Evaluating and Optimizing the Indoor Environment Quality of Historical Museums in UAE

تقييم وتحسين جودة البيئة الداخلية في المتاحف التاريخية
في دولة الإمارات العربية المتحدة

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Abstract

With the important role of museums in preserving the history for future generations in different societies, ancient historical artifacts are the main factor differentiating the indoor environments of museums from all other buildings environments.

This study identifies the current on going practices of UAE historical museums indoor environments in terms of artifact safety and preservation, intelligence and integration level of the different components, as well as the sustainability levels of the museums.

Surveys, on site measurements, as well as software simulations experiments were adopted for methodology, following the SOBANE strategy (Screening, Observation, Analysis and Expertise). These stages were implemented on three case study museums selected from Dubai and Sharjah.

Based on the evaluation result, further enhancement methods was proposed and assessed. The proposed solutions were framed within the museum parameters, considering the requirements for collection preservation, human health and comfort, as well as energy efficiency and intelligent components.

This paper aimed to involve the museum sector in the current concern of energy saving practices in the country, by adopting sustainable methods and increasing the efficiency of the environments as well as the building life cycle, which is a main concern for the historical areas.

This study is hoped to serve as a reference future guide for different museum's officials in the UAE to benefit from the information provided, and the evaluation results, in order to adopt strategies enhancing the indoor quality and energy performance of different museum projects across UAE.

Proposals, when possible were assessed in IESVE simulation software to quantify the energy reduction rates and evaluate the efficiency of implementation and the level of enhancements achieved.

Study results included reduction of 89% in light electricity, and overall 27.5% reduction in total electricy. Proposals were modeled and assesst with 99.62% accuracy from existing building.

Keywords: *Museums, Indoor Environment Quality, Sustainable Museums, Museums Practices, UAE, Museum Lighting.*

ملخص البحث

المحافظة على تاريخ الأمم ونقله للأجيال القادمة هو من أهم أدوار المتاحف في مختلف المجتمعات.
تواجد المقتنيات الأثرية والتحف الفنية النادرة توجب توفير بيئة داخلية ملائمة للحفاظ عليهم، من ما يؤدي الى ايجاد اختلاف عن بيئات باقي المباني.

هذا البحث يبرز الممارسات الحالية المتبعة في متاحف الامارات للحفاظ على المقتنيات الأثرية، ويقيم مستوى استدامة المبنى، بالاضافة الى مدى ذكاء وتكامل الأنظمة المستخدمة في مباني المتاحف التاريخية.

تمت الدراسة من خلال اتباع عدة مناهج منهم: زيارات ميدانية وقياس العوامل البيئية، استبيانات، بالاضافه الى إجراء تجارب من خلال الستخدام برنامج محاكاة.

يقدم البحث حلول ومقترحات لتحسين الوضع الحالي من خلال التقييم الذي اجري على ثلاث متاحف مختارة من دبي والشارقة. اخذين بالاعتبار متطلبات المقتنيات، صحة الانسان وراحته، بالاضافة الى اختيار حلول تقلل استهلاك الكهرباء وتحسن من مستوى الانظمة في المبنى.
عند الامكان تم اختبار الحلول المقدمة باستخدام برنامج IES VE لقياس معدل خفض استهلاك الكهرباء في كل مقترح.
تضمنت نتائج الدراسة تخفيض ٨٩٪ نسبة استهلاك الكهرباء في الإضاءه سنوياً. وتم تخفيض اجمالي الكهرباء بنسبة ٢٧.٥٪. دقة الحسابات والتجارب تمحورت حول نسبة ٩٩.٦٢٪ مقارنة بالمبنى الحالي.

يهدف هذا البحث الى توجيه اهتمام المتاحف في الدولة لمواكبة الممارسات الحالية في اطار تحسين و تخفيض استهلاك الطاقة والتوجه نحوالامستدامة.

من المؤمل ان يكون هذا البحث بمثابة مرجع لمسؤلي المتاحف في الامارات للاستفاده من المعلومات والنتائج الواردة، لاعتماد استراتيجيات تحسن من جودة بيئة المتاحف في اطار تقليل استهلاك الطاقة وتعزيز مستوى استدامة وذكاء المبنى.

إِلَى كُلِّ مَنْ أَنَارَ دَرْبِي بِالعِلْمِ

To all whom enlightened
my journey with knowledge

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Chapter 1

Introduction

1.1. Introduction

The growth in population and the increased energy demand is a very well-known fact nowadays, that all parties in different countries are seeking different methods to reduce their energy consumption and preserve the resources for the future generations. As this high demand on energy is resulting in inequity in the nature cycle in regenerating resources. The amount of carbon produced from the different fossil fuel consumption is increasing significantly, that can't be absorbed and replaced by nature.

Different countries based on their energy demand and consumption, are having various ecological footprints globally. The fast growth and great development that has happened over short time in GCC countries, has lead them to have strong ecological footprint on the world (Fig 1.1) (Global Footprint Network, 2010).

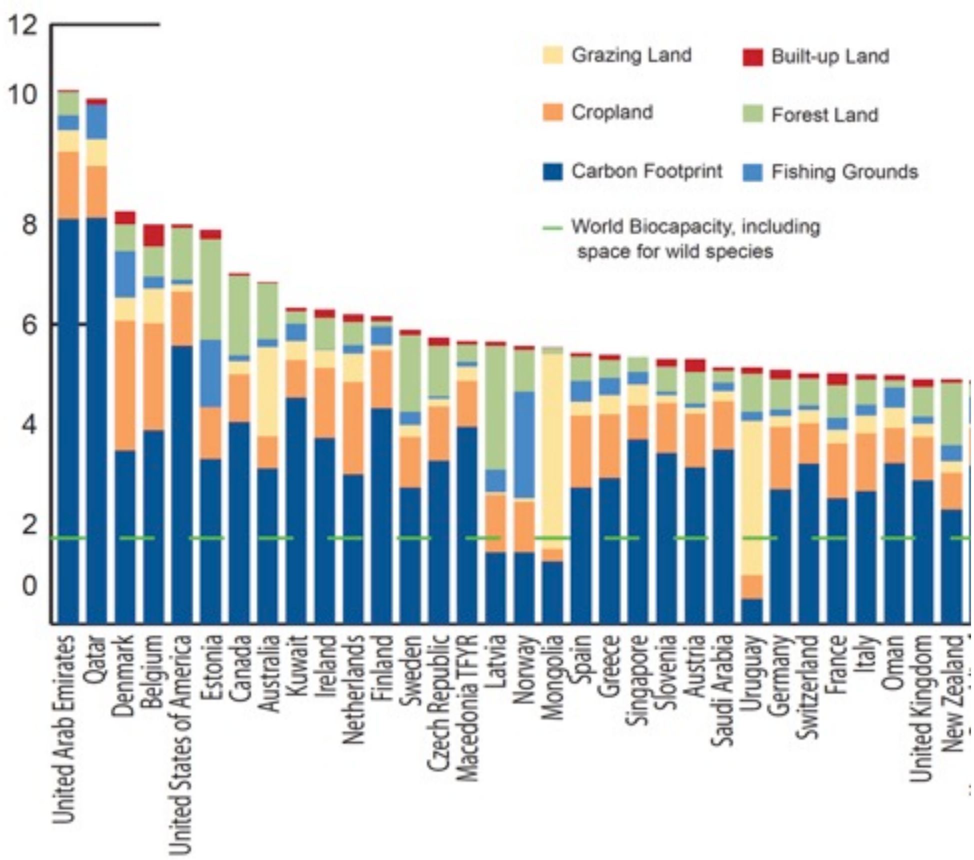

Figure 1.1 Ecological footprints by country per person 2007

(Global Footprint Network, 2010)

UAE's strong vision and commitment towards enhancing the crucial status towards the environment has improved this situation. According to the report published by the government in terms of the achievements of the country until 2013 the number of certified sustainable factories in the industrial sector had the growth of 150% from 2008 to 2012. Also, the energy generated from renewable resources in 2013 was 125 MWh. (UAE government, 2013). These indicate the concern of the government and the priority given to this aspect in order to enhance the impact on the environment. In 2014 the ecological footprint ranking of the country was changed to be the third as shown in (Fig. 1.2). These efforts are continues and the aim is to make the country a sustainable country in terms of environment and infrastructure by 2021. This is clearly addressed in the published national agenda for the country's vision for 2021 among other targets (UAE government, 2013).

The launch and completion of different sustainable projects in small and big scales are witnessed. Different customized rules and regulations such as ESTIDAMA in Abu Dhabi and the green building rules and regulations set by government of Dubai, are set to meet the local environmental conditions. Moreover, implementations of LEED rating standards for other projects in UAE are some of the efforts among many more.
Additionally, Dubai is hosting the most sustainable world Expo by 2020. The preparation for expo is changing the current condition and enhancing them. Also, this is leading the country in having bigger number of cultural projects.
From 2008 to 2013, the annual growth on cultural activities in the country increased by 33% and the income of the country from tourism had the growth of 6% annually from 2008 to 2012 (UAE vision 2021).

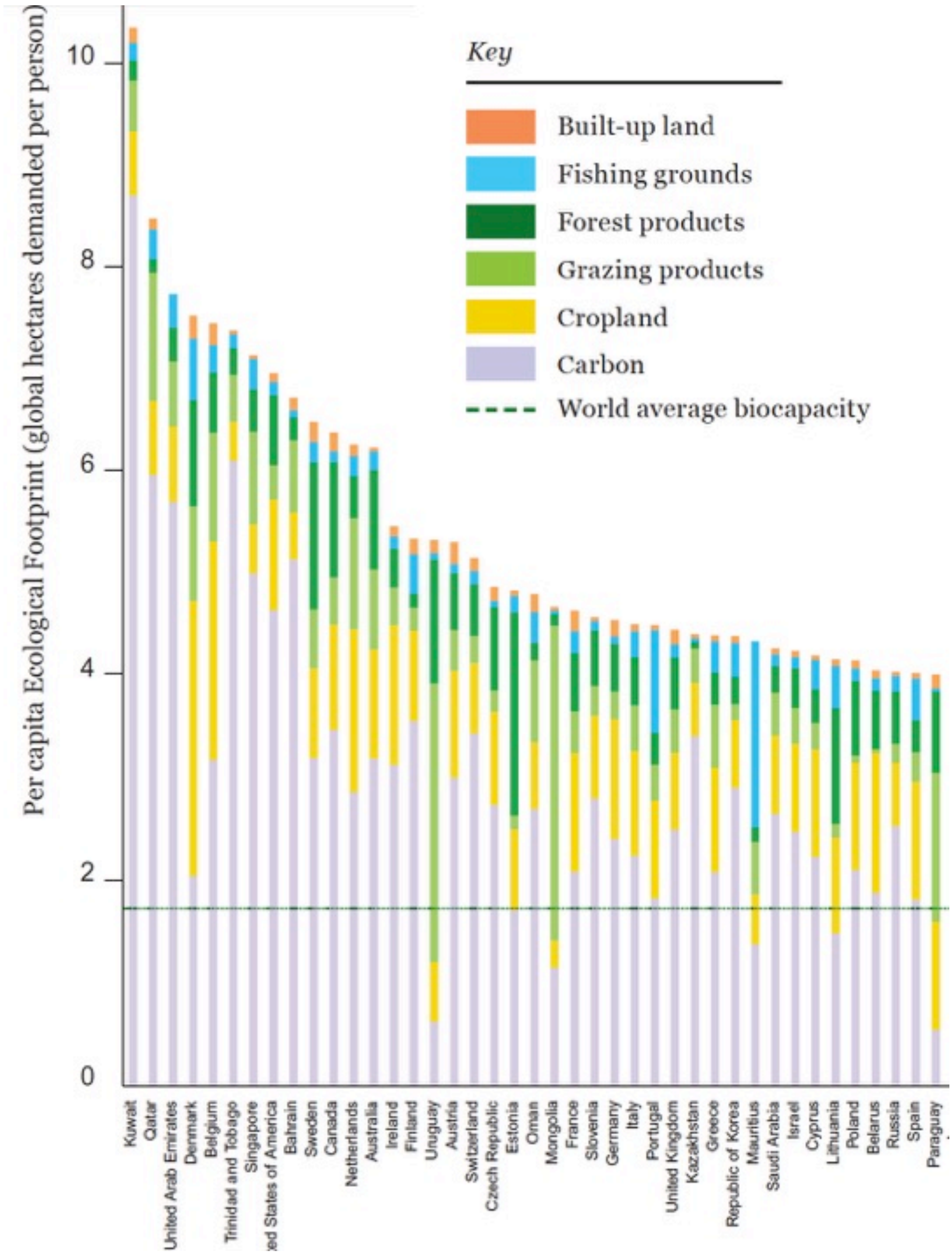

Figure 1.2. Ecological footprints by country per person 2014

(Global Footprint Network, 2014)

1.2. Study Motivations

With the growing demand for different cultural projects, specifically museum projects, the research in this filed is growing and different researches are conducted about museums.

Museums are the main link between past, present and future. They are a reliable source of information for researchers, and a good entertainer for teaching children history and other topics. In addition, they allow people to see different but original ancient artworks and artifact. Most importantly, museums are a main destination for tourists for learning the culture and history of the country they are visiting.

The presence of ancient historical artifacts is the main factor differentiating museums from all other buildings environments. Preserving these items require special environmental conditions that results in different energy consumption patterns than other types of buildings. Recent studies have been focusing on the energy consumption of museums and investigating the possibility for reduction and enhancements in their indoor environments. (López and Frontini, 2014)

On the other hand, since museums are considered as one of the main entertaining educational sources for different groups, they can have a remarkable role in influencing and encouraging the society and different parties the adaptation of enhanced lifestyle and practices, such as sustainability.

As for current museum practices status in UAE it can be considered a relatively new practice comparing to other parts of the world. Earlier museums in UAE such as Dubai museum, were established with the aim of introducing the culture and life style of the local community for tourists. Sharjah is considered as the leading and active emirate in terms of museums and cultural projects.

As of professional museum buildings built for museum purposes there wasn't any museum in Dubai. The first purpose built museum in Dubai was the Women's Museum opened in 2012 that is a privately owned project. (Ghubash, 2016) Other purpose built museum buildings are still in the construction and development stage like the Future museum and Union museum.
Moreover, in the past 5 years, Dubai saw the opening of many museums in different historical areas by renovating the historical houses of Shindagha and Fahidi district and converting them to museums and other cultural activities. With this growth in number of museums in short time, the attention and focus towards developing museum projects for historical and cultural preservation is understood.

Lower energy consumption rates are provided in sustainable buildings as well as intelligent buildings. Intelligent buildings with their adaptability provide a productive and cost-effective environment through optimisation of their basic elements such as structure, systems, services and managements, and the interrelationship between them.

The UAE government, with the strong promising futuristic vision and the different sustainable, smart projects, is a great place for providing such proposals. As intelligent and sustainable projects require upfront investments, which cost more but can payback in longer term and more importantly is the positive impact they will have on the environment. This might make it more challenging for the private sector (depending on the nature of their work) in order to invest in such long term projects. Targeting governmental sector will give chance of considering the long term return on investment possibility, helping the environment which also is a main concern in the government.

1.3. Aims

With the growing number of museum projects in the region, it is important to identify the baseline for correct practices to ensure the durability of the historical collections in such projects. As museum projects are meant to serve as a link from past to present and to be delivered for the future generations as well.

Currently, standards and guidelines for museum indoor environments in the region are lacking. Since there are no official regulations set to be implemented by museums, identifying the on going practice will clarify the current status in terms of the concern towards the durability and continuity of museums for future.

This research is a focus on different factors of indoor environments of UAE museums.

It aims to identify the current on going practices of museum indoor environments in terms of artifact safety and preservation, intelligence and integration level of the different components, as well as the sustainability level of the projects. Through the stages of the research the question of "What is the current status of UAE museums in terms of artefact preservation, human health and comfort, sustainability and intelligence level?" will be answered.

Based on the evaluation result, further enhancement methods will be investigated through the question of: "what are the possibilities for enhancing the current conditions?"

This paper aims to involve the museum sector in the current concern of energy saving practices in the country, as museums with their controlled environmental requirement consume more energy than regular buildings. Adopting sustainable methods will increase the efficiency of the environments as well as the building life cycle, which is a main concern for historical areas. Even though current number of museums are lower than other types of buildings however, they serve as an educational spaces for spreading knowledge. Equipping educational spaces contribute in reducing energy consumption, as well as providing environments to motivate and encourage residents and tourists in adapting to sustainable and environmental friendly life style that also will serve in implementation on other scopes in general helping the current concern of energy savings.

Case study museums were selected to examine the possibilities of the suggestions made. In terms of solutions proposed for energy reduction they were framed within the museum parameters considering the requirements for collection preservation, visitor satisfaction as well as energy efficiency and intelligent components.

Providing adoptable strategies for museum buildings will encourage their implementation, especially in UAE where the government is considered as a leading model in the region for moving towards smart and intelligent methods in different means.

Solutions and proposals, when possible were assessed in simulation software to quantify the energy reduction rates and evaluate the efficiency of implementation on the selected case studies to verify the level of enhancements they will have and validate the importance of adaptation for the museums.

This study is hoped to serve as a reference guide for different museum's officials in the UAE to benefit from the information provided, and the evaluation results, in order to adopt strategies enhancing the indoor quality and energy performance of different museum projects across UAE.

Additionally, in order to make the study realistic in approach, identifying clear ways and practical proposals are targeted, rather than general theoretical suggestions.

1.4. Objectives

- To evaluate current museum practices in UAE in terms of artifact preservation, human health and comfort, intelligence and sustainability level.
- Propose different solutions and methods in order to upgrade and enhance current status of UAE museums for the four categorize of: artifact preservation, human health and comfort, intelligence and sustainability level
- Assess and compare the possibility of implementing the proposed solutions. And identify the enhancement level each proposal can contribute to the indoor environment of the museum.
- Identify best practice and efficient solutions for adaptation for each case study suitable for their needs

1.5. Research Outline

This paper is divided to 6 chapters for the different stages of the research as follows:

Chapter 1: *Introduction*

Includes an overview for the current status of UAE within the sustainability filed and the importance of the current study with showing the aims and objectives.

Chapter 2: *Literature review*

Since this study is focused on different aspect in terms of the museums, this chapter enriched with information intersecting within the same field of study. The parameters required for museums in different aspect of indoor environments, earlier researches within the field of museum indoor environments are expressed. Sustainable buildings and intelligent building guidelines and requirements are provided. Studies conducted for energy retrofitting and sustaining existing museums, as well as the current knowledge gap in terms of enhancing current museums into sustainable intelligent museums are all expressed in details.

Chapter 3: *Methodology*

This chapter shows the different research methods adopted in different studies targeting museums indoor environment and museum energy saving approaches. Discussing each method by showing the advantage and disadvantage of them and the justification for choosing the methodology for the current study.

Chapter 4: *Case Study*

Since the study includes three case study museums, thus a separate chapter is specified to show the conditions and details of each selected museum.

Chapter 5: *Results, Findings and Discussion*

Shows the results from the three main stages of the research by providing discussion and comparisons in two separate sections:

1- Evaluation results for the current practices in the different case studies.
2- The proposed solutions for each case study and the results from assessing the proposals made and identifying best practice.

Chapter 6: *Conclusion and Recommendation*

Finally the last chapter will brief the research stages and the over all findings. Most importantly, the recommendations will include the future research potentials that can continue based on this study.

1.6. Study Limitation

The limited timeframe of the project was the main study limitation in this research. For indoor environment studies, continues monitoring and measurements for around one year, or different seasons is advised (elaborated in details in methodology chapter), however, due to time limitation, the study focused only on indoor environment monitoring for one season rather than the entire year.

Another limitation was the intelligence level evaluation, even though many researchers, including the author, have tested questionnaire; it was not as efficient for the evaluations of the museums. This could be mainly due to the very technical questions, and the target of highly intelligent buildings. While the case study buildings were much simpler in terms of integration of building components.

Chapter 2

Literature Review

2.1. Literature Review

Upgrading museums into sustainable intelligent buildings requires background information with clear specification about each aspect of museums. The boundaries should be clearly identified in order to have clear path to propose the solutions without exceeding these boundaries.

This chapter is a focus to show the environmental conditions and parameters along with the needed information that should be considered within the museum environments. It also, provides the studies conducted within the museums filed in order to enhance their indoor environment conditions in terms of energy efficiency or adaptation of intelligent methods in the field, with expressing about the advantages and the limitations of the studies along with the current knowledge gap in these fields.

This chapter also, highlights the intelligent and sustainable museums with showing the guidelines and parameters for each type as well as the meeting points between each era with different scopes each can contain.

2.2. Museums

According to the International Community of Museums (ICOM) (2007): "A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment."

The presence of ancient and historical artifacts that require specific environmental conditions for preservation makes the museum environments different from other built environments.

Museums with their importance to history and culture have got special attention from researchers on their vast subjects. Since this study is focused on museum indoor environments, it is crucial to show the required parameters for them.

The following section is dedicated to show the different parameters set by different parties.

2.2.1. Museums Indoor Environment Parameters

Artifacts, visitors and museum personnel are the three different categories within the Museum environments each of which has different requirements creating different research scopes within the same filed. As for the practices in the museum indoor environments, a compromise should be done to make the most desired balance between the artifacts preservation and the human comfort level. However, considering the collections conditions is a priority that should never been underestimated. (ASHRAE, 2011, Ferreny et al., 2012)

2.2.1.1. Artifacts

Depending on the artifacts components, the environmental conditions for their preservation will differ. Researches about artifacts have been focusing on the objects nature. Generally, artifacts are divided into the three categories: organic, inorganic and mixed materials. (Pavlogeorgatos 2003), Organic objects are those coming from plants, animals or natural elements, paper and leather are examples of them. Inorganic materials are referred to the items like stones, metal and bronze. Mixed material object is a combination of both.

To be more specific, each ancient item usually requires certain environmental conditions depending on its status when it was found and how it should be preserved and displayed. This could be a main reason why the microclimatic conditions have no exact fixed figures in the studies and standards. However, a range of environmental condition are set that each item should be kept within that range, depending on their nature. (ASHRAE, 2011; British standard 2000; British standard 2012)

Pavlogeorgatos (2003), in an early publication have gathered all the early guidelines and different studies identifying the different environmental parameters for museums and provided a benchmark literature review as a reference in the field. His paper discussed the different needed microclimatic parameters in terms of: Relative Humidity, Temperature, Illuminations, indoor air quality (Atmospheric Pollutants), as well as Noise and Vibration. The ideal conditions are shown, and the impacts on artifacts are expressed in case the mentioned parameters were above or below the identified rates. (Details for each factor is mentioned in the following section) Other researchers have benefitted from this study for furthering theirs studies in more focused areas of research, like; museum lighting, (Al-Sallal and Bin Dalmouk, 2011), hygrothemral conditions (Silva and Henriques, 2014), air conditioning systems for museums (Luo et al., 2016) as well as moisture gain or removals by HVAC, (Steeman et al., 2010).

When the microclimatic conditions, like temperature or relative humidity are not controlled or properly set, damages to ancient items can be significant over short period of time, or could cause small invisible changes like: accelerating the deterioration of the object or shortening their life. (2003) (ASHRAE, 2011) (Silva et al., 2016). Following part is showing the different microclimatic conditions need for the museums indoor environments. However, since this study is not concerned with noise in the museums, parameters and different researches are not included.

Relative Humidity (RH) and Temperature (T)

Depending on the region, local condition and the standards adopted in different museums, RH and T set points might be strictly controlled, or they can change by seasons and times. Providing uniform environmental conditions with minimum fluctuations favors the durability and long life of the exhibits if it was properly set. In countries with cold climate and having significant seasonal weather change, stabilizing the RH in the indoor environment becomes a challenge especially during winter when the temperature drops the RH gets higher.

Having higher RH than what is needed can cause serious harm to the collection like detaching the different parts of an object. Moisture contributes to mold growth and fungi. In organic objects with some moisture content like wood, inflation is a result of high humidity as well. Moreover, it accelerates the corrosion process of different metals in the exhibits, like bronze (except for gold). On the other hand, dehumidification is harmful when it exceeds the limit as well. It can cause cracks, size shrink, or breaking the item. Additionally, when the RH rises in higher temperature the environment becomes more ideal for microorganism and mold growth (Pavlogeorgatos, 2003; ASHRAE, 2011)

Through the different studies carried about the museums environments T and RH were always linked together. (Silva et al., 2016; Pavlogeorgatos, 2003; ASHRAE, 2011). Temperature fluctuation may weaken the materials particulate, which is not sensed and visible normally, resulting in having more fragile items. Temperature is usually is correlated with RH.

According to ASHRAE the ideal percentage of the required RH for museum exhibits have changed over time (2011).

As mentioned earlier there is no exact set point that is followed by all museum parties. RH of 50%-55% was known as ideal percentage for museum environments before. However, The new percentage was lowered to 45%±5% (Pavlogeorgatos, 2003). Other guidelines, like the British government guideline after 2012, changed the requirements to make the RH and T more flexible. This flexibility contributed to reduce the energy for humidification or dehumidification process. As, based on earlier studies keeping the RH of the indoor environment within 50% range was hard to achieve. (Kramer et al., 2015)

Table 2.1 summarizes the hygrothermal conditions in terms of T and RH in the different guidelines in different regions. Australian guidelines defined the standards differently based on the climate of each region by depending on Hot and Dry, Hot and humid and temperate regions.

In 2014 The Australian Institution for the conservation of cultural material (AICCM) have developed the guideline based on 2009 findings and specified tighter range in comparison to the Heritage Collections Council 2002 (HCC) specifications. While UK standards, allowed wider range of change through time, as expressed by Padifield et, al. (2014)

As shown in the table, T ranges varied based on the different guidelines, as well as different climate conditions. Fluctuation allowance for T ranged from ± 2°C to ±5°C. the variation of set points in RH was mostly 50% with the two options of ±5% or 10% daily. As shown earlier the more allowance in variation of RH, the more energy could be saved. However type and origin of collections should be considered as well.

Table 2.1. Temperature and Relative Humidity Parameters for museums indoor environments.by different standards. (AICCM, 2014; British standards, 2012; ASHRAE, 2011; HCC, 2002)

	T °C	T (24 hours)	T Seasonal	RH %	RH (24 hours)	RH Seasonal
AICCM 2014	15 °C – 25 °C	± 4 °C	-	45-55%	± 5%	40 – 60 %
UK standard 2012	18 °C – 24 °C	± 4 °C		50%	± 10%	
ASHRAE AA 2011	15 °C – 25 °C	±2°C	Up 5°C 5°C Down	50%	±5%	No change
ASHRAE A 2011	15 °C – 25 °C	±2°C	Up 5°C Down 10°C	50%	± 5%	Up 10% Down 10%
ASHRAE A 2011	15 °C – 25 °C	±2°C	Up 5°C Down 10°C	50%	± 10%	No change
ASHRAE B 2011	15 °C – 25 °C	±5°C	Up 10°C (but not above 30°C) Down as low as necessary to maintain RH control	50%	± 10%	Up 10% Down 10%
ASHRAE C 2011	Rarely over 30°C, usually below 25°C	-	-	Within range 25–75% RH Year round.	-	-
ASHRAE D 2011	-	-	-	Reliably below 75% RH	-	-
HCC **(Hot Humid) 2002**	22 °C – 28 °C Daily	-	10% acceptable 20% dangerous 40% Destructive	55% –70% Daily	-	Not to exceed 70% Not below 40%
HCC **(Hot Dry) 2002**	22 °C – 28 °C Daily	-		40% – 60% Daily	-	
HCC **(Temperate) 2002**	14 °C – 24 °C Daily	-		45% – 65% Daily	-	

Illuminations

Another key parameter for the museum environment is the lighting level. The exposure of light is very crucial for the collections. As for the collections requirements it is favorable not to be exposed to lights, as the different radiations from light contribute in the deterioration of the collections. UV and IR are the harmful components of lights for the artifacts. UV contributes in the degradation of the object and color change. Daylight is a main source for the strongest UV radiation from sun allowing big amount of UV radiations in the environment. Moreover, IR cause the rise in T in the environment and the surrounding and this heat is the harming factor for the collections. (Melendez et al., 2011; Pavlogeorgatos, 2003).

However, in order to view these collections by visitors, light is a must. Thus a compromise should be done in a way to make the possibility for visitors without jeopardizing the collections need. The color of light is important for how the artworks will be perceived by the viewer, as it will be rendering the different colors used in the paintings. Therefore, researchers and standards identified different conditions that are safe for the different types of collections.

According to Melendez et al. (2011) current accepted levels of UV radiation are 35 and 75 microwatts per lumen (W/lm) for highly sensitive and moderately sensitive objects, respectively.

Organic materials like papers are more sensitive to IR and UV radiation of lights and require special care. Light can fade them or change their color to yellow. When it comes to textile exhibits, tungsten bulbs are advised for their association with increasing the RH based on the heat they produce which benefits the textile preservation (Pavlogeorgatos, 2003). Recently LED lighting has been the focus for museum environments, as they have less UV radiation, moreover they reduce energy consumption.

According to (Kim and Chung, 2011) daylighting's main challenge to the museums is the deterioration of artifact as well as causing glare, which affects the visitors. Thus, daylighting should be studied and considered well in order to be implemented and it has been the focus of different researchers have for their studies. (Kim and Seo, 2012; Al–Sallal and Bin Dalmouk, 2011; Melendez et al., 2011; Kim and Chung, 2011; Kaya, 2015). Details of their studies are shown in the following sections.

Table 2.2 is a summary of lux levels assigned for different types of materials, as shown according to the standards different limits are allowed based on the object origin. HCC defined the sensitivity level of material as following:

- Very Sensitive: Includes textiles, water colours, prints and drawings, manuscripts, ethnographic objects
- Sensitive: Oil and tempera paintings, undyed leather, horn, oriental lacquer
- Insensitive: Metal, stone, ceramics and glass, jewellery (2002)

Table 2.2. Lux and UV limits for museums indoor environments by different standards. (UK Standard, 2012; HCC 2002; Havells and Sylvania, 2015; SHARE, 2000; IESNA 1996)

	Very Sensitive Objects		Sensitive		Insensitive	
	Lux lumen/ m^2	UV µwatt/ lumen	Lux lumen/ m^2	UV µwatt/ lumen	Lux lumen/ m^2	UV µwatt/lumen
UK Standard 2012	50		200		300	
HCC 2002	50	30	200	75	300	200
SHARE	50-80	0-75	200-250	0-75	Can be higher but not recommended	0-75
Havells Sylvania 2015	50		100		300	
IESNA Museum and Art Gallery Lighting 1996 p14	50	0	200	0	Depending on the exhibition	0

As shown in table 2.2 some standards specified the UV limits and some did not mention, it could be due to the fact of considering 0 levels in all conditions.

Moreover, based on the defined lux levels IESNA has defined light exposure limit through the year based on different materials. According to Al Sallal and Bin Dalmouk 50000 lux h/year is the annual exposure limit for 50 lux in IESNA. As for the 200-300 lux this limit is 480000 lux h/year. (2011)

What is crucial about the information presented in the table as well as the previous part through the shown references, there was no clear indication of IR impact or IR levels limits.

