting performance at extreme sub angles.

3.3.2. Instrumentation: On-site Measurements

In this study each prototype was examined in it is real surrounding, Dubai, UAE. The measurements were conducted on the tenth of June, July and August starting at 12:00 pm, 02:00 pm, and 04:00 pm, with 15 minutes interval between the different spaces.

<u>Measurement instruments</u>

Three illuminance meters were used for the light measurements on-site. TES light meters, model number 1336 data logging illuminance meters (Fig.15) were used for the measurements inside the spaces. The horizontal illuminance measurements were taken at the center point in each space, at height of 60 cm. One of the illuminance meters was used for measuring the exterior illuminance value. A Konica Minolta luminance meter LS model 110 (Fig.16) was used along with Kodak Gray Card to take the luminance measurement of the surfaces inside the space in order to calculate their reflectance.

Fig. 15 Illuminance meter TES 1336 www. Seoultester.co.kr

Fig. 16 Luminance meter Konica Minolta LS-110

3.3.3. Desktop Radiance 2.0 Lighting Program

DR was chosen for its ability to model a geometrically complex environment and simulate light behavior with precise numerical results and refined rendered images. It has been tested for its validity under real sky conditions and is able to calculate interior light levels with a high degree of accuracy [15].

The DR software was developed by Greg Ward from the Building Technologies Department of the Environmental Energy Technologies Division at the Lawrence Berkeley National Lab. DR employs a backward ray-tracing method to calculate the lighting. Ray-tracing is a method of generating realistic images by computer, in which the paths of individual rays of light are followed from the viewer to their points of origin. Since ray-tracing makes use of the actual physics and mathematics behind light, the images it produces are-realistic. DR is an advanced physically based rendering and simulation engine for lighting and daylighting [16].

This study used DR to calculate the interior illuminance level and to generate images for each prototype at the specified time of the year.

3.3.4. Desktop Radiance Input Parameters

DR is a plug-in of AutoCAD release 14 and 2000. Each Surface is modeled using AutoCAD command 3D face within AutoCAD. The materials and glazing are then assigned to each surface and the light sensors are placed within each model to do the initial runs. DR generates illuminance and luminance values on the specified sensors. Some bugs were found in DR which are explained in Appendix B.

The input parameters used in DR are provided in Appendix A. The test dates and times are as specified earlier, June 21, March 21, September 21, and December 21, at 9:00 am. 12:00 pm and 3:00 pm.

Reflectance Values of Materials Used in Desktop Radiance 2.0 Beta

Each daylighting system was tested for visual performance by comparing DR with on-site measurements. The reflectance value in DR was generated to match those of the real space. The luminance meter and the Kodak grey and white cards were used to measure the reflectance value of the materials on-site. Table 1 shows the materials reflectance value.

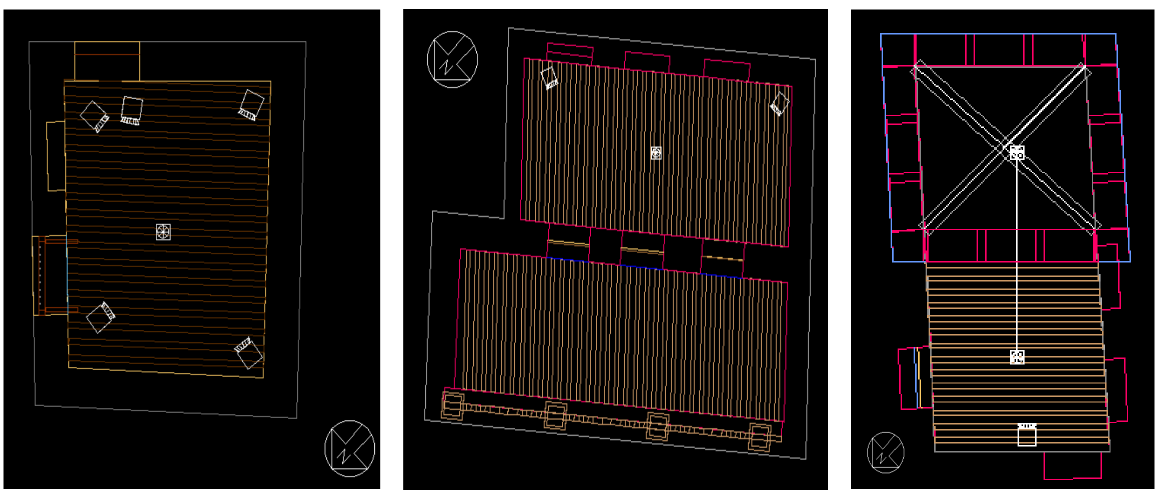
Table 1
Reflectance values

	On-Site		Desktop Radiance	
	Material Name	Reflectance (%)	Material Name	Reflectance (%)
Floor	carpet	19	Brown-grey	17.98
Walls, Daylight prototypes	Local Paint (Sarooj)	86.3	RAL_1014_Ivory	85.53
Ceiling, windows, door	Chandal Wood	29.8	Larch Wood	34
Iron Bars	Iron	N/A	Brushed Aluminum	79

Sensor Locations for Desktop Radiance 2.0 Beta and On-site

Sensors were located in each space based on the main task done at that particular space. Each point between on-site and DR was compared. Three tests were done for each space.

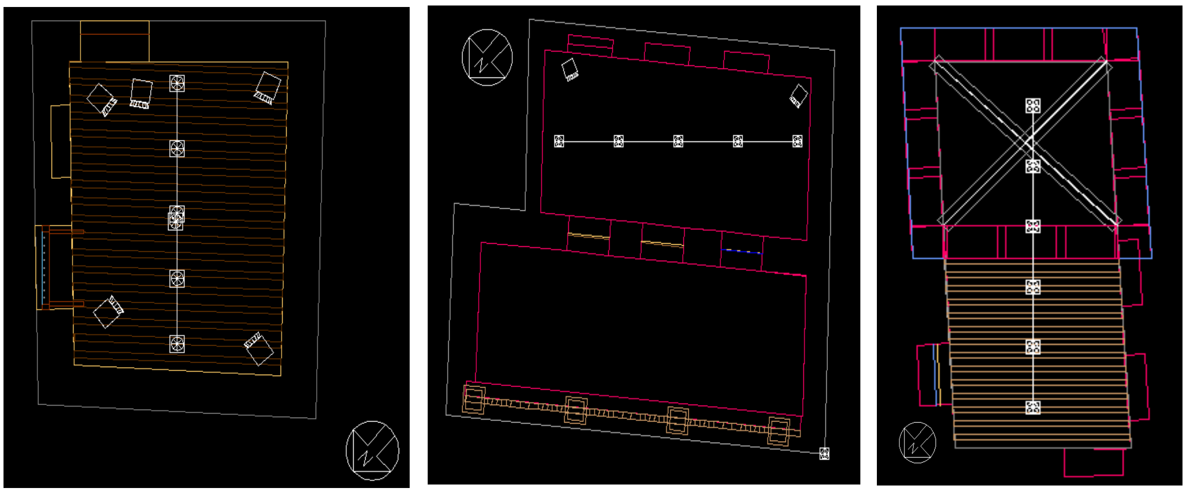
Test One was a comparison between on-site measurement and DR. (See to Fig.17). A single sensor placed at the center of each space with height of 60 cm was used as a reference point. Illuminance was calculated in DR for the same point. Values were compared for discrepancies.



(a) (b) (c)

Fig. 17 Sensor location for Test One (a) Room A (b) Room B (c) Room C

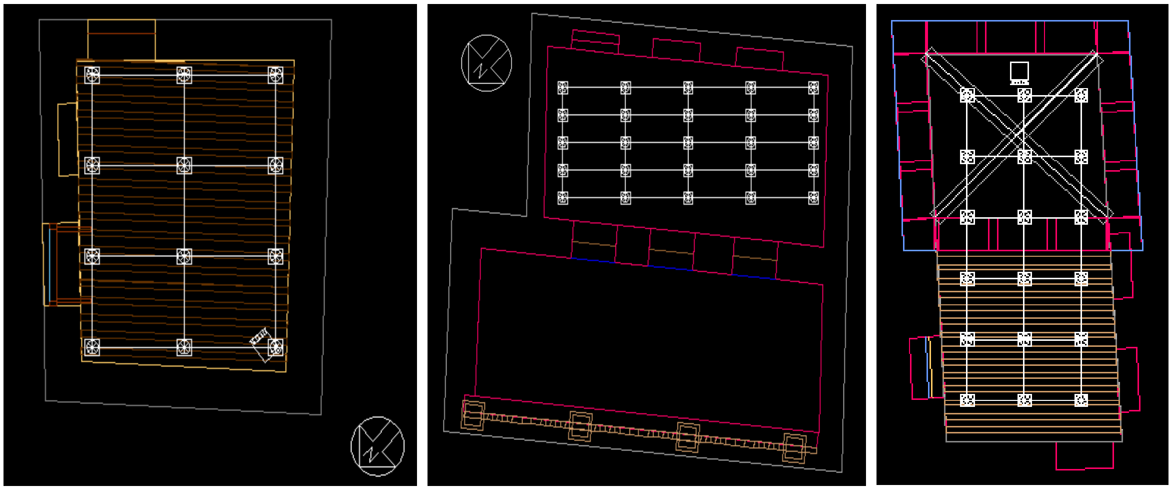
Test Two consisted of the daylight factor simulations in DR along the center line of the spaces at the height of 60 cm under overcast sky conditions. The simulation was conducted on January 10 at 9:00 am, representing the overcast period of the year. Fig.18 depicts sensor location in three rooms.



(a) (b) (c)

Fig. 18 Sensor location for Test Two (a) Room A (b) Room B (c) Room C

Test Three consisted in the simulations of illuminance levels and daylight uniformity. A rectangular reference grid was used for each space. Each space had a certain number of sensors based on its floor area. The sensors were placed on two locations, one at a height of 60 cm, representing the space as it was used in the old days and the other at 90 cm representing a modern day work plane height (Fig.19).



(a) (b) (c)

Fig. 19 Sensor location for Test Three (a) Room A (b) Room B (c) Room C

3.3.5. Lighting Analysis

The daylighting metrics calculated in this study were:

1. Daylight factor DF (%)

DF is the ratio of the interior illuminance level compared to the exterior horizontal illuminance level. This metric is used under the overcast sky conditions only.

2. Illuminance level (Lux)

Illuminance level is the visible energy (light) incident on a surface, measured in Lux. IESNA has made recommendations for the illuminance level for various tasks and building types [12]. The visual tasks that were considered in this study were for general and light office work.

3. Light distribution and uniformity

The light distribution and uniformity can be described as the relative illuminance at different points in space. Eye fatigue is caused if the light level differs too much in a space.

For the uniformity of light distribution, CIBSE guidelines for interior lighting were used to test the performance of each prototype [17]. In the CIBSE guidelines, the uniformity of illuminance is measured using the ratio of minimum illuminance to average illuminance, which should not be less than 0.7.

Diversity of illuminance is another metric that was used, some times referred as the ratio of the maximum to minimum illuminance level of the area 0.5m off the wall perimeter. This ratio should not exceed 5 to 1.

4. Glare

Glare is a byproduct of excessive brightness in relation to the adaptation of the eye. It is caused when occupants are either looking directly at a light source, (direct glare) or at surfaces reflecting bright areas into the field of view.

The luminance ratio is calculated to assess the presence of glare. This is the ratio between the task and its surroundings. This value should not exceed 10 to 1 between task and background according to CIBSE guidelines, and recommendations given by Stein and Reynolds [15]. For general tasks, ratios of 20 to 1 for fenestration and adjacent surfaces and of 40 to 1 for anywhere within the field of view are used.

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CHAPTER IV

ANALYSIS OF DAYLIGHT PROTOTYPES

This chapter includes a survey of the daylight opening prototypes found in the case studies discussed in Chapter III and their analysis, and a description of the architectural characteristics of each prototype.

4.1. Prototypes Survey Analysis

An inventory with the total number of each daylight opening prototypes found in each case study was recorded. The table below shows the results of each case study.

From Table 2 the first three daylight opening prototype were chosen to investigate their lighting performance. The fourth daylight opening prototype was excluded since it is located in circulation zones in the different case studies; and not present in any interior space. Fig. 20-23 shows architectural details of each prototype.

Table 2
Inventory of daylight opening prototype

Daylight Opening Type	Window A	Window B	Wind Tower (*Barjeel*)	Air Puller (*Malgaf*)
				
Case Study 1	30	7	1	6
Case Study 2	26	20	1	3
Case Study 3	32	32	1	0
Case Study 4	26	26	1	0
Case Study 5	21	15	1	5
Case Study 6	34	35	2	8
Case Study 7	48	33	2	5