Indoor Air Quality- *Atmospheric Pollutants*

Within museums indoor air quality, airborne particulates should not be ignored. They can leave their impact on the artifacts negatively. Aside from dust and other suspended solid particulates, chemical/gaseous pollutants like; Ozone, Sulfur dioxide and Nitrogen cause serious damages in the museum's indoor environment. They contribute in deoxidization, significant deterioration, as well as corrosion of metal.

These pollutants should be removed from the environment by different means. HVAC systems are equipped with some filters that can remove particulates only with the diameters of more than 2mm. The rest would stay in the environment, which can cause to chemical reactions and damage the collections (Pavlogeorgatos, 2003).

2.2.1.2. Visitors

One of the main purposes of establishing a museum is to introduce the history and culture to different visitors. According to Batallie (1930); visitors are the main component of any museum. They visit the museums individually or in groups and in the relatively short visit conducted, they can leave their impact on the museum's environment. Thus, the indoor environment of museums should be controlled and monitored in order to prevent any negative impact from the different visitors.

Visitors' satisfaction is a common study subject for the museum studies that different researchers have been considering in order to evaluate the quality of the museum's indoor environments from the visitors' point of view, which is part of post occupancy evaluation. These studies help to identify if the visitors have perceived what has been planned and prepared for them during their visits. Also, potential areas for enhancements can be identified through these evaluations. The following factors were identified by Jeong and Lee (2006) in their study as parameters to evaluate visitor satisfaction levels:

- *Exhibition Environments in the Museums*
  - ✓ Indoor Environments and Technology Use
  - ✓ Visual Locomotors and Signage Availability
  - ✓ Circulation Complexity
- *Ambient Environment*
  - ✓ Density of the Visitors
  - ✓ Noise Levels
- *Thermal Comfort*
  - ✓ Temperature
  - ✓ Humidity
- *Size of the Museum*

2.2.1.3. Museums Personnel

Other than visitors, museum personnel are the building occupants of the museums whom spend most of their time within the museum environment. Depending on their position and job requirements, they are more likely to get affected from their working environment. Being in direct contact with ancient items with different origins might be a common daily task for some of them.

Conservators usually study each artifact and work closely with the museum curators in order to prepare them for exhibition or to be stored. Based on what is wanted from the curator, some conservation stages might be more for the artifacts that will be displayed. Items that are meant for storage purposes without displaying them go under certain steps but the conservator might not focus on projecting the aesthetic details of that particular artifact. However, during restoration time, in both cases conservators make sure they are not harming the artifact or negatively shortening their life span and stabilize them. The main effort is done to stop their degradation process and qualify them for longer periods of time.

Conservators based on the conditions of each item, how it was found, and through which stages of conservation process they have been through assign the environmental conditions for displaying them. Throughout all the mentioned stages, conservators use different tools, machines and are exposed to various conditions. In some conditions, they are most likely to use some chemical with different concentrations depending on the needed action.

With knowing the importance of considering the museums personnel and conducting different studies about their health and comfort, however, this study will focus on museums' personnel whom are related to the exhibition environments only as the study scope is not involved with the laboratories and storage areas.

The following part shows the different studies conducted about the museum indoor environments and their focus area.

2.2.2. Studies About Museums Indoor Environment

Even though, the main focus of this research is enhancing indoor environment and energy performance. This section is dedicated to show studies related to indoor environment of museums that are not discussing the energy monitoring, performance and energy saving aspect. Through reviewing the literature it was noted that museum indoor environment is a vast research filed with a lot of concerns and important aspects that all should be considered. Mentioning the researchers in this field is crucial to identify the practices done and the gaps that still remain. Also since the energy saving of museums is a relatively new and challenging aspect it is important to adopt related matters to museums in the study rather than following stages concerning regular buildings. This section is only about studies focusing on museum indoor environments. The energy monitoring, performance and energy savings within museum indoor environments are discussed in details in section 2.6.2.

Museum indoor environments have got the attention of researchers by different scopes leading to develop different subfields of study and have developed over time to get certain attention and activity.

Luo et al., (2016) studied the hygrothermal conditions and changes and their impacts on the archeological artifacts particularly. Other studies were conducted in the museum stores where the impact on artifact is not influenced with human factor (Padfield et al., 2014; Ryhl-Svendsen et al., 2013; Ryhl-Svendsen, 2011). As a result, human comfort was not a consideration in their studies.
Mishra et al. (2016) focused on visitors' satisfaction in terms of thermal comfort. The results mainly depended on the time frame visitors spent in the museum. Gradual change of thermal perception of visitors during their visit in the first hour was shown in the study. The feedback from visitors spending around 20 min in the museum were mostly influenced based on the outdoor thermal conditions, the longer they stayed their perception would change and become influenced by the indoor conditions. Even though the importance of artifact preservation was mentioned in the study, however, the impacts of the thermal conditions on artifacts were not part of the study.
The type of museum can influence the type of research. Luo et al. (2016) focused on temperature and relative humidity particularly in an archeological museum. Showing the difference of such museums, as the archeological museums usually have ancient artifacts displayed from earth without any showcases. Their study proposed the suitable option based on experiments conducted for heating the space during cold winter to meet the visitor satisfaction and most importantly, the artifact conservation requirements.

2.2.2.1. Indoor Air Quality (IAQ)

Indoor air quality of museum environments topic remains a crucial scope of research over time. (Franzitta et al., 2010; Lee et al. 2011; Krupińska et al. 2012; Wang et al., 2012; Wang et al., 2012; Krupińska Grieken and Wael, 2013; D'Agostino and Congedo, 2014; Proietti et al. 2015; Zorpas and Skouroupatis, 2016).

Atmospheric air pollutants were discussed by Krupińska et al. (2012) Lee et al. (2011) Wang et al., (2015) Proietti et al. (2015), Chianese et al. (2012), Hu et al. (2015) and Abdul-Wahab, Salem and Ali (2015).

Chianese et al. (2012) study was about monitoring and measuring the air pollutants of a museum in Italy. The paper showed the values that should not be exceeded in terms of chemical/gaseous pollutants as well as the particulate matters in the environment in the Italian Law standards and the results of the measurements were compared to them. The monitoring results showed the Average PM10 exceeded the highest limit of standards (30 μg/m3) by 62%, which is significant, While PM25 did not exceed this limit.

The study also included measurements of outdoor environment and results were compared with indoor. The research showed the impact from outside to the indoor environment in terms of PM and other pollutants were transported to the indoor environment by visitors. Also the location of the museum played a role in having the pollutants inside.

Likewise, Krupińska et al. (2012) and Hu et al. (2015) also had similar research focus on measuring the NO2, SO2, O3 and particulate matter. While Wang et al. (2015) focused on Nitrogen only. The study by (Krupińska et al. 2012) showed very low concentration in the indoor environment in comparison to the outdoor in one museum. Hu et al. (2015) considered 5 museums with various locations, researchers have concluded the inefficient indoor environment dues to lack of proper control from outer environment.

Comparing the 3 mentioned studies Chianese et al. (2012) is stronger study in terms of showing the result because of the comparison to the standards. While,

Hu et al. (2015) study depended only on comparing the results with other similar studies conducted earlier. These studies referred to also might not be having satisfactory conditions. On the other hand, the study of Krupińska et al. (2012) lacked providing the standard of the volume limit for the indoor environment or comparing them with other studies. The results were mainly based on comparing the pollutants volume indoor vs outdoor concentration, by showing the significant lower pollutant concentration in the indoor environment resulted in concluding the safe condition. Even though, the measure volumes had significant difference between outdoor and indoor, the indoor concentration might remain higher than the safe situation in the standards.

Abdul-Wahab, Salem and Ali (2015) in a leading study for the region have measured the IAQ parameters of Bait al Zubair building in Oman. The building contained one level of museum exhibition and two residential blocks. The study measured the concentration of the air pollutants and most importantly the results were compared with the relevant standard for each category with comparing other set of standards as well, this made the study stand out among the other mentioned studies.

Moreover (Proietti et al. 2015) concentrated on dust as a pollutants and the contribution of dust on degradation process of the materials and artifacts. While, (Lee et al. 2011) study was focusing only to identify the sources of pollutant.

Moreover, Paner (2012) Harkawy et al. (2011) Sterflinger, (2010) focused on the mold and fungus within the museum environments and their causes. Paner in his study has examined ways and approaches to restore fungi and mold infested paintings of University of Santa Tomas museum in the Philippines by experimenting different fungicides and their impacts on the artworks (2012). However, Harkawy et al. (2011) conducted their study to focus on a later stage of conservation by checking the possibility of microbial recontamination in artifacts after going through the disinfection process. The study was done 10 years after the disinfection process that included the artifacts as well as their environment. Disinfection was done through a complex chemical process, to sterilize contaminated object and help to stop the microorganism reaction in manuscripts and ancient papers over long periods of time.

The findings of Harkawy et al. study proved the microbial recontamination, which concluded in the need for enhancing the indoor environment and to have full control over it, even though it has very limited human access. (2011)

Harkawy et al. (2011) López-Aparicio et al., (2011) studied natural ventilation and the impact on artifacts. Their study showed when the environment is naturally ventilated without controlling and filtering the air, even though it is providing the desired temperature for the collection. However, it is not safe because of the pollutants, mold growth and fungus.

Aside from indoor air pollutants, hygrothermal condition is a crucial parameter for museums indoor environment. They are directly related to ventilation and air conditioning systems of the museums. D'Agostino and Congedo, (2014) study was about museum ventilation, (Harkawy et al. 2011) showed the natural ventilation effect on the ancient items in museums with no HVAC systems. Ascione, Bellia and Caozzoli, (2013) discussed air conditioning in the museums. The impact of air curtain systems for archeological museums was studied by Luo et al. (2015). Other recent studies in regards to microclimatic conditions, HVAC systems and ventilation in general were intensively studied within museum indoor environments in terms of energy monitoring, performance and energy savings. While earlier studies discussed the variation of temperature and relative humidity effect on the artifacts The detailed elaboration is shown and discussed in section 2.2.2 of literature review as mentioned earlier.

2.2.2.2. Lighting

As expressed earlier, museum lighting is another key elements for the museum indoor environments. Lighting is a main element for viewing the artworks and artifacts in the museums. Accordingly it is directly related to artifact and visitors perception. As mentioned in previous section, in terms of artifact preservation the ideal condition is the total darkness. This is not feasible for viewing purposes. Therefore, a compromise should be done in way to show the objects without harming them. As for the studies about lighting in museum environments it is a very vast area with many researches in the field. However, the most recent studies have significantly focused on the energy optimization of lighting and potential ways to reduce energy consumption inside museums through adapting new lighting technologies. Section 2.6.2 from literature review is dedicated for this aspect while the below part is mainly showing other research topics focused on item degradation, visual appearance and other aspects not related to energy topic.

Wahab and Zuhardi, (2013) study was a focus on visual quality in terms of lighting, they have discussed the following variables in terms of visual performances and quality: Light distribution, Visual size and location of the target, Luminance and luminance contrast, Color difference, Glare, Shadow, Veiling reflections. Their study mainly focused on visitors' comfort scope and the aesthetic purpose of light.

Delgado et al., (2010) study was to make the lighting systems for museums safer by testing and examining different methods to improve luminance efficiency L/W of light.

LED lights have been actively used for different types of projects. In museum practices and researches, they became center of attention as well. As these lightings have longer lifecycle, require less energy, and associated with low costs as well. Most importantly as it is known, they produce enhanced quality of lights.

Tuzikas et al., (2014) Berns, (2010) Molini et al., (2010) and Viénot et al., (2011)

have investigated the feasibility of LED lighting for museums.

Molini et al., (2010) and Viénot et al., (2011) In their studies propose LED lights as best option for better visual quality with minimal damages to artworks. Moreover, Viénot et al., (2011) could prove that LED improves the visual quality and colorfulness for moderately degraded color objects, and present them in a condition better than their current state.

Tuzikas et al., (2014) In theirs study have introduced a new solid state lighting engine with the control of photochemical safety. The study has

considered the artwork and artifact requirement alongside the viewing requirements.
Color temperature, flexibility of color saturation, chromaticity are some factors discussed for reaching to proper visual appearance with considering constant damage irradiance. The research concluded on the advancement of LED light and the flexibility of providing smart controllable systems for museums with control over photochemical effect.

On the other hand, Macchia et al., (2013) aimed to set some standards for lighting in cultural heritage, to limit the degradation process to artifacts. Different types of lights were selected, compared in terms of their specification and experiment was carried out Effective Illuminance (lux) was measured for each type of light to compare the degradation process on a sample.

Beside artificial lighting, benefiting from daylight within the exhibition environments is another subject of interest for different researchers Kim and Seo, (2012) Al Sallal and Bin Dalmouk, (2011) Melendez et al., (2011), Kim and Chung, (2011) Kaya, (2015) considered daylight as a main topic for their studies.
Daylight also was considered as main factor contributing to energy savings in the museums. Studies related to daylight and energy conservation are explained in 2.6.2 section. In a different perception Kaya, (2015) in a master thesis examined daylight on visitors perception and satisfaction point of view in the museums in terms of the ambient environment. While others studied daylight as mentioned below;
Kim and Seo, (2012) have studied the possibilities of benefiting from the available skylight in the building and evaluated the possibilities of reusing it for the museum. Their study concluded the necessity of considering daylight factor from early architectural design phase in order to have efficient and beneficial light for museums. This indicates the possibility for purpose built buildings to be as museums. While, other studies evaluated the existing conditions for a non-purpose built historical building, later used as a

museum.

Likewise, Al Sallal and Bin Dalmouk, (2011) have studied the daylight factor as well. Their study was about the old heritage houses adopted into museum function. Although, their study was about studying the impact of daylight, but the concern was the windows rather than skylight. They also concluded with the negative impact of daylight that is resulting damages to the museum indoor environment in terms of artifacts.

Kim and Chung, (2011) have proposed alternative top light to the existing skylight of a museum in their study. They also concluded that daylight should be evaluated from early design stage of museums in order to be beneficial in terms of environment.

Even though Melendez et al., (2011) have noted the amount of daylight entering the museum is within the acceptable light level in comparison to the standards by measuring the lighting level of a museum. However, that condition did not last during the summer period as stronger solar radiation changed the results.

Pinilla et al., (2016) in their study over the impact of daylight to the exhibited artworks have provided guidebook for exhibition managers of the case study building to consider the areas of the museum that are not negatively impacted by daylight through different time and seasons.

Having shading devices, adjustable louvers are other techniques referred by Delgado et al., (2010) to have the right amount of light without raising the temperature inside the exhibition environment and reduce the UV radiation as much as possible.

In order to block the UV radiation from daylight or other types of lights, filters are used in the museums. Lighting filters beside lighting systems, are another aspect considered in museum indoor environments. (Delgado et al., 2010) in their study have proposed different types of light filters by enhancing the luminance efficiency to have safer lighting systems for sensitive works (Delgado et al., 2010)

From the reviewed literature, it can be concluded that daylight in existing buildings transformed to museums is not successful, as they were not planned to serve a museum building. In the purpose built museums capturing daylight is studied well and considered from different aspects, and considered from early stages. Thus, it had successful implementations. However, in these studies, skylight is implemented instead of the windows. As existing windows were harmful.

In conclusion this section showed the studies dedicated for indoor environment of museums in terms of Indoor Air Quality, Hygrothermal conditions as well as lighting. As of studies related to acoustics are not shown here because they don't fall within the scope of the current study. As shown, some scopes are discussed in more details while others are referred to be more specific in the coming sections due to their energy concern aspects.

The following section is dedicated to sustainability and intelligence aspects of museums by showing the guidelines of sustainable as well as intelligent buildings along with studies related to energy conservation from indoor environments of museums.

This part is elaborated to show the limitations of the indoor environments of museums, so while considering the sustainable aspect to benefit from the results mentioned here not to adopt strategies might be beneficial for normal buildings while they are harmful for museums and are proven by studies in the field.

2.3. Sustainable Buildings Guidelines

There are different guidelines about sustainable and green buildings worldwide. Depending on the region, climate condition, and the current condition of that region these guidelines address and consider the required scopes.

As for UAE, there are number of systems that are adopted for sustainable buildings (e.g. ESTIDAMA and, Green Building regulations). Based on the project, the followed guideline might vary. But what is important is that based on regulation, new buildings should be environmental friendly. The earliest followed guidelines were the international ones like LEED. Afterwards, local guidelines set by the government of each emirate were developed. These guidelines are designed specifically to meet the local climate and environmental conditions of UAE, thus they could be more efficient for local adaptation.

In Abu Dhabi, Estidama is the sustainability standard followed, and for rating the sustainability level of a particular project, the pearl rating system is followed for the buildings. In Dubai, the green building guidelines set by Dubai municipality is followed. As of Sharjah, currently there are no specified guidelines that are mandatory for implementation as in Dubai and Abu Dhabi. in the same way

Dubai municipality for all buildings in Dubai was following the green building regulation. Green building regulation is the guidelines set from 2010 based on culture and the local conditions in UAE. These guidelines are mandatory to be applied for all new buildings (residential, public and industrial buildings). It includes 76 clauses that all should be met. According to Hussein Lootah, Director General Dubai Municipality, almost 90% of the buildings built in Dubai are green by now and have followed the Green building regulation system. In 2016, the municipality has announced a new rating system to be adopted as a replacement to the 2010 standard. (Gulf News, 2016)

Since these guidelines are new, and have not been applied yet, the following part is dedicated to show the details for this system. The important aspect to be considered is the green building guidelines will not be followed after September and the Sa'afat Green building evaluation system will replace them.

2.3.1. Al Sa'afat Green Building Evaluation System

Based on the feedback gained from the building professionals as well as the experience gained from implementing the green building guidelines, the municipality has furthered the researches and investigations to enhance these regulations. In 2016 Al Sa'afat, Green Building Evaluation System, a new rating system for evaluating sustainable buildings was launched. The rating system will replace the previous green building regulations and will be implemented for the new buildings. Reducing energy consumption, CO2 emissions and increasing building life cycle are the main targets of this rating system.

Buildings rated by Al Sa'afat, will be under one of the four categorize of: Bronze, Silver, Gold or Platinum. The bronze category is the only mandatory section from the guidelines that should be implemented to all new buildings, the remaining three categories are optional which provide higher standards with more efficient strategies. The project cost by adaptation of Al Sa'afat guidelines will not exceed 5%. According to municipality officials the return on investment (ROI) is estimated to be from 2 to 4 years.

Al Sa'afat certificate should be renewed for the obtained buildings after three years based on another testing and evaluation. This will ensure the continues quality control for the buildings.

Post occupancy evaluation is a new main point of consideration that is added to this rating system. Before, the testing and commissioning stage was done before handing the project to the clients. However, for obtaining the Al Sa'afat certificate the building should be fully tested in worst-case scenario within one year of completion. This should be done at full occupancy and in the hot summer conditions in order to ensure functionality of the different systems without errors.

The new rating system is more performance oriented and it is aimed to make the buildings more energy efficient comparing to the previous regulations based on controlling the running activities and systems.

Now, Building Management Systems should be capable of monitoring and control for air and water flow are required. Indoor Air Quality is a priority that BMS systems should keep track on and control.

In terms of the HVAC systems, based on the practices from previous years, water chilled ventilation systems showed inefficient consumption of energy due to the salt contaminants in water that led to get hard water. In Al Sa'afat, in addition to having the energy efficient ventilation system the performance of the system is examined as well, for instance, the softness of water is measured to ensure quality as well. Another important practice with the new rating system is cooling the common areas within the building such as corridors and parking spaces. The cooling should be done through sustainable practices without the use of electricity energized machines.

Unlike before, humidity measuring devices should be installed in order to measure the relative humidity to prevent any fungus and mould growth within the indoor environment.

Lighting systems should have sensors and the BMS to control the light based on occupancy patterns.

The U-value for the building envelope in gold and platinum rating is reduced from 0.57 W/m2 K to 0.40 W/m2 K for walls and flooring, while for bronze and silver stay the same as before.

Moreover, new buildings should provide a study and to consider the shading impacts from the surrounding environment and other buildings on it.

As for the relation of the building with its surrounding the heat island effect is reduced by specifying materials with less thermal storage properties.

Al Sa'afat factors have been examined by simulation software, and no existing project implemented this rating system on as real case study. It is hoped by September 2016, the actual practices and feedback of adapting the new strategies on real projects will be identified.

2.4. Intelligent Buildings

Intelligent building title was used in early 80s in United States addressing buildings advanced in information technology and developed by time. (Wong, Li and Wang, 2005) Different organizations have defined intelligent buildings differently. (Pennell, 2013; Nguyen and Reiter, 2013; Brad and Murar 2014; Jamaludin 2011; Ghaffarianhoseini 2012)

The importance and multidisciplinary areas covered in such buildings can be understood from this variation in definition. According to Caffrey:

“An intelligent building is one that provides a productive and cost-effective environment through optimization of its basic elements: Structure, system, services and managements, and the interrelationship between them.”

Caffrey, R.1985 - Intelligent Buildings Institute, Washington DC

System, service, and performance oriented are the categories that all the vast definitions of intelligent buildings fall under from early times. (Arkin and Paciuk,1997; Wang, 2010; Kaya and Kahraman 2014; AlWaer et al. 2013; Ghaffarianhoseini et al., 2015)

The rapid development in technology has led the constant development for intelligent buildings like other fields. By looking at the intelligent building pyramid (table 2.3) through different times, intelligent buildings criteria have changed and developed. (Bacnet, 2015) (Ghaffarianhoseini et al., (2015) Accordingly, an intelligent building from the past might lose its intelligence feature for the present. Also, the scopes contained in the intelligent building pyramid, gets more in time (table 2.3). As shown in the pyramid, after 2010 Intelligent Buildings get to consider energy and sustainability aspect as well.

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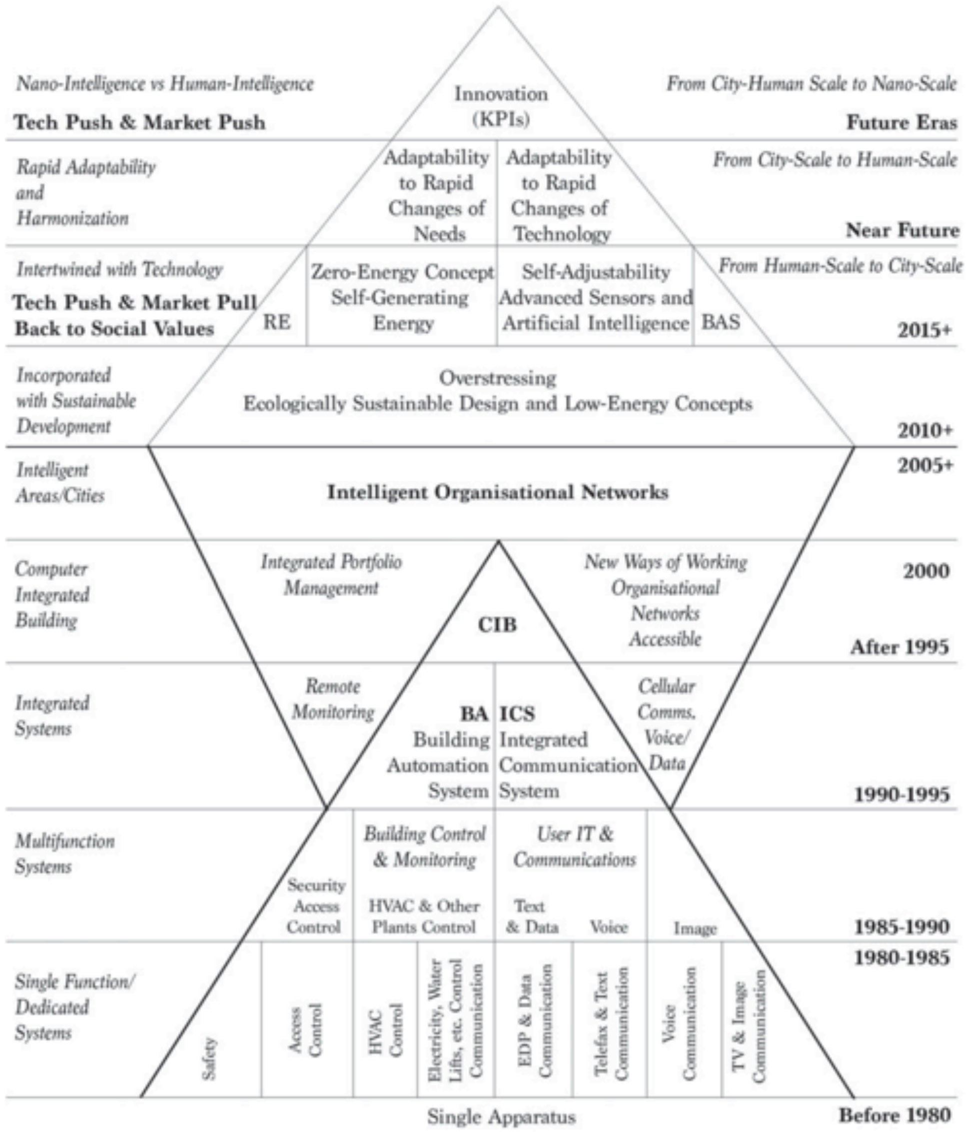


Figure 4. Updated IB pyramid (after Harrison, 1999 in Clements-Croome, 2004, p. 26).

Table. 2.3. Intelligent building pyramid pic (Ghaffarianhoseini et al., 2015)

From the studies in this field, it is also noted that earlier studies were mostly defining, categorizing and raising the awareness about intelligent buildings by different means. (Harrison, et al., 1998; Atkin, 1988; Huhtanen, 2000; Wigginton & Harris, 2002; Clements-Croome, 2004; Youssef, 2005)

For example Huhtanen (2000) in his study to make the concept of system integration in a smart building understandable and easy, he used the illustrations in Figure 2.1. In this figure the different building components were shown and referenced as a human body parts. Explain that how the human body parts work in relation together the intelligent building components also should be integrated and related to each other as well. This basic and simple referral shows the possibility of lack of understanding in the field at that time.

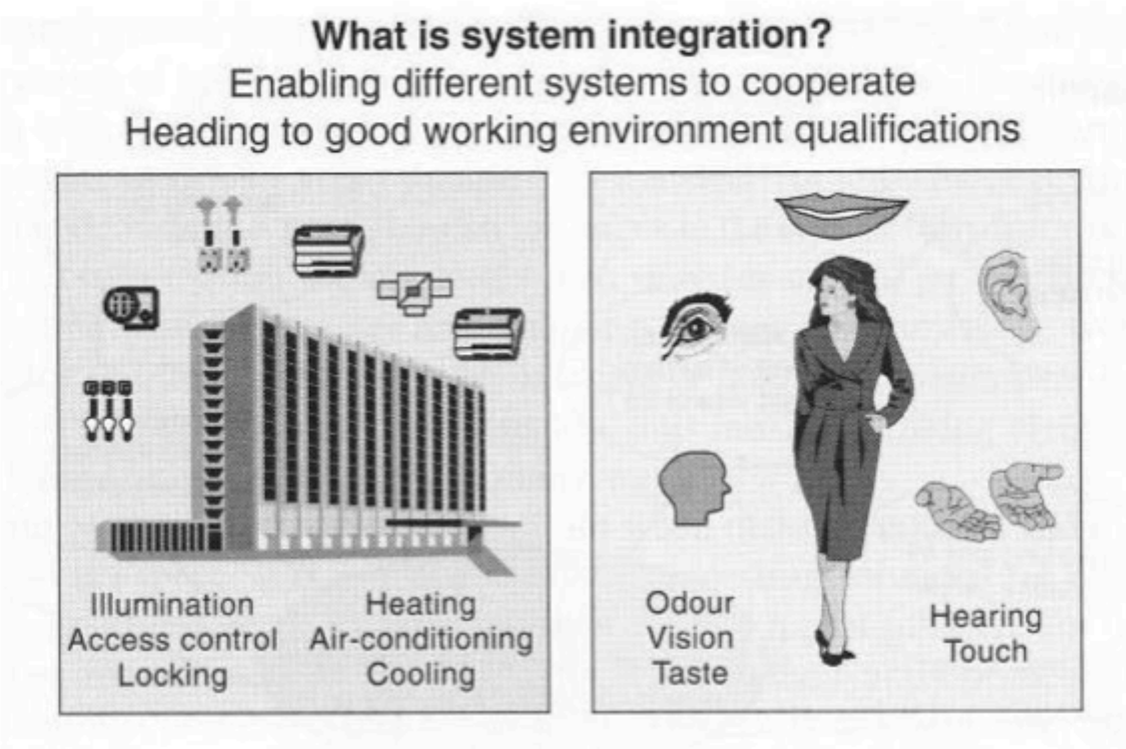


Figure 2.1. Comparisons of intelligent building components to human body parts.

(Huhtanen, 2000)

However, in recent studies, by benefitting from the earlier definitions and categories, researches also evaluated intelligence level, propose more advanced solutions in terms of integration as well as enhancing the intelligence of a specific building component depending on the function and type of the building. (Wong, Li and Lai, 2008; Chen, Wang and Feng 2016; Wanger et al, 2014; Wong and Li, 2010)

It is also noted that the term smart was associated with buildings advanced with technological advancements. While intelligent did not necessary depend on automation and technology, but was more focused to the integration and advancements in the building components to fulfill and respond to occupants needs. Buckmen, Mayfield and Beck, (2014) in their study concluded with the lack of proper definition for smart buildings in their study by viewing the available literature in this topic.

However, in all cases it was identified that technology alone will not enhance any aspect, everything should be implemented in the right way and integrated properly and technology could serve as a tool to achieve this goal. (Ghaffarianhoseini et al., 2015; Clements-Croome 2013; Buckman, Mayfield, and Beck 2014; Arditi, Mango and Marco, 2015).

In early 2000 researchers have realized intelligent buildings were causing higher energy consumption, (Hartkopf 2004; Cook and Das 2007). While in the recent years due to the development in this field, to make energy saving as a key feature of such buildings. (Strumiłło and Ł.dÅLz, 2014; Ghaffarianhoseini et al., 2013a; Ghaffarianhoseini, 2012; Ghaffarianhoseini et al., 2013 b; Yang and Wang, 2013; Nguyen and Aiello 2013)

Ghaffarianhoseini et al., (2015) have summarized the key components of intelligent buildings in his study based on different definitions on different time in Table 2.4.

To configure the intelligence status of a building, it is important to make evaluation for that building. In fact, the evaluation will show the integration level between the different systems as well as their functionality level inside the building will be tested. Through time, it was known that the high level of intelligence means higher level of building system and components integration. (Arkin and Paciuk, 1997; Wong, Li and Lai, 2008)

Table 2.4. Key components of intelligent buildings. (Ghaffarianhoseini et al., 2015)

Table 1. Key features and components of IBs based on available definitions.