4.2. Architectural Characteristics of Each Prototype

Window A; *Dreeshah*

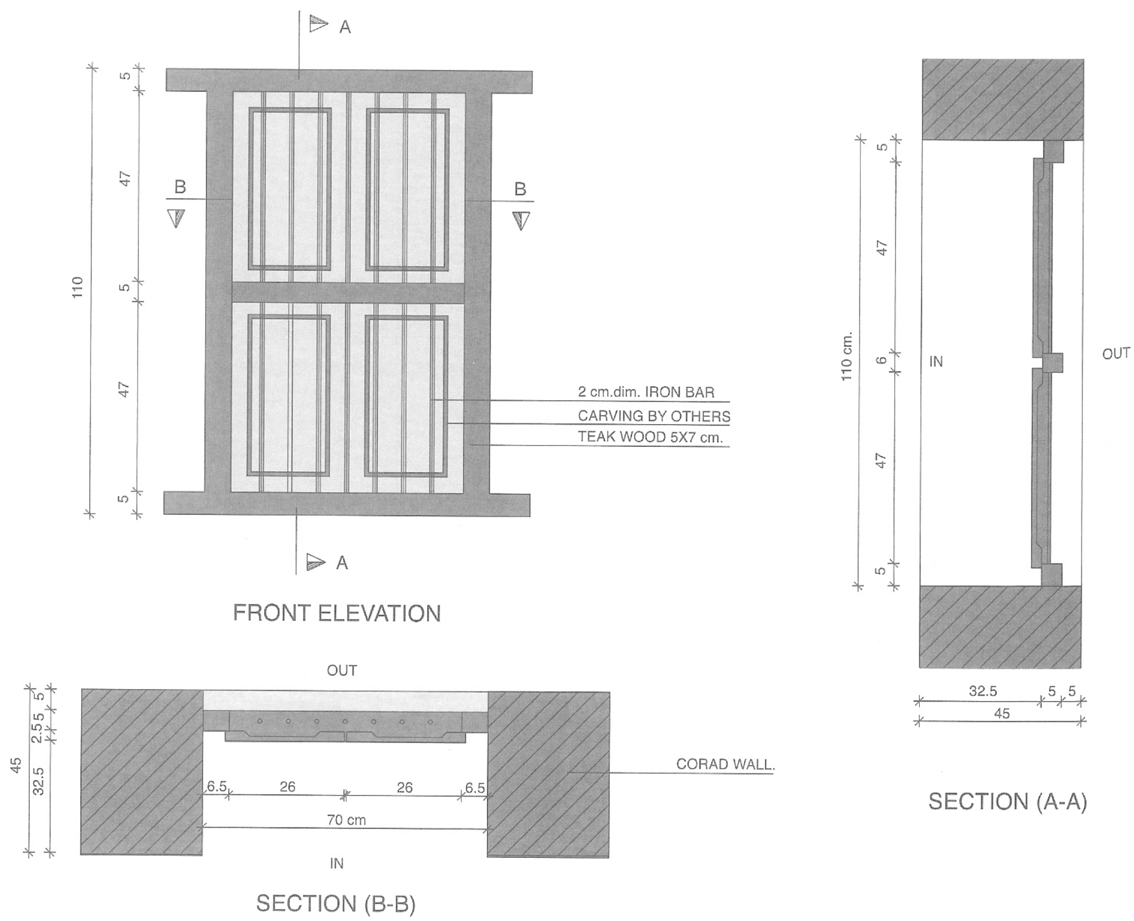


Fig. 20 Example of window A; Dreeshah

Window B; Gypsum Decorative Panels

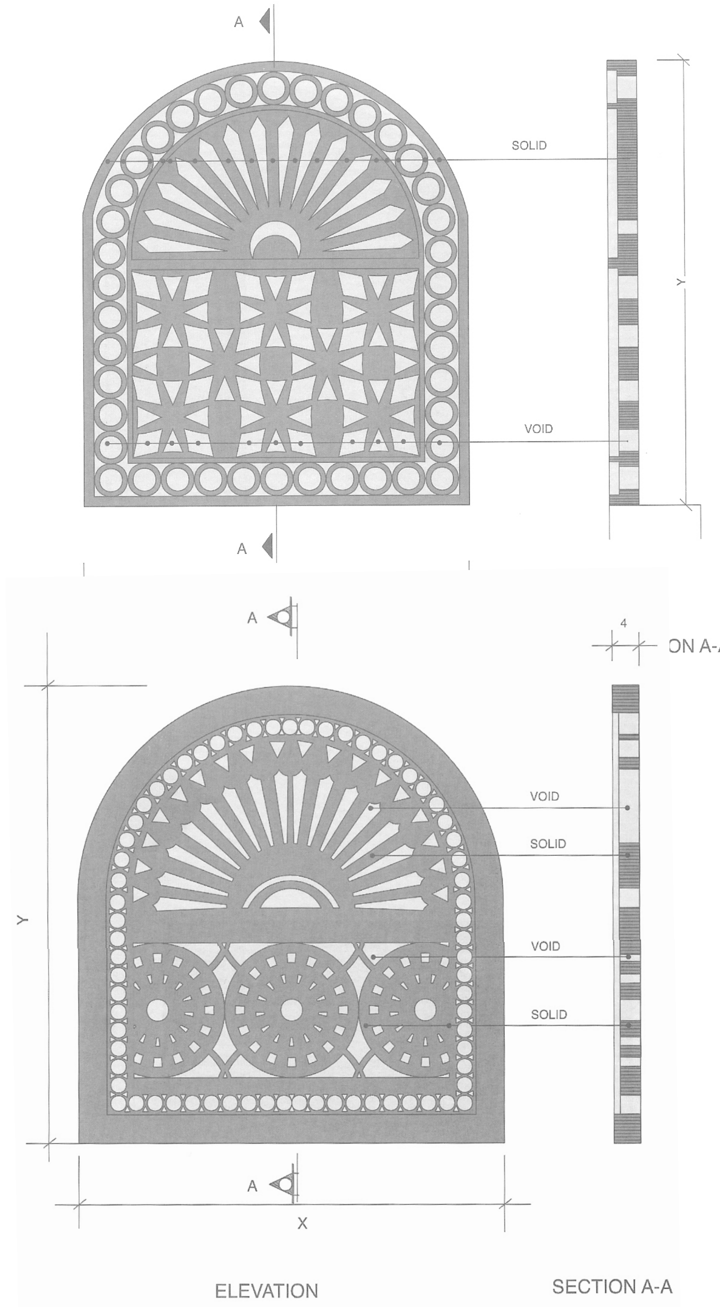


Fig. 21 Example of window B; Gypsum Decorative Panels

Wind tower *Barjeel*

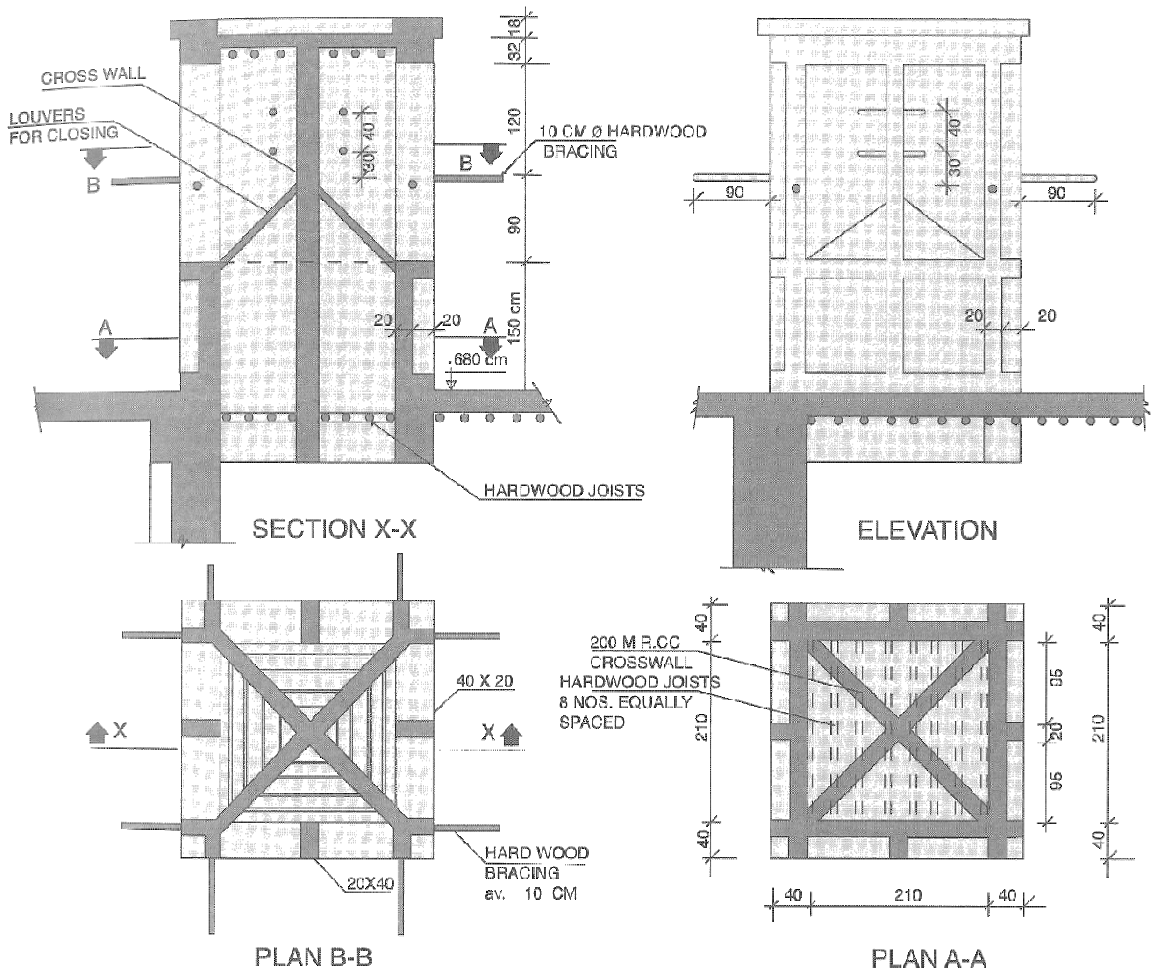


Fig. 22 Example of wind tower Barjeel

CHAPTER V

LIGHTING PERFORMANCE EVALUATION

After the definition and selection of the daylight opening prototypes, the daylighting performance of the prototypes were simulated with DR, and evaluated using the metrics described in Chapter III:, illuminance level, illuminance distribution, uniformity, and glare.

5.1. On-site Measurements

Three different spaces in Case study 3 were chosen to conduct the measurements. These spaces were chosen because each prototype was found solely in the space without the influence of the others. Fig. 23 shows the selected spaces. Room A represents the double panel window which is east oriented. It has an opening to wall ratio of 1 to 8.5, and opening to floor ratio of 1 to 6.9.

Room B reflects the gypsum panel which is oriented to the north; it has an opening to wall ratio of 1 to 8.1, and opening to floor ratio of 1 to 10. Finally room C represents the wind tower which has an opening in each orientation. It has an opening to wall ratio of 1 to 0.68, and opening to floor ratio of 1 to 0.49.

Illuminance measurements under clear sky conditions were taken on-site in order to compare them with the DR results and detect any discrepancies that may occur.

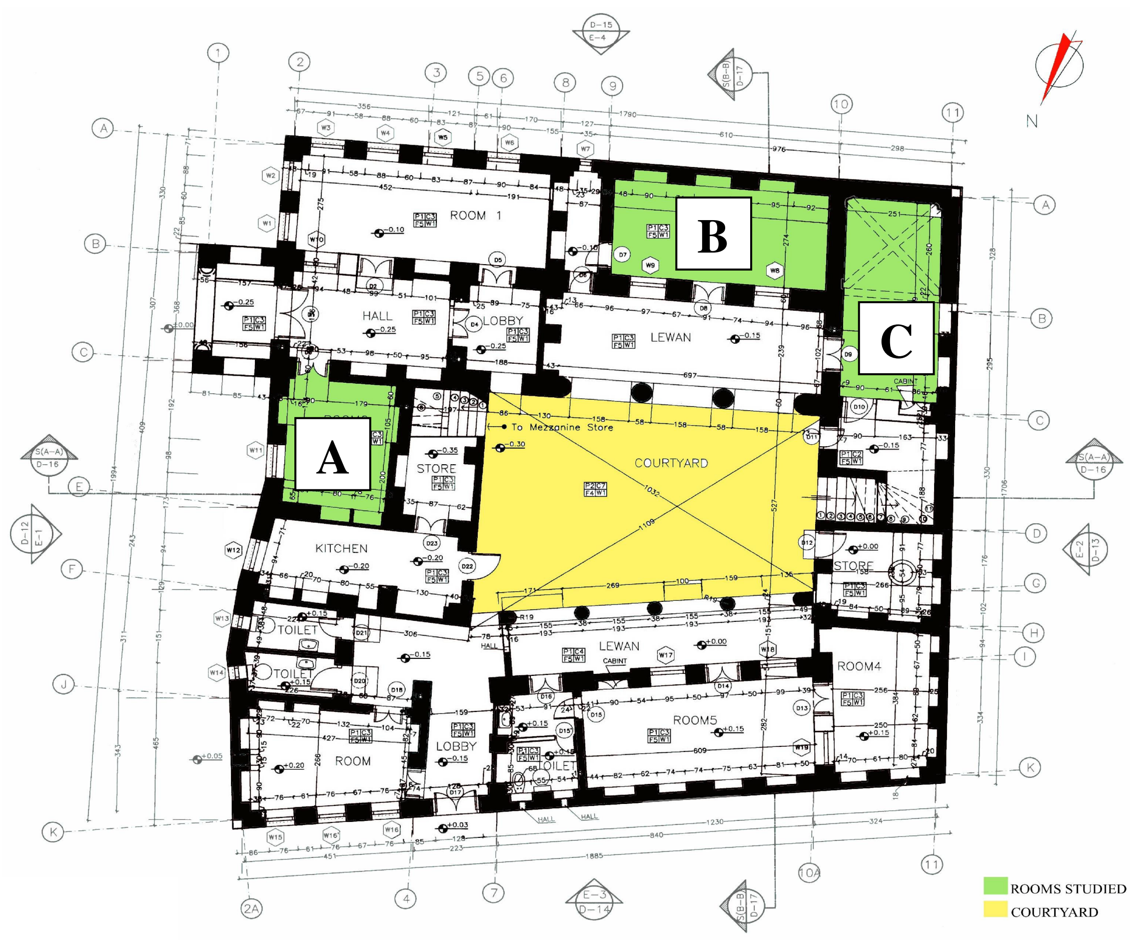


Fig. 23 Selected spaces in Plot 143

5.1.1. Double Panel Window On-site Results

As explained earlier in Chapter III in the lighting performance methodology section, one reference point was assigned at the center of the space with a height of 60 cm from the ground. The illuminance value of that point was measured at 12:15 pm, 02:15 pm and 04:15 pm on June 10, July 10 and August 10. Table 3 below shows these measurements. (HEI; Horizontal Exterior Illuminance)

Table 3
Illuminance values of reference point – Room A

	ROOM A								
	10-Jun			10-Jul			10-Aug		
	12:15 pm	02:15 pm	04:15 pm	12:15 pm	02:15 pm	04:15 pm	12:15 pm	02:15 pm	04:15 pm
On-site LUX	262.5	206.6	186.1	252.9	201.2	184.0	245.3	196.9	180.8
On-Site HEI	114056	72450	44203	112226	74620	47927	113345	68930	49385

5.1.2. Gypsum Decorative Panels On-site Results

The same procedure was conducted for Room B. The illuminance value of that point was measured at 12:30pm, 02:30pm and 04:30pm on June 10, July 10 and August 10. Table 4 below shows the values measured at reference point.

Table 4
Illuminance values of reference point – Room B

	ROOM B								
	10-Jun			10-Jul			10-Aug		
	12:30 pm	02:30 pm	04:30 pm	12:30 pm	02:30 pm	04:30 pm	12:30 pm	02:30 pm	04:30 pm
On-site LUX	176.5	138.8	131.3	158.2	133.4	142.0	137.7	128.0	119.4
On-Site HEI	114056	72450	44203	112226.8	74620	47927	113345.8	68930	49385

5.1.3. Wind Tower On-site Results

For Room C two reference points were assigned as described earlier in chapter III, one exactly under the wind tower and one at the center of the remaining of the room. The illuminance value of both points was measured at 12:00pm, 02:00pm and 04:00pm on June 10, July 10 and August 10. Table 5 below shows the values measured at reference point.

Table 5
Illuminance values of reference point – Room C

	ROOM C; Center of room								
	10-Jun			10-Jul			10-Aug		
	12:00 pm	02:00 pm	04:00 pm	12:00 pm	02:00 pm	04:00 pm	12:00 pm	02:00 pm	04:00 pm
Centre of room LUX	50.6	68.9	57.0	42.0	72.1	59.2	49.5	67.8	51.6
Wind Tower LUX	170.0	304.5	266.8	137.7	323.9	265.8	188.3	345.4	286.2

5.2. Comparison between On-site Measurements and Desktop RADIANCE 2.0 Beta Simulation

Comparisons between on-site measurements and DR are done for each daylight opening prototype: double panel window, gypsum decorative panel, and wind tower without any glazing (using a special illum glazing in DR).

5.2.1. Clear Sky Test Results

The results show that, for the clear sky condition, the illuminance values from on-site measurements and from DR are similar, with the measurements from DR being slightly higher than the illuminance values measured on-site except for the case under the wind tower. The overall discrepancy is about 10%.

It appears that DR, for the tested location of latitude 24.77°N in a CIE clear sky condition, might overestimate the illuminance value by about 10%. However this value increases to as much as 49% afternoons in the summer. Moreover, the actual clear sky in UAE might produce more illuminance value than is calculated in DR.

For the clear sky test, horizontal exterior illuminance (HEI) is measured as a reference to the interior horizontal illuminance value for each space. The value as generated from the sky file in DR is calculated for comparison and is presented in Tables 6, 7 and 8 and fig. 24-28 for Rooms A, B and C, respectively.

Some possible causes of the discrepancy in clear sky conditions include the following:

- The clear sky measured is actual UAE sky conditions and not CIE clear sky used in the sky model for DR calculations.
- The spaces were modeled in a very simple form. Some details such as furniture were excluded to easily use the 3D model in DR and this might result in the variation in the illuminance value.
- The dates of the last calibration of both light meter and illuminance meter are unknown.

Table 6
Horizontal exterior illuminance (HEI) level in Lux – Room A

	ROOM A								
	10-Jun			10-Jul			10-Aug		
	12:15 pm	02:15 pm	04:15 pm	12:15 pm	02:15 pm	04:15 pm	12:15 pm	02:15 pm	04:15 pm
On-Site HEI	114056	72450	44203	112226.8	74620	47927	113345.8	68930	49385
RADIANCE HEI	822272	70238	44121	822272	71033	45471	78852	69791	43290

- The materials defined in DR have slightly different reflectance value than that found on-site; this could have altered the illuminance value.

- The spaces generated in DR did not include furniture; this might increase the illuminance value.

- The dates of the last calibration of both light meter and illuminance meter are unknown.

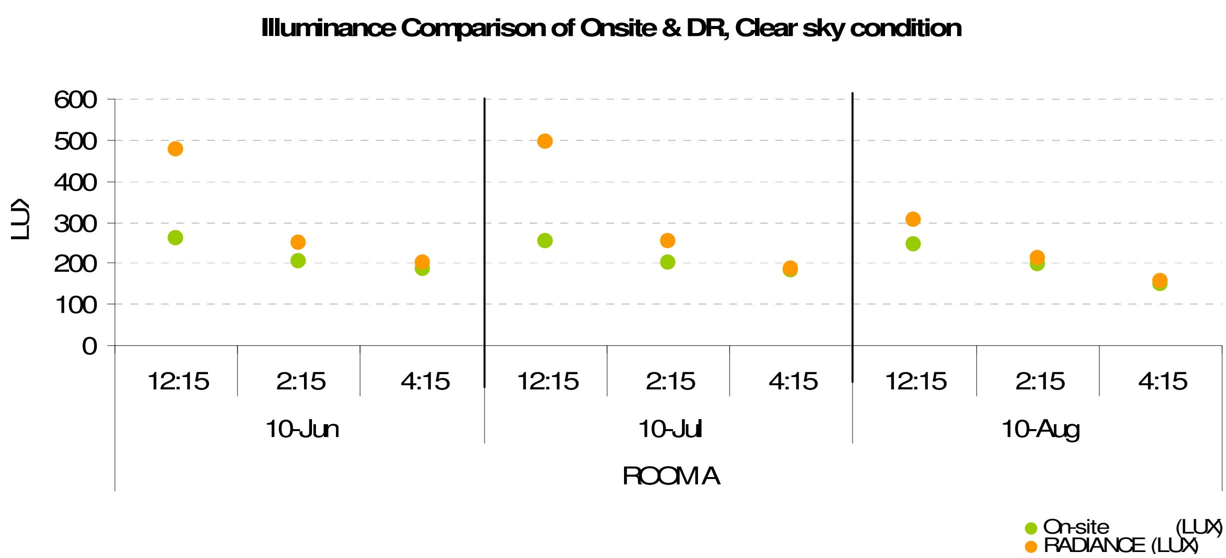


Fig. 24 Room A: Illuminance comparison of on-site measurments & DR, clear sky condition

Table 7
Horizontal exterior illuminance (HEI) level in Lux – Room B

	ROOM B								
	10-Jun			10-Jul			10-Aug		
	12:30 pm	02:30 pm	04:30 pm	12:30 pm	02:30 pm	04:30 pm	12:30 pm	02:30 pm	04:30 pm
On-Site HEI	114056	72450	44203	112226.8	74620	47927	113345.8	68930	49385
RADIANCE HEI	9893	71000	42061	94900	71898	43583	84529	70615	41115

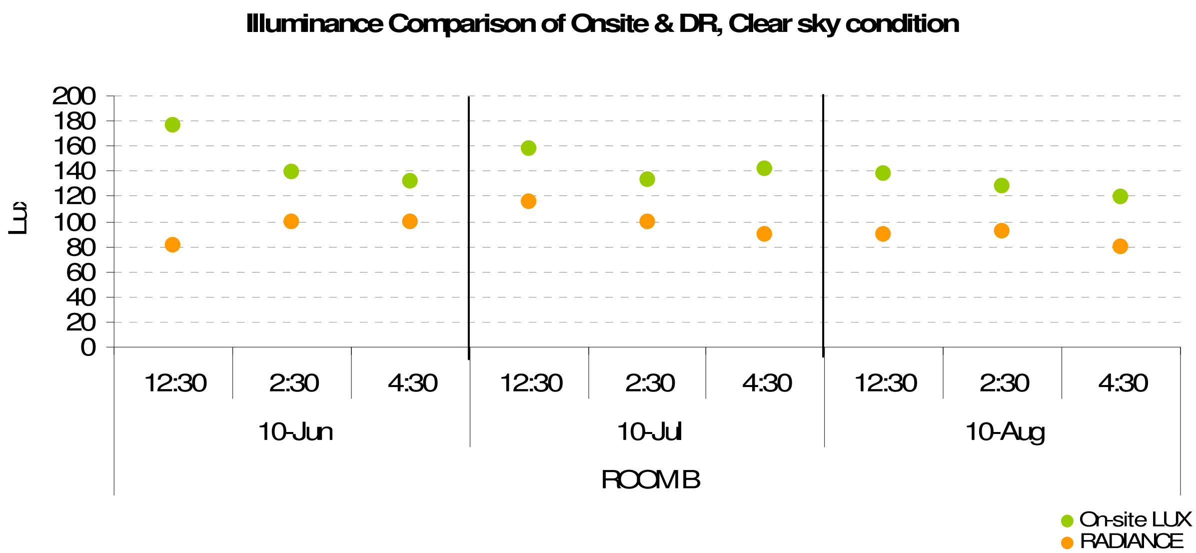


Fig. 25 Room B: Illuminance comparison of on-site measurments & DR, clear sky conditions

Table 8
Horizontal exterior illuminance (HEI) level in Lux – Room C

	ROOM C								
	10-Jun			10-Jul			10-Aug		
	12:00 pm	02:00 pm	04:00 pm	12:00 pm	02:00 pm	04:00 pm	12:00 pm	02:00 pm	04:00 pm
On-Site HEI	113357	76396	55780	100068	79108	54467	98346	76256	56135
RADIANCE HEI	90020	75906	50751	87325	76651	52205	83244	75455	50089

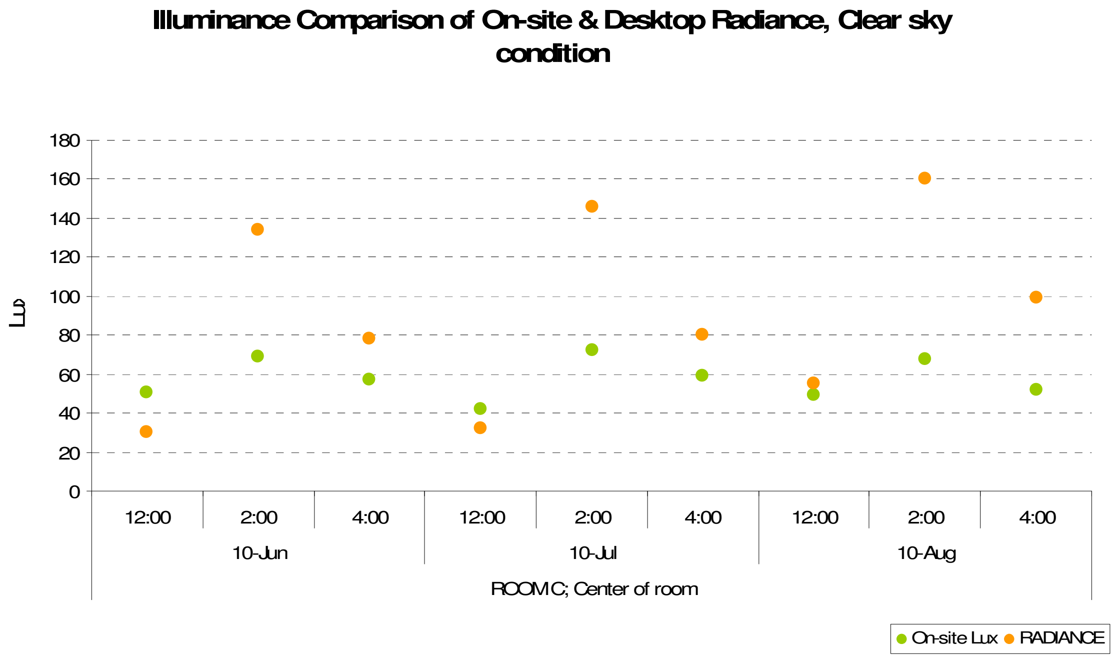


Fig. 26 Room C: Illuminance comparison of on-site measurements & DR, clear sky condition

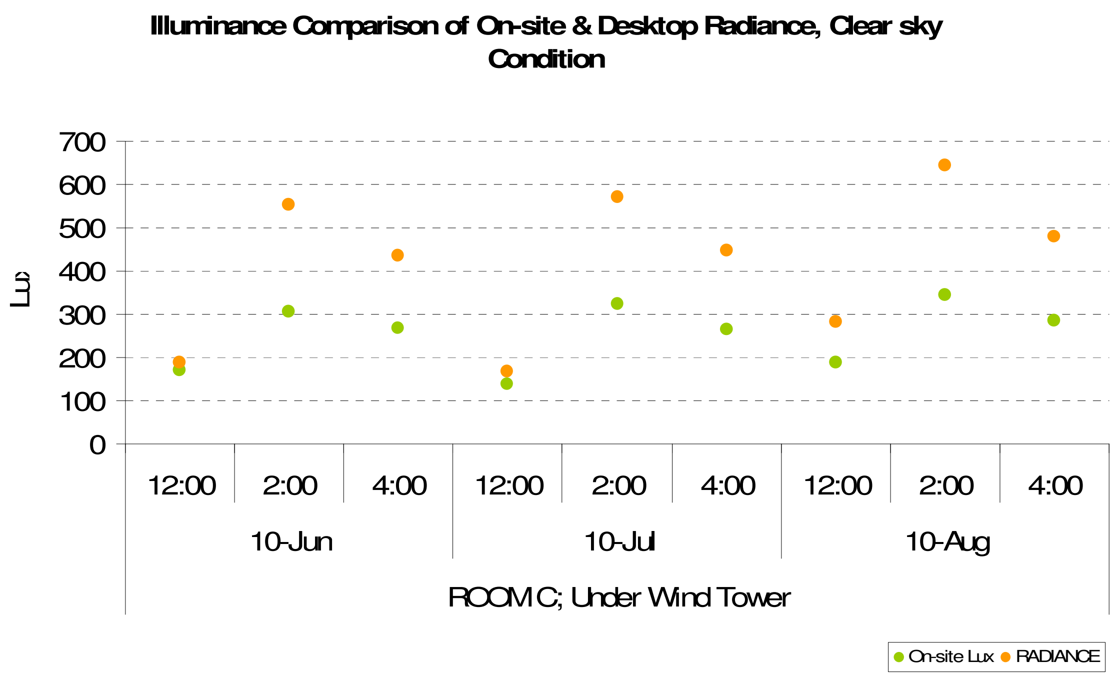


Fig. 27 Room C under wind tower: Illuminance comparison of on-site measurements & DR, clear sky condition

5.3. Double Panel Window Analysis

5.3.1. Daylight Factor

For the Double Panel Window, the maximum daylight factor is 3% and the minimum is 1%. This prototype falls beyond the recommended value of 5% of CIBSE

.

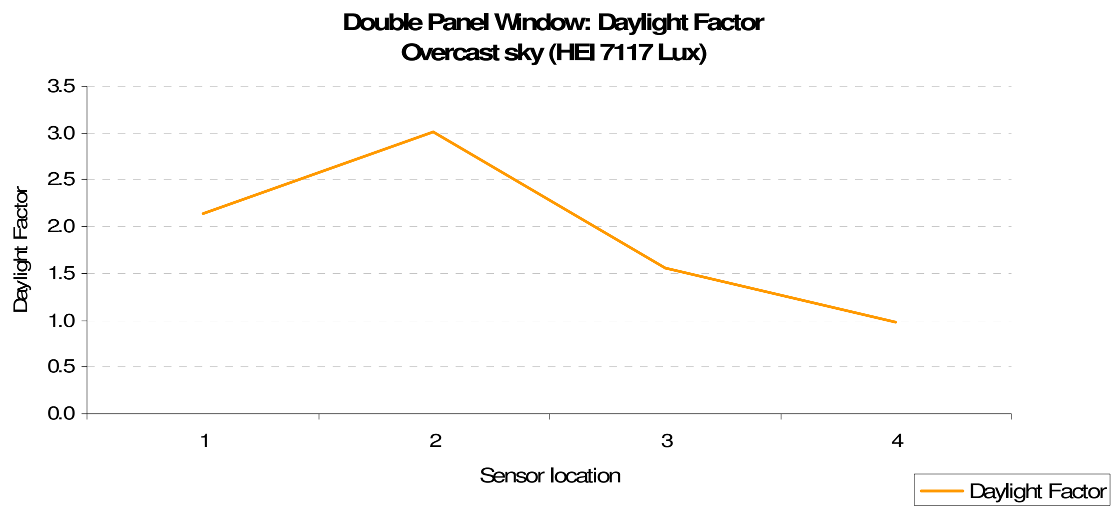


Fig. 28 Room A Double Panel Window: Daylight factor, overcast sky condition

5.3.2. Illuminance Level Analysis

The Double Panel Window illuminance levels do not vary much seasonally but change clearly throughout the day; morning values differ than the afternoon values because this window is facing east. For example, at 09:00am on June 21, the maximum illuminance level reaches up to 2200 Lux at height of 60 cm and 90 cm. The images in Figure 29 below show the daylighting variation inside the space.

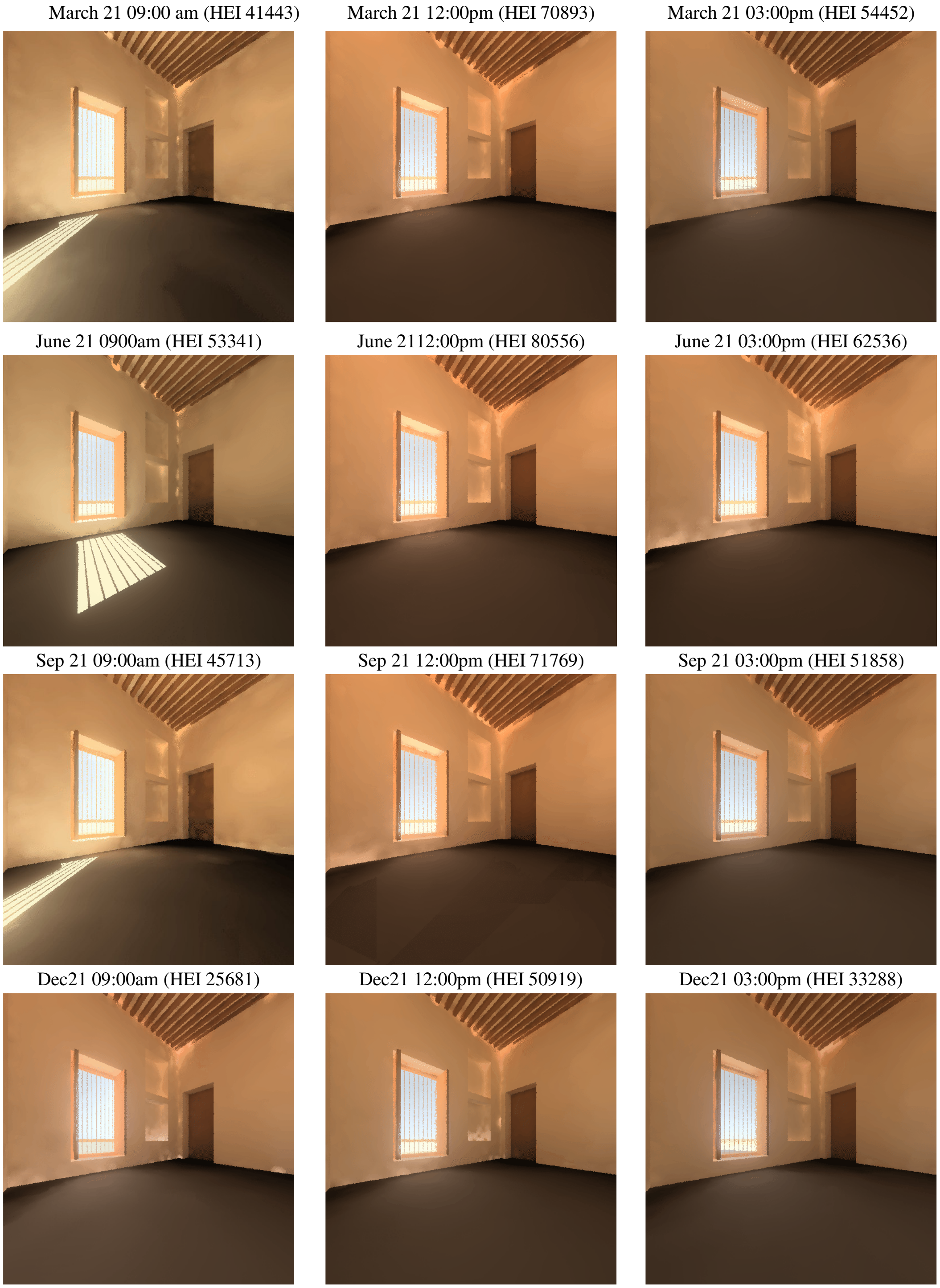


Fig. 29 Room A- East facing: Daylight variation at solstices and equinoxes

5.3.3. Illuminance Distribution and Uniformity Analysis

The sensor locations were set in a rectangular grid, as shown in Chapter III, to calculate the horizontal illuminance level in the building. The contour plots of horizontal illuminance levels in a reference grid of each prototype were analyzed. The illuminance gradient (or diversity of illuminance in CIBSE guidelines) and uniformity of illuminance parameters were used for analyzing the illuminance uniformity. For the illuminance gradient (the ratio of maximum to minimum illuminance), the lower the value is, the better uniformity it yields; while for uniformity of illuminance (the ratio of minimum to average illuminance), a higher value indicates better uniformity.

The horizontal illuminance contours of the double panel window are illustrated in Figures 30-35, for clear sky conditions.

The illuminance gradient values are presented in Table 9, and uniformity of illuminance values are presented in Table 10.