Period	Key features and components	Key references
1980s	Maximizing return on investment	Symposium on IBs in Toronto (1985)
	Information communication network and automatically controlled system	Leifer (1988)
	Productive and cost-effective	
1990s	Application of sophisticated operational systems to lifecycle cost efficiency, and ecological performance	Bedos et al. (1990)
	Human as the focal point	Bystrom (1990) and Yasuyoshi (1993)
	Dynamic and responsive	
	The emergence of information and communication technology (ICT) and automated systems	Kroner (1997)
	Maximizing the technical performance, investment and operating cost savings, and flexibility	Clements-Croome (1997)
	Responding to the social and technological changes	Clements-Croome (1997)
	Maximizing the effectiveness of the building's occupants and efficient management of resources	
2000–2005	Responding to user expectations and quality of life	Wigginton and Harris (2002) and Preiser and Schramm (2002)
	The role of user interactions and social changes	Wigginton and Harris (2002) and Wong, Li, and Wang (2005)
	Responding to the changing demands of the owner, the occupier and the environment	Arup (2003)
	Flexibility and adaptability	Hagras et al. (2003)
2005–2010	The efficiency aspect, the cost aspect, the environmental aspect, the health aspect and the security aspect	Gray (2006)
	Safer, more productive and more operationally efficient for the owners	Ehrlich (2007)
	Communicating between building systems and with their owners	Gnerre, Cmar, and Fuller (2007)
	Energy-saving features	Cook and Das (2007)
	Incorporation of smart active features and passive design techniques	Ochoa and Capeluto (2008)
	Eco-intelligent	Goleman (2009)
2010–2015	People, products, and processes	AlWaer and Clements-Croome (2010)
	User involvement in sustainable energy performance of buildings	Janda (2011)
	Considering the users' interactions and even the social values of users	Jamaludin (2011) and Ghaffarianhoseini et al., (2011)
	Ecologically sustainable design	Ghaffarianhoseini (2012)
	Embedded sensors, automation	Chen (2013)
	Innovation as an enabler and new products such as cloud computing, embedded sensors, and smart materials	AlWaer et al. (2013)
	Responding to the needs and social well-being of the occupants and of society	Clements-Croome (2013)
	Suitability for their planned use and success at fulfilling the brief	Clements-Croome (2013b)
	Energy-intelligent concept	Nguyen and Aiello (2013)
	Satisfying occupants' need with high energy efficiency	Yang (2013b)
	Sensory design	Kerr (2013)
	Buildings management systems (BMS)	Johnstone (2013)
	Intelligent control strategies, including smart grids, smart metering, demand response control	Worall (2013)
	Adaptability of buildings to climate change	Thompson, Cooper, and Gething (2014)
	Added values based on technology, function, and economy	Huang (2014)
	Learning capability, self-adjustability, and the relationship between occupants and environment	Kaya and Kahraman (2014)
	Energy-saving strategies	Strumiłło and Łódź (2014)

It is known that, the initial coast for Intelligent and sustainable buildings is higher than the budget for ordinary buildings. However the life cycle and the running cost are much less in such buildings. (Alwaer and Clements, 2010) (Ghaffarianhoseini et al., 2015) Clements-Croome (2015) also related this to lowering health care cost as well. Since building professionals usually prefer lower initial cost projects, regulations and rules will direct them towards coping with them. Alwaer and Clements (2010) also discussed the same aspect in terms of the regulations set by government and rules and how they can lead to increase the number of intelligent building projects. They also identified related methods in their study. It is noteworthy that their suggested methods already have increased the number of such projects.

Wong, Li and Lai (2008) in a benchmark study in this field, addressed the intelligence level in the building to 8 key indicators, this indication has clarified the areas in which evaluators should be focusing and targeting from the building. The 8 indicators are mentioned below:

1. Integrated building management system (IBMS)
2. HVAC and ventilation control systems
3. Telecom and data system (ITS)
4. Addressable fire detection and alarm (AFA) systems
5. Smart/ Energy efficient lift system (LS)
6. Security monitoring and access (SEC)
7. Digital addressable lighting control (DALI)
8. Computerized maintenance management system (CMMS)

According to Wong, Li and Lai (2008), these eight indicators should be evaluated based on four different categorize from the system adopted in the buildings these categorization helped to structure the building evaluation process:

1. Autonomy
2. Controllability for complicated dynamics
3. Bio-inspired behavior
4. Man-machine interaction (Wong, Li and Lai, 2008)

On the other hand, Ghaffarianhoseini et al., (2015) in a new study have categorized the key performance indicators to the four elements of:

1. Smartness and Technology Awareness
2. Economic and Cost Efficiency
3. Personal and Social Sensitivity
4. Environmental Responsiveness.

Their study depended on the earlier literature within IBs field. The identified key indicators included some explanations to check if are adopted within the category or not. While Ghaffarianhoseini et al., (2015) study remains as a key reference for literature in IBs, however, the indicators in the study of Wong, Li and Lai (2008), are detailed and specific to a point that can benefit researchers to adopt same way and evaluate targeted buildings in terms of their intelligence level and show where they are standing.

Moreover, Chen, Wang and Feng (2016) in their study have measured the cost benefit of the intelligent systems in buildings. According to Chen et al., (2016) all studies in the intelligent buildings field qualitatively focusing on building evaluation. While, their study is a quantitative approach considered tangible and intangible benefits. Their study unlike other studies considered the labor cost, and fire insurance savings beside the other aspects considered in all studies like, capital investment, system investment and energy savings.

As shown in Ghaffarianhoseini et al. (2015) study, intelligent buildings recently got more sustainable features and adopt approaches of sustainable buildings.

The following section is about Sustainable Buildings and Guidelines followed by a comparison between intelligent buildings and sustainable buildings.

As of intelligent museums, from the reviewed literature, it seems that this concept is not implemented the way it was done for other types of buildings. It tends to be as a new era in the initial stages of intelligent meaning that is expressed earlier. More often it is referred as advancement in technology and automation of the museums rather than different building component integration. Researchers relate intelligence mainly to visitors' tour experience inside the museum with the importance of having updated methods corresponding to visitors needs. Introducing devices, sensor systems and frame works for smart guiding systems inside the museums by reacting to the visitors behavior by different means and making it as easy as possible to guide them through their mobile phones. (Yu et al., 2008) (Zhou et al., 2009) (Ayala et al., 2014)

2.4.1. Sustainable Buildings VS Intelligent Buildings

From the previous sections the following Table 2.2 summarizes the main aspects of intelligent buildings as well as sustainable buildings.

Table 2.5. Intelligent buildings VS Sustainable Buildings specification, information extracted by the author from LEED study guide, 2014 and Wong, Li and Lai, (2008).

	Intelligent Buildings	Sustainable Buildings
Concerned areas	• Integrated building management system (IBMS) • HVAC and ventilation control systems • Telecom and data system (ITS) • Addressable fire detection and alarm (AFA) systems • Smart/ Energy efficient lift system (LS) • Security monitoring and access (SEC) • Digital addressable lighting control (DALI) • Computerized maintenance management system (CMMS)	• Location and Transportation • Sustainable Sites • Water Efficiency • Energy and Atmosphere • Indoor Environmental Quality • Innovation • Regional Priority
Results	• Productive environment • Cost-effective environment Optimizing and interrelating basic elements of building: Structure, system, services and managements	• Efficiently using energy, water, land, and materials • Protecting occupant health and improving employee productivity • Reducing waste and pollution from each green building • Continuously looking for ways to improve performance

As shown in Table 2.4, intelligent buildings are mostly dealing with a specifically detailed building component, while sustainable buildings address the wider scope, and consider the building as a whole part of its surrounding and environment. It considers social economical and environmental perspective with taking into account the different stages of a building lifecycle with the practices related to that.

2.5. Intelligent Sustainable Museums

Even though there are thousands of museums around the word with more than 10 billion annual visitors, researchers believe the field of museums studies should develop more as there is high demand particularly in the context of sustainability within museums. (Ferreny et al, 2012; Kramer et al., 2015)

To have an energy efficient museum building, it means to reduce energy consumption without putting the museums collections at any risk. (Martin, 2008) Therefore, the percentage in energy consumption reduction in museum buildings might be less in comparison to other types of regular buildings. This also could be another fact that derived specialists to avoid this field of study.

According to different studies energy efficiency wasn't considered a priority in the museums field before. (Papadopoulos, Avgelis and Santamouris, 2003) Ferreny et al, 2012) In fact, in a study conducted by the Museums Association in UK, among the 704 different cultural projects funded by the Arts Council England (ACE), the highest carbon foot print in 2012- 2013 was assigned to museum projects with the average of 1346 tone per museum. (Harris, 2014)

With all the development happened in the field of sustainability some still believe that museum sustainability is only a subject that been talked about and there are no real actions within this context. (Atkinson, 2014)

According to Kramer et al. the attention to energy efficiency in museums increased from 2005 and led to higher number of research in the field in 2010. (2015)

In the UK, the Museum Association organisation are playing a key role in this field with actively initiating studies targeting different UK museums and awareness programs for moving towards more environmentally friendly museums. Also, the Arts Council England (ACE), which is providing funding for UK based cultural projects, set programs for making their funded projects more sustainable with reducing their costs and different aspects.

When addressing sustainable intelligent museums as a research scope, it is important to consider all aspects of sustainability and intelligence within the scopes of museums. The information related to different eras of museums has been expressed in the previous section. The following part is dedicated to show the sustainable buildings and intelligent buildings definitions and guidelines, similarities and differences of each scope are shown and most importantly upgrading existing museums into such buildings are discussed. In this part, the conducted studies section is discussing the different eras of museum indoor environments and the studies that particularly focused on the sustainable and intelligent methods for the exhibition environments.

2.6. Upgrading Existing Museums

2.6.1. Guidelines

Guidelines for turning existing museums into sustainable projects have been released by different parties. These guidelines consider the wide scope of sustainability and have provided step by step procedure helping the museums adopt and follow in order to enhance their current conditions.
South West Federation of museums and art galleries (SW Fed) on their guide to help meeting the accreditation requirements for museums in UK have depended on this calculation method for carbon foot prints as well. (Museum Accreditation Section 1: Environmental sustainability, 2011). The accreditation scheme is set of standards to show the baseline of actions to be done in museums and define good quality practices as well as elevate the quality of different museums. (Accreditation Scheme for Museums and Galleries in the United Kingdom: Accreditation Standard, October 2011).
The SWFed guide for achieving Environmental sustainability for museums targets the following areas of museums with showing how to address them:

- Utilities
- Materials used / products sold
- Energy conservation
- Waste
- Transport
- Public programmes

- Awareness of environmental sustainability issues

On the other hand, a step by step guide was prepared by; Museums, Libraries and Archives East Midlands, and Renaissance East Midlands, to show how this sustainability could be achieved. It identified 5 stages:

1- Monitoring Data
2- Walk around tool
3- Target Scorecard
4- Action plan
5- Implementation

This guide with its stages was implemented on 6 chosen case study museums provided in the same guide with showing the enhancement levels in terms of savings. This helps other museums on how the guidelines were followed in the different mentioned stages.

Also, Silva and Henderson (2011), in their study targeting sustainability in the conservation section of the museum, have covered a wide scope as well and it is not limited to a tight certain aspect. As shown, different areas of the museum are linked and various parties get involved. Even visitors of the museum who are not in direct interaction with the conservation staff are targeted in this study. Pencarelli Cerquetti and Splendiani (2016), in their study also emphasize on the importance of considering the whole dimensions of sustainability scopes in museum practices.

The museum of English Rural life has developed a template for calculating the Carbon footprints of museums in rural areas and made it available for public to benefit from. This calculator considers the annual consumption of electricity, gas and oil. The capital investments rate in the museum. Commuting methods of staff and the commuting distance is important aspect that is calculated. Moreover, the visitor’s transportation method to reach to the museum is taken into considerations. The calculator shows the results of emission per square meter, per visitor and per full time staff. (University of Reading, 2007)

Additionally, from the mentioned guidelines and researches, it shows the practice of upgrading museums into sustainable projects, like other sustainability approaches, wide scopes are involved and it is not limited to a small area. Moreover, museums due to their cultural recognition and educational role can have a stronger impact for encouragements as well as driving the societies for adopting sustainable practices, thus leading environmental friendly approaches are expected more form them.

Other than the mentioned guidelines, organizations like; the international community of museums (ICOM) in Europe is providing support and guidance for member museums in different parts. The support is mostly in terms of helping the museums in their practices rather than provide funding opportunities. Depending on the museum and their conditions experts from ICOM would help the museums upgrade their current conditions, get advises for best practice in terms artifact preservation and energy savings as well.

Beside the researches for setting guidelines for museum sustainability with their wide scope of activities, there are other studies conducted with detailed targets focusing on narrow subjects within the same field.

2.6.2. Studies About Energy Efficiency of Museum indoor Environments

Researches for museum energy efficiency had varied in scopes. (López and Frontini, 2014) have examined ways and approaches to enhance the energy consumption in the historic buildings by choosing 3 case studies. Their study did not focus on the indoor environment as much as it focused on the exterior elements such as renewable energy, (benefiting from solar panels), sealing the window as well as the insulation of the facades. (Santoli, 2015) investigated the landscaping of cultural heritage and their role in energy

On the other hand Salata et al. (2015) Pedro, Tavares and Coelho (2013), Somasekhar and Umakanth (2014), Salata et al. (2015), Pedro, Tavares and Coelho (2013), and Somasekhar and Umakanth (2014) Studies discussed museum energy efficiency from lighting point of view. While, Ferdyn-Grygierek and Baranowski (2013), Ferdyn-Grygierek and Baranowski

(2015), Arroyo et al., (2016), Silva et al. (2016), ventilation and HVAC systems were the main focus.
Moreover Mueller (2013) considered the thermal condition as well as lighting and their role in energy saving the museum environment.

Benefiting from daylight is an important aspect in sustainable projects in order to save energy and enhance indoor environments with providing proper color rendering and visual comfort. However, when the topic is about museums, this aspect becomes very crucial and challenging. As artifact degradation is heavily depending on the light exposure, particularly UV radiation.

As discussed in 2.2.2.2 Section, studies investigating daylight within museum indoor exhibition environments, proved the negative impact of the existing daylight in museums over the artifacts if not treated or designed based on requirements. (Al Sallal and Bin Dalmoul, 2011; del Hoyo-Meléndez, Mecklenburg and Doménech-Carbó, 2011; Kim and Chung, 2011; Kim, Seo, 2012).
Mueller (2013) showed the possibility of energy reduction by benefitting from daylight factor by referring to "Emil-Schumacher-Museum, Hagen". According to Mueller skylight can provide more manageable lighting in terms of artifact preservation. Integrating movable shading devices and having full control over daylight entering the museum environment is a critical point to be integrated with benefitting from daylight. The study provided information of the needed energy for lighting however, it lack information on how much reduction daylight is causing to light electricity or total electricity. Also, how these systems could be integrated without negatively impacting artifacts were not specified in the paper.

In terms of energy savings through artificial lighting, Salata et al. (2015) study was focusing on the exterior lighting, specifically the energy monitoring and maintaining the facades of historical buildings. Pedro, Tavares and Coelho, (2013) and Somasekhar and Umakanth (2014) targeted the museums indoor lightings in their research. Somasekhar and Umakanth (2014) have reduced the energy consumption of a museum by adopting PIR (Passive Infrared) sensors, in which, lightings were connected in a network and the PIR system detected the presence of the visitors. Lights will be at their best maximum intensity of consuming 300 mA of current, while, in case of no visitor and empty exhibition the lights will be dimmed and consumption will reduce to around 150 mA. According to the study 100 MW per day would be saved (current daily energy consumption is 6600 MW per day), only by adopting this method. It is more cost efficient in comparison to other possibilities mentioned in the study.

On the other hand, Pedro, Tavares and Coelho, (2013) have compared the energy consumption rate, cost as well as the electricity charges for three types of lighting; 35 W Halogen, 20 W Halogen and 6 W LED lights. The lighting specifications and their impacts on artifacts were examined through software simulation based on a chosen case study exhibition room. Study showed the adaptation of LED light is best in comparison to the rest of the examined lighting. Moreover, Investment cost, annual energy consumption rate, costs, maintenance costs as well as annual CO_2 emissions were compared. Result showed much better conditions for adopting LED lights in terms of annual energy consumption (KWh) annual energy cost, annual maintenance cost, as well as the annual CO_2 emissions. Only upfront investment was much higher in comparison to the other lights. (Exact figures presented in table 2.5 below) Halogen 20 W lights would need 1.1 year while LED lights would take 1.8 years for return on investment. However compared results showed LED lights would be more energy and cost efficient for longer times.

Table 2.6. Pedro, Tavares and Coelho, study results for different types of light (2013)

	35 W Hal	20 W Hal	6 W LED
Investment cost	37.36	37.36	145.12
Annual energy consumption (kWh)	509.6	291.2	87.36
Annual energy costs (€)	86.63	49.50	14.85
Annual maintenance costs (€)	13.60	13.60	5.28
Annual CO_2 emissions (kg)	188.04	107.45	32.24

With regards to air conditioning and HVAC, Silva et al. (2016) showed the importance of considering the local climatic conditions in the process of the energy saving concerns as well. According to Silva et al. (2016) this factor was not considered in earlier researches. Their study showed that the HVAC system was not effective in terms of controlling the environment. However based on the risk assessment done, low risk was identified. Moreover, the study emphasized the need for making the data collection period longer to obtain proper results.

Arroyo et al. (2016) dedicated their study about decision for choosing proper HVAC system for net zero energy museums. In their study have identified 6 different stages for decision making: (1) identify client needs, (2) set design goals, (3) generate or identify alternatives, (4) collect data, (5) choose an alternative, and (6) Reconsider.

Where their focus was mainly on how to compare the different available alternatives (step 5) for decision making. Following their approach of CBA (choosing based on Alternative) they have simplified the explanations and followed the following 7 steps in applying the approach in their case study, by identifying 3 alternative HVAC system.

1- Identify alternatives 2- Define factors 3- Define the “must” and “want to have” criteria for each factor 4- Summarize the attributes of each alternative 5- Decide the advantages of each alternative 6-Decide the importance of each advantage 7- Evaluate cost data. The final decision identified the best alternative in terms of lower life-cycle cost comparing to other systems.

While earlier studies concentrated on a single focus point in terms of energy saving of museum indoor environments, recent publications indicated the crucial role of assessing multiple disciplines in the museums in terms of enhancing the energy performance of the museums (Rota, Congrati and Di Corato, 2015; Ascione et al., 2015; Ge et al., 2015)

Ascione et al. (2015) emphasized on this aspect in their study targeting to investigating the structural and energy performances behavior. Rota, Congrati and Di Corato, (2015) monitored energy efficiency of 36 museum in Italy by considering the building's HVAC systems, lighting, renewable sources and new technologies as well as safety and security systems adopted in each. Based on the study researchers developed a handbook for museum managements to follow in terms of enhancing the conditions based on the study.

Ge et al. (2015) also made life cycle energy analysis for a museum that considered all stages of construction and other phases of the project.

However, Ferreny et al. (2012) study was based on comparing the amount of energy resources consumed in the museums rather than examining and evaluating the indoor environment elements. This study categorized types of buildings and considered different types of resources (e.g. Electricity, natural gas, oil, etc.) it also examined he water flow of each museum.

Khodeir, Aly and Trek (2016) in their study have identified the different phases and actions should be taken in order to make sustainable retrofitting in HBs:

1- Initiation: is by setting a vision of what to be achieved and evaluating current status of the targeted project.
2- Planning: includes seeking for solutions and designs to overcome the stated problems.
3- Seeking for alternatives: evaluating different options and alternatives to check the best options through assessing them by simulation software.
4- Implementation of the final decision: to start the application on HB based on the best examined option.
5- Performance assessment: includes Mock-ups assessment if there is design and changes, Risk assessment, Sustainable performance assessment (process performance, system performance, building

performance, market performance, financial performance)

As expressed above the study provides holistic approach for focusing on all aspects of the HB from the earliest stage of thinking of enhancements to target all stages. As shown seeking for alternatives is a key stage in order to achieve best results as shown in Arroyo et al. (2016) study.

From this section, the practice of upgrading museums to be more energy efficient and intelligent is a common methods that is been practiced and studied about. As seen it can be implemented on already established and running museums rather than adopting strategies only for new practices. The following part is showing the knowledge gap in this field based on the author's perception.

2.7. Knowledge Gap

As mentioned in the introduction, the practice of museums projects is relatively new in the UAE. From the reviewed literature, there is lack of publications in terms of assessing the indoor environments quality of museums in the region in general, and UAE in particular. While this topic was considered long time ago and researches has developed in this aspect. Considering the local conditions and differences between the UAE and other parts is important for IEQ assessing and improvements. As in this region the demand for cooling the environment is continues throughout the year. While, other places have the season variation and consideration of cooling as well as the heating demands there. This is important aspect in terms of checking the artifacts conditions and protecting them over long and short terms.

In terms of energy saving and sustainability, based on the information obtained from the new rating system by Dubai Municipality, (Al Sa'afat green building rating system), it is noticed that post occupancy evaluation, IEQ, IAQ, performance and environmental monitoring (such as RH) is a new guideline set to be followed for new buildings shortly and have included museums as a public building without specifically addressing the special conditions of museums.

However, these guidelines are not designed for existing buildings, neither upgrading cultural heritage sites. Upgrading existing buildings is more challenging and needs a lot of efforts, as sometimes this upgrade require to change a lot of old patterns and practices, while starting something new does not need the process of changing what is there already.

Moreover, while energy reduction and environmental considerations are new in the UAE, enhancing and reducing energy consumption in museums has not been a consideration in the fields of museums in UAE before, and it is relatively new in other regions as well. In UAE museums, IEQ assessments has not been considered by researchers in order to enhance the study field and develop it for a better conditions in terms of energy.

Besides, Dubai and Abu Dhabi are the only two Emirates setting and considering the sustainability aspects in the buildings from the UAE. Other Emirates have not yet translated their environmental efforts into set of mandatory guidelines to be adopted and implemented by all parties in different means.

From all the above and due to the growing demand of museums in general and the increasing number of private ones, filling the current knowledge gap as well as providing guidelines considering the different scopes of the indoor environment can ensure the proper conservation of artifacts. Also, Driving the attention to museum sustainability is very important from different perspectives. In terms of government, providing museums that are educational and concerning the environmental aspects is big help to educate tourists, visitors as well as the local population for adaptation of sustainable methods in life.

The motivation for private sector museums might be more motivating in terms of reducing the amount of their utility bills. With the high budget paid for the monthly electricity bills, knowing there is ways to reduce the energy would contribute directly to reduce the bill amounts, which is a way to support the individual private museums.

From what have been mentioned, the literature review section provided the information needed to conduct the study in this region based on what have been done in other parts, as well as showing the advancements in technology that can be considered in suggesting the upgrades in addition to which subfields to be focused in the studying for UAE museums.

To make the study, the method should be decided to identify the stages and steps. The following chapter is dedicated for methodology.

Chapter 3

Methodology

3

3. Methodology

Selecting methodologies is one if the most significant part of a research. While selecting the methodologies to be adopted in any study, different criteria should be taken into consideration. Some of these criteria's are: time frame of the study, cost, team conducting the study and their abilities and most importantly is the aim of the study. As mentioned in 1.2 section the aim of the study is to enhance indoor environment and reduce the energy consumption from the indoor environments of the current UAE museums without causing any risks for the museum collection or the artifact conditions.

Since this study is targeting to evaluate and enhance different aspects of museums indoor environments, the holistic approach in enhancing energy performance makes it is necessary to consider the requirements for each individual field (like lighting and ventilation). Thus, the adaptation of mixed methodology will give the flexibility and possibility for considering the desired aspects. The adopted methodology should be appropriate for the different stages of the study including identification, evaluation as well as assessment of proposal. Thus it should adopt a method applicable for current situation as well as making prediction for the future when assessing the proposals for the enhancements.

The following section will show different methodologies adopted in studies targeting the indoor environment of museums as well as energy conservation evaluations.

3.1. Research Approaches

Researchers studying indoor environment quality (IEQ) of museums have adopted different methodologies based on the scope of focus in their research.

The following part is showing the different methods, explaining details of each method and how are implemented in the particular study. Moreover the pros and cons for each method in comparisons to this study will be expressed while a separate section for justification of the methodology adopted in this research is specified.

3.1.1. Survey

Studies dealing with gathering information, seeking opinion and evaluating conditions from people point of view usually adopt survey as a main method. Depending on the specification of the research and the author’s choice, research survey can seek general information such as seeking the building occupant’s opinion on the building environment. Such survey requires feedback from big numbers of users. On the other hand, the survey can also include detailed technical question for the professionals in the field.
Surveys have different sub categories in terms of how the information is gathered.

Questionnaire

Questionnaire is a tool used for conducting surveys in written method. The questions can be asked in yes /no or providing options for the answers or to be written. Depending on the nature of the research and the targeted population questionnaires feedback can be gathered in person, or online digitally. One advantage of online questionnaire is the fast outreach to big population without the limitation of geographical locations.
However, when the study is targeting a certain group of people in specific place, a site feedback is more convenient such as museum indoor environment. (Kaya, 2015; Dragicevic and Letunic, 2014; Raha et al. 2013).

In order to prepare a good survey with the targeted points, researchers examine the clarity and efficiency level of the survey on a smaller targeted population with same specifications for the study. This approach is called pilot study and was adopted in Jeong and Lee, (2006) research on two museums. Kaya, (2015) implemented the pilot on random population. However, other researchers benefit from the successful results of earlier similar studies and implement same survey questions to guarantee the efficiency of the questions and save the time for not conducting a pilot study.

Jeong and Lee, (2006) successful study served as a reference study in the field of museums indoor environments from the visitors' satisfactions point of view. The same method was adopted by Raha et al. (2013) thus the pilot stage was not conducted by them. From the visitors perception Jeong and Lee, (2006) Kaya, (2015) Dragicevic and Letunic, (2014) Raha et al. (2013) and Chiappa et al. (2013) (Mishra, et al al. 2016) studied visitor satisfaction level towards the indoor environment.

Nevertheless, since the current study is not concerned with visitors satisfaction at museums indoor environments and only targeting energy reduction within the artifact conservation limits and enhancement of the current status of the museum parameters, this type of surveys would be beneficial only as a second phase. Thus it is not implemented for the current stage.

Depending on successful studies for questionnaires will help in the result of the study in terms of limiting the errors of the research with ensuring correct questions. Wong, Li and Lai (2008) in their study about intelligent buildings have identified the key parameters and detailed indicators that served as a reference questionnaires for evaluating intelligence level and integration level of building components. This type of technical and detailed questionnaires usually targets the building professionals of a specific field, as ordinary people cannot answer them.

Questionnaire are efficient when the required information are very specific and to the point, however, is not the only tool for conducting survey especially when the information needed is not easily written or they need elaboration and discussion, and the targeted population are smaller. In this case interviews can be conducted.

Interviews

Interview is mostly done when there is a need to get information on a particular matter from the professionals of the field on a relatively broader aspect. The number of people interviewed depends on the study itself. However, usually it is much smaller number in comparison to questionnaire.

Interviews are done mostly verbally /recorded, and it provides more flexibility for the interviewer to re-direct the other following questions or ask for more details based on the answers given. Usually the interview duration is longer in time, however it is more informative in understanding. To make the interview managed semi structured or structured method is adopted in terms of the interview questions. This was done by Leijonhufvud and Henning, (2014), and Hashim, Taib, Alias (2014) in their researches, it helps directing the conversation in a proper way also it provides the possibility for comparing the feedback with different practices in museums.

Survey results should be analysed and presented properly, for people to understand the findings. In terms of the feedback from interviews can be embodied in the findings of the research and discussed. However, for the questionnaires with bigger population managing the answers and feedback are mandatory to present proper results. There are websites and different software that manage the survey results into graphs and diagrams and provide analysis with less errors. (SurveyCTO, 2016)
From the mentioned studies Kaya, (2015) has used software to manage the data and analyse the results, while others presented the results in percentages and compared each answers for each group of question in terms of each museum and overall responses. Rota Corgnati and Corato (2015) Dragicevic and Letunic, (2014) Raha et al. (2013) Jeong and Lee, (2006)
Moreover, Rota Corgnati and Corato (2015) presented the results of energy consumption and cost by statistical charts to show the differences of the museums based on the building volume.
When bigger numbers are surveyed

Moreover, to evaluate current conditions of museums indoor environment it is important to understand the current practices done. Therefore, seeking museum professionals' feedback is necessary.

3.1.2. Monitoring and Site Measurements

Monitoring and site measurements were conducted for studies dealing with the artifact and the environment it self without the target of obtaining information from people. It is a quantitative approach, usually used to check the current and on-going condition, whether the environmental conditions set within the standard limit of artifacts or not. Ferdyn-Grygierek, (2014) targeted evaluating the indoor environment by measuring temperature, RH and CO2 concentration, Zivkovi and Dˇziki´, (2015) targeted Indoor Air Quality (IAQ). As for lighting Pinilla et al., (2016) depended on on-site measurements by measuring the daylight of a museum to evaluate and study the risk factor over artworks in exhibit. While Al Sallal and Bin Dalmouk, (2011) in their study for daylight depended on measurements for validating of other adopted method.

On-site monitoring and measurements require providing explanation and justification in terms of:

Measuring Devices (Type, Calibration, Accuracy percentage)

Times and period of obtained measurements

Location and spots of measurements

Measuring devices can be data loggers that measure the conditions continuously with assigning frequent time of measurements, or on-spot one time measuring device. Data loggers are useful in terms of recording continues conditions and providing enough number and information in order to analyse and make a graphical trend for the measured parameters. The trend will help verifying the change happening. Data loggers were used in the study conducted by Ferdyn-Grygierek, (2014). While, on spot measuring device is a manual one time measuring method, it can serve same way to the data logger however, it is harder as all the readings should be obtained manually. Since the study by Al Sallal and Bin Dalmouk, (2011) used site measurements for validation on spot measuring devices were used.

In museums, IEQ studies researchers have depended on long period of monitoring and measurements. This is to include complete consideration in terms of seasonal variation and the fluctuation happened during different times. Pinilla et al., (2016) monitoring lasted from 2007 to 2013, while Ferdyn-Grygierek, (2014) measurement continued from 2009 to 2010,

Moving to the areas measurements took place Ferdyn-Grygierek (2014) study targeted the indoor environment. However, measurement took place indoor and outdoor with explanation for the record frequency in the data logger. This was done to check what is the influence from outside to the indoor environment. The research provided detailed explanation of number of sensors, the location and the areas there where fixed.

3.1.3. Software Simulation

Software simulation is a common methodology used in the studies concerning energy efficiency. Researchers have used the simulation software for examining different possibilities and experiments to be implemented in the future within the indoor environment. Energy performance, examining different types of light and ventilation systems, as well as studying potential solutions for adaptations, calculating the heating and cooling load, energy consumption rate are some of the concentrations in the museums studies adopting this method. (Balocco et al., 2015; Ferdyn-Grygierek, 2014; Karmer et al., 2015)

Using simulation software gives the opportunity to make different number of experiments through virtual model as close as the real life building with much reduced cost in comparison to reality. Types of software used differ based on the different study scopes and target area (Karmer et al., 2015; Cong et al, et al. 2015; Ferdyn-Grygierek, 2014). The accuracy of results depends on the software used in terms of being proven and valid in practice and most importantly is the data input. Therefore it is related to the software user and knowledge as well.