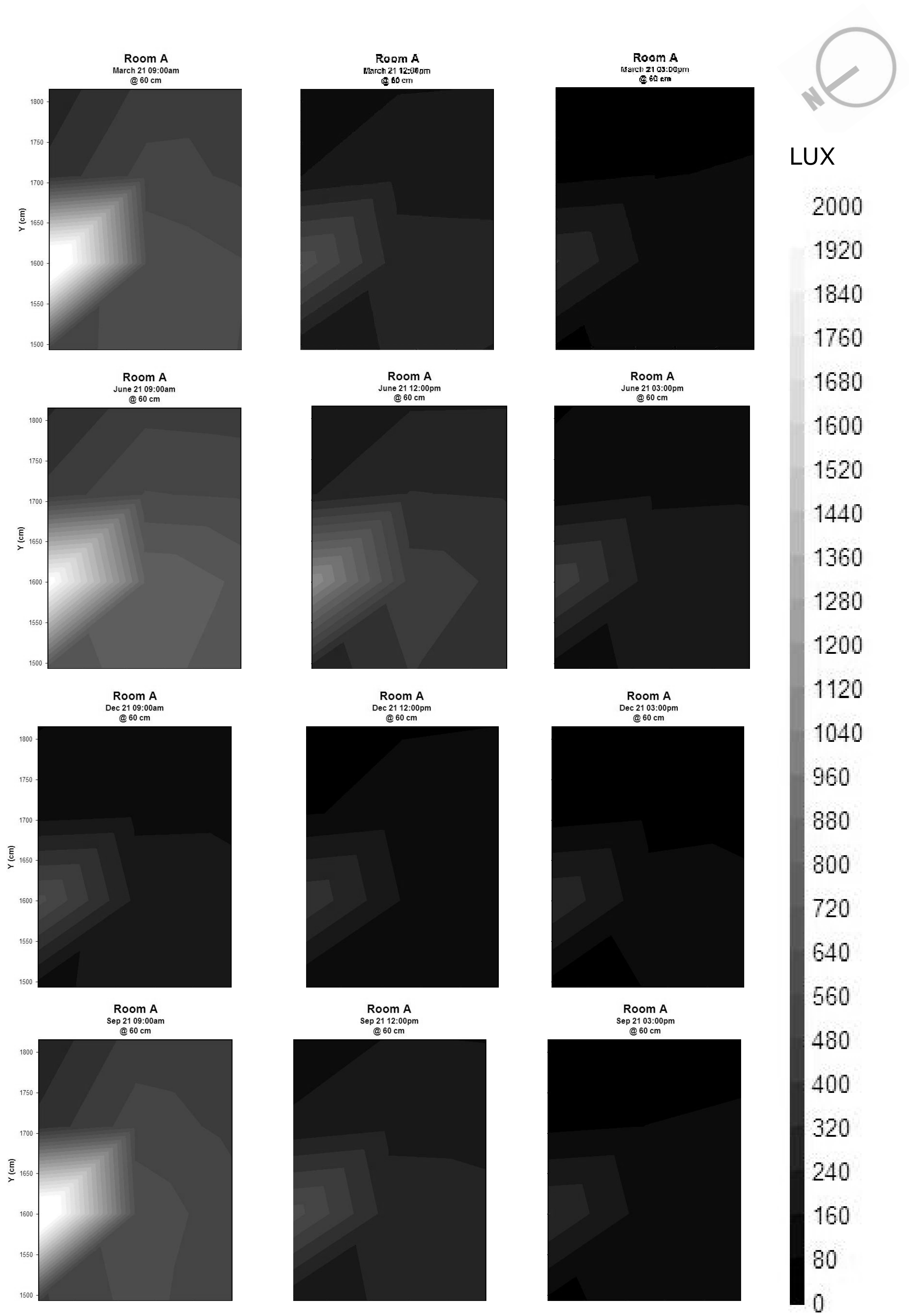


Fig. 30 Room A: Double Panel Window at 60cm: Illuminance contour on plan, clear sky condition

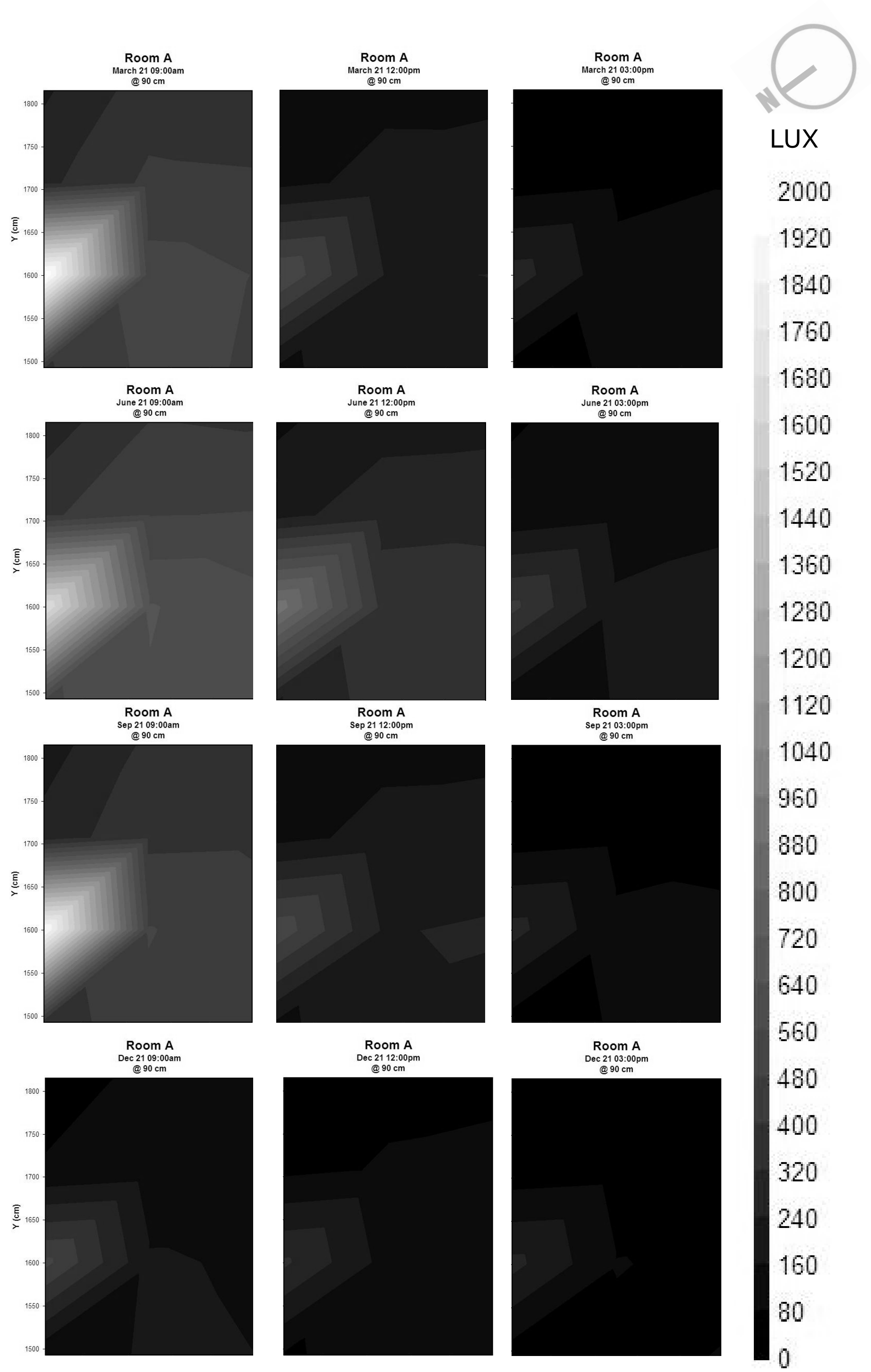


Fig. 31 Room A: Double Panel Window at 90cm: Illuminance contour on plan, clear sky condition

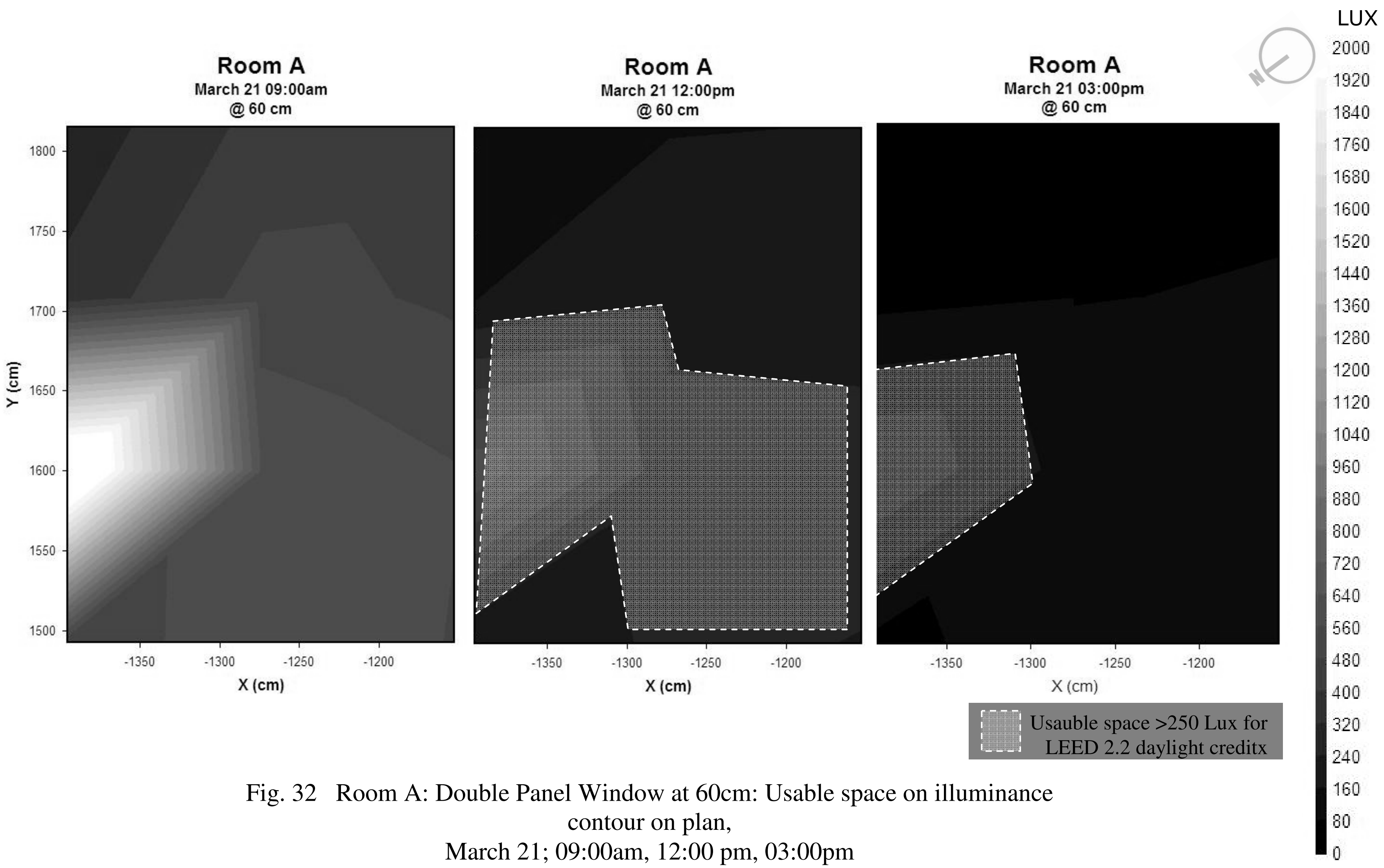


Fig. 32 Room A: Double Panel Window at 60cm: Usable space on illuminance contour on plan,
March 21; 09:00am, 12:00 pm, 03:00pm

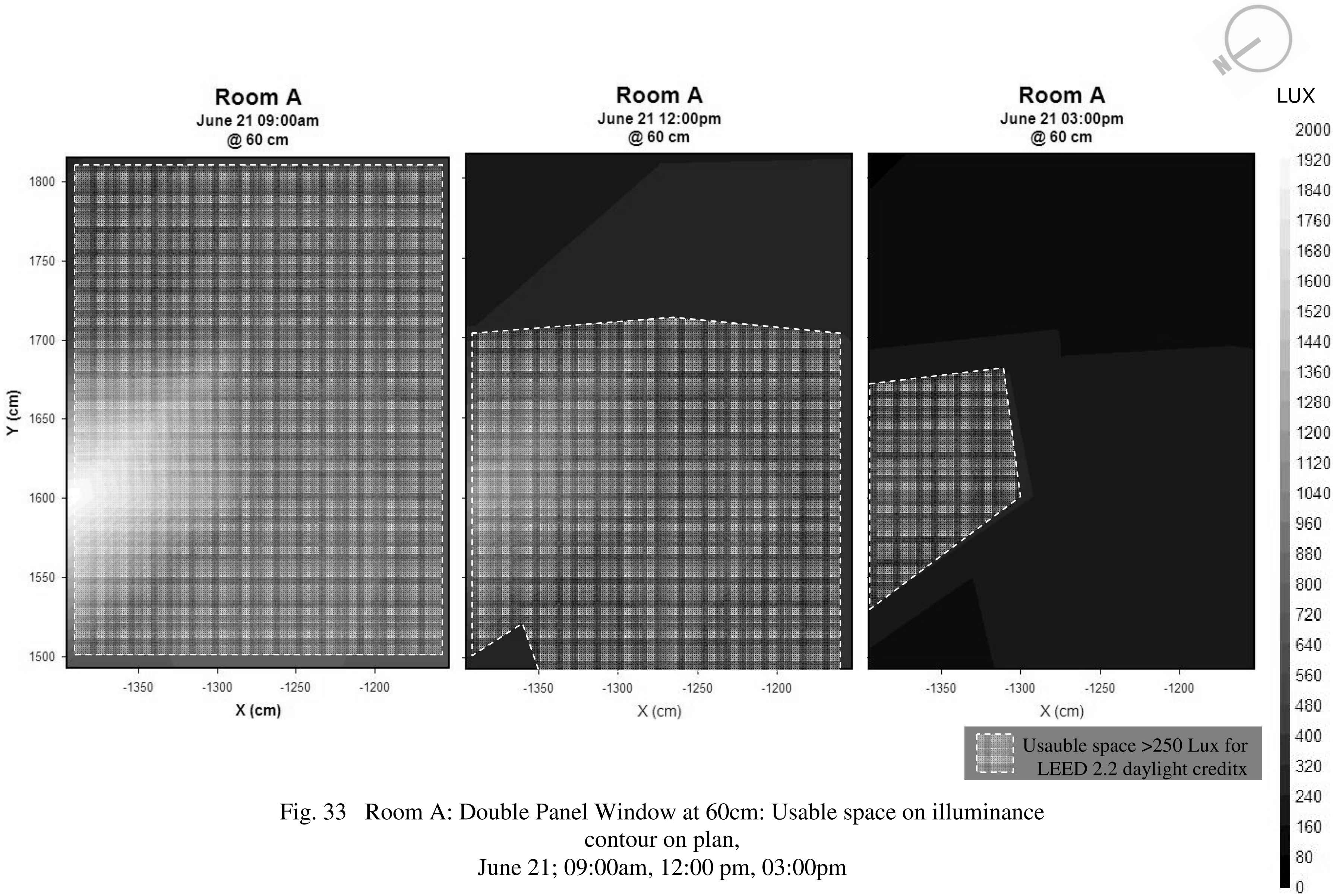


Fig. 33 Room A: Double Panel Window at 60cm: Usable space on illuminance contour on plan,
June 21; 09:00am, 12:00 pm, 03:00pm

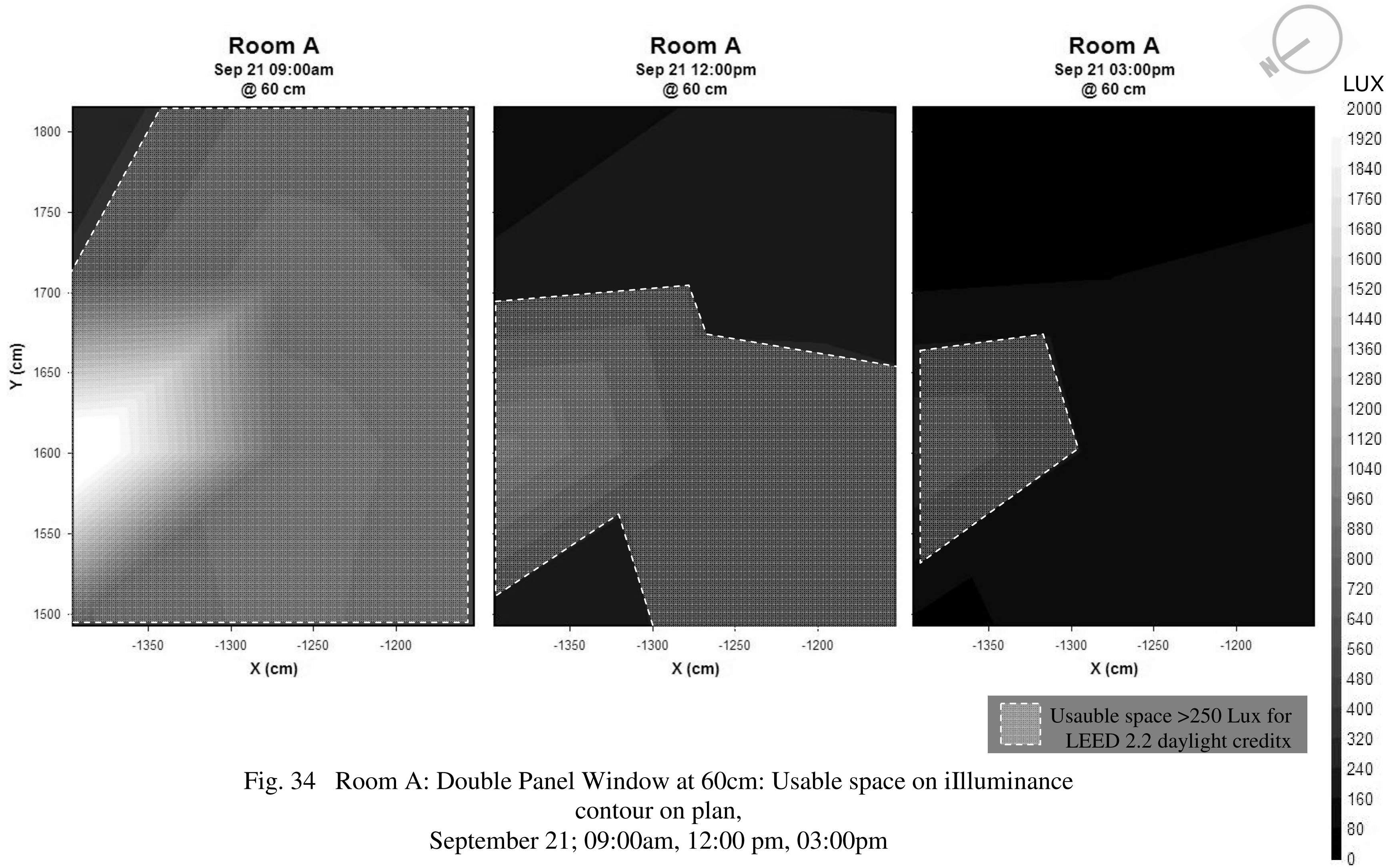


Fig. 34 Room A: Double Panel Window at 60cm: Usable space on iIlluminance contour on plan,
September 21; 09:00am, 12:00 pm, 03:00pm