Software simulation requires professional knowledge and information of the existing museums buildings to create the model. In terms of data needed, location of the building weather information, building dimension, materials and specifications are important. Currently some software are being more helpful in terms of easing the input information by providing wide range of weather data and library options that users can choose and depend on like IES VE software.

After building the virtual model, a very crucial stage in using simulation software is the validation of the model. Validation stage is carried out to check the error in the virtual model and reality. This can help identify the mistakes and errors caused by the user or the obtained information from the virtual model. Validation can be done by on site measurements (Al Sallal and Bin Dalmouk, 2011; Kim and Chung, 2011). Research was carried out and considered valid by Al Sallal and Bin Dalmouk, (2011) with the error of ± 4% from reality, while Kim and Chung calculated correction factor (CF). In their study, the correction factor is calculated based on identifying the Relative Error (RE) among the actual measurement and the software number as below:

RE = [(ME – SE) / ME] X 100%

ME: The measured illuminance value on each measurement point

SE: The corresponding simulated illuminance value calculated using the software.

The ER in their measurements was around 8%. Therefore, the Corrected Simulation (CS) and the correction factor (CF) should be re-calculated for each point with the following way:

Correction Factor (CF) = average value of relative errors at each point

The values of the CF and CS are defined as follows: (Kim and Chung, 2011).

CS = Simulation Results X CF at each point

After validation the main stage of the research starts which is implementing the experiments and testing them. The experiments can be in terms of making changes in the building structure, envelope, systems or adding elements in the building environment. Usually experiments are done as much as possible in order to reach to a best practice in terms of energy and implementation requirement.

Last stage is the data analysis and the comparisons made between the different experiments through the software. This analysis is crucial to help identifying the efficiency of the solutions and different options. It concludes if there is any practice can be done for the targeted case? Also which practice among other experiments represents the best option to be implemented in reality?

IES VE simulation software is a known software in the region having the possibility of examining different indoor environmental options in terms of Lighting, ventilation, heating and cooling demand. It allows the selection of different location in the world as well as providing weather data for them or location near to them. In terms of modelling the building, the library provides verity of different construction details, building components systems to be selected and implemented in the building, helping in reducing the efforts and mistakes while modelling. The author should do validation of the built model in this research case. Moreover, analysis should be presented from the concerned area point of view.

3.1.4. Experimental

Experimental method is helpful to examine different options for the study and check the best results based on making some modification on one or more factor with keeping other factors controlled. Considering artifacts as very precious ancient and nonreplicable objects, experimental methodology is not appropriate for experimenting directly on them. Nevertheless, this was done by some researchers in terms of lighting experiments. Liu et al. (2013) study included the color rendering and color quality of light by exposing the artworks to a fixed lux level lighting with different color rendering generated by a machine. The experiments targeted to identify the best color fidelity (most natural color) by observers. Pinto et al. (2010) study also, was conducted on exposing 20 artworks and checking the light changes on the original items.

In studies targeting the IEQ of museums, when adopting experimental methods, experiments were not directly applied to museum artifacts in many studies. Kim and Chung, (2011) Schieweck and Salthammer, (2011) Viénot, Coron and Lavédrine, (2011) The experiments were done on samples or scaled models Kim and Chung, (2011) to avoid any direct damages to artifacts. This method was mostly used for artworks and lighting in order to see the visual appearance and the color rendering of different types of light.

Kim and Chung, (2011) to experiment daylight and different options have made a scaled model from the museum building and applied different options in terms of checking design possibilities. However, the scaled model resulted in giving errors in terms of measurements due to different reasons of not being close to real conditions, thus the study results mainly depended on software simulation experiments rather than real environment.

Schieweck and Salthammer, (2011) has made a successful implementation of methodology as the study was focusing on implementing the experiments on showcases. The experiments were carried out on different types of showcases by comparing the conditions in them especially by measuring the VOC which are curtail for harming artifacts.

Experimental studies lead the study to much higher cost with higher risk of not proper implementation. It will require longer time to make appropriate conditions for experiments (Schieweck and Salthammer, 2011). Delgado et al., (2010) experimental study required manufacturing different types of light filters in order to test their efficiency. Also the study by Viénot, Coron and Lavédrine, (2011) targeted lighting in museums by experimenting different possibilities in terms of color fading, however, the experiments were carried out on normal printed paper to check the impact over it but to conduct the study researchers had to build an environment to have control over other factors and colors of the environment.

In conclusion in order to have better results it is best to make the experiments on the real items. However this is very dangerous for museum collections. Also experimental methods require manufacturing or building the environment, which is associated with much higher budget, and require time. This method served best for studies targeting lighting as expressed above.

3.1.5. Case Study

Considering the time frame, manpower of the current research project, it is not possible to study all current existing museums in UAE. Thus, it is necessary to limit down the number of involved museums within the study scope to be manageable. Moreover in order to have realistic assessment of the proposals it is mandatory to have a base model in order to check and evaluate what is done and then based on the existing situation to move forward and enhance what already exits. Selection should be made to representative projects to assess the different conditions. This approach is known as case study selection, it was implemented in (Ge et al. 2015; Arroyo et al. 2016; Vaezizade and Kazemzade, 2013; Kramer et al. 2015 a,b; Salata et al. 2015; Todorovic, 2015; Belia, 2015; Franco et al., 2015) studies.

This approach involves considering specific numbers of museums depending on the conditions available among other options in terms of museums study. Selection should be made based on criteria assigned and to follow some strategy.

This approach is adopted in studies aiming in making representation of wider selection. However, they require detailed examinations, implementation and assessment in order to obtain the results of the study. The results could be applicable for the other excluded cases in the research project.

The difference between case study selection and other specific project oriented studies is in the criteria and representational approach. Even though there are no identical conditions, however, the selected case study should be the best representation of the bigger projects. Thus the number of involved case studies may be more than one case as they have contrasting or different conditions that might result in different findings in the study. On the other hand, specific project oriented studies may not be considering the wider scopes of other projects. Their aim is solely based on studying the selected targets without specifying criteria.

3.1.6. Mixed methodology

Some studies require more than one approach and method in order to reach to their objectives. As one method will not fulfil the requirements of all stages of the research, these researches follow mixed methodology.

Literature review is the base of all studies in IEQ of museums. Authors conduct a stage of literature review to show the background knowledge within the scope of their research, current research stages, and most importantly the knowledge gap. Even though in some other fields researchers might depend only on literature review to complete the research, however, the number of such studies in IEQ of museums is very limited. The purpose of these studies mainly is gathering earlier information within the subject area (field of museums) to provide a holistic study as a reference for practice and gathering the vast era and results. (Pavlogeorgatos, 2003) (Khodeir et al, 2016) If the information provided is detailed with proper focus, they can serve as a benchmark study in the filed.
Other than literature review, researchers might depend on survey, software simulation or site monitoring and measurements.
Studies dealing with evaluation of current situation and proposals for future enhancements, especially considering energy consumption, usually require adaptation of more than one methodology. Other than literature review, simulation software is the common method among them. The second method that deals with the evaluation of the on going practice varies from on site measurement or surveys or a combination of both. (Graaf, Dessouky and Müller, 2014; D’agostino et al. 2015; Lucci, 2016) (Ferdyn-Grygierek, 2014)

Graaf, Dessouky and Müller (2014) in their study on lighting in the museum have depended on literature to get the required standards. Moreover their study included on site measurements for indoor and outdoor lighting level, in addition to software simulation. Measurements were carried on recording the annual exposure of light from daylight and artificial light inside the museum. The software simulation was used for calculating the annual energy consumption for current situation, additionally two different enhancement proposals were examined by the software on order to check the efficiency of each proposal as well as the possible energy reduction rate in terms of cooling load required. As shown in the study without adopting mixed methods the current status and the possible enhancement would not be achieved.

Additionally Ferdyn-Grygierek, (2014) targeted the indoor air quality of the museum in terms of CO2 concentration as well as studying the hygrothermal conditions. Methodologies included; on site measurement of RH and T inside and outside the exhibition halls by data loggers. Also simulation software was used for the heating gain and cooling demand of the building. Solutions were examined through software simulation by author.

While D’agostino et al. (2015) and Lucchi (2016a,b) in their studies targeting energy analysis for museums in old buildings have developed the early SOBANE strategy for the prevention and control of thermal problems for humans and applied it on the museum environments for preventive conservation. SOBANE includes four different crucial stages:

1-Screening: identify main or small problems and resolve them right away

2-Observation: gathering information of current conditions

3-Analysis: using professional tools and staff for identifying problems not solved from previous stage to get exact and detailed situation

4-Expertize: depending on the exact problems identified in analysis stage, proposing the solutions and examining them as necessary.

According to the study by D’agostino et al. (2015) screening should not be included in museum studies, as any change is very crucial to the museums that require complex conditions. However, Lucchi (2016a,b) have included this stage in the study by walking through the museum. Screening stage can also depend on the position of the researcher and authority has in museums, as making on site action need authority.

Observation is getting the knowledge in the field based on literature and most importantly to identify the existing with comparing them with standards. This also might require surveys and interviews.

In the analysis stage D'agostino et al. (2015) has depended on the information obtained from the observation stage in terms of the common problems in HVAC systems of the museums and focused in resolving them within the focus of the study. Since its an in depth checking stage IAQ monitoring and measurements were carried, then the conditions were compared with the standards. Although the research has provided solutions in terms on enhancements, however the effectiveness were not verified. The importance of verification through software was emphasized in the conclusion.

As shown in previous methods, most studies conducted are usually targeting one field of the museum indoor environments. Thus, a single methodology is adopted in such studies based on the elements to be considered. While, studies for energy efficiency in museums are very limited in terms of museum indoor environment quality. It is shown that this attention is a recent orientation in the researches.

In regards to the methodologies adopted, the studies considering the holistic approach of considering the different elements of indoor environment quality, had complex series of methodologies. Since, the concerned area is not only one scope, energy evaluation and enhancements are done for lighting and ventilation by examining the different possibilities. They included the onsite measurement as well as the software simulation approach. Measurements were carried out to get the existing conditions and evaluating them. Also, measurements were done over long period of times depending on the study if targeting the seasonal variation in terms of thermal conditions. (Mishra et al. 2016; Rota, Corgnati and Corato, 2015)

However, all studies depended on software simulation as a main aspect for evaluating the energy performance and the examining different proposals for implementations. While the other method varied from interview with building professionals, survey for people perception, checklist and so on.
Following the SOBANE strategy can help structure the study in terms of clarifying the requirements of each stage of the research, with making the guideline and structure for the stages. Even thought the implementation is new in the museum field, however it shows how to manage a big research targeting the evaluation and enhancements for existing museums that also is a new concentration in the research field as well. Author will be depending on SOBANE strategy for approaching this research by implementing the mixed methodology aspect.

3.2. Justification of Methodology and Study Stages

As mentioned in 1.4 section this study is having 3 main stages of: i) evaluation of current museum practices and conditions in terms of indoor environment, ii) proposals for enhancement of current situation, and finally iii) assessing the applicability and energy efficiency of the proposals. Each stage of the research has different requirement and approach in order to be done. Most important consideration while doing all the stages is not to cause any harm or risks to the artifacts. This is a very recent orientation in terms of museum indoor environment studies that is taking holistic approach and not focusing on single element. While conducting this type of research 1- artifacts preservation 2- human comfort and 3- energy conservation are the 3 elements controlling all actions. (Lucci, 2016 a,b; D’agostino et al., 2015).

As mentioned in section 3.2.5 considering the time frame, manpower of the current research project, it is not possible to study all current existing museums in UAE. Thus, it is necessary to limit down the number of involved museums within the study scope to be manageable and select case studies. Since more than one case study is involved in the current research a separate section is specified for the criteria and selection stages for the case studies in the coming chapter.

Moreover, IAQ parameters are excluded from this study, as the study focus is on energy performance within the safety of collection. Hence, IAQ cannot be measured in terms of energy consumption, excluding this will make the study manageable in terms of manpower, abilities and timeframe. Thus, the study is concerned with hygrothemral and lighting parameters within the indoor environments of the museums.

This research study will follow the same approach of SOBANE developed by D'agostino et al. (2015) and Lucchi (2016) to be practical with the museums field. However, it will include some modifications and adjustments in order to comply with the current conditions of the region as well as the current research possibilities. According to D'agostino et al. (2015) some stages require immediate actions and intervention. However, this research will not issue immediate actions as the author is not in a position of having the authority of interfering within the museums. Any required action will be proposed as a set of guidelines to be implemented with showing their efficiency.

The following part is explaining about each study stage and the methodology for implementation as well as the justification for it.

Phase 1: Evaluation

The first stage of the study is evaluation of the current practices of current museums. Based on SOBANE strategy implemented by D'agostino et al. (2015) on museums, this stage is about screening to identify small problems and resolve them right away. According to D'agostino et al. (2015) musuems are complex thus it was not implemented in their study. Also, resolving problems on the museums in the current study is out of the author authority, therefore, not included here as well.

The second stage of SOBANE, is observation and gathering information this is partially concerned with the literature review as defined by D'agostino et al. (2015). The author has heavily depended on an intense numbers of literature review stage in regards to the museums indoor environment quality, collections requirement, different practices and current energy conservation application for museums. However, as mentioned earlier this stage is not enough because the studies are not concerned for the region apart from Al Sallal and Bin Dalmouk, (2011) Abdul-Wahab, Salem and Ali (2015) studies. Therefore it should involve museum management and professionals. This stage of evaluation requires big effort and consumes time at this stage. As currently publication in evaluating the indoor environments of the local museums are lacking. Moreover it was found that only in Sharjah has one main authority that run all the museums. On the other hand, Dubai has multiple authorities involved for different projects related to museums.

Approvals for the study should be obtained and most importantly to understand how that particular museum is run and managed in terms of the indoor environment quality different people should be targeted. Self evaluation and site visit can help generate a general knowledge, nonetheless, different technical information and management aspects should be obtained about systems adopted and specification.

Survey is necessary for gathering information to help obtaining clearer input on the current energy consumption rates, which museum guideline and standard is followed and what are parameters set for different artefacts. What is the specification and information for different systems?

Lucci, (2016) D'agostino et al., (2015) and Wong, Li and Lai (2008) all have adopted survey methodology to obtain this type of information mainly based on interviews or questionnaire. D'agostino et al., (2015) conducted the survey by depending on questionnaire approach to ease the understanding for the personnel involved. Since the study conducted by Wong, Li and Lai (2008) is very well detailed and targeting the different aspects of buildings in terms of intelligence. Also it has already proved the success of its implementation in evaluation. Depending on their questionnaire will be beneficial, as the current study is targeting in evaluating the current conditions and their intelligence level of museums and enhance them within this scope as well. However, for this study, the questionnaire should be modified to make it relevant to museums. This questionnaire will target the building management or facilities management teams in the museum and the findings will make the classification of intelligent level of each museum.

Moreover, in order to get the information for artifact's indoor parameters implemented in each museum, the collection department should be involved to explain the requirements based on the nature of owned collections. Semi structured interview is important at this stage as not all the details of the current museums are known to the author. That is due to the lack of research publications and guidelines for museum practices in this region. The interview questions are extracted from the reviewed literature of previous studies in other regions, the later is mentioned in literature review chapter. Interviews will help in orienting the discussion with the museum professionals to gain the needed information and having them structured will benefit in making the comparisons in terms of the different museums of the case study. Moreover, it is less technical in comparison to the intelligence evaluation. (Lucci, 2016) Wong, Li and Lai (2008).

On the other hand, to validate the information obtained from the management and to check to what extend the implementation was successful it is mandatory to do measurements for indoor environment parameters. On site measurements was done by Pinilla et al. (2016) for measuring lighting and by Ferdyn-Grygierek (2014) for measuring hygrothermal parameters. This stage of on site measurements is the analysis stage in SOBAE strategy adopted by D'agostino et al., (2015) and Lucchi, (2016). D'agostino et al., (2015) study proposed the on site measurement based on following certain standard and guideline.

As explained earlier to check on going practice it is mandatory to have continues measurements from the targeted areas. This will identify the fluctuations of the environmental parameters and show the changes happened. Standard time that measurement campaigns have gone through is one year or more (Ferdyn-Grygierek, 2014; Pinilla et al. 2016). This allows enough time to monitor the gradual change to the indoor environment as well as to identify the seasonal changes. However, this time frame cannot fall within the current research due to limitation of time. Since museums are controlled environments and environmental monitoring and records are mandatory, the author will obtain the data recorded by each case study museum. Some museums that do not have ancient artifact as their collection might not follow the system of environment monitoring and data record, however, the study is concerned only with museums with ancient artifacts.

A limitation that will be in this approach is that each museum might be having different systems and devices for monitoring and record. Even though, this will be enough to give the indication of the range where each museum stands in terms of the percentage of time the indoor environment parameters fall within the standards.

Also, in case of limitations in terms of obtaining permissions or no data records, the author should obtain on site spot measurements. This would be considered as a main limitation to the study, however this will be the best possible solution.

As each museum in UAE have different exhibition halls and the study concerns more than one exhibition room in each museum. More than one data logger tool will be needed to have same time data collection for continues period of one museum. Due to resources limitation this is not a possibility. Otherwise much longer time period for IE measurements should be specified and the reading of each exhibition will not be obtained on the same day.

On spot measurement will be best solution in terms of available time and resources. The author by using one device, the author can obtain readings of different exhibition rooms of one museum. Readings should be obtained for different hours of one day on specified areas of each exhibition rooms. The readings should be compared and analyzed in order to check the fluctuation between different times of the day.

The numbers obtained from the measurements should be compared with the standards in order to identify the level of differences between practice and standards. To have better identification, classification for each museum level will be made like Lucchi, (2016 a). However, Lucchi, (2016 a) identified the museums levels based on: building envelope, mechanical systems, electrical installations, renewable sources, presence of monitoring systems, management procedures, trainings, and public involvement to four levels. But since the current study is targeting museum indoor environmental parameter implementation, and practices, as well as intelligence level and building component, the classification will be based on different levels from the obtained feedback from the different stages mentioned earlier. Categorization will be on three levels of:

1- Museums indoor environment practices
2- Integration level of building components
3- Energy conservation concerns and practices

This is done after the analysis stage of SOBANE strategy and will indicate each museum ranking level.

Phase 2: Proposals

Phase 2 of this research falls in expertize stage of SOBANE. It includes proposing the solutions for the problems identified through the earlier undergone stages (D'agostino et al., 2015). The proposals of the research will be based on literature review stage that explained about the advanced practices done for the museums indoor environment. Additionally, to identify the current available technologies in the region for the museums, interviews with experts from the market specialized in museums and have worked on local museum projects to be conducted. These interviews help in ensuring the compatibility for adaptation in museum conditions. As well as understanding how the work has been done from the supplier point of view with details.

The proposals in this study will be presented for each museum as a separate section to make them easily understood and addressing the targeted area. Most important aspects for the proposals is considering the three main facts of:

1- Collection preservation
2- Human comfort
3- Energy conservation

After having the proposals for each case study project, phase 3 of the research will begin.

Phase 3: Proposal Assessment

Having set of proposals will help to improve existing conditions, however, they should be assessed in order to check the level of enhancements each one can have. This stage needs the implementation of software simulation for virtualizing the performance based on the given conditions to check the results without applying them in reality. This is a common method adopted in researches aiming in energy conservation as well as studies to predict the possibility of implementation (Karmer et al., 2015; Cong et al, et al. 2015; Ferdyn - Grygierek, 2014) As they are cost friendly and save greater time to test and try different options, while other methods can not give results near to reality in short time and low budget.

As for the software selection, IES VE software is required for this research to assess the proposals. Since the study is concerned with hygrothemral conditions as well as lighting, it is not convenient to examine each aspect in separate simulation software. A platform providing assessment for different scopes will give better results. IES VE is common software used in this region for energy simulation of different aspects of a building and is used for the upcoming museum projects according to the professionals in the field (IES VE, 2016; Farh Naz, 2016). Most importantly it is recommended by LEED rating system.

Following is some of the IES VE options features that will be used from the software after modeling the concerned areas in ModelIT tool.

- **Weather Tool:** to choose weather data file for different countries including UAE.
- **Apache Tool:** calculates heating and cooling loads of the building. Author will benefit from this tool to check the difference in cooling loads according to different conditions and changes of happens in the set points of the HVAC. Relative humidity control and contribution in energy consumption. As well as the energy reduction or increase based on the diffrent lighting heat gain in the place.

- **Lighting Tool:** has the flexibility for checking the artificial lighting, lux levels and examines different options for lighting and the enhancements that can be done in the space.
- **Sun Cast:** to show the solar radiation and shadings in the building. Even though the study is concerned with the indoor environment. However, running the shading calculations based on the changes happening is essential in terms of the hygrothermal fluctuations that can be caused inside the gallery rooms.
- **Vista Pro:** Is the tool used to present the results of the different experiments happened. It provides the flexibility of showing the data in charts, diagrams or tables with numbers. It also makes it possible to compare different experiment results in one place. Which is the key factor to make the decision for the best practice.

Chapter 3

Case Study

4

4.1. Case Study Selection Criteria

UAE with its global recognition for being a tourist attractive country has limited numbers of museums. The professional practice of museums can be considered as a relatively new field in the UAE. Most museums in the past were established mainly, to introduce the lifestyle, and culture of the local people to the tourists. (Al Ain Museum, Dubai Museum)

The criteria set for choosing a case study building was derived from the definition of museums set by the International Community of Museums (ICOM) (2007), mentioned in the literature review chapter 2. Accordingly, the museums not open for public were excluded from the study. Also, since the main factor is the presence of original historical artifacts in the environment, museums with no historical artifacts were excluded as well.

Museum in general are established in two types of buildings:

1- Purpose built museum buildings.
2- Reusing existing buildings for museum functions.

Recently, growing numbers of projects are being developed in order to open new museums in historical buildings/ sites as well as purpose built museums.

Existing buildings that have been turned to museums were either historically important buildings in terms of their age, or relatively new buildings but had vital function in the past and is not taking place anymore, e.g Sharjah Museum of Islamic Civilizations. The number of current purpose built museums in the UAE is limited with considering the under construction projects or the ones not yet officially opened.

As there is no current evaluation for museums in UAE, there is no foundation to base on and move the study forward, the current study should start from the base and evaluate different aspects of the current museum practices. Compare the conditions with other practices and most importantly study the current energy performance. However, considering the research time frame and the number of museums in the UAE makes it challenging to consider all the museums for this study. Moreover, since there are different museums under same management and share relatively same conditions, selecting examples can be a good starting point. Additionally, since the study involves enhancements and assessments of suggestions they should be done on a selected project in order to see the results and compare the feasibility of implementations.

In terms of the case study selection it was important to consider the museums that require different environmental conditions from regular buildings. Thus, exhibiting original ancient artifact to be as a main consideration of the museum to be considered. A list of museums in Dubai and Sharjah was prepared by the author to conduct visits to projects not visited before in terms of checking the exhibitions and collections. Abu Dhabi and other Emirtaes were excluded from the current study for the challenges in terms of location as well as the difficulties for obtaining approvals from the authorities. Also the main known museums in Abu Dhabi are still not finished or not yet opened to public.

Since the case studies should be best representation of other museums government and privately owned museum should be looked at. Governmental projects as they represent the majority of current museums. Moreover, due to the increasing number of private museums since 2012, it is important to consider the practices and provide guidelines for them.

To validate this consideration, the author has conducted different site visits to museums by end of May 2016. The purpose was to check the type of collections each museum has in their exhibitions. The target was set to choose one purpose built museum, and one museum in historical building.

Based on the site visits and information obtained about different museums, a lot of museums were excluded from the study for not having the mentioned conditions. Three case study museums were selected;

1- Sharjah Museums of Islamic Civilization – Governmental project located in Sharjah.
2- Crossroad of Civilization – Private Project located in Dubai
3- Saroog Al Hadid Archealogical Museum - Governmental project located in Dubai.

4.2. Selected Case Studies

Based on the site visits, it was found that most museums were hosted in non-purpose built buildings. Mostly were heritage buildings, that later were turned into museums in Dubai and Sharjah. Most of these museums did not exhibit ancient artifacts, however the buildings themselves require special attention for preservation purposes.

In terms of purpose built museums the Women Museums UAE in Deira, Dubai is established in 2012. (Figure 4.1)

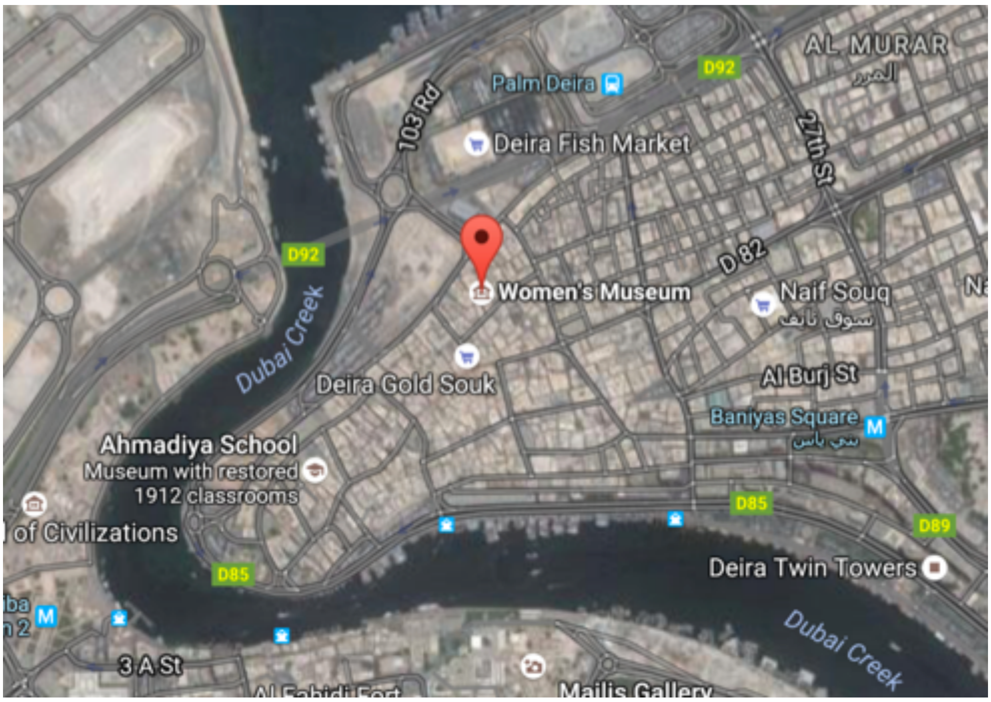


Figure 4.1 Women’s Museum UAE location map pinned in red. (Google Maps, 2016)

Even though the museum has original artifacts in the exhibited collections, the ancient artifacts types are not sensitive to the environmental conditions (Gold Items) Figure 4.2 shows a view from the collection in display. Therefore, the building is classified as an ordinary building without the need for implementation of museum indoor environmental requirements and the museums was excluded from the study.

Figure 4.2. View from The Women's Museum UAE exhibition environment. (Women Museum, 2016)

Louvre Abu Dhabi museum, the Union museums in Dubai are other purpose built museums in UAE, but since they were still not opened for public they were excluded as the museum was not yet officially opened.

On the other hand, Sharjah Museum of Islamic Civilization (SMIC) from Sharjah hosts big number of ancient artifacts with big variety of origins. Based on the variation in types of collections exhibited, the museum can be as a good representation for museum requiring special environmental conditions. However, the building is not purpose built, neither a historical building. The building was one of the important souqs of the area built in late 1808's known as Al Majarrah.

SMIC was chosen as a first case study, as it hosts a variety of collections and artifacts with different origins requiring specific and special care. Sharjah Art museum was excluded, even though it hosts artworks but there is no variation in terms of collections origins and dates.

Crossroad of Civilizations Museum in Shindagah area, in Dubai, is another good site as it is exhibits various types of ancient artifacts hosted in historical building. Moreover, the museum is privately owned, this museum can be representation for the growing number of private museum projects as well in terms of practices and limitations faced by them.

Saroog Al Hadid museum is another museum in one of the historical buildings in Shindagah area, in Dubai. The museums is very recently opened (June 2016) exhibiting various types of ancient items. This museum is chosen for this research because it is governmental project and it is the first practice of government in terms of exhibiting ancient items in historical building.
Even though, Crossroad of Civilizations Museum and Saroog Al Hadid museum are having similar conditions in terms of hosting ancient items in historical buildings, but based on the site visits, their indoor environments had totally different parameters. Moreover, principal of practices in both museums were contrasting (This is explained in details in the results chapter) Hence, comparisons in terms of government vs private practices can be done.

4.3. Case Studies Specifications

Based on the focus and aim of the study all selected case studies are from the same country UAE, in the two Emirates of Dubai and Sharjah shown in Figure 4.3.

Figure 4.3. UAE map indicating Dubai in blue and Sharjah in green color.

4.3.1. Dubai Geographical Location and Weather Conditions

Dubai with total area of 4,114 sq km as shown in figure.4.3 is located on UAE costal line (latitude of 25.1 and longitude of 55.2) Dubai Creek is dividing the city into two parts of; Deira, and Bur Dubai. (UAE Government, 2013)

Dubai is a hot and humid city. Temperature in the summer ranges around average of 43 degrees and in winter this average does not go less than 18 degree. Highest recorded RH was 82% and lowest of 13% in 2015. (Dubai Static Centre,2015) Wind direction usually is coming from South and North West with very low speed (Weather Spark, 2013).

4.3.2. Sharjah Geographical Location and Weather Conditions

As shown in figure. 4.3 Sharjah is the neighbouring city for Dubai (sharing southern borders) distributed in UAE with latitude of 25.53 and longitude of 55.07 (National Center of Meteorology & Seismology, 2016). With total of 2650 sq. km is the third largest Emirate in UAE connecting to the two borders together, one side is the sea and the second side is on border of Oman. (The Official Portal of UAE Government)

Being near to Dubai allows almost similar weather conditions of hot summers and moderate winters. According to the weather conditions of Maliha station from National Center of Meteorology & Seismology highest mean temperature ranged around 43 degrees from 2003 to 2015 and lowest mean temperature was around 11 degrees in winter figure. 4.4.