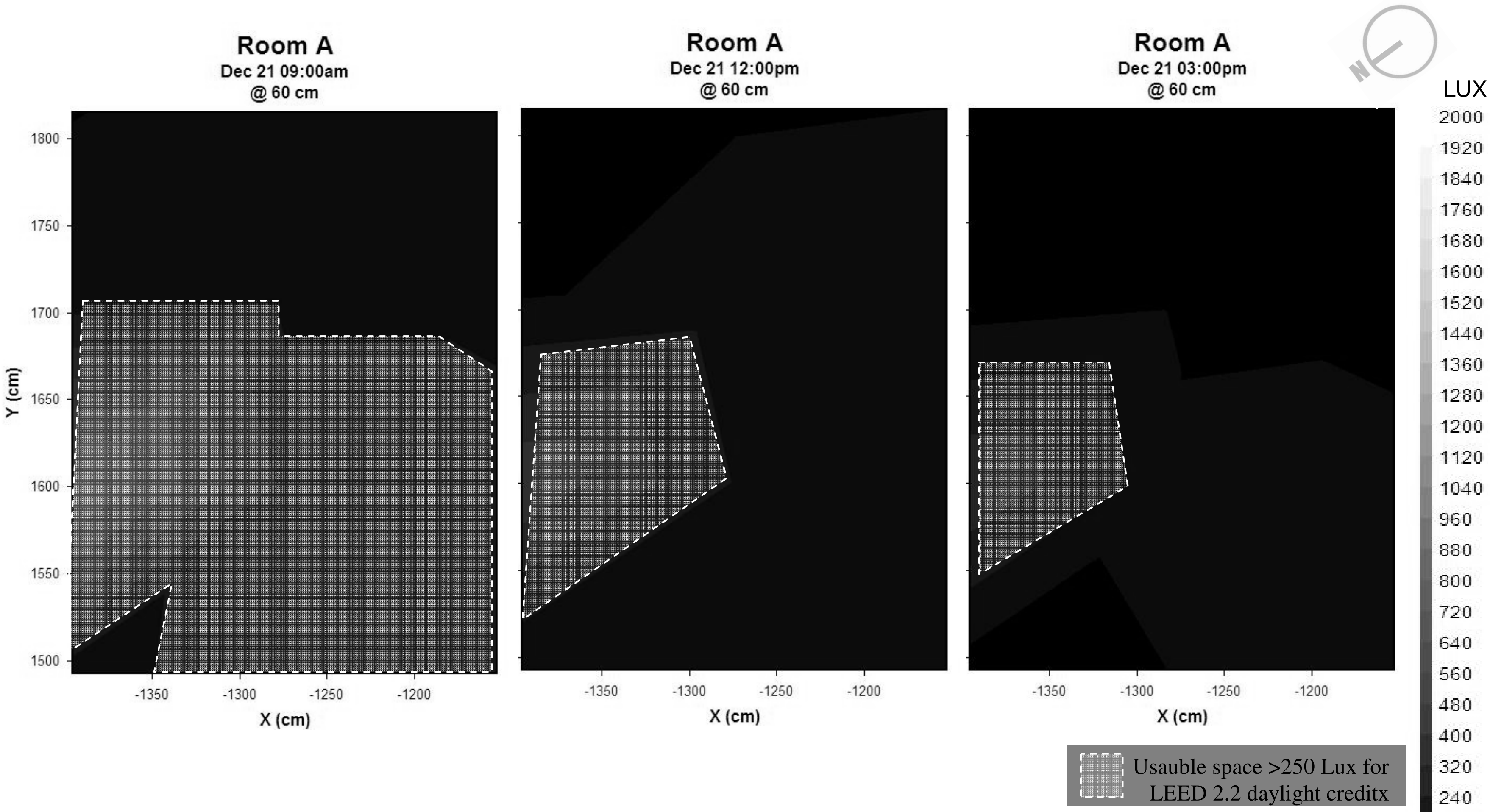


Fig. 35 Room A: Double Panel Window at 60cm: Usable space on illuminance contour on plan,
December 21: 09:00am, 12:00 pm, 03:00pm

Table 9
Double panel window: Illuminance gradient at 60cm & 90 cm

		Room A	
		60cm	90cm
Clear Sky			
21-Mar	09:00am	9	9
	12:00pm	6	6
	03:00pm	9	9
21-Jun	09:00am	6	6
	12:00pm	7	6
	03:00pm	6	6
21-Sep	09:00am	9	10
	12:00pm	5	6
	03:00pm	9	9
21-Dec	09:00am	8	8
	12:00pm	7	7
	03:00pm	13	11

Table 10
Double panel window: Uniformity of illuminance at 60 cm & 90 cm

		Room A	
		60cm	90cm
Clear Sky			
21-Mar	09:00am	0.42	0.44
	12:00pm	0.46	0.48
	03:00pm	0.35	0.48
21-Jun	09:00am	0.44	0.46
	12:00pm	0.43	0.37
	03:00pm	0.43	0.37
21-Sep	09:00am	0.41	0.46
	12:00pm	0.48	0.36
	03:00pm	0.36	0.36
21-Dec	09:00am	0.42	0.42
	12:00pm	0.40	0.36
	03:00pm	0.29	0.36

From the images and both tables this prototype does not meet CIBSE. For the illuminance gradient, CIBSE recommends that the ratio of maximum-to-minimum should not exceed 5:1. In the case of the double panel window, the minimum value is 6 and the maximum value is 13, so it is double the recommended value.

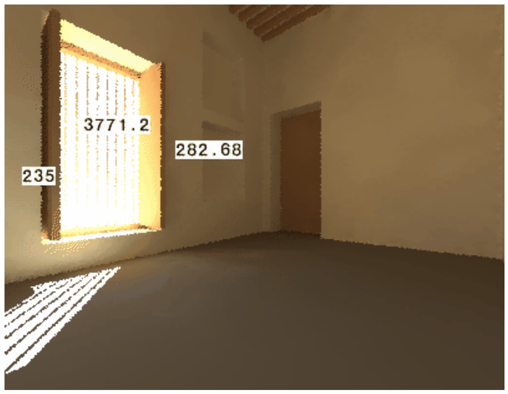
From the uniformity of illuminance table the maximum value is 0.48, while the CIBSE recommendation was that the value should not fall beyond 0.7.

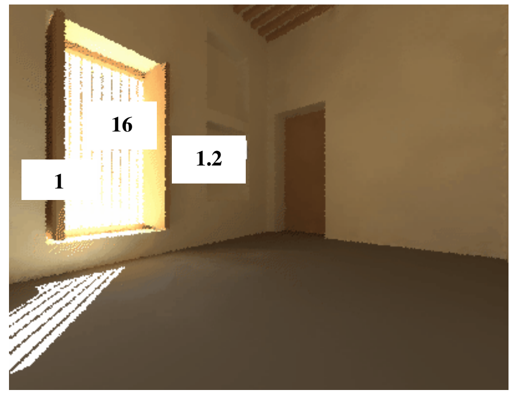
Illuminance levels measured at 90 cm are more uniform than at 60cm because of its proximity to daylight source.

To meet LEED 2.2 daylight credit 75% of all regularly occupied areas must achieve at least 250 lux at noon in the equinox. From Fig. 33 Room A has achieved this requirment.

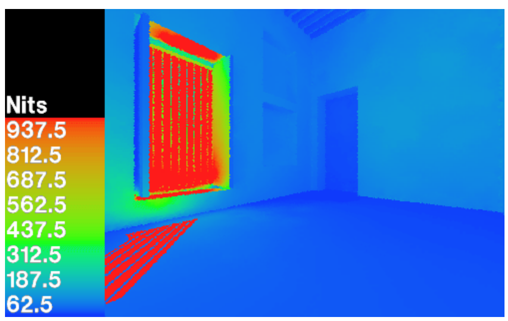
5.3.4. Glare Analysis

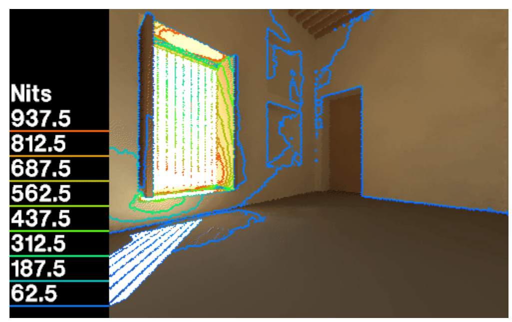
Luminance value and rendering of the reference points are presented in Fig. 36. Since this space is facing east, luminance value was calculated for June 21 at 09:00am.





(a) (b)





(c) (d)

Fig. 36 Double Panel Window: Glare analysis pictures from DR (a) luminance at reference points in the room (b) luminance ratio (c) falsecolor (d) iso-contour rendering

According to CIBSE recommendations of luminance difference ratio within the field of view the value should not exceed 10:1. In this case the value was 16:1; which falls beyond CIBSE value. According to Stein and Reynolds recommendation it falls within the recommended value.

5.4. Gypsum Decorative Panels Analysis

5.4.1. Daylight Factor

For the Gypsum Decorative Panels, the maximum daylight factor is 0.16 % and the minimum is 0.11%. According to CIBSE the minimum recommended daylight factor should not fall below 5%. See Fig. 37.

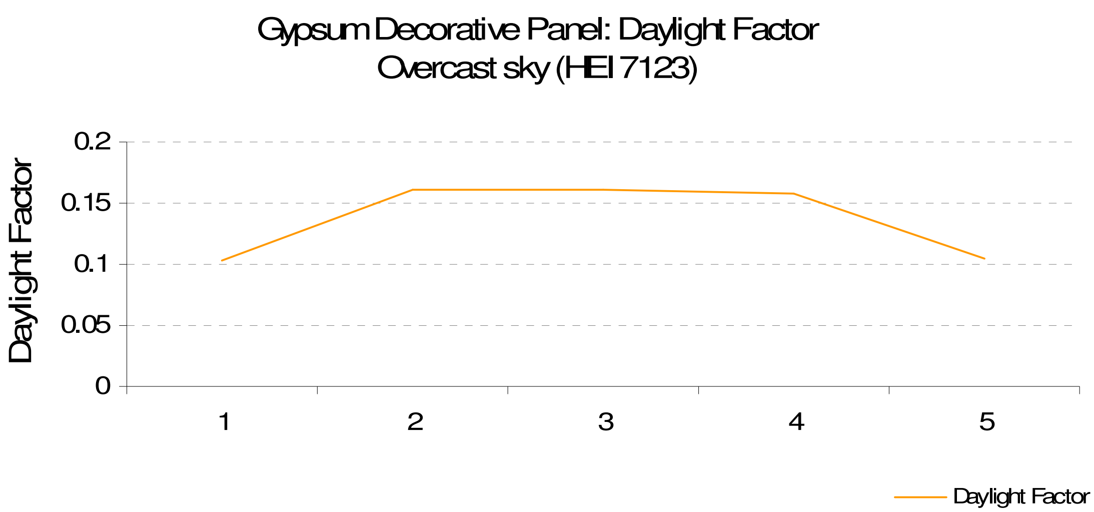


Fig. 37 Room B gypsum decorative panels: Daylight factor, overcast sky condition

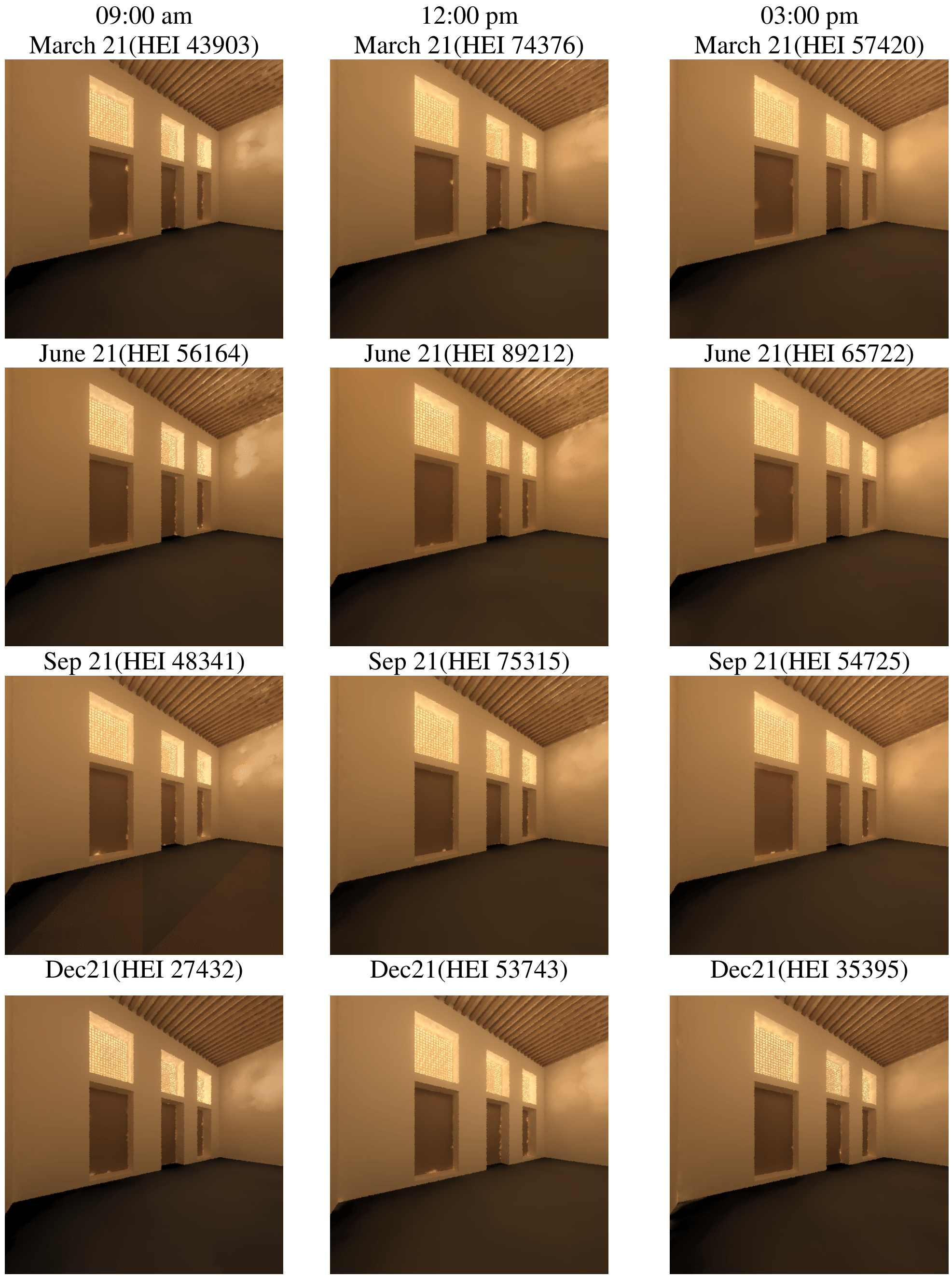


Fig. 38 Room B-North facing: Daylight variation at solstice and equinoxes

5.4.2. Illuminance Level Analysis

The gypsum decorative panels illuminance levels do not vary much either seasonally or throughout the day because the room is facing North. Figure 38 shows the daylighting variation.

5.4.3. Illuminance Distribution and Uniformity Analysis

The horizontal illuminance contours of the gypsum decorative panel are illustrated in Fig. 39 & Fig. 40 for clear sky conditions.

Maximum illuminance level in space B is below 120 Lux, there for it falls below the required 300 Lux of useable space.

The illuminance gradient values are presented in Table 11, and uniformity of illuminance values are presented in Table 12.

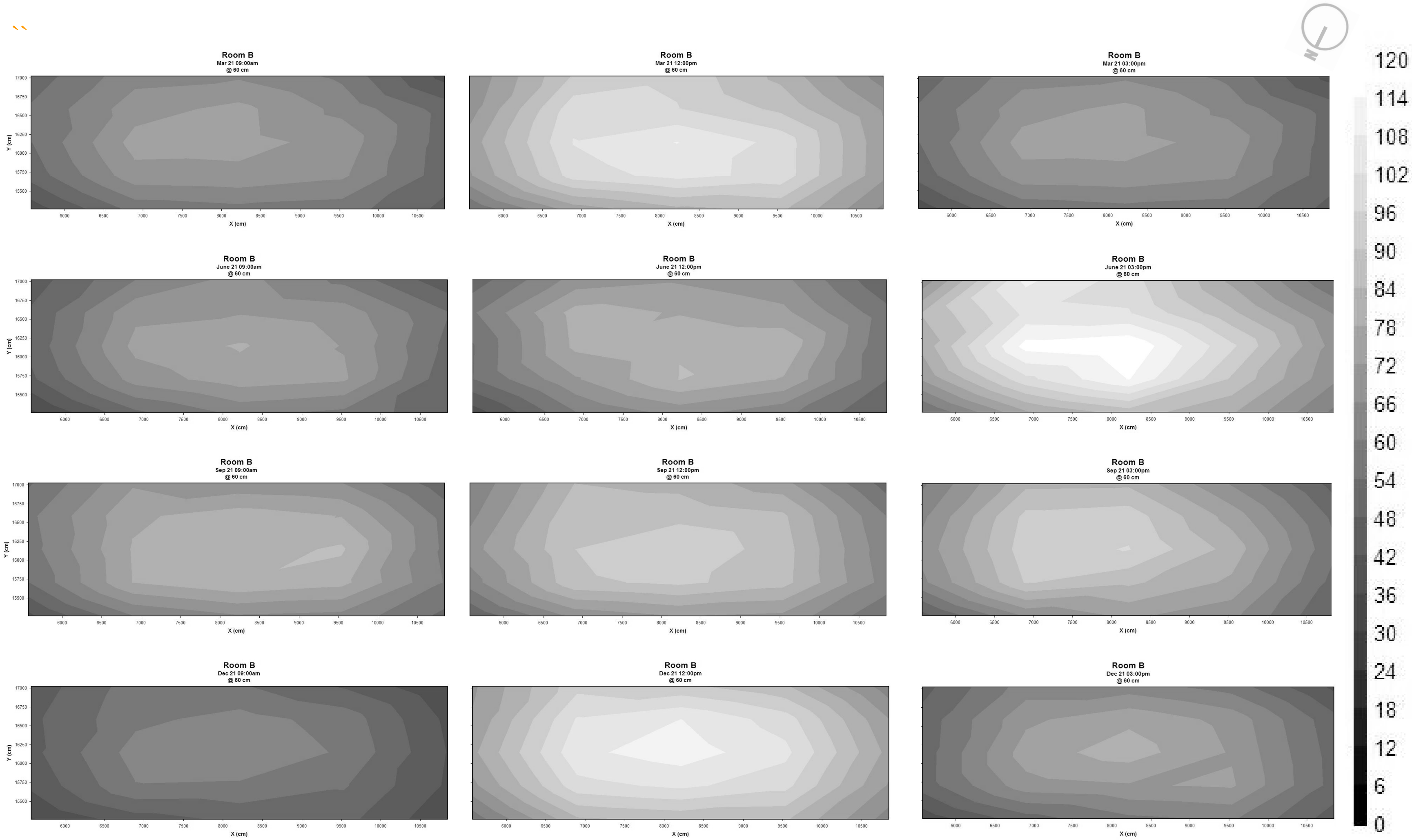


Fig 39 Room B gypsum decorative panel at 60 cm: Illuminance contour on plan, clear sky condition

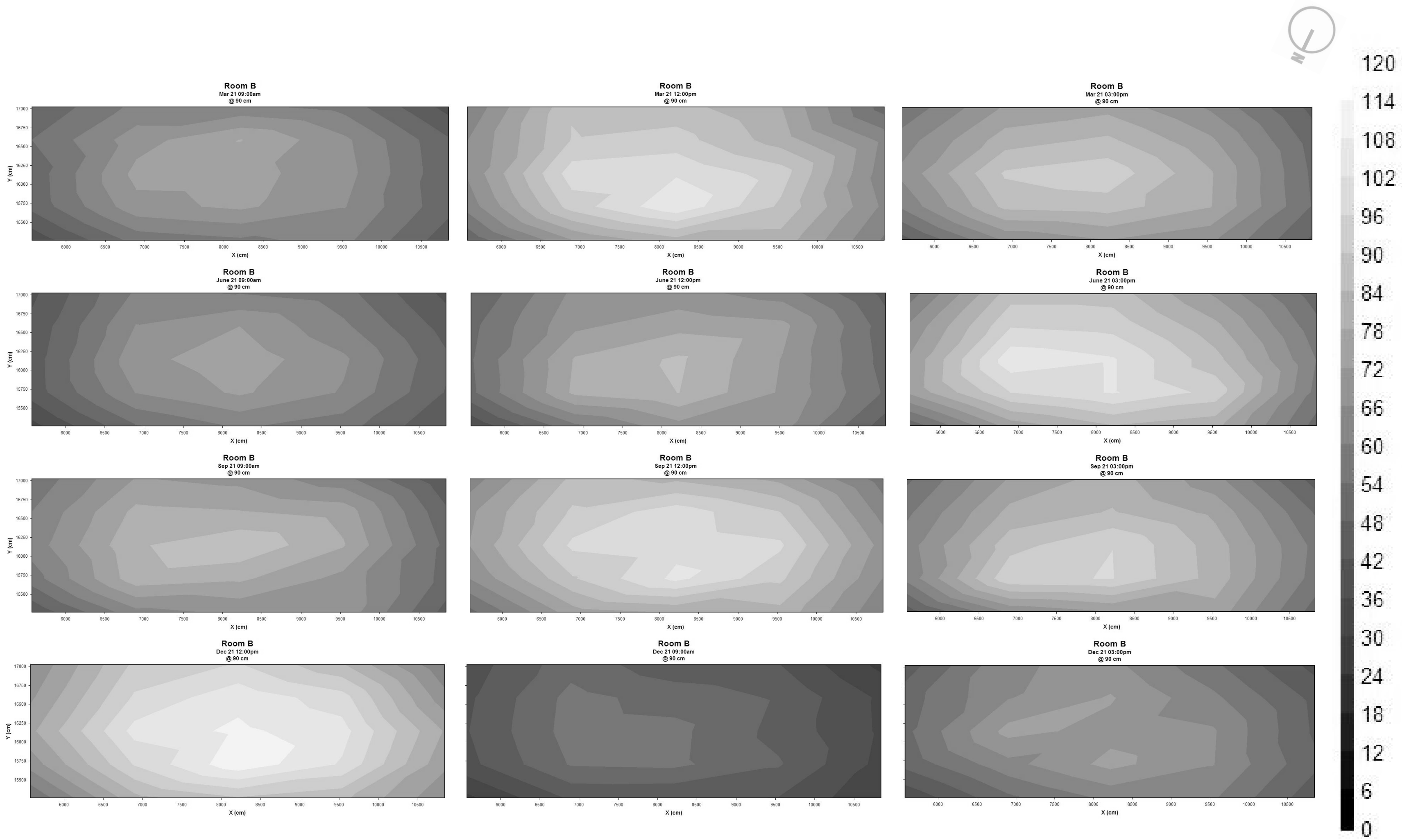


Fig. 40 Room B gypsum decorative panel at 90 cm:iIlluminance contour on plan, clear sky condition

Table 11
Gypsum decorative panel: Illuminance gradient at 60cm & 90 cm

		Room B	
		60cm	90cm
Clear Sky			
21-Mar	09:00am	2	2
	12:00pm	2	2
	03:00pm	2	2
21-Jun	09:00am	2	2
	12:00pm	2	2
	03:00pm	2	2
21-Sep	09:00am	2	2
	12:00pm	2	2
	03:00pm	2	2
21-Dec	09:00am	2	2
	12:00pm	2	2
	03:00pm	2	2

Table 12
Gypsum decorative panel: Uniformity of illuminance at 60 cm &90 cm

		Room B	
		60cm	90cm
Clear Sky			
21-Mar	09:00am	0.66	0.65
	12:00pm	0.66	0.64
	03:00pm	0.66	0.66
21-Jun	09:00am	0.59	0.61
	12:00pm	0.60	0.59
	03:00pm	0.63	0.65
21-Sep	09:00am	0.61	0.65
	12:00pm	0.66	0.66
	03:00pm	0.64	0.64
21-Dec	09:00am	0.71	0.65
	12:00pm	0.66	0.64
	03:00pm	0.64	0.65

From the images and both tables this prototype has a uniform gradient; CIBSE recommendation was that the ratio of maximum-to-minimum should not exceed 5:1. In the case of the Double panel window the minimum value is 2, which shows a space with a very uniform gradient with almost no variation.

In the uniformity of illuminance, the values ranged from 0.59 to 0.66 except for one case on 21 December at 09:00 am where the value was 0.71, which is little bit lower than the recommended value of 0.7 assigned by CIBSE. Both heights show similar variation.

This space does not meet LEED 2.2 credit because it should acheive at least 250 lux and the maximum lux in this space is 120.

5.4.4. Glare Analysis

Luminance value and rendering of the reference points are presented in Fig. 41. Since this space is facing north, luminance value was conducted on June 21 at 12:00 pm

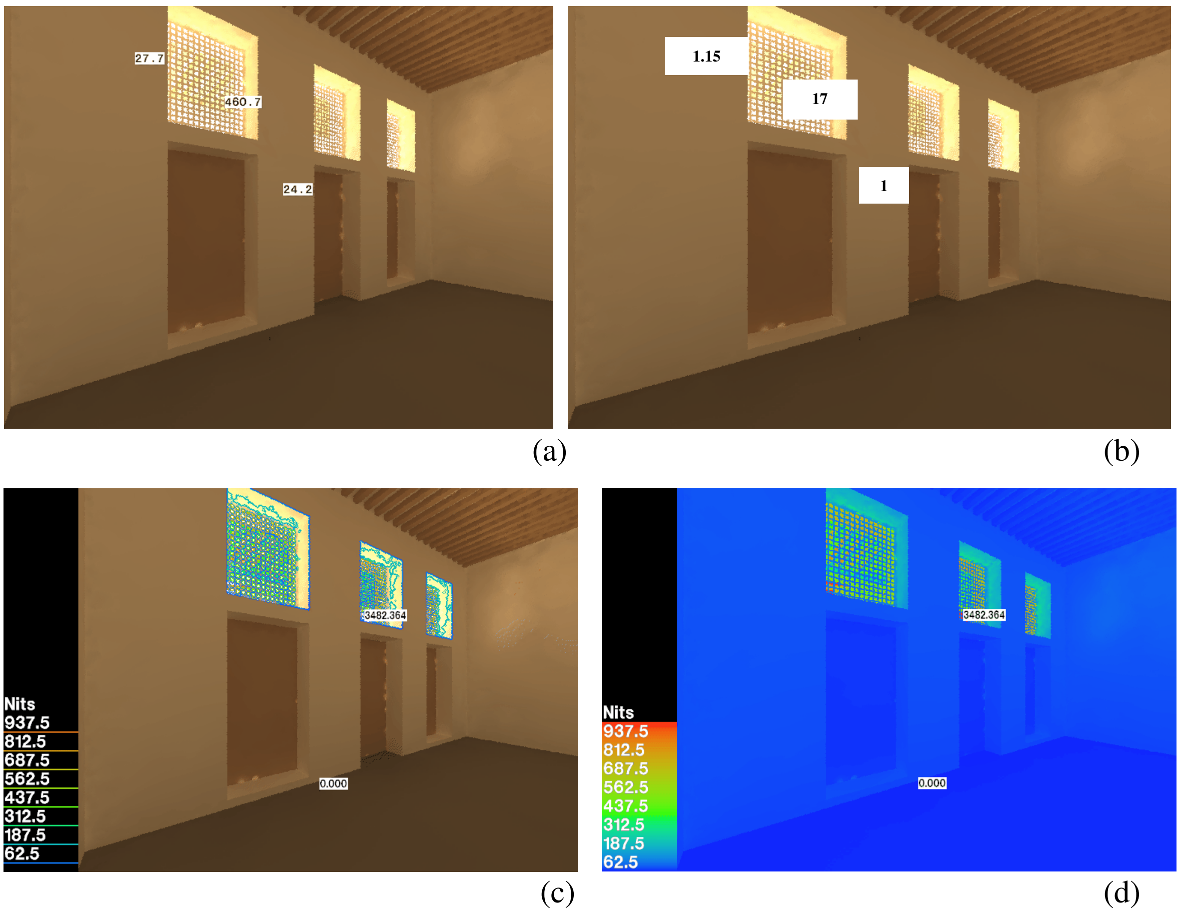


Fig. 41 Gypsum Decorative Panel: Glare analysis pictures from DR (a) luminance at reference points in the room (b) luminance ratio (c) falsecolor (d) iso-contour rendering

According to CIBSE recommendations for luminance difference ratio, the value should not exceed 10:1. In this case the value was 17:1, which exceeds CIBSE maximum recommended value. According to Stein and Reynolds' recommendation it falls within the recommended value.

5.5. Wind Tower Analysis

5.5.1. Daylight Factor

The daylight factor was used with overcast sky conditions; two reference points were placed in room B, one under the wind tower and one at the middle of the room.

From Fig. 42 the maximum daylight factor is 1.22 % and the minimum is 0.18%. According to both CIBSE the value falls way beyond the recommended.

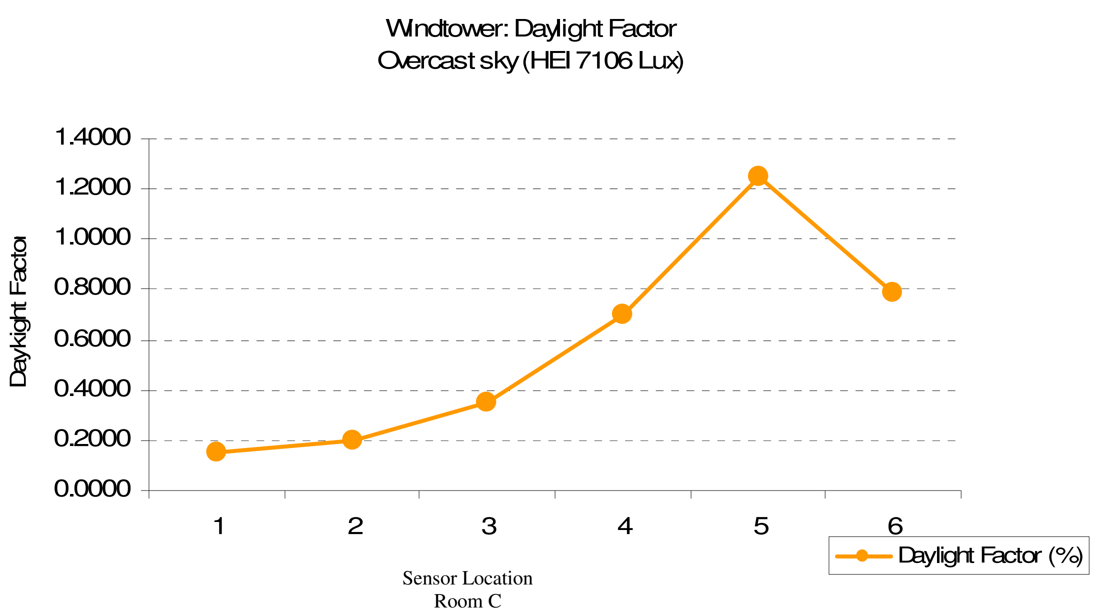


Fig. 42 Room C gypsum decorative panels: Daylight factor, overcast sky condition

5.5.2. Illuminance Level Analysis

The wind tower illuminance levels do not vary much seasonally but it does throughout the day under the wind tower exactly.

The images in the Fig.43 below show the daylighting variation inside the space.