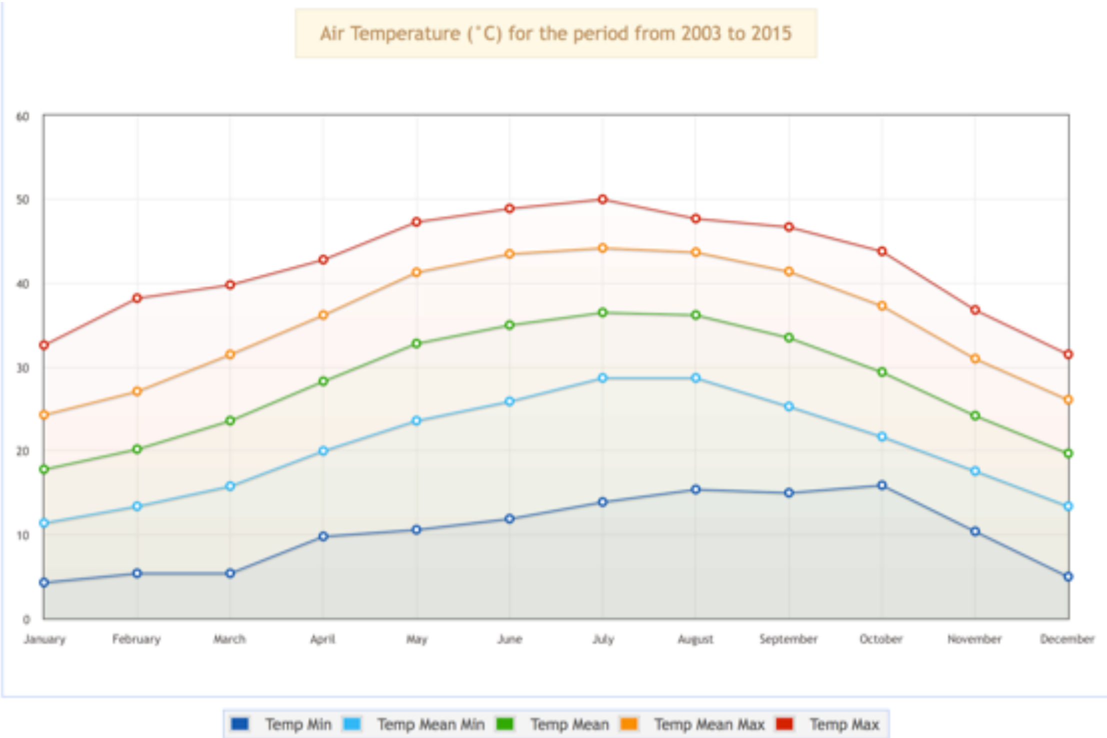


Figure. 4.4. Air Temperature from Maliha station for 2003 to 2015. (National Center of Meteorology & Seismology, 2015)

As for RH being on the coastal line similarly to Dubai makes humidity higher according to the records from Maliha station from National Center of Meteorology & Seismology highest mean RH was 88% and lowest mean RH was 11% for 2003 to 2015 making the average ranges between 63% to 32% figure 4.5.

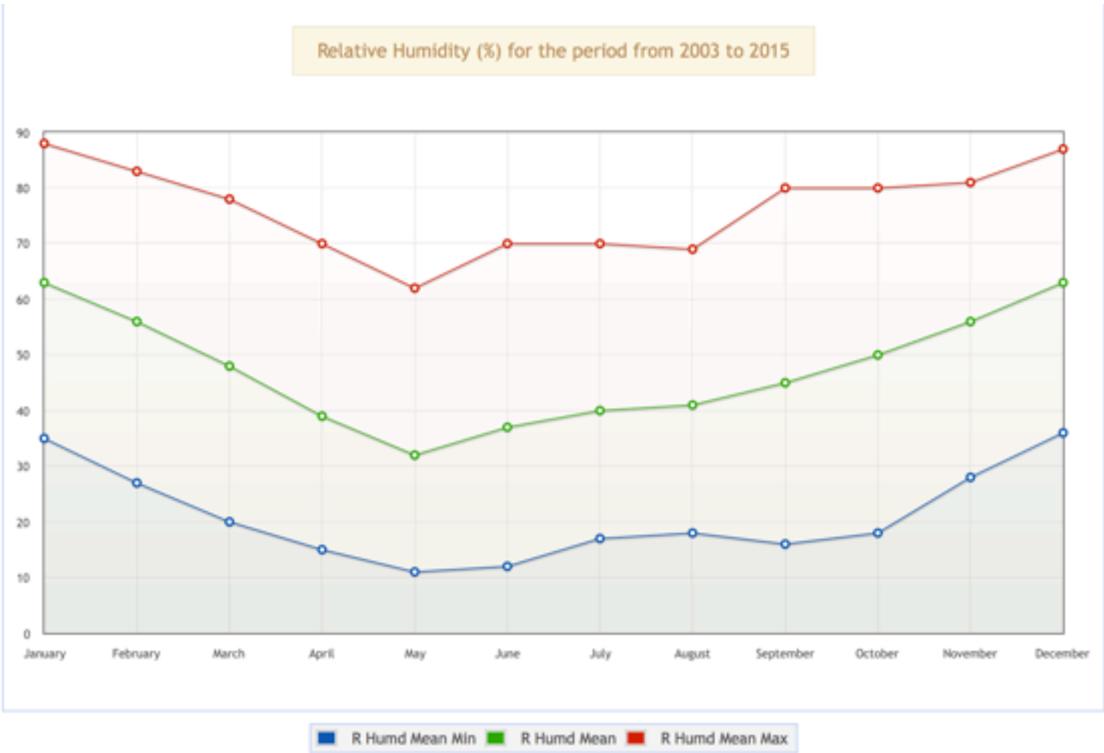


Figure. 4.5. Relative Humidity from Maliha station for 2003 to 2015. (National Center of Meteorology & Seismology, 2015)

Considering the mentioned climatic conditions, the proposals for enhancing the selected case studies should be suitable for the extreme hot conditions in UAE summers, that makes it contrasting with the other parts of the worlds that are having moderate summers and extreme winters.

Recently, Dubai municipality have given the chance to individuals and private parties, to establish museum projects in Shindagah historical houses. Thus, the numbers of private museums are growing significantly. Choosing a representative privately owned case study museum will give indication of the current condition of such museums. Also when proposing the proposals for enhancement it is very crucial to consider the conditions as well as the limitations these museums face in order to solve their problems.

Shindaghah area is one of Dubai’s historical sites marked as one of the most important areas that is still active. It is located on Dubai creek in Bur Dubai Side. Two of the chosen case studies are located in this historical site.

Buildings in this area are all traditional buildings with the traditional architecture feature. Which were built based on the local climate conditions with the available materials.

Passive method of ventilation was applied through the construction of the “Barjeels” (meaning wind towers), capturing the wind and allowing natural ventilation inside the houses. The structure was built around a central court yard creating privacy, and most importantly allowing air circulation inside the house. The structure of the ceiling included Chandal and Bamboo. Chandal is referred to the mangrove tree trunks with 8-10 cm diameter and the length would be from 5 to 9 meters that were imported to the country. Chandals were mainly used in the ceilings as the beams of the houses arranged next to each other with a gap of 20 to 25 cm between each. Cubical structured woods, later on replaced these circular beams.

Construction materials are simple from coral stone walls, covered with material called “sarooj”. Sarooj was made by pressuring and burning the local mud, then powdering it and turning it into a strong mixture to attach the stones and cover the walls of the structures.

Thickness of the walls was creating good thermal insulation with the outdoor. The walls based on the materials were absorbing heat and humidity providing comfortable interior. During dry time the humidity absorbed by the walls were evaporated, thus reduces the dryness of the air creating comfortable environments for building occupants. Exterior wall from the outer part of the houses had either smaller windows or no windows at all.

The compact style of houses creating narrow alleys made provided shading in the neighbourhood.

Renovation works by the municipality carried on these houses by using same traditional methods in order to preserve their historical features.
These buildings were re adopted with different functions. However, due to the current situation and usage the sustainable features are not as before. (Dubai Municipality, 2005)

4.3.3. Case Study 1: Crossroad of Civilizations Museum

Crossroad of Civilizations Museum established by Mr. Ahmad Al Mansouri is located on Al Khaleej road of in Bur Dubai before Shindaghah tunnel (latitude 25.26 and longitude 55.28) next to Dubai Creek (Figure.4.6).

Figure. 4.6. Location of Crossroad of Civilizations Museum pinned in red. (Google maps, 2016)

The information mentioned below is based on the site visits conducted by the author to Crossroad of Civilizations Museum as well as an interview conducted with Mr. Ahmad Al Mansouri founder of the museum by end of July 2016. The drawings are obtained from Dubai Municipality based on the restoration done for the historical house before turning it to a museum. The author had updated some of the drawings based on the current use of the museum.

Figure.4.7 shows the Crossroad of Civilizations Museum plan, areas identified in red indicates the exhibition areas that are the main concern of this study. As shown, the spaces are distributed around the central courtyard. Visitors enter the museum to a small room, and then they should walk through the courtyard in order to visit the different exhibition areas (blue arrow in the plan show the circulation of the visitors from entrance and their path through the court-yard).

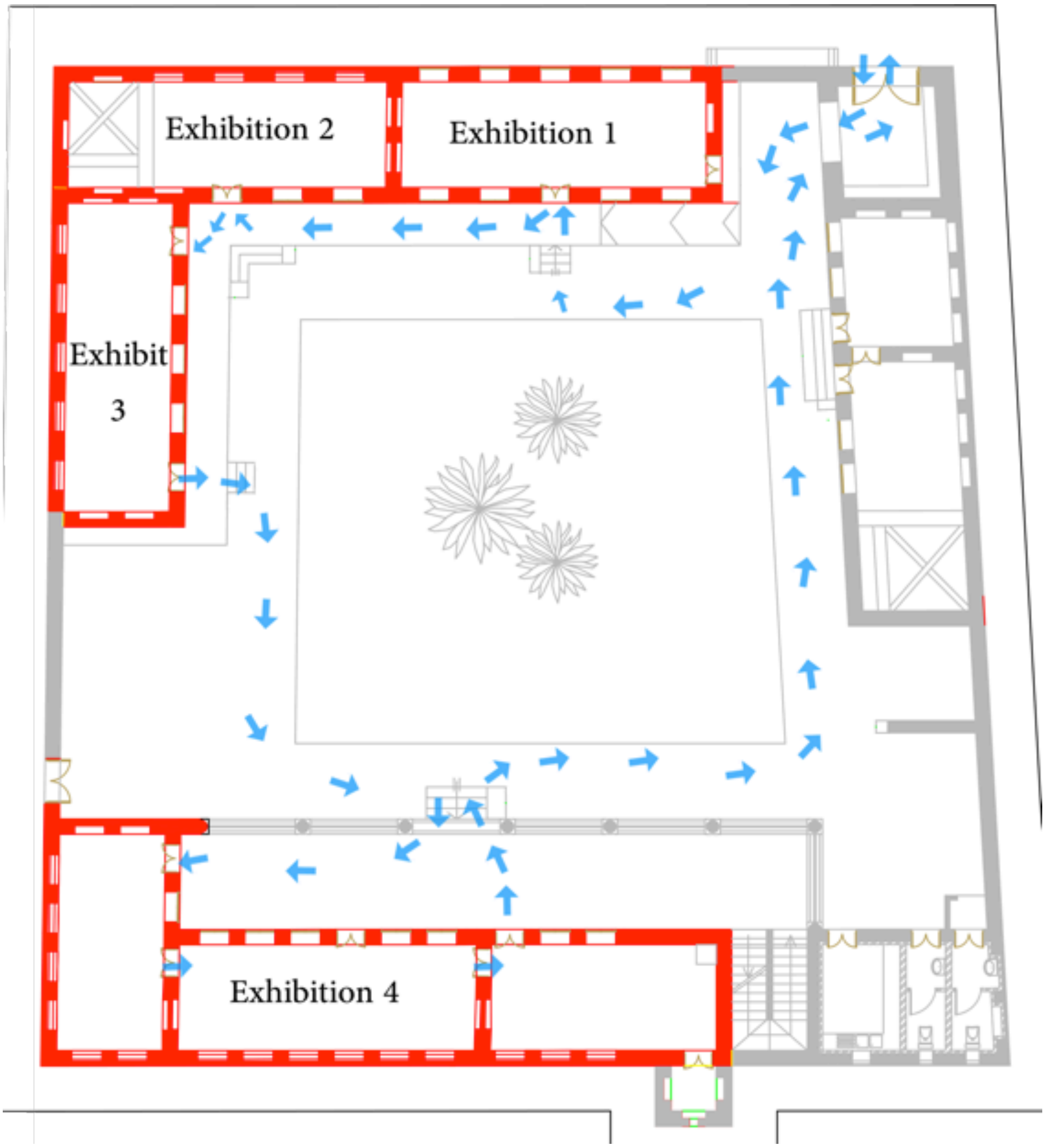


Figure.4.7. Case study 1 plan view and circulation (Crossroad of Civilizations Museum)

All the exhibition halls are small comparing to the building space having narrow width (3.5 m) with approximate same floor areas for three of the exhibits. The exhibition areas are 60 cm elevated from the ground and have a path of 150 cm width in front of the two exhibition areas. The linked rooms are considered as one exhibition in this study (Figure. 4.7). The details for each exhibition is exhibition is shown in Table 4.2

Table 4.1. Details of exhibitions in Crossroad of Civilizations Museum (CCM)

Exhibition no	Floor Area (m2)	Wall Thickness (cm)	Exhibition Height (cm)	Raised from floor (cm)	No of Display cases fixed in the wall	No of Display cases in the room	No of AC Units
1	35.35	50	360 +	60	13	4	2
2	36.75	50	360	60	12	4	2
3	35.7	50	360	60	12	4	2
4	76.73	50	360	60	27	8	4

As shown in Table 4.1. the wall structure is thick comparing to normal walls (55cm), that making it as a good thermal insulator by itself (U-values for the building was not available). Like other historical buildings the wall are not made from cement blocks, coral stones are the component of the wall as well as a layer of Sarooj from outside and the inside has layer of plaster.

The main museum entrance is located at the tower area in the northern elevation of the museum indicated in Appendix A.

For the ceiling structure as mentioned earlier, the beaming structure for the local architecture before was depending on Chandel wood. Appindix A shows the ceiling plan for ground floor in different exhibitions indicated in red. The chandels 10 to 12 cm diameter and are arranged with 25 cm gaps from each other. A layer of bamboo is covering the gaps between the Chandels.

The layers of the ceiling from inside the room towards the outside are as follow:

- Chandal
- Bamboo
- 1000 Guage Polythene sheet
- Roof Gyosum Screed (10-15cm) as slope (1%)
- 2 cots Betumene Paint
- 4mm Membrane

- Sand + Mortar 5 cm
- Traditional Tiles

Moreover exhibition 1 has one area that is linked to the historical wind tower. Thus, the height of area gets higher from other parts of the other exhibitions that are 360 cm. the windtower is closed by glass allowing indirect light to enter the space. One display case is located blow the wind tower structure.

The area before entering Exhibition 4 is covered with the ceiling of the above floor, unlike the other exhibition rooms. The second floor is the space for the offices and it is acting as a shading element by covering over the area in front of the entrance. Figure.4.8. is a section showing the two levels of the area. This side is also elevated 60 cm from ground and the height of the ground floor is 360 cm. Based on the structure, the indoor conditions of this exhibition is different from the other exhibitions.

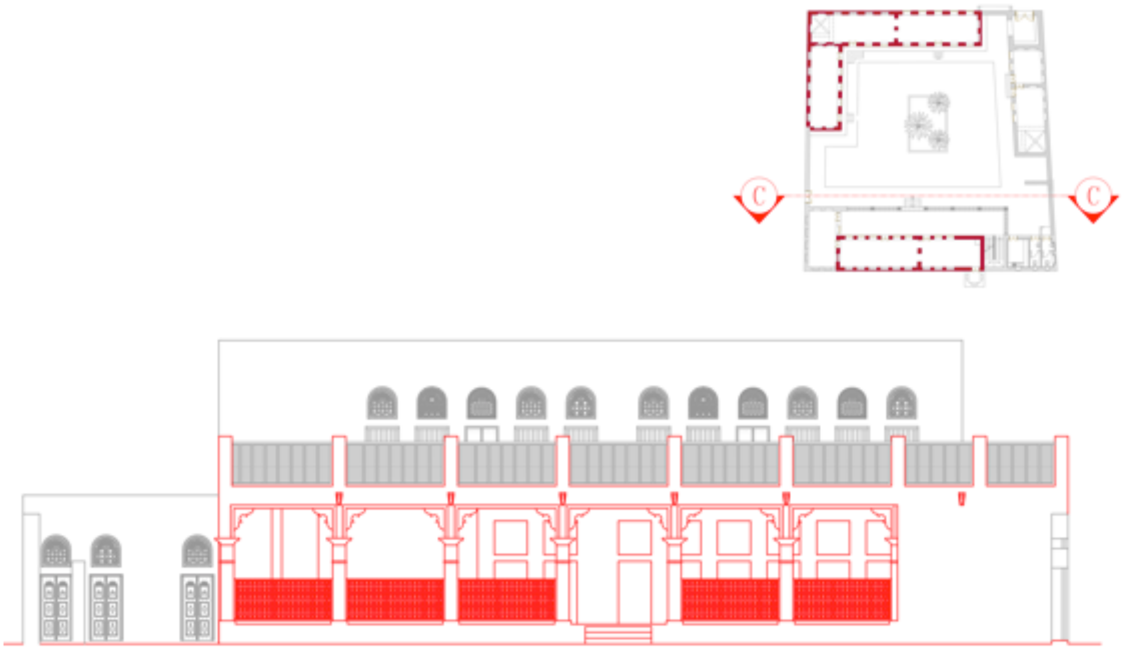


Figure.4.8. Section from Crossroad Civilizations Museum showing the two levels of the building.

The structure has many windows, which can be harmful for the artifacts. (Appendix A) However, due to the limited exhibition space and small area, the founder has made display boxes in the window spaces, thus opening are closed with the boxes shown in the Figure 4.9. and no daylight entering the space. In order to prevent humidity and moisture from outside, a layer of Polyurethane was sprayed between the display cabinet and the window opening. Also the traditional feature of the window is kept the same from outside with wooden door with rails over shown in (Appendix A)

Figure 4.9. Window spaces in CCM exhibitions

Traditional doors are used for the exhibition entrances, these doors are not well tight and sealed thus, the rooms are not well sealed toward the outdoor environment, thus there is impact from the outdoor to the indoor space.

As for the indoor spaces, ordinary split unit AC systems are adopted in the building. The Ac are kept running continuously in the museum, during the night alternate AC from each room is kept on.

The lighting used in the museum inside the display boxes that are fixed on the wall is florescent light. While the exhibition environment are lighten with halogen lights hanging from the ceiling. The lights are manually switched on and off, and it is kept on during the operation hours of the museum without closing.

The display boxes are ordinary show cases made from wooden base and glass box. Used for displaying different items with different origins. All the exhibition areas hosted variety of objects from pottery, ancient manuscripts and books as well as fabric along with pots metals and other materials. Appendix A is showing some of the variation in the museum collection.

4.3.4. Case Study 2: Saroog Al Hadid Archaeology Museum (SHAM)

The second case study museum is Saroog Al Hadid Archaeology Museum. Also, located in Shindagha area in Dubai. (latitude 25.27 and longitude 55.29) Figure. 4.10.

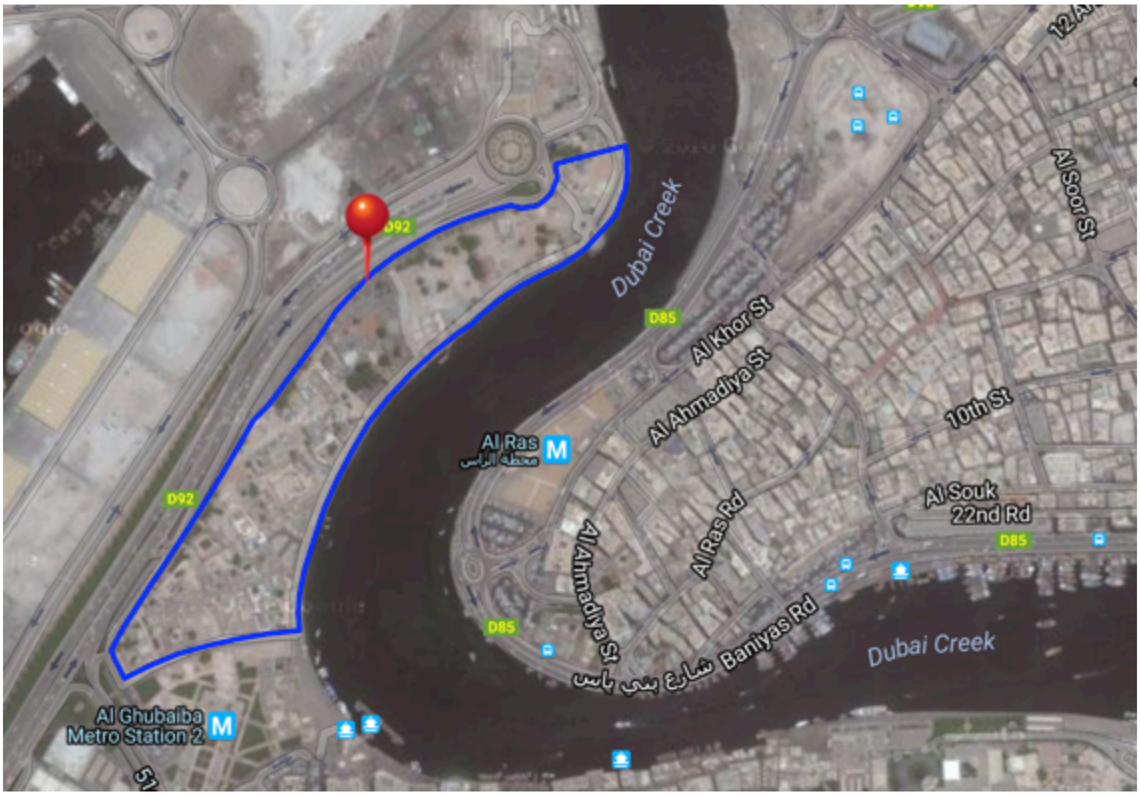


Figure.4.10. Location of Saroog Al Hadid Archaeological Museum, blue line indicates the Shindagah historical area. (Makani, 2016)

The museum was opened in June 2016. It is owned by the government and is hosted in one of the historical houses of the area. The house belonged to Sheikh Jumaa bin Maktoum Al Maktoum built in 1928. (Appendix A. contain photos of the building from outside.)

Even though this museum is in the same area of the first case study and have built in almost same types of houses, however, it is included in this research as it is considered a modern museum with different approach comparing to the other current existing museums.

In terms of building materials and building features, since the museum building is similar to case study 1, similar information not repeated as detailed in this part.

Appendix A shows the front elevation of the museum, the existing window spaces are also close for the museum usage and covered from inside. The second floor is not been used for exhibition proposes thus it is excluded from the study. The height of the first floor ends at 460 cm with the ceiling structure.

Figure.4.11. shows the plan of the museum indicating the exhibition areas in red color, which is the main consideration in this research. The blue arrows show the circulation of visitors as they enter the museum and how they exit.

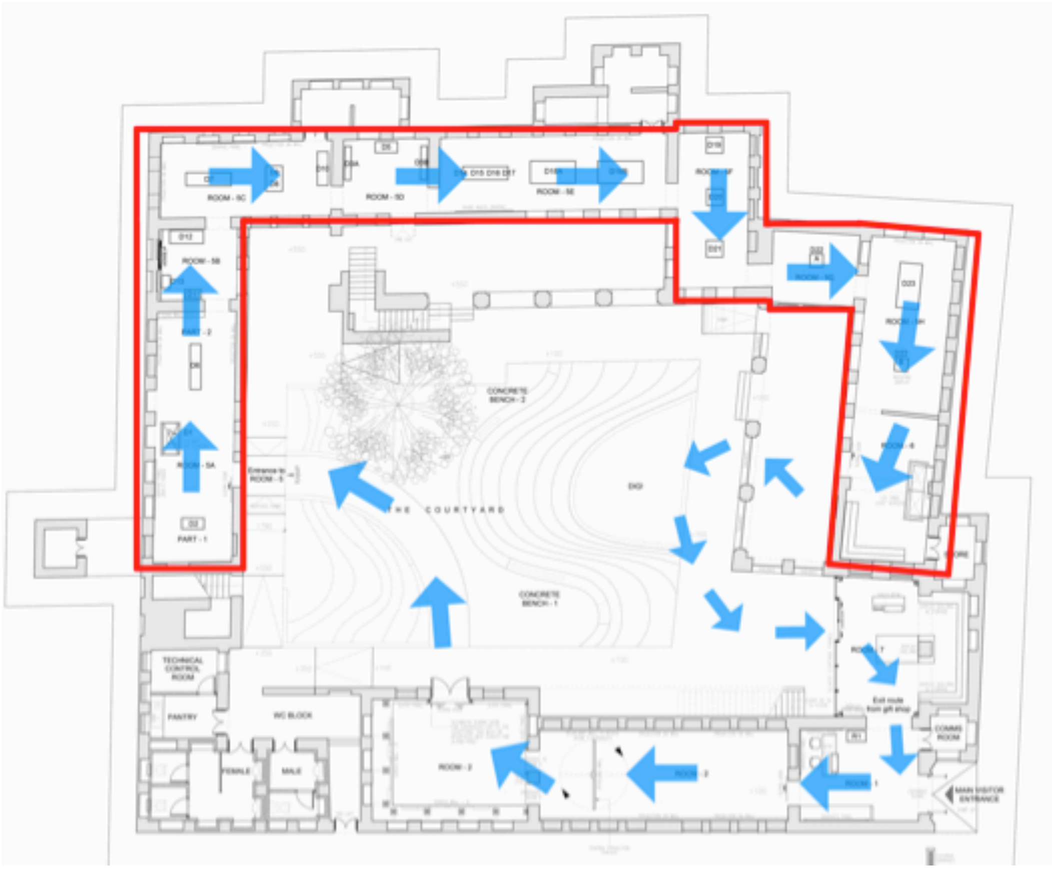


Figure.4.11. Case study 2 plan view and circulation (Dubai Municipality, 2016)

As shown, during the museum tour, visitors should walk through the courtyard to proceed to other parts of the museum. However, the red indicated areas, which host the artifacts, requires only one time entrance and exit, unlike case study 1. This way keeps the influence from the outdoor much less to the indoor environment of the exhibition providing more controlled area.

Appendix A indicates the starting of the tour. The photos indicate how each area is. After entering the museum, visitors are directed to a space showing the story of the museum in a movie projected surrounding them on the three walls. After finishing the movie the facing wall rotates. Thus, visitors are guided to another interactive space with different display cases showing different related items.

After passing through the court yard, people enter main exhibition areas. Exhibitions are divided based on different time periods. The width of the exhibition areas is ranging between 350 and 375 cm. Most important feature is linking each room of the exhibition areas to the other one. Therefore the movement of the visitors inside the area is designed without going outside the building.

The artifacts in display are dating back to more than 5000 years ago were found in the archaeological site is UAE (Saroog Al Hadid site) discovered in 2010 by H.H Sheikh Mohammed Bin Rashid Al Maktoum. Appendix A shows different areas of the museums with some of the artifacts in display. This museum can be considered as the first governmental museum that is displaying ancient artifact inside a historical building. Based on the site visits conducted by the author during May 2016, it was observed that the museums hosted in historical buildings do not have original artifacts in display. This was also mentioned by the Municipality staff during the different interviews conducted by the author in July 2016.

The collections in display vary in terms of their type: Pottery, metals, weapons, bones, woods and other items are found from archaeological site. Appendix A. Show some the exhibition areas.
The artifacts are distributed based on their dates and time periods creating the different exhibition halls.
In terms of the indoor elements, the display cases are specifically made for the museums by a company specialized in creating showcases for

museums (Dubai Municipality, 2016). The boxes are sealed and designed to prevent any influence from their surrounding environment in terms of temperature and humidity fluctuations. The boxes are high, thus it is preventing any visitors from leaning over them in the same time providing the flexibility of changing the artifacts in display at ease in the future.

As for the lighting system, there is no daylight allowed to the exhibition environment. The museum is equipped with Digital Addressable Lighting system (DALI). Appendix A conatins the details for different lights implemented. The lighting specification, each room has one sensor, lightings are anti-glare and dimmable, however, according to the museum staff they are only programmed to turn on and off and do not change according to occupancy patterns. The lighting can be controlled from the reception by a simple user-friendly control panel providing on-off option as well as the option for cleaning.

As for electricity consumption, according to Dubai municipality officials, expected electricity consumption the building is around 500,000 kWh/year.

The museum is operating from 8 am to 2:30 pm like the government working hours and closed on Friday and Saturday for the summer period. The number of visitors in June was not recorded (the musuems was opene end of June) and in July was 180 visitor, mostly individual or couple visitors. The groups were small number of 4 to 5 people as a start however the museum has welcomed one group of 14 visitors in that month.

4.3.5. Case Study 3: Sharjah Museum of Islamic Civilization (SMIC)

Third case study in this research is the eldest museum in comparison to the other two case studies. Located in Sharjah with latitude 25.365167 and longitude 55.389167. As shown in Figure.4.12. the museum is facing the sea.

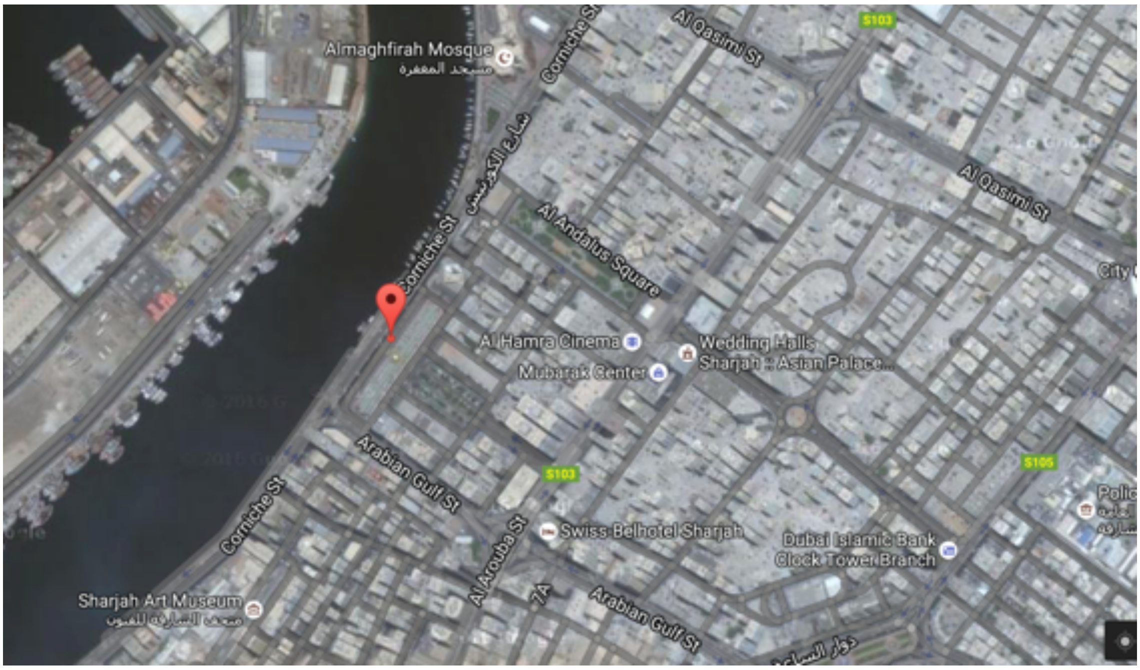


Figure.4.12. Location of Sharjah Museum of Islamic Civilization. (Google maps, 2016)

The museums was first opened in 1996 in a different building, however the new museum in the current building was opened in 2008 (Sharjah Museums Department, 2016). The new museums is moved to a two story building known as Al Majarah Souq built from 1980's, with Islamic design architecture features. Having a gold plated dome in the center of the building making it to stand out among other buildings in the area (Appendix A). Al Majarah Souq was a trading place for different goods for long time. It was famous for being one of the first air-conditioned malls at that time (Ghazal, 2011).