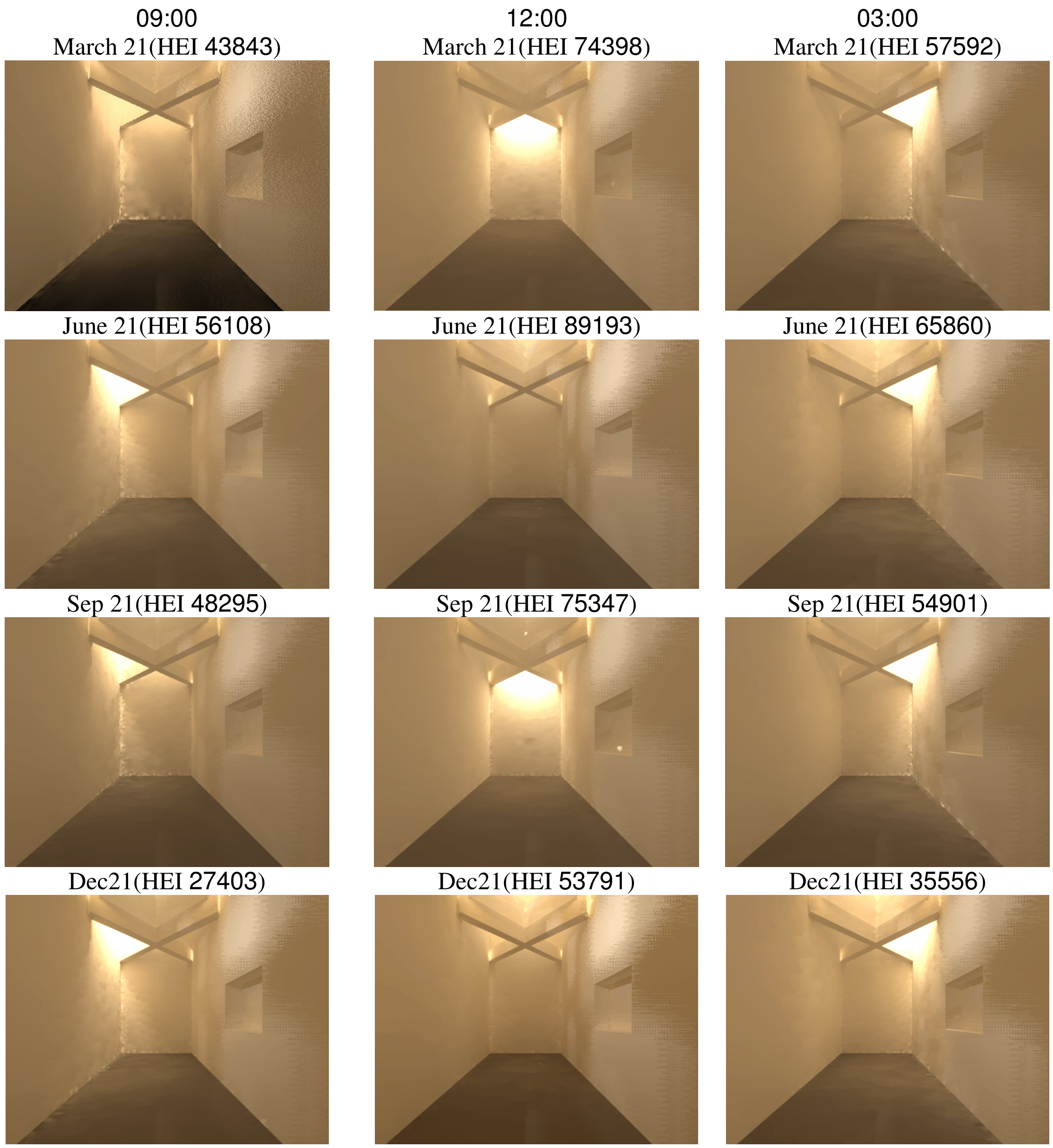


Fig. 43 Room C-four way orientation: Daylight variation at solstices and equinoxes

5.5.3. Illuminance Distribution and Uniformity Analysis

The sensor locations were set in a rectangular grid, as shown in Chapter III, to calculate the horizontal illuminance level in the building. The contour plots of horizontal illuminance levels in a reference grid of each prototype were analyzed. The illuminance gradient (or diversity of illuminance in CIBSE guidelines) and uniformity of illuminance parameters were used for analyzing the illuminance uniformity. For the illuminance gradient (the ratio of maximum to minimum illuminance), the lower the value, the better uniformity it yields, while for uniformity of illuminance (the ratio of minimum to average illuminance), a higher value indicates better uniformity.

The horizontal illuminance contours of wind tower are illustrated in Fig.44 to Fig.47 for clear sky conditions.

The illuminance gradient values are presented in Table 13, and uniformity of illuminance values are presented in Table 14.

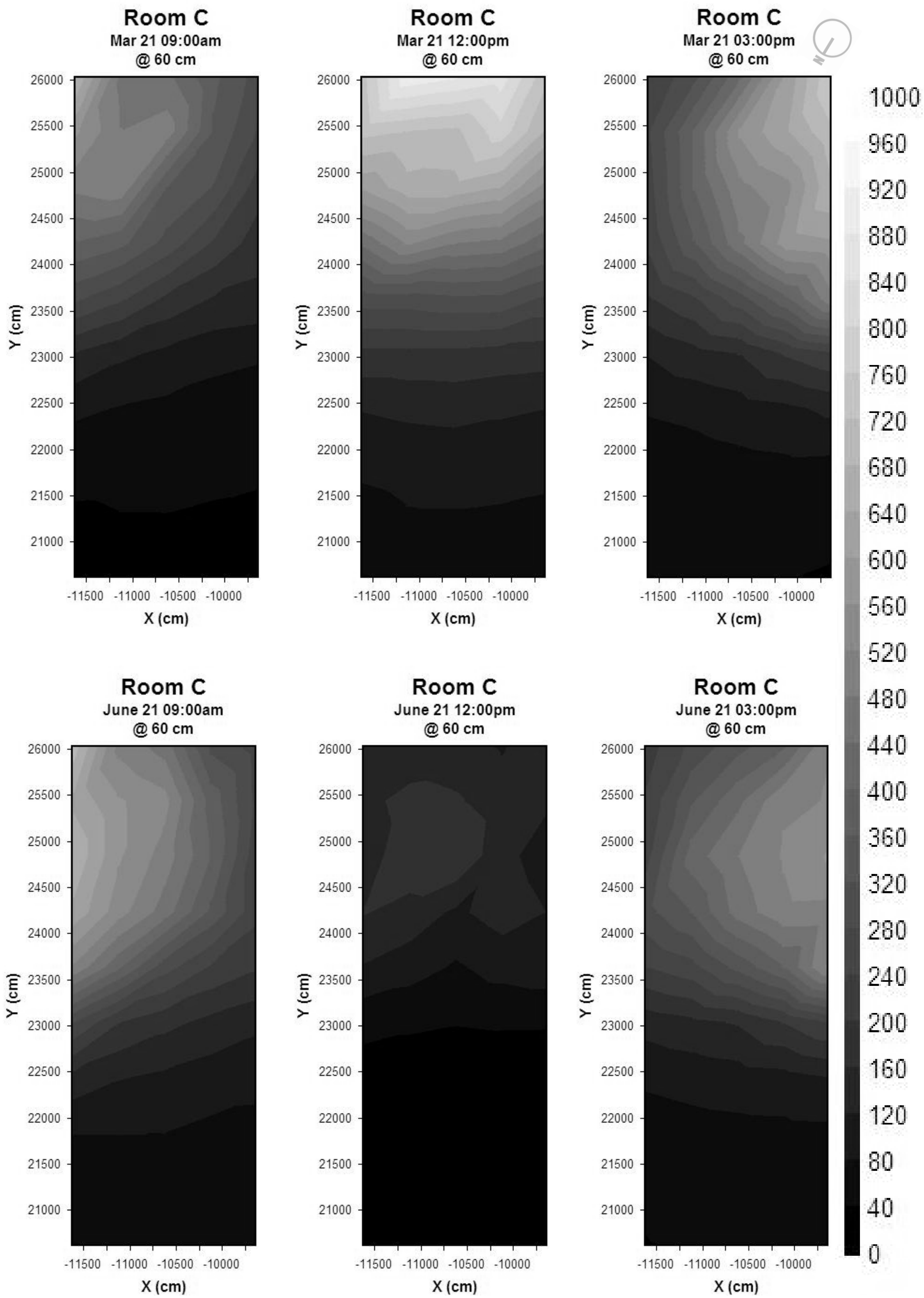


Fig. 44 Room C wind tower at 60cm: Illuminance contour on plan, clear sky condition (spring equinox & summer solistice)

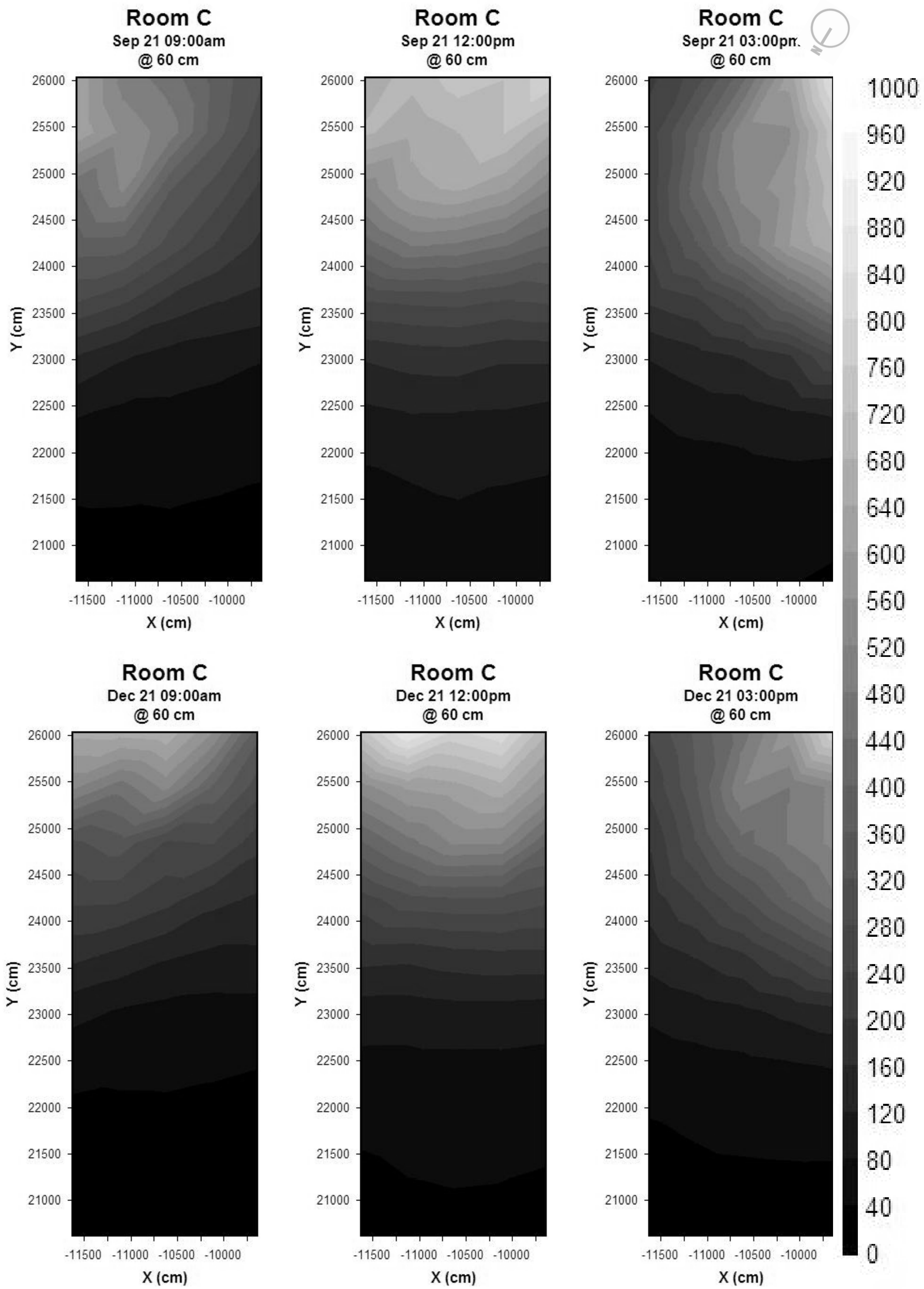


Fig. 45 Room C wind tower at 60cm: Illuminance contour on plan, clear sky condition (fall equinox & winter solistice)

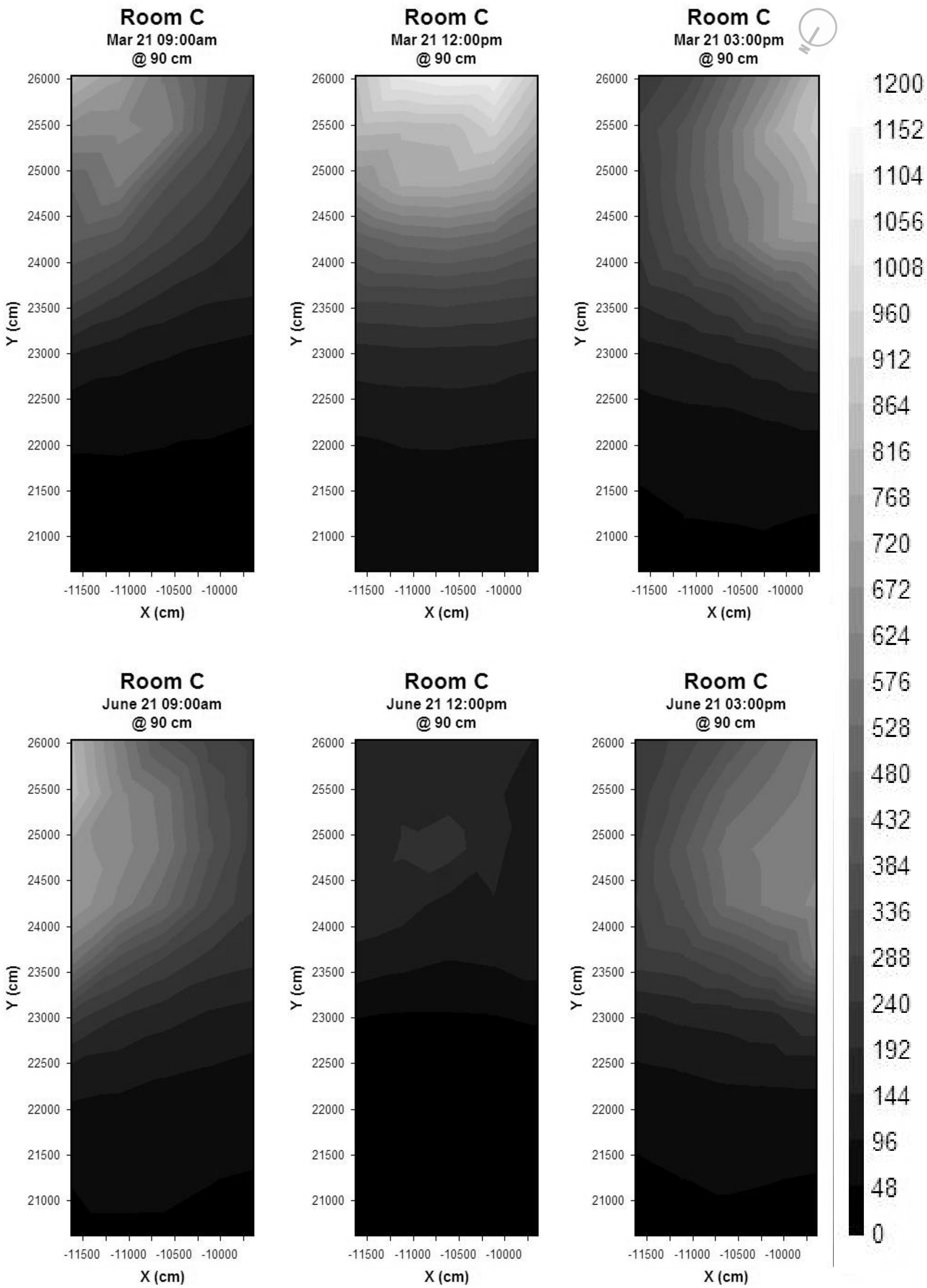


Fig. 46 Room C wind tower at 90 cm: Illuminance contour on plan, clear sky condition (spring equinox & summer solistice)

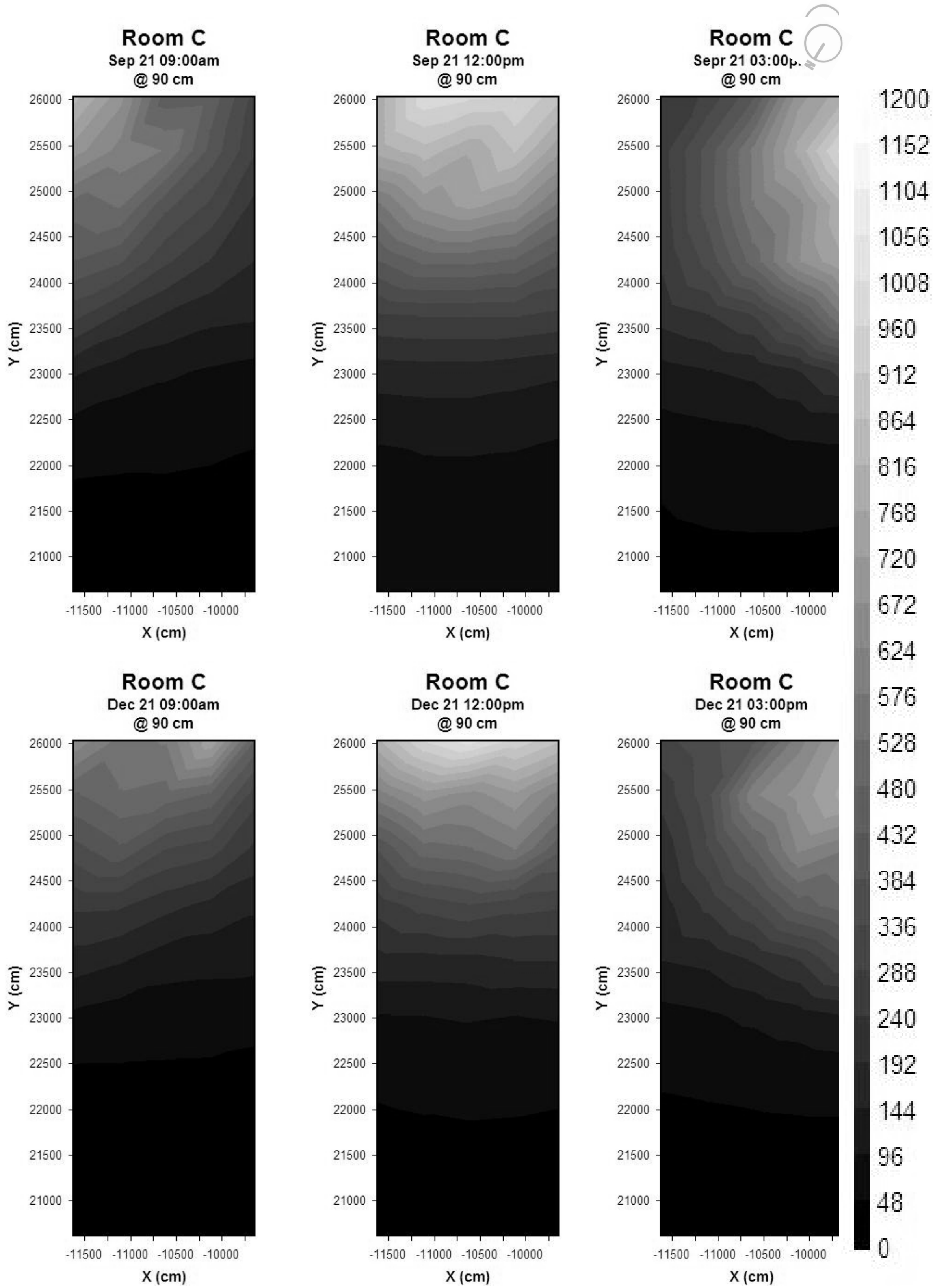


Fig. 47 Room C wind tower at 90 cm: IIlluminance contour on plan, clear sky condition (fall equinox & winter solistice)

Table 13
Wind tower: Illuminance gradient at 60cm & 90cm

		Space C 60cm	Space C 90cm
Clear Sky			
21-Mar	09:00am	22	35
	12:00pm	14	18
	03:00pm	21	25
21-Jun	09:00am	15	22
	12:00pm	16	17
	03:00pm	14	19
21-Sep	09:00am	23	38
	12:00pm	13	37
	03:00pm	25	28
21-Dec	09:00am	30	38
	12:00pm	27	37
	03:00pm	31	34

Table 14
Wind tower: Uniformity of illuminance at 60cm & 90cm

		Space C 60cm	Space C 90cm
Clear Sky			
21-Mar	09:00am	0.15	0.11
	12:00pm	0.18	0.16
	03:00pm	0.14	0.12
21-Jun	09:00am	0.18	0.14
	12:00pm	0.16	0.14
	03:00pm	0.16	0.13
21-Sep	09:00am	0.13	0.10
	12:00pm	0.19	0.10
	03:00pm	0.13	0.12
21-Dec	09:00am	0.12	0.10
	12:00pm	0.12	0.10
	03:00pm	0.12	0.10

It can be seen from the images and both tables this prototype has a non-uniform gradient. The CIBSE recommendation is that the ratio of maximum-to-minimum should not exceed 5:1. In the case of the wind tower the minimum value is 14, and the maximum 38. For the uniformity of illuminance, the values ranged from 0.10 to 0.18, which is lower than the recommended value of 0.7 assigned by CIBSE.

Both heights shows similar variation and both fall within the recommended values of CIBSE.

For LEED 2.2 credit this space does not meet the 75% of the required area at the equinox.

5.5.4. Glare Analysis

Luminance value and rendering of the reference points are present in Fig. 48. Luminance value was conducted on March 21 at 12:00pm.

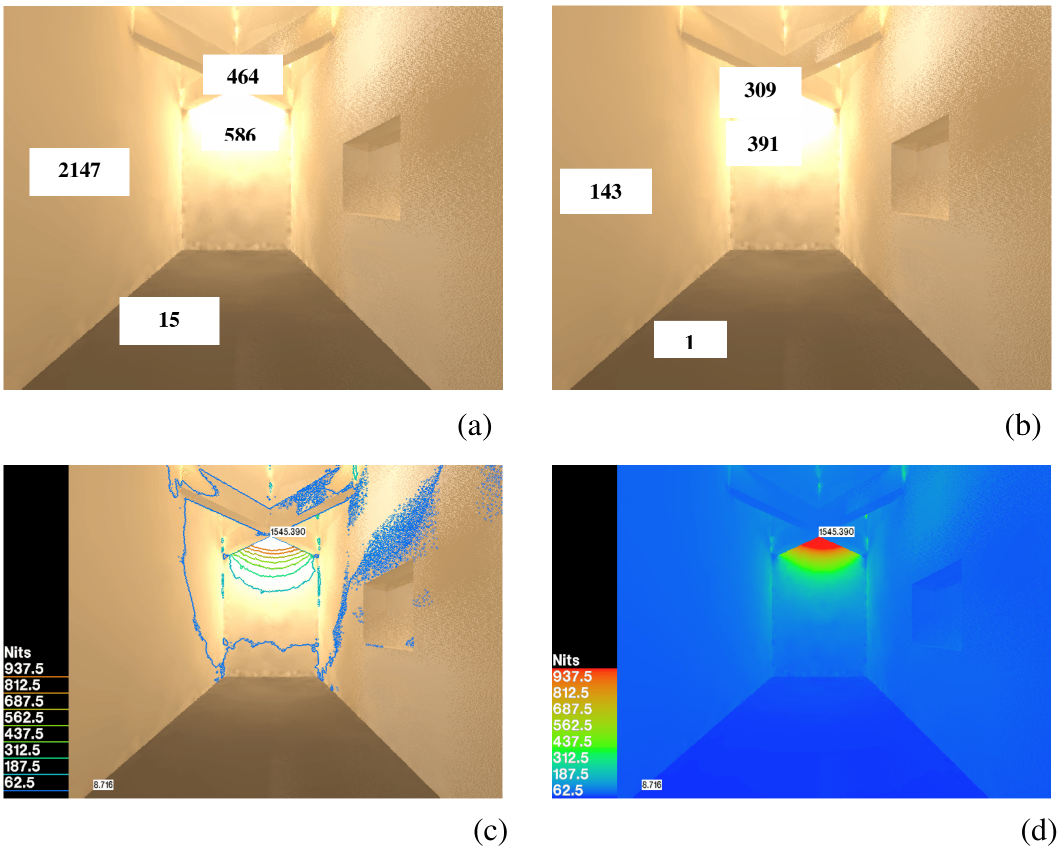


Fig. 48 Wind Tower: Glare analysis pictures from DR (a) luminance at reference points in the room (b) luminance ratio (c) falsecolor (d) iso-contour rendering.

According to CIBSE recommendations of luminance difference ratio the value should not exceed 10:1. In this case the value was 391:1 which exceed the required. According to Stein and Reynolds recommendation it falls beyond the recommended value.

5.6. Summary on Lighting Performance Evaluation

5.6.1. Summary on Illuminance Level

Since the exact task of the space was not defined, and light office work and general space were assigned as the task of the space, the values assigned by CIBSE are;

Offices: 300- 500 Lux

General areas: 100-200 Lux.

For double panel window performance in terms of illuminance level, the values change dramatically in the course of the day and throughout the year. The maximum illuminance value was 2000 Lux, which occurred at 09:00 am on March 21, June 21 and September 21. This value is much higher than the recommended task illumination provided by CIBSE. It can work for both office and general area task.

Gypsum Decorative Panel illuminance value measured between 18-120 Lux, the minimum value happened at 09:00 am on March 21 and December 21. The maximum value of 120 Lux occurred at 03:00 pm on June 21. These variations of values make it more useable in general area tasks. The values remain within the same range throughout the year.

Wind tower has a significant variance in the illuminance value; it ranges from 40-1000 Lux. With certain measures this prototype could be incorporated in spaces for both office and general use.

5.6.2. Summary on Illuminance Distribution and Uniformity

Tables 15-16 below summarize the illuminance gradient and tables 17-18 summarize uniformity of Illuminance of all prototypes for easier comparison of values.

Table 15
All prototypes: Illuminance gradient at 60 cm

60cm		Space A	Space B	Space C
Clear Sky				
21-Mar	09:00am	9	2	22
	12:00pm	6	2	14
	03:00pm	9	2	21
21-Jun	09:00am	6	2	15
	12:00pm	7	2	16
	03:00pm	6	2	14
21-Sep	09:00am	9	2	23
	12:00pm	5	2	13
	03:00pm	9	2	25
21-Dec	09:00am	8	2	30
	12:00pm	7	2	27
	03:00pm	13	2	31

Table 16
All prototypes: Illuminance gradient at 90 cm

90cm		Space A	Space B	Space C
Clear Sky				
21-Mar	09:00am	9	2	35
	12:00pm	6	2	18
	03:00pm	9	2	25
21-Jun	09:00am	6	2	22
	12:00pm	6	2	17
	03:00pm	6	2	19
21-Sep	09:00am	10	2	38
	12:00pm	6	2	37
	03:00pm	9	2	28
21-Dec	09:00am	8	2	38
	12:00pm	7	2	37
	03:00pm	11	2	34

Best performance

Table 17
All prototypes: Uniformity of illuminance at 60 cm

60cm		Space A	Space B	Space C
Clear Sky				
21-Mar	09:00am	0.42	0.66	0.23
	12:00pm	0.46	0.66	0.26
	03:00pm	0.35	0.66	0.20
21-Jun	09:00am	0.44	0.59	0.23
	12:00pm	0.43	0.60	0.44
	03:00pm	0.43	0.63	0.29
21-Sep	09:00am	0.41	0.61	0.24
	12:00pm	0.48	0.66	0.27
	03:00pm	0.36	0.64	0.20
21-Dec	09:00am	0.42	0.71	0.20
	12:00pm	0.40	0.66	0.22
	03:00pm	0.29	0.64	0.18

Table 18
All prototypes: Uniformity of illuminance at 90 cm

90cm		Space A	Space B	Space C
Clear Sky				
21-Mar	09:00am	0.44	0.65	0.11
	12:00pm	0.48	0.64	0.16
	03:00pm	0.48	0.66	0.12
21-Jun	09:00am	0.46	0.61	0.14
	12:00pm	0.37	0.59	0.14
	03:00pm	0.37	0.65	0.13
21-Sep	09:00am	0.46	0.65	0.10
	12:00pm	0.36	0.66	0.10
	03:00pm	0.36	0.64	0.12
21-Dec	09:00am	0.42	0.65	0.10
	12:00pm	0.36	0.64	0.10
	03:00pm	0.36	0.65	0.10

Best performance

From the above tables, the gypsum decorative panel performs the best among the three prototypes in both terms of illuminance gradient and uniformity of illuminance. The wind tower performs the worst in terms of illuminance gradient and uniformity, falling below the required values assigned by CIBSE.

Work plane height does not alter the values much. Having the work plane at either 60 cm or 90 cm does not change the illuminance gradient or the illuminance uniformity much; in fact, the values are almost identical.

5.6.3. Summary on Glare Analysis

The glare analysis of all prototypes showed that the space have higher variations of luminance levels than the recommended (for office listing) by CIBSE. Both gypsum decorative panels and double panel window fell within Stein and Reynolds assigned value. This might be because of the miniature aperture it is consisted of, which filters sun rays and minimize the angle of view.

Wind tower showed higher luminance ratios compared to the other two prototypes.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The three prototypes evaluated in this research showed different outcomes. From the results, the overall lighting performance of the gypsum decorative panel prototype outperforms the other prototypes under CIE clear sky conditions. It presented better uniformity and distribution than other systems, with a lower illuminance level. Illuminance level can be increased by adding more window area.

Even though double panel window yields a higher illuminance level than the two other prototypes during most of the year, the double panel window prototype has poor lighting performance in terms of glare, light distribution and uniformity. This can be reduced by using diffuse film or glazing on the opening.

The wind tower performed well mainly under the area of the wind tower itself, but adding another window to the space will increase the illuminance level throughout the space, resulting in a better illuminance gradient and uniformity.

These conclusions are made based on the performance of the three prototypes only and can be applied only to identical systems with similar space geometry and orientation. Hence, these results cannot be generalized to all double panel windows, gypsum decorative panels, or wind towers. A different space environment incorporating glazing will result in different performance.

When considering glare, additional glare design strategies could be tested, such as the addition of external shading devices.

From the above study and analysis derived from it, we can clearly see the lessons learned from studying these systems. With four panels to choose from, and with its placement on a lower than usual level, the double panel window is a flexible design strategy. Occupants can decide which panel to close or open based on their needs. The gypsum decorative panel has an innovative technique of filtering sun rays. With the use of intricate small openings in the panel allowing a percentage of the total light entering the space, thus controlling the light level as desired. The wind tower in addition to its importance in terms of ventilating, it has a unique design of providing adequate light throughout the year. With its four sided opening light can enter the space anytime of the year.

These three prototypes carry an aesthetic and identity value to the culture of the UAE. Through the use of the derived values and conclusions, local public awareness can be increased on the importance of preserving indigenous buildings and the numerous lessons that can be learned from their study.

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APPENDIX A

INPUT PARAMETERS DETAILS

<u>Desktop Radiance 2.0 Beta input parameter tables.</u>

For Image Rendering in Simulation Manager

Sky and Weather	CIE Clear
Location	Dubai, UAE
Simulation Quantity	Luminance
Simulation Mode	Batch
Ambient Bounces	5
Mkillum Option	1
Turbidity	2

For Illuminance, Luminance Calculation in Simulation Manager

Sky and Weather	CIE Clear
Location	Dubai, UAE
Simulation Quantity	Illuminance/ Luminance
Simulation Mode	Batch to ASCII
Ambient Bounces	5
Mkillum Option	1
Turbidity	2

For Daylight Factor Calculation in Simulation Manager

Sky and Weather	CIE Overcast
Location	Dubai, UAE
Simulation Quantity	Illuminance/ Luminance
Simulation Mode	Batch to ASCII
Ambient Bounces	5
Mkillum Option	1
Turbidity	2

For Iso-contour, False Color Image Rendering in Image Analyzer

Units	Metric (Lux/ Candela per Square Meter)
Quantity	Illuminance/ Daylight Factor/Luminance
Scale	Linear

Reflectance Value Table

	On-Site		Desktop Radiance	
	Material Name	Reflectance (%)	Material Name	Reflectance (%)
Floor	carpet	19	Brown-grey	17.98
Walls, Daylight prototypes	Local Paint (Sarooj)	86.3	RAL_1014_Ivory	85.53
Ceiling, windows, door	Chandal Wood	29.8	Larch Wood	34
Iron Bars	Iron	N/A	Brushed Aluminum	79

APPENDIX B

DESKTOP RADIANCE 2.0 BETA BUGS

Two problems were encountered during the runs of DR;

Setting Camera Height

Problem: When definig a camera position in the Analysis option the height of the camera does not match that entered in the input field. If the height entered was 1 meter the camera is placed at 50 cm high, it always places the camera at half the specified height.

Solution: When defining the height always specify a height double than the required one.

Define Location

Problem: When setting a new location sometimes the time simulated does not match the real time specified.

Solution: To make sure that the simulated time is the correct one

- first you need to set the time zone to other.
- Make sure that the turbidity value is set to the correct value. Turbidity value of any location can be found at http://www.helioclim.net/linke/
- Make sure that the standard meridian has a negative value if it is in the eastern part of GMT.

VITA

Name: Maitha Mohammed AlNuaimi

Place of Birth: Dubai, United Arab Emirates

Address: P.O.Box: 252

Sharjah, United Arab Emirates

Educational Background: United Arab Emirates University, Alain, UAE

Bachelor of Science in Architecture (2001)

Texas A&M University, College Station, Texas,

Master of Science in Architecture (2007)

Interests: Architectural Daylighting and Sustainable Design

Organization:

President of the TAMU Student Chapter of the IESNA (Illuminating Engineering Society of North America) 2005-2006

Board member of the TAMU Student Chapter of the IESNA (Illuminating Engineering Society of North America) 2003-2005

Student member of IESNA 2003-2007

Awards:

Selected to attend the IESNA Centennial Conference New York, January 2005