Visitors are welcomed from 8 am to 8pm from Saturday to Thursday and on Fridays from 4 to 8pm.

Government of Sharjah owns the museum; the Emirate is famous for being the pioneer in the country for having cultural projects and cultural activities. This museum like the other 18 museums in this emirate is run and management by Sharjah Museums department.

The building follows the architecture style of the time, and does not follow the historical buildings features. The total floor area of the museums is

13,820 m^2. The structure is cement and built from concrete blocks. Walls thickness is 30 cm. The central dome is dividing the building into two wings. Exhibitions floor area is 6,137.09 m^2.

The museum has exhibitions for permanent collection as well as a hall for temporary exhibits hosted at the museum. Visitors as they enter the building will be in the indoor space all the time for moving around the exhibition places, unlike the other two case studies. Seven exhibition rooms are distributed among the two floors of the museum. As shown in the below diagram. (Figure. 4.13.)

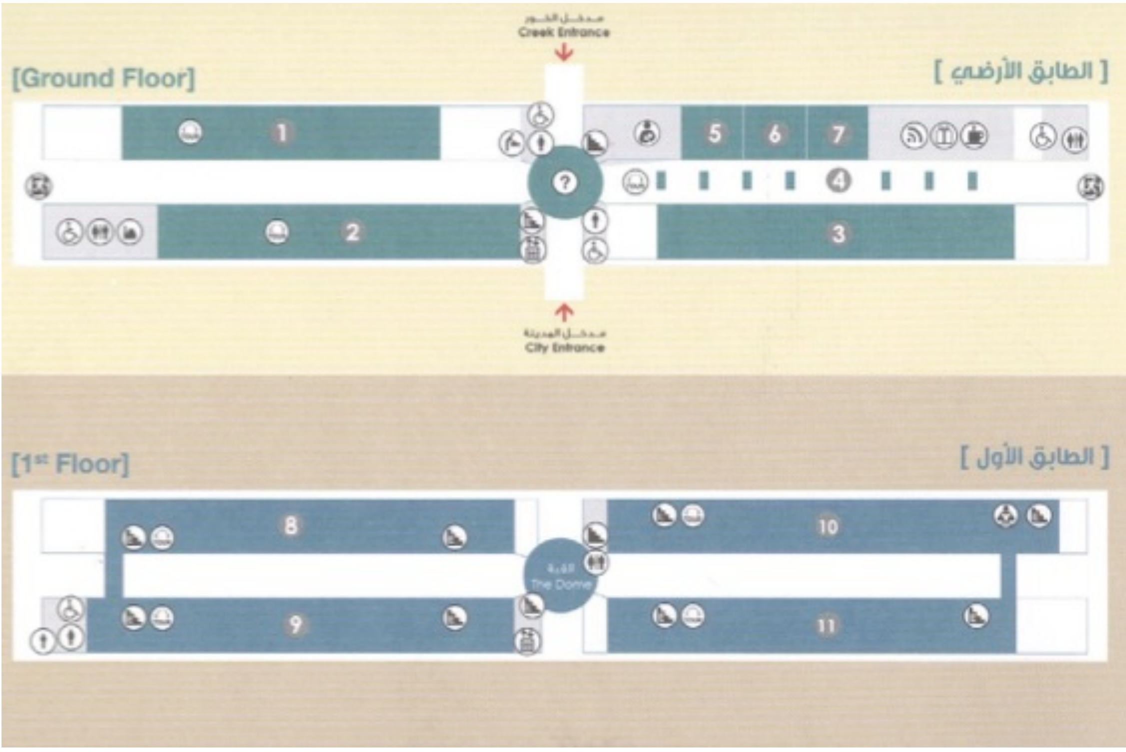


Figure. 4.13. Sharjah Museum of Islamic Civilization space diagram. (SMD, 2016)

The exhibition rooms in the ground floor are excluded from the current study, as the temporary exhibit (room 3 in Fig. 4.12) was closed and preparation for new exhibition was going on. Also the exhibition room 1 concept was about introducing Islam to visitors without having much ancient artifacts in display. Room 2 dedicated for the science exhibition for Islamic periods, was undergoing some maintenance work and installation for display screen thus it was excluded.

However, the most important part of the museum is the exhibition rooms in the first floor as all exhibits are dedicated for Islamic ancient historic artifcats with different origins. Even thought the exhibitions halls are huge comparing to the other two case studies, however, they are linked to each other by bridges in the first floor in order to ease the circulation among the different exhibits.

The museum display cases are specifically designed for museums with the flexibility in size and height. (Sharjah Museums Department, 2016) As for the museum collections, (Appendix A) is showing the variation of the museum artifacts, from papers, textiles pottery coins and etc,,,.

This museum unlike the other two case studies has Building Management System (BMS) that keeps records and monitoring from the indoor environment of the exhibition spaces. The building management system is connected with the HVAC system and fire fighting systems with water pumps.

However, the lights are not connected to the system. Types of lights are halogen bulbs, they are switched on in the morning and turn off after the closing of the museum. The exhibition environments are controlled and monitored following standards from UK (details provided in chapter 5).

This chapter contained information obtained by the author for the different case studies through conducting different site visits and surveys, however, it was general indication and specification for starting the research on. The following chapter is the main part of the research that is dedicated for the results and findings for each case study in terms of the three stages of (evaluation, proposals and assessment) in the study.

Chapter 5

Results, Findings and Discussion

5. Results and Discussion Outline

Considering the three stages of the research shown in Figure.5.1. This chapter is divided to two main parts: first part is showing the results and findings of the evaluation stage and the second part is dedicated for the proposals and their assessment. All these are done by depending on SOBANE strategy explained in details in the methodology chapter 3.

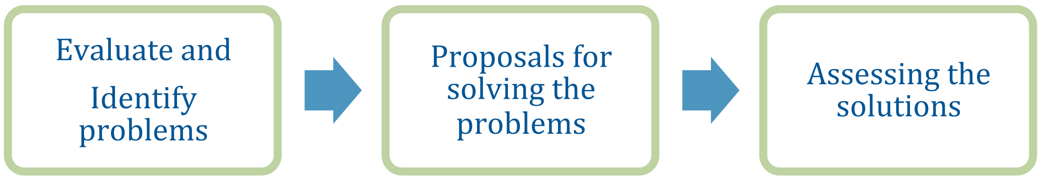


Figure. 5.1 Research Stages

First section is the results of evaluation for each case study following SOBANE strategy, which includes the observation and analysis stage. The results for each case study will be shown separately, a comparison between the case studies will be done at the end of the evaluation section. At the end, the identified challenges will be presented in order to find best solutions for resolving them they will be categorized based on 4 forms of:

1- Museum practices
2- Artifact conservation
3- Intelligence level and energy saving
4- Health and comfort

The second section is proposals solving the identified problems and enhancement solutions for each of the case studies. This is the analysis stage of SOBANE. Proposals for each case study are targeting the identified problems and proposed separately. These proposals are framed based on literature review as well as surveys by interviewing professionals from the field. Also considering the successful practices of other museums.

The third stage of the study is dedicated for the assessment of the proposals for each case study. The assessment part will be embodied with the proposals thus the solution and their assessment will be linked together in one section. The end will address each case study by the best options of proposals for implementing the enhancements on them. Assessment is done in order to quantify the proposals as well as to check the efficiency of implementations.

5.1. Section 1: Evaluation Results

5.1.1. Data Collection for Evaluation and identifying Current Problems

This section answers the question of "what is the current status of UAE museums?"

In order to complete this stage, adaptation of different methods was required. Initially the author conducted site visit for each case study in order to get general overview from the current environment. Different interviews and meetings with the museum personnel and officials in different departments were conducted.

As shown in the following diagram, (Figure 5.2.) the evaluation was targeting to identify the museum practices and problems faced in regards to the 3 main aspects of:

1- Collection preservation
2- Human comfort
3- Intelligence level and Energy conservation

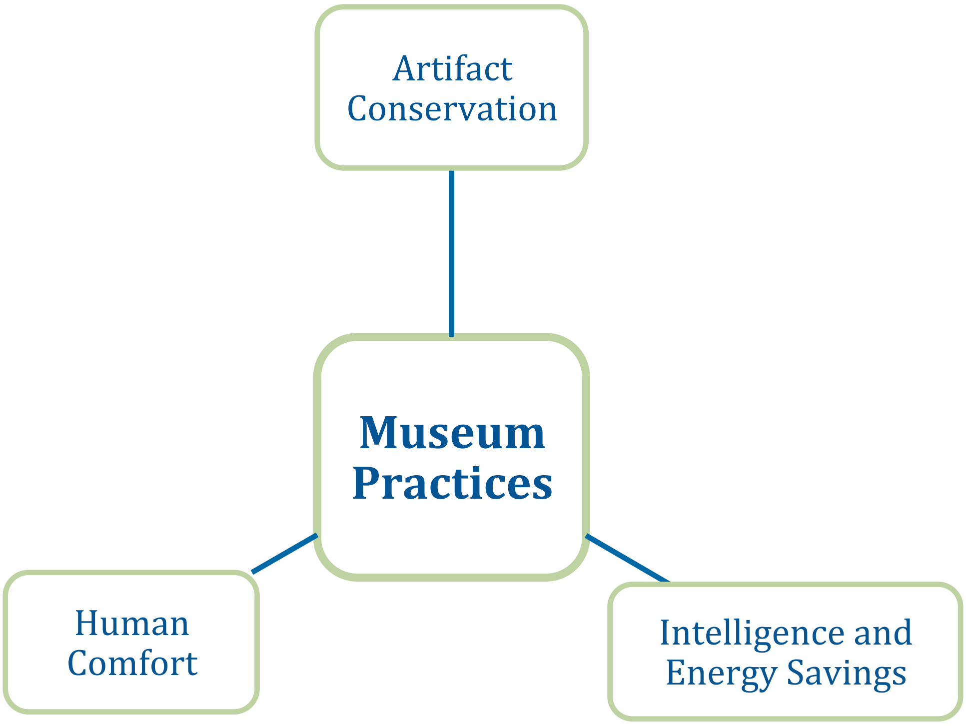


Figure. 5.2. Evaluation Scopes

As mentioned earlier, following the SOBANE strategy integrated the adaptation of different methods in order to obtain the information for evaluating and identifying the current problems of the chosen museums.

Following is the materials used for evaluating the mentioned aspects; However, depending on each case study, practices done and the museum policy involving different departments, originations, as well as different stages was required in order to complete the information for each part. The questionnaires were similar for al case studies. (provided in the appetencies) However, obtaining the information required the involvement of different parties in each case study. Table 5.1 shows the methods of obtaining the information for concerned are.

Table 5.1 Adopted methods for obtaining information in for the research

Identifying current museum practices for artifact conservation	Site Visit Survey	Appendix B
Energy related information Intelligent level evaluation	Survey Survey	Appendix B Appendix B
Evaluation of adapted practices in museums in terms of indoor environment	On Site Measurement	

5.1.2. Survey Data Collection Details

Based on the conducted literature review about the museum indoor environment requirement and practices, questionnaire (Appendix B) was prepared targeting the collections/ conservation department. The questions involved the assigned parameters for artifact as well as the conditions for human factor in terms of the working environment.

In terms of sustainability practices, the survey questions were derived from the Aly and Trek, Congrati and Di Corato, (2015) study that had more general approach. Targeting practices policies and different considerations of energy saving particularly.

As of intelligent evaluation, the questionnaire (Appendix B) was very detailed and technical targeting the building management and the facilities management of the museums. The questions were adopted from Wong, Li and Lai study (2008), and developed to target the museum practices. It included eight sections of the museums and how the different components of the buildings were integrated.

Further information for was obtained for completing the information for the simulation software and the assessing stage. The information included the building materials and structure, visitor numbers, working hours, closing days, as well as the current status in terms of energy consumption.

5.1.3. On Site Measurements Details

The author had to conduct on site measurements for indoor environment parameters as case study 1 did not follow certain guideline for artifact preservation and environment was not monitored, no measurements was done for the exhibition places. Moreover, since case study 2 was recently opened previous data from indoor environment was not available. To make all the case studies under go similar evaluation stages to make the comparisons near, measurements were carried out in case study 3 as well.

On site measurements were carried out by end of July and during August 2016 the dates depended on the approval obtained for each case study management. Exitech 4 in 1 Humidity, Temperature, Airflow and Light Meter model 45170 environmental measuring device was used. Based on the device manual specification, the range for Temperature (T) is from -100°C to 1300°C in the range of 0°C to 50°C accuracy level is ±1.2 °C and out of this range accuracy becomes (±1% + 1°C) with resolution of 0.1°C in all ranges.

Relative Humidity (RH) range is 10% to 90%. Accuracy for 10% to 70% is ±4% and in the range of higher than 70% accuracy becomes ±4%rdg +1.2% RH with resolution of 0.1% in all the conditions. Light is measured in 0 to 2200 lux with 1lux resolution and accuracy of ±5%rdg + 8 digits.

Measurements were done for each museum for one day at 3 times of the day 10 am – 12 pm and 3 pm to check the indoor conditions during the peak times of heat in summer. Targeting the extreme weather condition for evaluating the indoor environment is specified by Al Sa'afaat Rating system in Dubai municipality mentioned in details in literature revive chapter 2 section 2.3.1.

Inside and outside temperature and RH were measured in of each museum exhibitions. The measurement device was used based on the instructions in the manual and it was kept on 150 cm height from ground to be on the head level of the people. The author has specified the measuring points during the measurements at 10 am and was marked on a printed plan to have the results of the same place. The outside T and RH parameters were measured 150 cm before entering the exhibition environment at 150 cm height with same device. To show the different temperature visitors are exposed to as they enter the exhibition environment.

Lux levels were measured in different locations of each exhibition room based on the assessment of the author. However, it all measurements included the two options of:

1) Near to the exhibition entrance to check the visibility and illumence levels of the visitors paths

2) Near to display cases where there the lights were pointed at. (Figure.5.3)

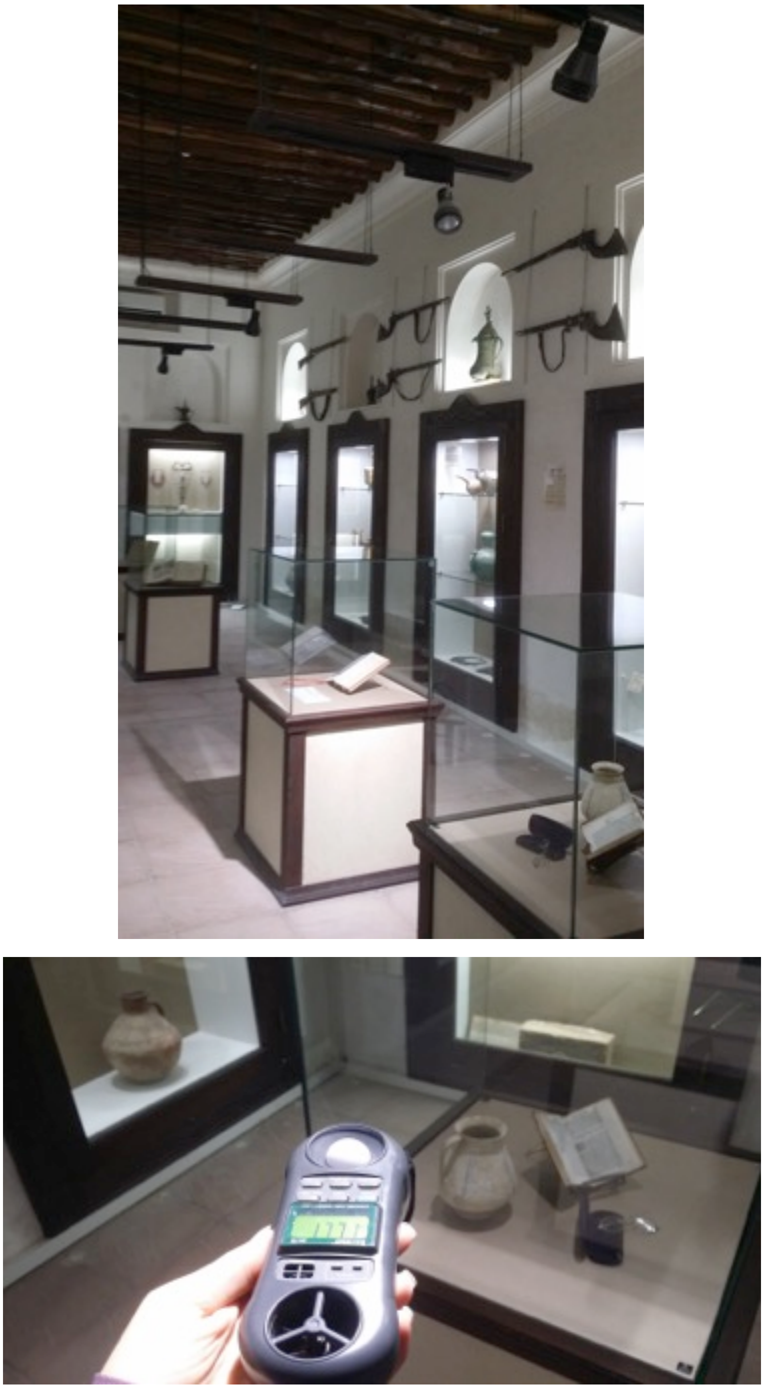


Figure.5.3. Lux meter position near to display case.

Where the displayed collections origins were different the author also measured the exposed light amount to the artififacts depending on the case study.
In all areas measuring device was held still until numbers of the screen stabilize the readings were noted down on a prepared sheet (Appendix B).

The following part is dedicated for presenting the results of the data collected for each case study. On site measurement results are presented for each case study is analysed in the same section by charts and comparisons between the exhibitions of the same project as well as comparing the readings with the standards and guidelines for museums. Comparing the results of measurements of same points at different times is the reflection of what environmental changes are happening around the artifacts of that particular zone during the day.
Moreover, considering the variation of conditions of different points of the exhibition at a particular time range would reflect the visitors' experience of environmental conditions during their tour across the exhibition areas. As the measurements were following the sequence of the tour path and been taken after each and they were not all taken at once at the same exact time.
A separate part is dedicated for comparing the results of the case studies together to show the differences between them.

5.1.4. Evaluation Results for Case Study 1: CCM

5.1.4.1. Survey Results and discussion

Table 5.2 summarizes the results for evaluating the current conditions based on the in person semi structured interview conducted with the founder of the museum on 28th of July 2016 As well as the questionnaire that was sent for completing the required information. The table is dividing the results based on the main aspects of the study mentioned in Figure.5.2.

Table 5.2 CCM Summery of identified problems conditions based on site visits and interviews

Museum Practices	Artifact Preservation	Intelligence Level and Energy Saving	Health and Comfort
No indoor parameters implemented (No guideline followed)	Different types and origins of artifacts exhibited same place	No Intelligent components - Questionnaire not applicable	Glare when entering from outside
Indoor environment not controlled and not monitored	Too much dust in Display cases	No integration between building components	Visitors are forced to go out and inside many times through the visit
Lack of knowledge for artifact preservation	Display cases not sealed towards the surrounding environment	No Strategy for Energy Saving	Smell of humidity in some exhibitions
Lack of access to resources and suppliers for museum facilities	Florescent light tube installed inside display cases directly	Lighting type consumes a lot of energy	IAQ not monitored and controlled
Lack of guidelines for museums	Display cases placed close to entrance areas	Inefficient AC units on overnight	Exhibition rooms are dusty
No Guiding Systems for visitors	IAQ impact on artifact not considered	Lightings on when not needed	
Poor Maintenance	Exhibition environments are dusty	Exhibitions not sealed towards outer environment	
HAVC units not suitable for museum environment			
IAQ not considered			

Museum practices and policies adopted are the main factor that results in different conditions and status of museums. This includes the considerations taken into account during the establishment and design stage of the museum. The decision made for selecting different systems (for example lighting, cooling and display cases), how visitors' journey is planned and oriented smoothly with comfort between the different sections of the museum should be decided early.

Additionally, beside the proper establishment stages, it is crucial to implement a certain strategy for maintaining and properly running the museum on daily basis. The strategy helps the efficiency of the systems integrated as well as preventing any gradual change and future damage to the collections.

As shown in table 5.2, based on the feedback gathered, it could be concluded that lack of guidelines and standards for establishing and running museums resulted in poor museum practice implementation. Artifact collectors need more resources and knowledge in order to preserve their collections and exhibit them safely in the correct way for public.

It can be noted that the identified problems related to artifacts are mostly concerned with the establishment and designing stage of the museum. Also, since there is no strategy for maintaining the exhibition spaces, artifacts conditions are not how they should be presented.

Dust accumulation on artifacts is a result of poor display case design as well as poor maintenance and cleaning the items inside the cases (Figure.5.4). However, since the historical items are very fragile and sensitive regular cleaning by unspecialized people could be more damaging, thus prevention is the most important action needed to prevent any damage to artifacts.

Figure. 5.4. Dust accumulation in Display cases show poor maintenance and poor display case design

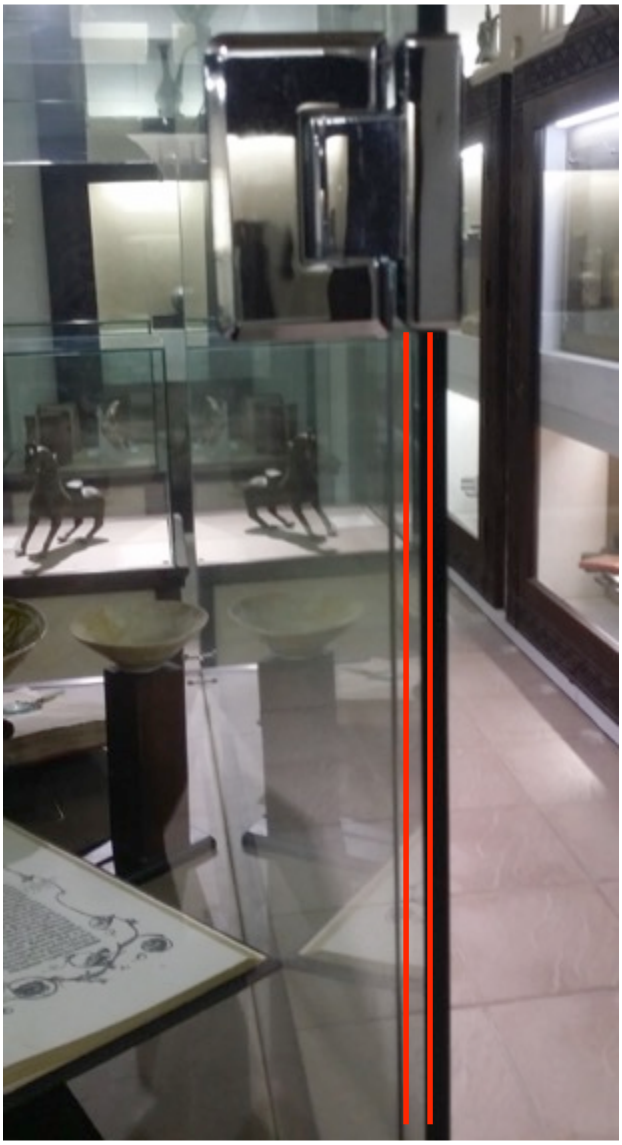


Figure. 5.5 Red lines show the gaps in the in the corners of the display cases

Figure. 5.6. Florescent light tube installed inside display cases directly

As of the intelligence level, the questionnaire was not applicable since there is no integration between building components and no adaptation of intelligent systems the museum is not equipped with BMS system as the systems such as lighting and the HVAC systems are basic systems not possible to be integrated.

Also as mentioned in the table currently there is no practice towards energy saving approaches and strategies as well, however there is a will for adapting energy saving approaches in order to cut down the monthly utility bills. Appendix B includes a table with the energy consumption rates for 7 months in the museum.

5.1.4.2. On Site Measurements Results CCM

On spot site measurements were carried out on 29th of July 2016. During the measurement campaign from 10 am to 3 pm it was observed that the museum did not have any visitors. (Appendix B contains details about the location of measurements for each exhibition environment)

RH and T were taken in one spot in the middle of the room as the exhibition room sizes were small. Lux levels were measured at the following 2 points:

1) Near to the exhibition entrance

2) Near to display cases to check the amount of light exposure towards the artifacts as well as the visibility of the artifacts for the visitors.

During lux level measurements it was noted that the available lights are not stable as they are hanging from the ceiling and some could be moving from the AC wind. Also, some lights needed maintenances as they were blinking or not working continuously. The measurements results for the three areas are included in Appendix B.

T Results Discussion - On Site Measurements

Based on the above tables the readings for T and RH were transformed into charts in order to make the analysis and comparisons of the exhibitions better understood by showing their trends. Figure.5.7. is made based on T readings from the three exhibitions; it shows the temperature variation in the 3 exhibitions at different times.

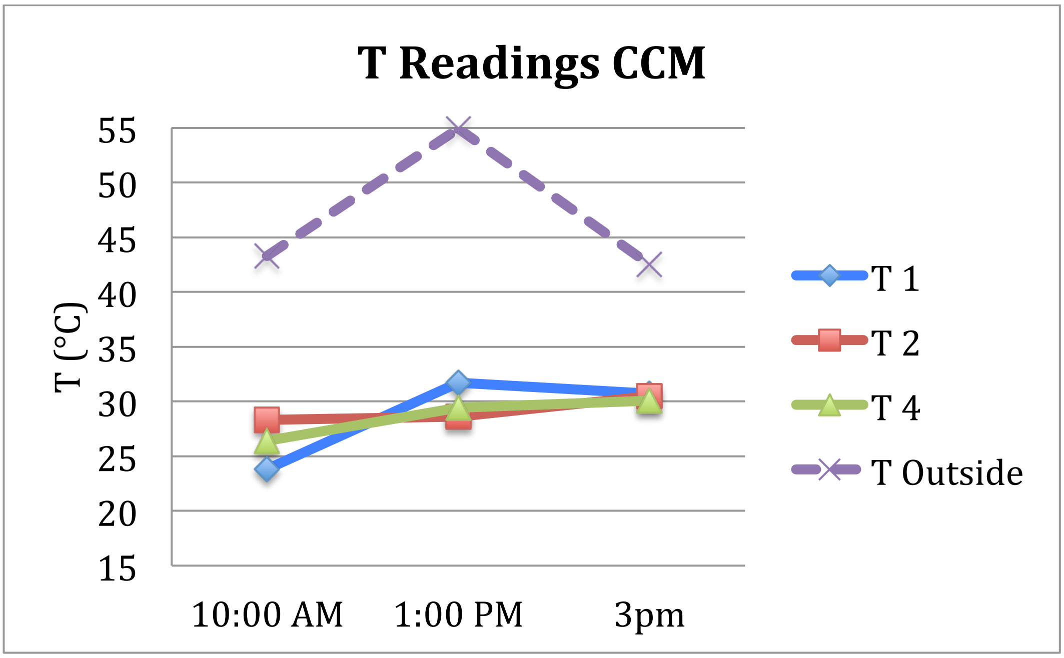


Figure.5.7. Temperature readings in the 3 exhibitions at different times.

As shown in the tables and the chart, T is not completely stable in any of the exhibition rooms. The temperature rises from 10 am to 1pm. Significant T variation is recorded for exhibition 1 from 10 am to 1pm. T rise was almost 8°C in that time. Exhibition 2 had almost same T in this time period and exhibition 4 had the rise of 3°C. T started to drop down after 1 pm in exhibition 1 which is following the trend of outdoor changes. However in the other 2 exhibitions T continued to rise after 1 pm but the raise is not big amount (2°C in exhibition 2 and only 0.5°C in exhibition 4). As in exhibition 4 the indoor T gradual increase from 10 am to 1 pm and after 1pm had only 0.5°C. While exhibit 2 T had only 0.3°C rise from 10 am to 1pm. This increased by 2°C after 1 pm. The mentioned variation is not significant in comparisons with the change happened in exhibit 1 at this period of time.

Artifact Preservation Discussion

By referring to Table 2.1. in literature review section, the standards for indoor environmental parameters for museum exhibitions had various ranges depending on the standard and the region. Temperature ranges was from 15°C to 25 °C or 18 °C - 24 °C with the allowance of fluctuation around 2°C, 4°C, 5°C for 24 hours within the mentioned range not to exceed 30°C. As of RH percentage ranges was from 45% to 55% with ± 5%, or 50% with ± 10% fluctuation for 24 hours within the mentioned range, not to exceed 70% or drop below 40%. (ASHRAE, 2011; AICCM, 2014; HCC, 2002)

Here, since the museum is not following any standards for maintaining indoor environmental parameters the comparison of the measured conditions will be made based on UK standards with T of 18°C – 24°C ± 4°C and RH percentage of 50% with ± 10% fluctuations during the day. As this standard is adopted and implemented by Case study 3. Also ASHRAE guidelines will be considered as they have classifications for different scenarios for different museum approaches. Table 5.3 includes the measured T levels across the different exhibitions of CCM. Numbers in blue indicate the range being above 24 (UK Standard) and 25°C (ASHRAE standards) and red indicates the Danger zone.

Table 5.3. CCM - T for different exhibitions

	10:00 AM	1:00 PM	3pm	T Fluctuation
T 1	23.8	31.7	30.7	7.9
T 2	28.3	28.6	30.5	2.2
T 4	26.4	29.4	30.1	3.7
Difference in T	4.5	3.1	0.6	

As shown T was safe only once in gallery 1 at 10am the rest of the times it was above 30°C, the other galleries the starting T was already above 25°C. As for the fluctuations gallery 1 was up to 7.9°C which is higher than allowance in UK and AHSRAE standards. And it is significant change for indoor parameters that is harmful for the collections. This reflects the poor conditions for the museum and the risk for artifacts.

Health and Comfort Discussion

As for health and comfort considerations, as shown earlier, and based on the museum circulation design, visitors have to go in and out many times in a relatively short time in the beginning of their tour. By comparing the inside T and outside T results of the different exhibitions varies between 20°C to 30°C. that is big difference for the human body in short time.

Having shaded area in front of exhibit 4 made the outdoor and indoor difference much less in comparisons to the other two rooms.

RH Results Discussion - On Site Measurements

Moving to RH measurements, the chart presented in fig.5.8 is for the RH% obtained from the measurements from each exhibition. RH percentage in exhibition 1 dropped significantly for almost 12% from 10 am to 1pm. However at 3 pm with the reduced temperature in exhibition 1 RH increased from 35.8 % at 1 pm to reach to 39.3% at 3 pm. similar trend is noted in the other two exhibits. At 10 am RH is high and starts to drop down until 1pm, and again at 3pm rises.

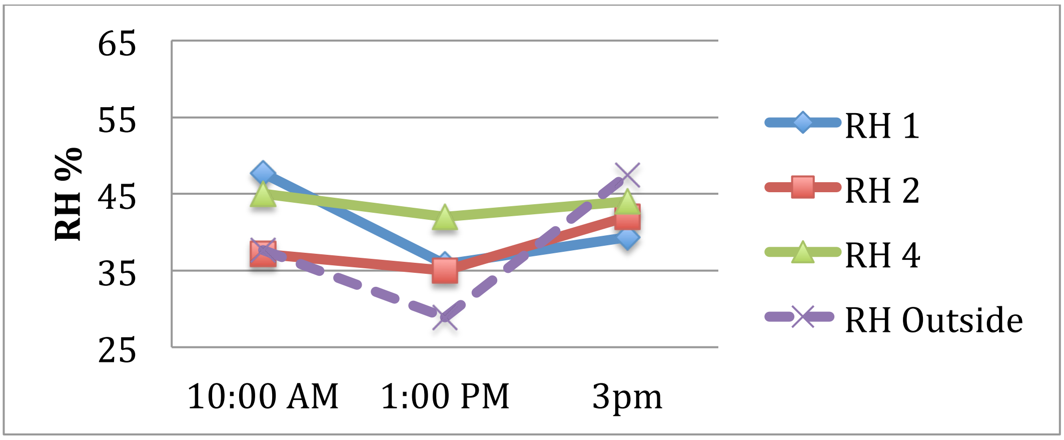


Figure.5.8. RH % readings in the 3 exhibitions at different times in CCM. (author)

By looking at the trend, exhibit no 4 can be considered as most stable environment in terms of RH with only 2% and 3% fluctuations in different times. While exhibition 1 had the big change from 47.7% dropped to 35% and again raised to 39.3%.

Artifact Preservation Discussion

Table 5.4 shows the percentage of RH of the different exhibits at CCM. 4 times RH was within the 45% to 50% at 10 am. This indicates the need for taking action specially since the display cases are not sealed properly and can be impacted easily by their surrounding environment.

Table 5.4. CCM RH % for different exhibitions

	10:00 AM	1:00 PM	3pm	
RH 1	47.7	35.8	39.3	11.9
RH 2	37.2	35	42	7
RH 4	45	42	44	3

As mentioned earlier in literature review and by comparing the two charts of T and RH, these two factors are related in opposite way, when T raises RH drops down and vies versa. When there was significant rise of T in exhibit 1 RH percentage also dropped significantly.

Also, having shaded area in front of exhibit 4 resulted to less variation in indoor parameter fluctuations this also proves that the exhibits are not sealed properly towards the outdoor environment.

Luminance Results Discussion - On Site Measurements

As for indoor illuminance, even though all window openings were closed however it was noted that exhibit 1 had the window above the door not closed and it was allowing daylight in the room (figure 5.9). Spot measurements were conducted in similar places with holding device facing upwards, keeping the device away from the body to stop any shadow influence on the readings. However, the readings varied in exhibitions during different times specifically in the areas near to the exhibition spaces.

Figure.5.9. Daylight source in exhibition 1.

It was noted that some of the lights in the exhibits were blinking and some would be on for sometime and turn off for a while and again work. Also the height of the ceiling was very high and lighting systems were installed hanging from it but they were not stable, thus the light itself would be moving to some extend. Tables 5.5 to 5.7 are showing the readings for the different exhibits.

Table 5.5. CCM Light on spot measurements exhibition 1

	10 am	1 pm	3pm	Notes
Light Inside (Door)	216	137	90	
Light Inside (Display)	1771	1520	1400	
Light Outside	Error	Error	Error	Higher than device range

Table 5.6. CCM Light on spot measurements exhibition 2

	10 am	1 pm	3pm	
Light Inside (Door)	303	80	78	
Light Inside (Display)	1100	800	500	
Light Outside	Error	Error	Error	Higher than device range

Table 5.7. CCM Light on spot measurements exhibition 4

	10 am	1 pm	3pm	
Light Inside (Door)	55	50	58	
Light Inside (Display)	1800	1380	1360	
Light Outside	Error	Error	Error	Higher than device range

Artifact Preservation Discussion

By referring to the below table showing UK standards for the Lux levels of the exhibition environments, as shown the lux levels varies depending on the item and the sensitivity level of the object itself. Since the display cases had variety of objects in the same place, the safe zone of each display box cannot be identified, unless considering the lowest lux level of 50 lux for all items.

Table 5.8. lux levels based on UK Standard

Very Sensitive Objects		Sensitive		Insensitive	
Lux lumen/m^2	UV µwatt/ lumen	Lux lumen/m^2	UV µwatt/ lumen	Lux lumen/m^2	UV µwatt/ lumen
50	0	200	0	300	0

Based on the readings obtained from the areas near to display cases, the light level is very high and dangerous for the artifacts, specially for the sensitive items like the books and papers in display. They could get faded and their color will change. Lowest Lux level was 500 lux recorded at 3pm in exhibition room 2 and highest was 1800 lux. Since the glass of the display cases is not treated and there are no filters for the light this indicates high risk for the collections in display.

According to the founder of the museums the hanging lights were halogen bulbs and did not have UV filters also IR radiation are not eliminated thus they heat is generated in the environment as well. In conclusion in terms of artifact conservations, considering the high exposure to light with considering the unfiltered lights that are not filtering UV radiations as well as the implementation of normal display glasses the collections are at great risk.

As for the health and comfort, the light level near to the doors was measured to check the visibility and clarity of the paths. Lux level was much less near to the doors as there was no light directed to the area. However readings was not same during different hours of the day. Hiving higher levels in the paths will increase the ease of movements of visitors inside the exhibits.

Health and Comfort Discussion

An important aspect for lighting in terms of human health and comfort is considering the glare, since visitors for visiting 3 of the exhibition areas are going outdoors and the entrance of the exhibits are fully exposed (there is no shade to reduce the light), people after entering the exhibition environment after being in that bright conditions will be having glare as the environment outside is very bright and after enetering the exhibition the lux level drops down to much lower levels near the entrance. Also since each exhibition is small room this would continue for most of the time inside the exhibit.

In conclusion Table 5.9 summarize the discussed results obtained in the stage of on site measurements for CCM. As shown previously the measurements obtained emphasis on the need of enhancing the current museum practices in terms of the indoor environment. These measurements mainly targeted the aspects related to toe artifacts preservations and comparing them with the standards quantitatively and also targeted the human comfort aspect only. And the measurements were not related to the intelligence level and museum practice parts of the study. However, the problems identified below show the result of poor practice, the solutions can be made based on intelligent approaches. Which will be discussed in a later section of the study.

Table 5.9. CCM identified problems based on measurements

Identified Problems Related to Artifact	Identified Problems Related to Health and Comfort
Indoor T fluctuations exceeded standard	Big difference between outdoor and indoor luminaire causing glare
Indoor T above Standard limit	
Indoor RH below standard	
Indoor RH fluctuations exceeded standard	
Lux levels not same through out the day	
Lux levels higher than standards	

5.1.5. Evaluation Results for Case Study 2: SHAM

5.1.5.1. Survey Results and discussion

Based on the interview conducted with the conservation department at Dubai Municipality for evaluating the conditions and practices, there was no specific guidelines or a standard that is implemented by details, however the archaeological items depending on the conditions, how they were found and the conservator's knowledge and attitude towards conservation the conditions would be assigned. Table 5.10 is the summery showing the range of conditions based on the material.

Table 5.10. Indoor parameters set for different collections in Dubai Municipality

	Temperature	Humidity %	Illuminance
Fabric	20 ±2	45 - 55	
Paper	20 ±2	45- 55	Max 50 lux no UV
Rubber and Plastic	20 ±2	15	
Coins & Metals	20 ±2	Below 30	300 lux
Other Specify, eg: paintings	20 ±2	50 - 55	

As shown the temperature set is lower than UK standards and ASHRAE. However, RH percentage varied based on the material.

To preserve this variation of conditions in the museum, the display cases were chosen carefully as a separate unit controlling conditions inside without the influence of the surrounding environment, however, these display cases do not have continues monitoring to check if the range are still the same or changes.

According to Shatha Al Mulla, (Dubai Municipality) the rooms were opened to each other in this museum in order to make the environment more controlled towards the outdoor. Moreover it was noted that in the areas having the entrance and exit doors, the display did not contain any ancient artifacts. Thus the influence of outdoor is much reduced.

In terms of energy saving in the museum, in the establishment stage LED lighting system was chosen to reduce energy consumption from the light is a main action. Also making the rooms connected to each other reduces the cooling demand because the influence of outside is much less when each room would be opened to outside. However there is no strategy or plan for actions to be taken for energy reduction on daily basis like; the lighting system is on all the time with or without visitors.

As of intelligent level, the museum is having integration of different component in terms of easing the control and operation of the shows. Lighting, video and audio systems of the museum are all linked together. They are controlled from the reception, with the only 2 options on and off.

Lighting is DALI system providing automatic lighting. One whole connected lighting system. The system provide user interface via intranet or remote control.

The system provide multiple level and control mode for occupants to program custom-made settings however currently two mode are programmed for normal visiting hours and the second option is the cleaning mode with brighter light.

The system can be Pre-programmed to the expected response and flexible to adjust based on the visitors occupancy pattern. Adaptive to occupancy work schedule, control of lighting zones, different dimmable options. Even though the options are available however, the features are not been integrated currently.

Moving to health and comfort of the visitors, an advantage in this case study is that the visitors have to only walk outside for one time in order to get into the other exhibition areas thus the continues interaction of the body with the outdoor is much less.

Table 5.11 and 5.12 are a summery of evaluation based on the survey stage for the current conditions.

Table 5.11. Summery of case study 2: SHAM good conditions based on site visits and interviews

Good Museum Practices	Good Artifact related Considerations	Good Energy Saving related Considerations	Good Health and Comfort related Considerations
Exhibitions designed by experts in museums	Display cases specifically designed for artifacts	Integrating DALI lighting System	Linking the exhibits to limit the thermal shock for visitors
Linking the exhibits to limit the number of times visitors have to go outside during the tour	Display Cases Control temperature and humidity	Linking the exhibits to reduce cooling demands	
	Display Cases Control UV from light		
	Display Cases Placed away from entrances		
	Linking the exhibits to control the indoor environment for artifacts		

Table 5.12. Summery of case study 2: SHAM identified problems based on site visits and interviews

Problems related to Museum Practices	Problems Related to Artifact	Problems Related to Energy Saving	Problems Related to Health and Comfort
No exact indoor guideline followed and implemented		No Strategy for Energy Saving	Glare when entering from outside
Indoor environment not controlled and not monitored		Lightings on when not needed	
IAQ not considered		Little integration between building components	
HAVC units do not control RH			

5.1.5.2. On Site Measurements Results SHAM

On site measurements were carried out on 24th of August 2016. The areas on spot measurements were taken at are available in Appendix B. Since there are no separate exhibition rooms, and all are open to each other, each indoor parameter of the exhibition is presented in a separate table. T and RH were measured in similar 4 different areas of the exhibition.

Light measurements were conducted for more parts to measure the path, display case exposure as well as the display cases that had internal lightings.

T On Site Measurements Results and Discussion

On spot T measurement results of 4 areas of the exhibitions are included in Appendix B. The measurements also included outdoor T (before entering the exhibition and after exiting from the environment).

As shown in the readings T is almost the same across the different points of the exhibition places at 10 am. At 1 pm and 3 pm T near to the door was higher than other places. Yet in other points it was uniformed. This shows the influence of outdoor T to the indoor when the door opens and closes. Considering the inner areas of the exhibition at 10 am, the indoor T was higher in comparison to 1pm and 3 pm. However, this variation was ranging from 2°C to 3°C. The difference between outdoor and indoor T was 9°C. As shown, during different time of the day the entrance had no shade at 10 am while at 1pm and 3 pm the entrance area was shaded. And that influenced the numbers obtained. However for the exit area of the exhibition only at 3pm it was not shaded.

Fig. 5.8 presents the reading in the chart showing the trends for the measurements. T in point 1 shows an upward trend with rise of temperature from 10 am to 3 pm, as outside temperature increases, the area next to the door also gets hotter. Moreover conditions in measuring point 2 and 3 were matching all the time. While point 4 had only little change with the other points. By reading the numbers in the table 5.13 the difference is max 1°C. It can be concluded that T was almost same in the different parts of the exhibition except for the entrance area. However T was not stable through out different times of the day and had little changes.

Table 5.13 SHAM T fluctuations

	10:00 AM	1:00 PM	3pm	T Fluctuation
T 1	23.9	25	28	4.1
T 2	24	21	20.8	3.2
T 3	24	21	20.8	3.2
T 4	23	22	20	3
Difference in T	1	4	8	

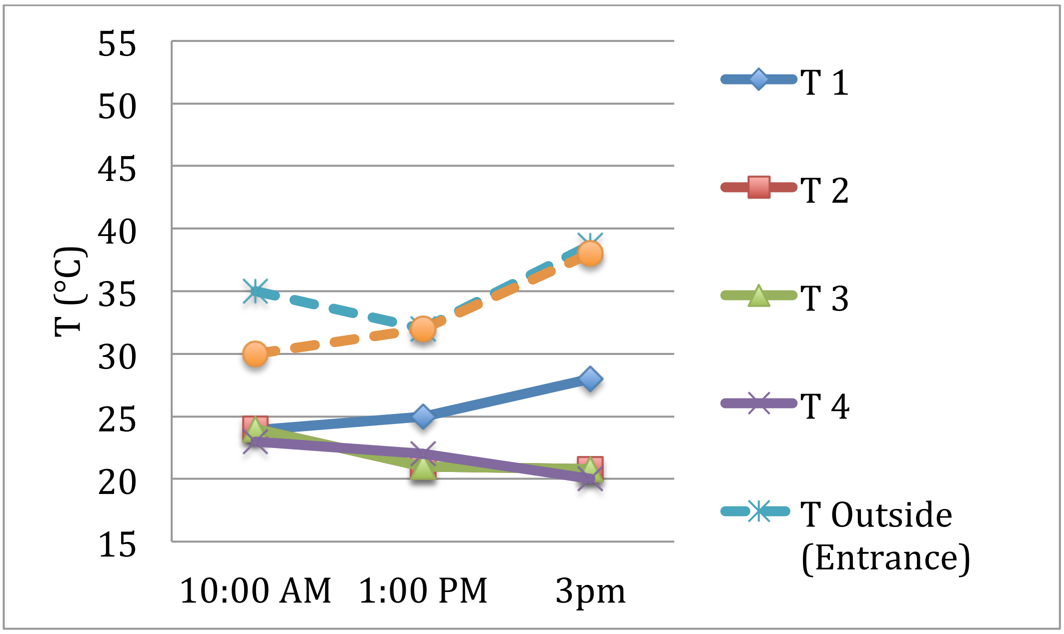


Figure. 5.10. T on site measurement in different parts of SHAM exhibition

Artifact Preservation Discussion

Comparing the readings with the standards, T was above 24°C only twice (indicated in blue in table 5.13) and was recorded in the areas in front of the entrance doors. As of fluctuations can still be considered safe for UK standards to some extend since it was only 4.1°C (during the measuring time), and the allowed is 4°C fluctuations through the day, as for ASHRAE, 2°C is the allowed amount, thus they fall out of the allowed number all the time.

Health and Comfort Discussion

In terms of health and comfort as the outside temperature rise at 1 and 3 pm when people enter the environment the indoor is having higher T in comparison to other points thus it will help making gradual body adaptation to the colder environment.

As for the indoor T change during the tour inside the exhibition, visitors under go change in T for 8°C at 3 pm that can be considered big change in T.

RH On Site Measurements Results and Discussion

As shown in table 5.14 and figure. 5.11, the RH percentage in the environment was not as uniformed as T. RH varied from 40% to 58% across different parts of the exhibits at 10 am for 18%. At 1pm the variation was from 39% to 47% and 3pm was from 43% to 55%.

Table 5.14. On spot Exhibition RH % results

	10 am	1 pm	3pm	RH Fluctuation
RH 1	45	39	43	**6**
RH 2	40	45	49	**9**
RH 3	46	37	44	**9**
RH 4	58	47	55	**11**
RH Outside **(Entrance)**	42 no shade	55 shade	42 shade	-
RH Outside **(Exit Area)**	41 shade	64 shade	42 no shade	-

Artifact Preservation Discussion

The differences of readings in different parts of the exhibitions could be the results for providing the required RH for different types of artifacts. Though, by looking at the results for point 2 as an example at 10 am; 40% was the lowest recorded RH among other points in the environment. At 1pm RH increased to 45% for the same point while it is not the lowest RH among other parts. Also at 3pm the recorded RH was 49%, which is still not lowest recording. If the variation of RH was based on making suitable conditions for artifcats lowest RH recoding should remain low even with the little fluctuations. By referring to the information obtained from Eng. Al Mulla on the HVAC system details, this variation can be explained as the result of controlling T without considering RH of the environment. As it was mentioned by Al Mulla HVAC systems are not being equipped with humidity controllers.

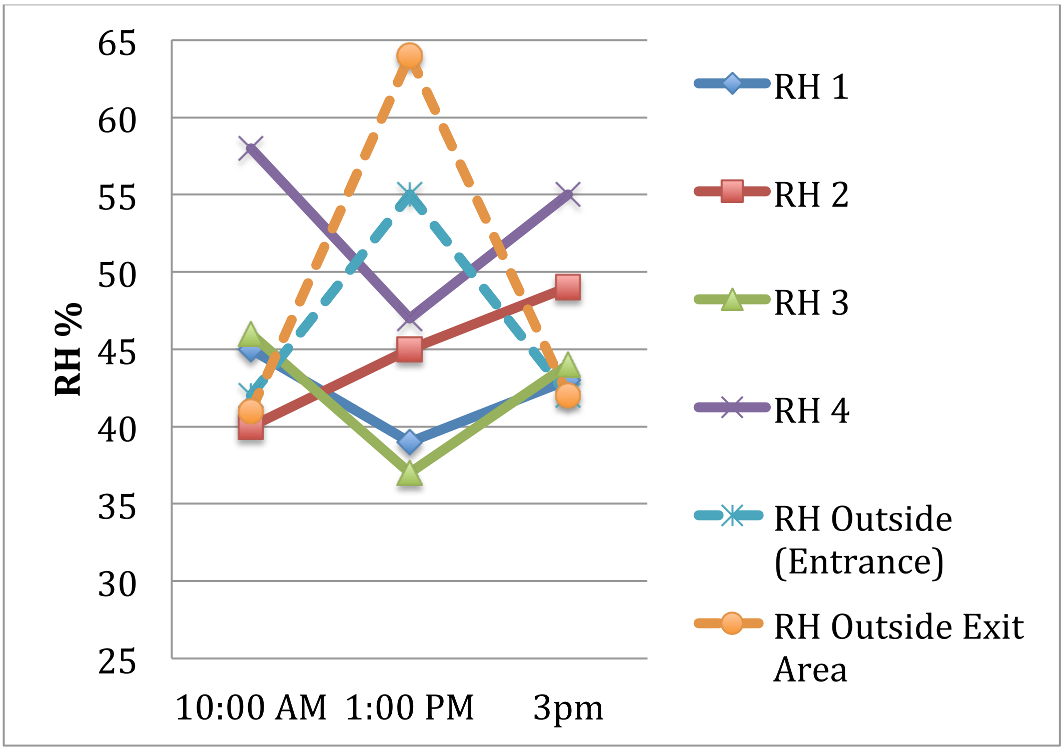


Figure.5.11. RH% on site measurement in different parts of SHAM exhibition

By comparing the different points and times, outside RH and inside RH at point 2 were similar percentage at 10 am. While this percentage at point 1 and 3 at was higher than outdoors in the same time. At point 1,3 and 4 RH drops down at 1pm while it rise up outdoors. However in point 2 it follows the same upward trend of outdoor. Point 2 shows gradual rise from 40% to 49% from 10 am to 3 pm. While, the percentages of other points dropped down at 1pm and again rise at 3 pm. This change was 6% decrease from 10 am to 1pm at point

SHAM museum also, did not have maintained environment in terms of RH. As shown in table 5.14 RH fluctuated by 11% that exceeded the UK standard by 1% and ASHRAE by 6%. The RH in the environment was below 45% (indicated in blue and red) and also dropped below 40% that is not a safe situation. However, since the T is controlled in the environment and the display cases are RH controlled internally, this situation is not as danger as of Case Study 1, as the display cases are sealed towards the environment.

Luminance Results Discussion - On Site Measurements

As for illuminance level, based on the results presented in table 5.15 records shows much more uniformed patterns with only little fluctuations in the readings. It was noted that each space had video projection on the wall of the place providing information about the artifacts as well as the historical site. Each video had different parts with different lighting level, thus the differences in the lux levels can be the result. As measurement were taken during various part of the videos.

Table 5.15. SHAM on spot Exhibition Illuminance

	10 am	1 pm	3pm	
Light Inside (Door)	66	65	65	
Light Inside (Display)	1800	1850	1855	
Light Inside 2	250	255	253	
Light Inside 3	155	150	158	
Light Inside 4	63	65	65	
Light Inside 5	1400	1450	1449	On display table
Light Inside 6	80	48	90	
Light Outside **(Entrance)**	Error	Error	689 shade	
Light Outside **Exit Area**	Error	Error	Error	

Artifact Preservation Discussion

Numbers identified in red in table 5.15 indicates the areas that lux levels were very high in comparison to the standards. These areas were near to the display area where the light was pointed at them. Other areas were below 300 lux. Considering the items in display, pottery and stones that are not light sensitive object were displayed in that place. Considering UK standards this level should be below 300 lux. While some other standards shown in table 2.2 in chapter 2 did not identify certain lux level for insensitive items. More over considering the type of light (LED) and the non-existence of UV from light and the specification of display cases reduces the danger level to the artifacts.

Health and Comfort Discussion

Considering the outdoor lux level (which was out of the measuring zone in the device) and the very low lux level in the entrance of the exhibition, glare is resulted after entering the exhibition. Since visitors are not going in and out many times during their tour, this experience would last for short time.

Table 5.16 is a summery of the evaluation based on the measurement obtained from SHAM in terms of artifact preservation as well as health and comfort.

Table 5.16. SHAM identified problems based on measurements

Problems Related to Artifact	**Problems Related to Health and Comfort**
Indoor T fluctuations exceeded standard	Glare
Indoor T exceeded Standards	
Indoor RH below standard limit	
Indoor RH fluctuations exceeded standard	

5.1.6. Evaluation Results for Case Study3: SMIC

5.1.6.1. Survey Results and discussion

Survey was conducted with different departments of the museum based on the following details:

For evaluating intelligence level of the museum and the integration level of building components, survey questionnaire (presented in Appendix B) was answered by the building management department through email.

In person Interview with building management department personnel was conducted for obtaining information about building component and how the museum facilities are run (explained on field)

For evaluating practices for artifacts preservation conditions, survey questionnaire (presented in Appendix B) was answered by head of collections department.

Tables 5.17-5.18. are summarizing the evaluation results based on the surveys conducted as well as the site visits.

Table 5.17. SMIC Evaluation results based on site visits and interviews

Problems related to Museum Practices	Problems Related to Artifact	Problems Related to Energy Saving	Problems Related to Health and Comfort
The adopted standards are not designed for the local conditions	IAQ not monitored and not controlled	No Strategy for Energy Saving	IAQ not monitored and not controlled
IAQ not monitored and not controlled		Lighting type consumes a lot of energy	
		Lightings on when not needed during working hours	
		Little integration between building components	

Table 5.18. SMIC Positive points Based on site visits and interviews

Good Museum Practices	Good Artifact related Considerations	Good Energy Saving related Considerations	Good Health and Comfort related Considerations
Adaptations of international standards	T and RH are studied for each type of artifact	HVAC system is connected to BMS	Visitors are moving inside the building for visiting different exhibitions
Exhibitions designed by experts in museums	Lux levels controlled for different types of Artifacts	Chillers are turned off when desired T and RH achieved in different zones	
Indoor Environment of Exhibitions monitored and controlled continuously	UV radiations are filtered from lights		
Assigning special departments for museum care	T and RH are controlled and monitored		
Monthly Indoor environments reports prepared for collections department	Display cases specifically designed for artifacts		
Different Exhibitions are distributed inside a building not outdoor	Display Cases Control humidity		
HVAC systems for exhibitions equipped with humidifiers and dehumidifiers	Display Cases Control UV from light		
	Display Cases with ancient artifacts placed away from entrances		

5.1.6.2. Intelligence Level Evaluation Results

SMIC because of the adaptation of building management system and having some level of integration between the building components, the questionnaire for intelligent level evaluation ould be answered to some extend. However, since the system is old and not all parts are linked the intelligence level could be considered as a basic in terms of current technologies for building integration. Following is the list of available options in the museums in terms of intelligence.

Guiding systems

- Museum equipped with guiding system 4 languages support
- System flexible for future expansions

Lighting

- The system provides automatic lighting
- Display cases lighting systems turn on and off during the visiting hours
- One whole connected lighting system
- Adaptive to occupancy work schedule
- Control of lighting zones
- The system provide user interface via intranet or remote control
- The system provide multiple level and control mode for occupants to program custom-made settings
- The I-Light control system is capable of being integrated into a BMS, but is not done currently
- Can the system be Pre-programmed to the expected response and flexible to adjust based on the visitors occupancy pattern but this feature is not been done

Air conditioning and HVAC

- System equipped with sensors
- The HVAC system Interface with Building Management System
- Records running hours and report when there is equipment failure

- System allow Pre-programmed responses and zoning control
- System provide graphical representation and real-time interactive operation action icons

Security system and access control

DSX Security system integrated in the building with the feature of access control.

The environment is monitored through the CCTV cameras and different staff are appointed to be available around visitors to warn or communicate with the visitors in case of misbehaviours in the exhibitions. The security staff communicates with the monitoring room by wireless devices.

Lift control system

Hydraulic lift system is used in the buildings with the feature of voice announcement and suitable for special needs people.

Addressable fire detection and alarm system (AFA*)*

- FSP & FACP
- The system allow Integration and control of sensors, detectors, fire fighting equipment
- Integrated in Building Management system
- The system interact with HVAC systems
- System interact with lift systems
- The fire fighting system is specially designed and suitable for museum environments. Since water sprinklers in the museums are very dangerous for collections, in case of fire, Nitrogen gas will be released in the environment to 5% to stop the fire.
- The exhibition halls do not have any of water pips in the structure to avoid any water leakage and impact on the environment.

As shown above, elements directly related to the exhibition environment and have important role in the collection preservation (lighting, HVAC and AFA system) are more advanced and have different feature of integration.

In terms of energy saving the HVAC system could be considered as the most energy saver component in terms of programming it in operating the AHU units to maintain the assigned T and RH and would turn off when the required T and RH are achieved. Air chillier operate when the T level is not at the desired set point based on the monitoring done from the exhibition environments in terms of RH and T. The chosen HVAC system for the exhibition environment is equipped with humidifiers to keep the humidity at the desired set point for the artifact preservation.

As for lighting systems they are advanced but not integrated to be used in more efficient ways with the visitors occupancy detection and operation. Current lights (Halogen lights) consume much more energy than LED light.

5.1.6.3. Museum practices

Museum practices and policy implementation play strong role on the collection preservation. Where there is consideration for indoor environment, policies been adopted to control the conditions. Thus, artifacts will be preserved in the desired environment.

Based on the survey with the collection's department Table 5.19 presents the policy for indoor environment parameters in terms of T RH and lux levels for the different types of the collections objects. According to Hazzelle, (Collections manager at Sharjah Museums departments), the numbers are derived by following UK standards for indoor parameters of the museums.

Table 5.19. Indoor parameters set for different collections at SMIC. (Sharjah Museums Department, 2016)

	Temperature		Humidity		Illuminance	
	max	**min**	max	min	max	min
Fabric	**24**	**5**	**65**	**40**	**50 lux**	**No light**
Paper	**24**	**5**	**65**	**40**	**50 lux**	**No light**
Pottery/ceramics	**24**	**5**	**65**	**40**	**300 lux**	**No light**
Coins & Metals	**24**	**5**	**40**	**Less than 15**	**200 lux**	**No light**
Other Specify, eg: paintings	**24**	**5**	**65**	**40**	**50 lux**	**No light**

Moreover the galleries are located in a fair distance from the main entrances of the museum. Also, even though galleries are all located in the indoor environment of the building, however it was noted that display items near to the entrance and exit areas did not contain the ancient artifacts. That reflects the concern towards avoiding any influence from the outer part of the exhibition towards the sensitive artifacts.

One of the disadvantages of the museums practice is the lack of IAQ data, IAQ is not monitored in the exhibition environment and not considered currently.

Artifact Preservation

As expressed in table 5.18 earlier, all the features and positive actions made for the artifacts are results of good decision and aiming for artifact preservation. Also the knowledge of what is exactly required for the collection safety led to the choice and implementation summarized in table 5.19.

Energy savings

Energy savings in the museums are a results of decisions made earlier for implementations. The advantage of the museums for energy saving is the BMS control over the HVAC systems.

The positive aspect in this case study is that visitors enter the building and inside the building itself all activities are happening. There is no need for going outside the building in order to reach to different galleries. Thus the influence from outdoor is much reduced.

This also serves the health and comfort of the visitors in terms of maintaining body temperature to similar conditions across the visit.

5.1.6.4. SMIC On Site Measurements Results Details

On site measurements were carried out on 25th of August 2016. As mentioned earlier only the galleries located on the first floor of the museum are included in the study for having the various ancient artifacts. The areas on spot measurements were taken at are provided in Appendix B.

The size of the galleries is much bigger than the other museums. Thus, T and RH were measured at different points of the exhibition in order to check the uniformity of the environment in different areas. Moreover, since exhibitions had different artificats in terms of their origin some readings were taken next to the artifacts' display cases in order to check the results with standards and the variation of conditions in their surrounding areas.

On site measurements results for T, RH and lighting level in the 4 selected galleries of the museum are included in Appendix B, and the following section has each category with their discussions.

T On Site Measurements Results and Discussion

The analysis for the measurements of T in SMIC is provided in figures 5.12 to 5.17 as well as the tables following them (tables 5.20 to 5.23).

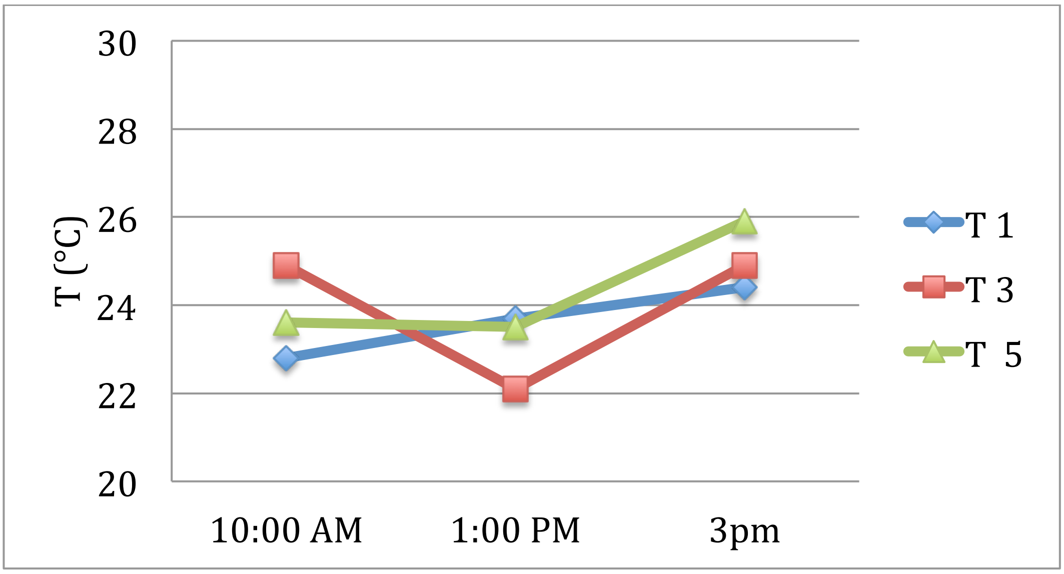


Figure.5.12. SMIC Gallery 1 Temperature variation of different points at different times of the day.

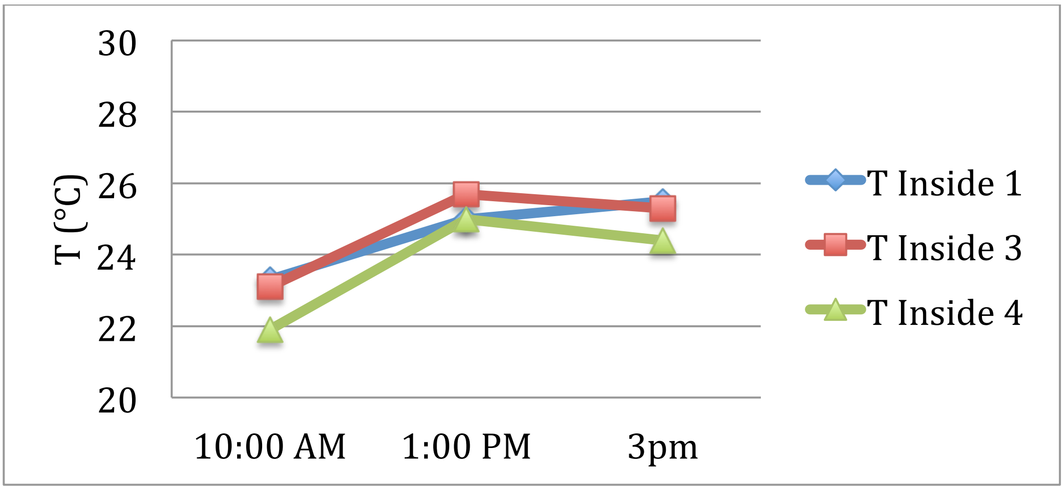


Figure.5.13. SMIC Gallery 2 Temperature variation of different points at different times of the day.

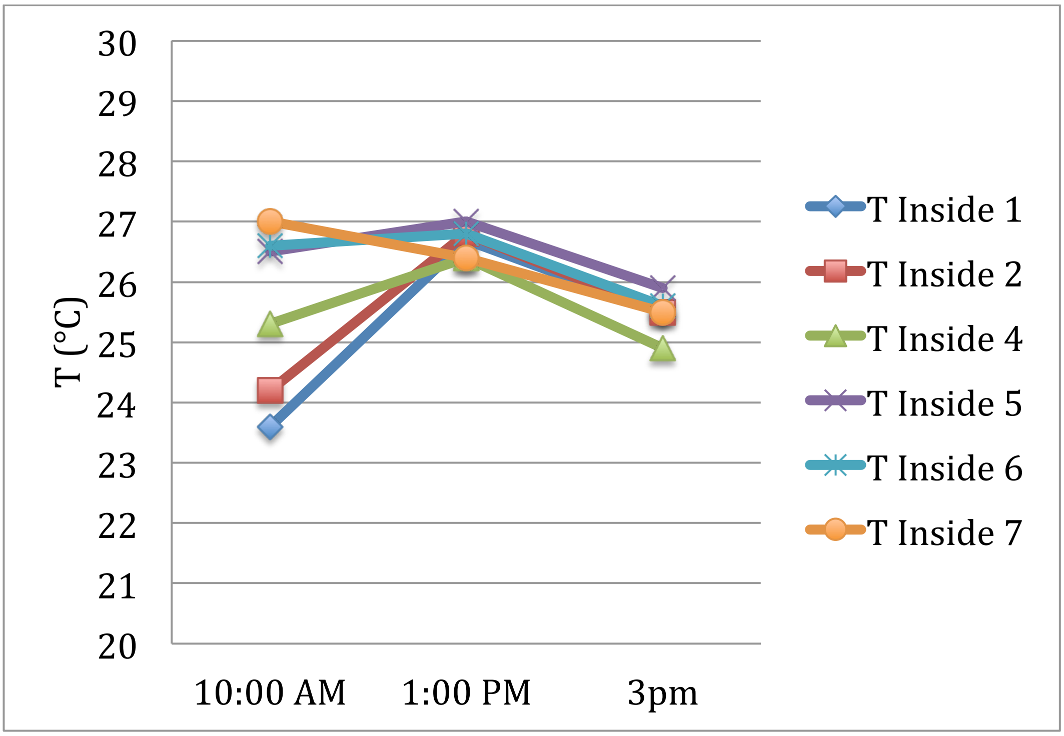


Figure.5.14. SMIC Gallery 3 Temperature variation of different points at different times of the day.

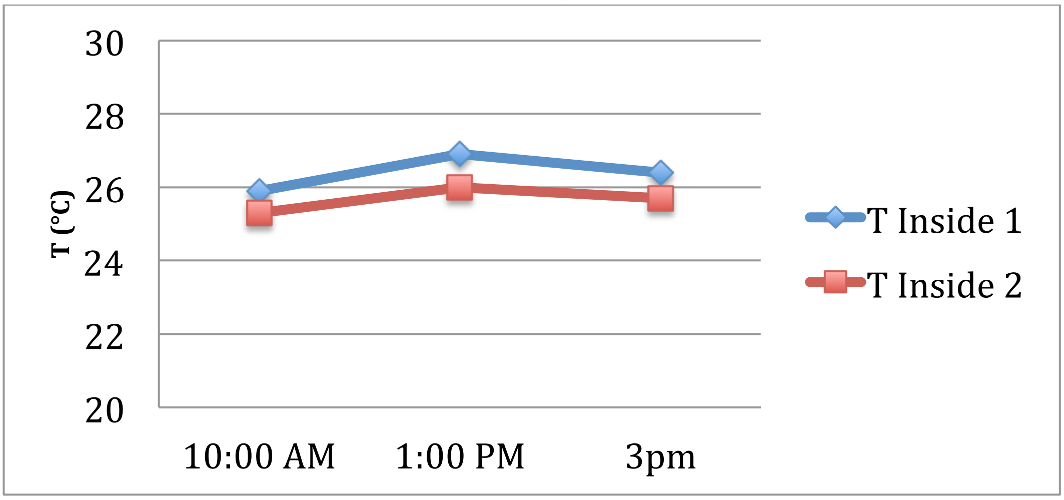


Figure.5.15. SMIC Gallery 4 Temperature variation of different points at different times of the day.

As shown in table 5.20 T in gallery 1 varied for less than 1°C in the different measured points. As for the different times of the day the max recorded fluctuation was 2.3°C and happened in point 5. The trend for T change in different points is having an increase trend, while, at point 3 T dropped at 1pm unlike other points.

Gallery 2 T at 10 am varied from 21.9 °C to 23.3 °C in different parts. Point 1 had moderate increase from 23.3 °C at 10 am to 25°C (for less than 2

°C) at 1pm and a slight increase of 0.5°C till 3pm. While point 2 T started from 23.3°C and increased to 25.7°C till 1 pm and dropped by 3pm to 25.4°C. Similar trend with slight difference of numbers is noted in the other galleries (3 and 4) as they all have rise of T till 1 pm and a slight drop until 3pm. However T in gallery 3 dropped more than other exhibits after 1pm.

Table 5.20. SMIC Gallery 1 measured T at different points

	10:00 AM	1:00 PM	3pm	T Fluctuation
T 1	22.8	23.7	24.4	**1.6**
T 3	24.9	22.1	24.9	**2.8**
T 5	23.6	23.5	25.9	**2.4**
Difference in T	**2.1**	**1.6**	**1.5**	

Table 5.21. SMIC Gallery 2 measured T at different points

	10:00 AM	1:00 PM	3pm	T Fluctuation
T 1	23.3	25	25.5	**2.2**
T 3	23.1	25.7	25.3	**2.6**
T 4	21.9	25	24.4	**3.1**
Difference in T	**1.4**	**0.7**	**1.1**	

Table 5.22. SMIC Gallery 3 measured T at different points

	10:00 AM	1:00 PM	3pm	T Fluctuation
T 1	23.6	26.7	25.5	3.1
T 2	24.2	26.8	25.5	2.6
T 4	25.3	26.4	24.9	1.5
T 5	26.5	27	25.9	1.1
T 6	26.6	26.8	25.6	1.2
T 7	27	26.4	25.5	1.5
Difference in T	3.4	0.6	1	

Table 5.23. SMIC Gallery 4 measured T at different points

	10:00 AM	1:00 PM	3pm	T Fluctuation
T 1	25.9	26.9	26.4	1
T 2	25.3	26	25.7	0.7
Difference in T	0.6	0.9	0.7	

Artifact Preservation

Based on the feedback from the BM department the daily set point for T 21°C during the entire year to ease the control in terms of T and RH rise and drop.

Considering UK standards with T of 18°C – 24°C with ± 4°C fluctuations during the day that is implemented in this museum. The daily variation should not exceed 25°C and should not go below 17°C. Whereas even though fluctuations were in the safe range (below 4°C) but the T ranges in different parts were from 21.9 °C to 27 °C that exceeded the max assigned T. Tables 5.20 to 5.23 indicates the T above 24°C (UK Standard) and

25°C (based on the fluctuation allowance from the set point and ASHRAE standards) for the museum Galleries in blue. As shown in the tables gallery 1 was in the safe zone only once the T was higher. While gallery 3 most of the time T was above 24°C, while gallery 4 did not go below 25 all the time. However, T did not reach to 30°C which is the danger zone, so it can be still considered as safe but needing considerations.

Health and Comfort

The difference in T of different parts of the galleries is shown in tables 5.20 to 5.23. This reflects what temperature changes will be sensed by the visitors as they move along the museum. This difference in T in SMIC is not big and was little amount the highest was 3.4°C in gallery 3 during the measured times.

RH On Site Measurements Results and Discussion

In terms of RH percentage in this case study, by referring to tables 5.24 to 5.27 less fluctuations and more control in the environment is observed. SMIC is following and RH percentage of 50% with ± 10% fluctuations during the day (UK standard). Based on the feedback from the BM department the daily set point for RH is set to 55% As shown, gallery 1 and 2 did not have any unsafe readings. While RH in gallery 3 was below standard in point 6 and 7. Also RH in gallery 4 in both locations was below 45% while only once at 3 pm it stayed on 45%.

Table 5.24. SMIC Gallery 1 measured RH at different points Gallery

	10:00 AM	1:00 PM	3pm	
RH 1	54	51.6	47.5	**6.5**
RH 3	49	50.5	52.5	**3.5**
RH 5	52	53.5	45.8	**7.7**

Table 5.25. SMIC Gallery 2 measured RH at different points Gallery

	10:00 AM	1:00 PM	3pm	
RH 1	53.5	47.8	45.1	**8.4**
RH 3	50.1	50.5	45.7	**4.8**
RH 4	54.5	47.7	46.9	**7.6**

Table 5.26. SMIC Gallery 3 measured RH at different points

	10:00 AM	1:00 PM	3pm	
RH 1	49	45.9	46.8	**3.1**
RH 2	47.5	45	46.2	**2.5**
RH 3	50.1	50.5	45.7	**4.8**
RH 4	50.9	55	48.5	**6.5**
RH 5	50.9	50.5	49.4	**1.5**
RH 6	43.3	45.6	44.2	**2.3**
RH 7	44.1	43.7	44.2	**0.5**

Table 5.27. SMIC Gallery 4 measured RH at different points

	10:00 AM	1:00 PM	3pm	
RH 1	44.6	44	43.6	**1**
RH 2	44.9	43	45	**2**

Lowest RH percentage was recorded at gallery 4 point 2 at 1 pm with 43% and the highest readings did not exceed 55%.

Charts presented in figures 5.15 to 5.17 are illustrating the RH change trends happening in the galleries. Gallery 3 at measuring point 4 had more fluctuations in comparison to other galleries and points. While, point 1 in gallery 2 had a downward trend of dropping from 53.5% to 45.1% creating the biggest percentage drop of 8.4% through the day.

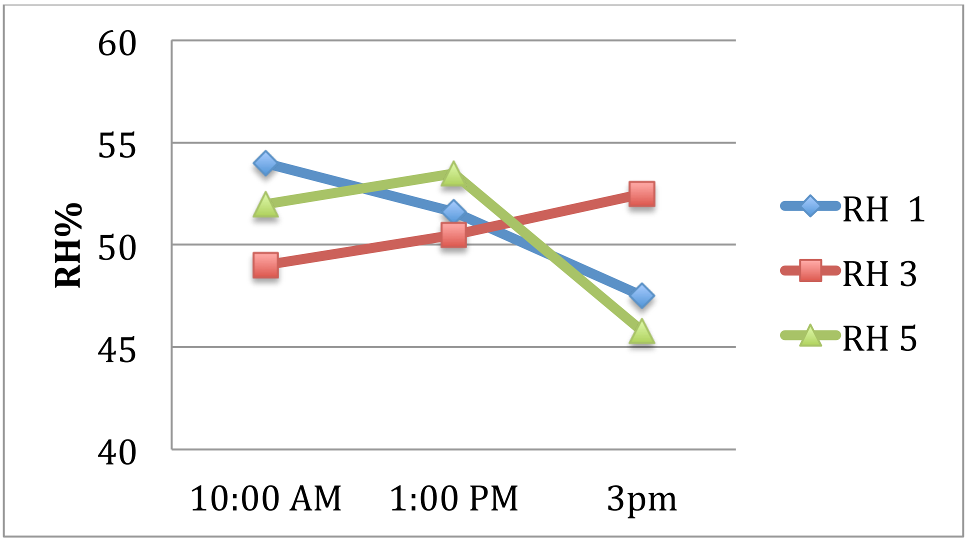


Figure. 5.16. SMIC Gallery 1 RH variation of different points at different times of the day

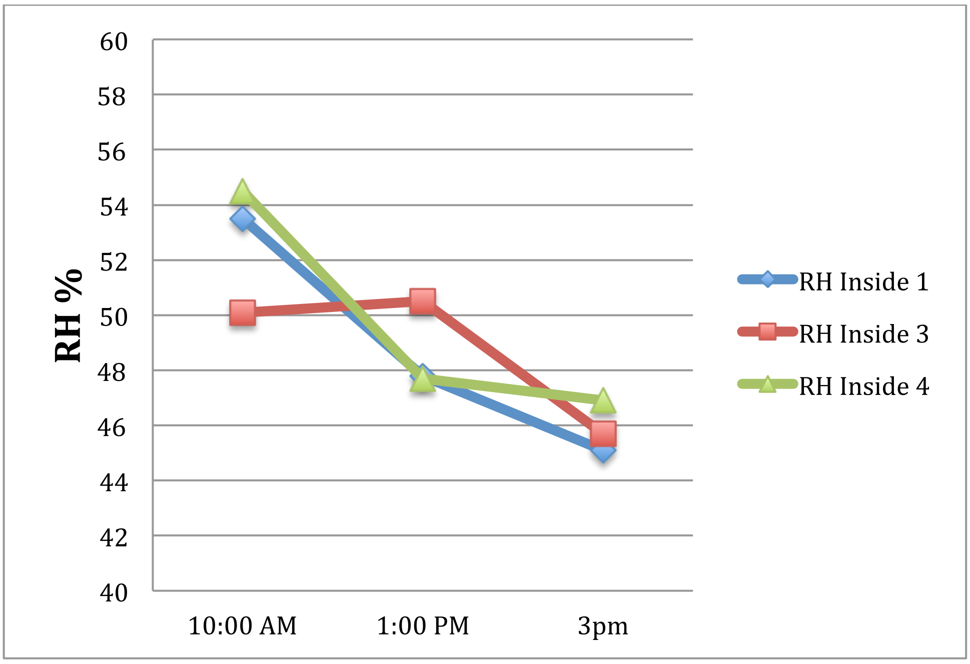


Figure. 5.17. SMIC Gallery 2 RH variation of different points at different times of the day

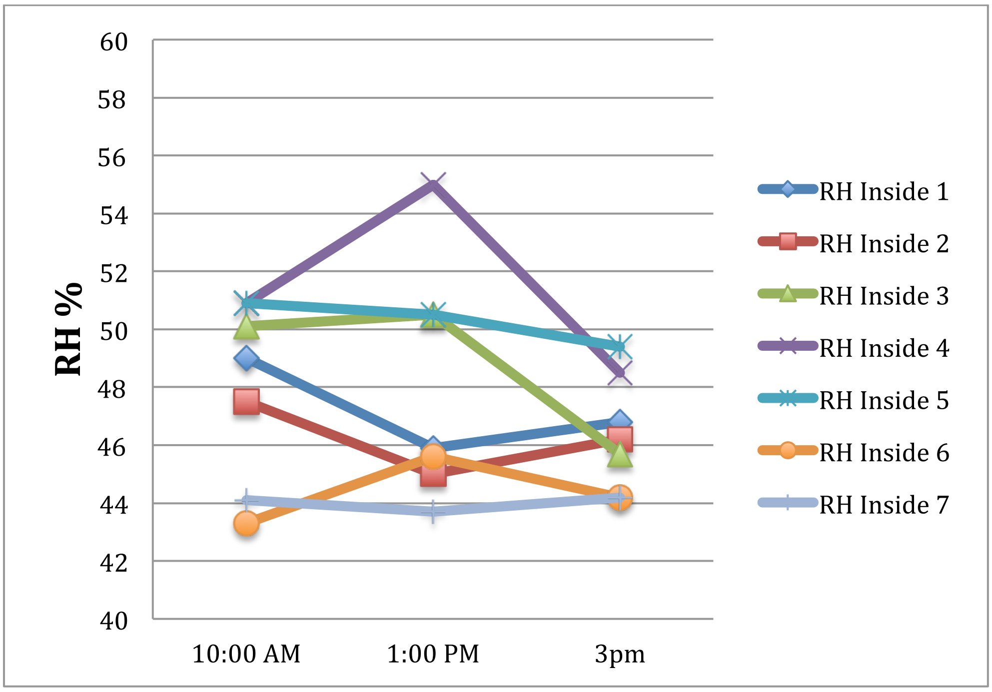


Figure. 5.18. SMIC Gallery 3 RH variation of different points at different times of the day

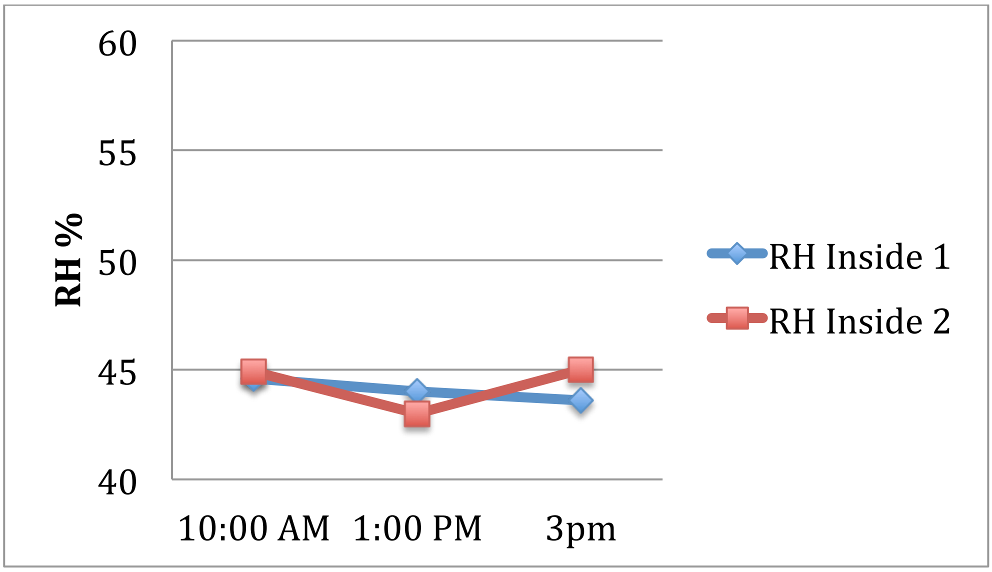


Figure. 5.19. SMIC Gallery 4 RH variation of different points at different times of the day

The results show low risk in terms of RH conditions for the artifact preservation. However, the numbers obtained can be considered safe as the display cases themselves are RH controlled cases.

In terms health and comfort of the visitors, the different RH percentage of different point of each exhibitions did not vary much thus it does not impact the comfort of visitors negatively.

Luminance On Site Measurements Results and Discussion

Moving to indoor illuminance levels, a shown in the tables recorded numbers are much lower in comparison to the other two case studies. Lux level varied based on the items in display and the location of measurements however max recorded was 255 lux with same height of other places and 1400 lux when the lux meter was kept on one of the display tables that had direct light exposure to the items. Lux was almost uniformed in the different exhibitions and the very small different in numbers could be due the placement of the lux meter with a slight change in position in different times of the day. As shown in tables 5.28 to 5.31 none of the numbers exceeded the 300 lux as the highest allowed lux level by UK standards.

Table 5.28. Measured Lux levels at SMIC Gallery 1

	10 am	1 pm	3pm	
Light Inside 1	28	23	28	Walking Path
Light Inside 2	35	38	32	Pottery Display
Light Inside 3	12	12	14	Quran Book
Light Inside 4	51	55	57	Walking Path
Light Inside 5	10	9	12	
Light Inside 6	21	20	21	

Table 5.29. Measured Lux levels at SMIC Gallery 2

	10 am	1 pm	3pm	
Light Inside 1	40	37	45	Walking Path
Light Inside 2	40	40	40	Cloth Display
Light Inside 3	70	70	72	Copper
Light Inside 4	80	80	81	Wood
Light Inside 5	15	16	13	Long Fabric
Light Inside 6	120	176	155	Paper

Table 5.30. Measured Lux levels at SMIC Gallery 3

	10 am	1 pm	3pm	
Light Inside 1	76	70	72	Walking Path
Light Inside 2	80	103	107	Brass Display
Light Inside 3	10	11	18	Copper
Light Inside 4	4	4	5	Middle Area
Light Inside 5	12	11	11	Cloth
Light Inside 6	132	132	130	Books
Light Inside 7	21	26	25	Glass & Crystal

Table 5.31. Measured Lux levels at SMIC Gallery 4

	10 am	1 pm	3pm	
Light Inside 1	21	25	30	Walking Path
Light Inside 2	198	187	186	Copper
Light Inside 3	212	201	229	Warrior Metal Outfit
Light Inside 4	107	105	105	On table 90 cm Height

5.1.7. Case Studies Comparisons

By comparing the three case studies together it can be concluded that case study 3 (SMIC) had the most control over the environment in terms of all factors of RH percentage, temperature of the environment as well as the exhibition lighting. T and RH is controlled and monitored continually in the different galleries by the building management system. The Air Handling Units (AHU) for the exhibition environments are equipped with humidifiers and dehumidifiers in order to have full control and provide the most uniformed indoor environment for artifact preservation. While in SHAM only T was controlled in the environment without the consideration of RH. Whereas, in CCM with the existence of AC units did not help in maintaining the proper T in the exhibits.

As noted in the results SMIC had the lowest visible light (lux) level numbers in comparison to the other two museums. Lighting system adopted in SMIC was halogen lights, therefore, UV filters added to lights for protection of the collections. No source of daylight was available in SMIC. Whereas case study 2 (SHAM) had DALI system with LED light and they do not have UV or IR and they have longer lifespan and save more energy. As of CCM florescent lights was used inside the display boxes and halogen lights was used for the exhibition environment. According to the founder the exhibition lights produce heat (which is the sign for IR) and there was no UV filters for them.

None of the museums had dimmable lights for reducing or turning off the lights in the time no visitors are in the galleries. However SHAM museum had the option of brighter lighting for being used during cleaning of the museum. All lighting was on throughout the day in the 3 case studies.
For the lack of resources (UV meters) only lux levels of the environment were measured and the UV is depending on the feedback gathered from the museums is compared.

5.1.8. Considerations

Even though measurements are only from 10am to 3pm however, these are the crucial hours in terms of T rise outdoor.
Comparing the outdoor temperature of the days measurement campaigns were conducted, CCM had the highest T at 1 pm by reaching up to 54.9 °C, while other sites measurements were taken at a later time in the summer (end of August) where temperature was lower in general. Even though the difference in outdoor and indoor temperature can influence different results especially in environments not sealed properly like CCM. However, the dates were made based on the obtained approvals. This is considered as one of the study limitations. Nevertheless, the overall readings indicate the poor control over the environment in CCM.

5.2. Section 2: Proposals and Assessment Based on Evaluation Results

After the evaluation of the current conditions of the selected case studies, based on the identified situation in terms of good conditions and current challenges, this section will answer the "what are the possibilities for enhancing the current conditions?" This stage is the Expertize stage in SOBANE strategy that identifies solutions and assessment for the identified problems.

This part is dedicated for the proposals for each case study based on the identified situation. Depending on the points that require enhancement, one or more proposal is suggested. Each proposal will be assessed in order to identify the best practice for implementation. The base line for the proposals is the consideration for artifact preservation. According to the situation, some radical changes are required in order to preserve the artifacts. These changes will provide the opportunity for targeting the energy saving approach in the museums, which is not yet implemented in UAE.

Following the case study evaluations, each case study proposals are provided separately in the three eras of :

1- Artifact preservation
2- Health and comfort
3- Energy saving and intelligence

The assessments for the proposals are made in the relevant section of each case study.

Since this study is only concerned with the exhibition environments and factors contribute in energy saving, author did not consider other approaches targeting all museum aspects with the different environments. Nevertheless, based on the different case studies, if big changes were implemented, even though the proposal is for the exhibition environment, however, the assessment of proposals are made by considering the whole project and how much it contributes in enhancement overall. Moreover, since the measurements were carried on during summer, the solutions provided are based on the summer evaluation period and targeting each case study specifically.

The small enhancements that can be done immediately on site are mentioned here, as author did not have the authority for taking action in the museums and apply any changes.

5.2.1. Proposals for Case Study 1:CCM

Figure 5.18 to 5.20 are showing the categories for each solution based on the identified challenges in CCM in terms of the three areas of the study: artifact preservation, energy saving as well as the human health and comfort. The information and challenges are extracted from the evaluation results presented in tables in section 5.1 of this paper.

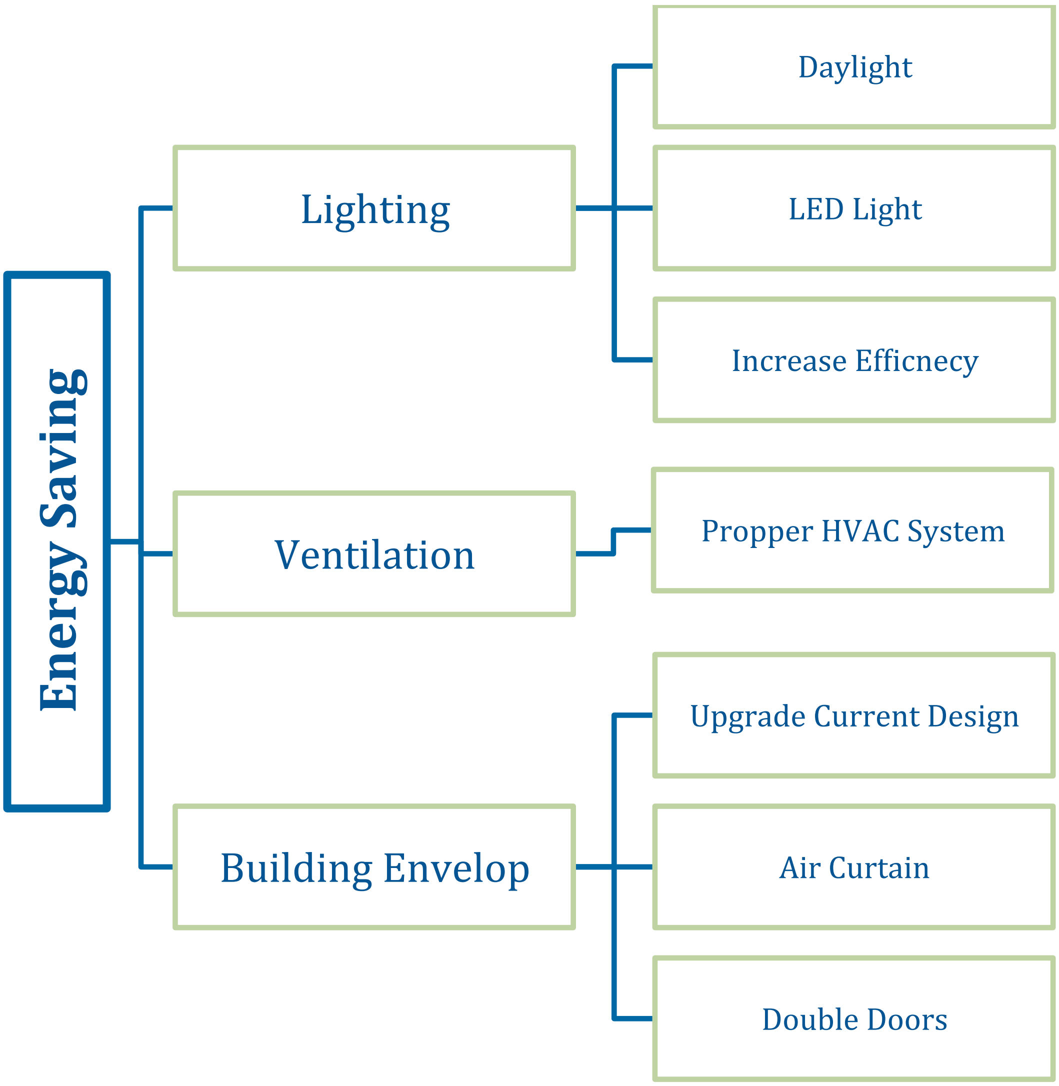


Figure. 5.20. CCM Proposals scopes in terms of energy saving in the exhibitions

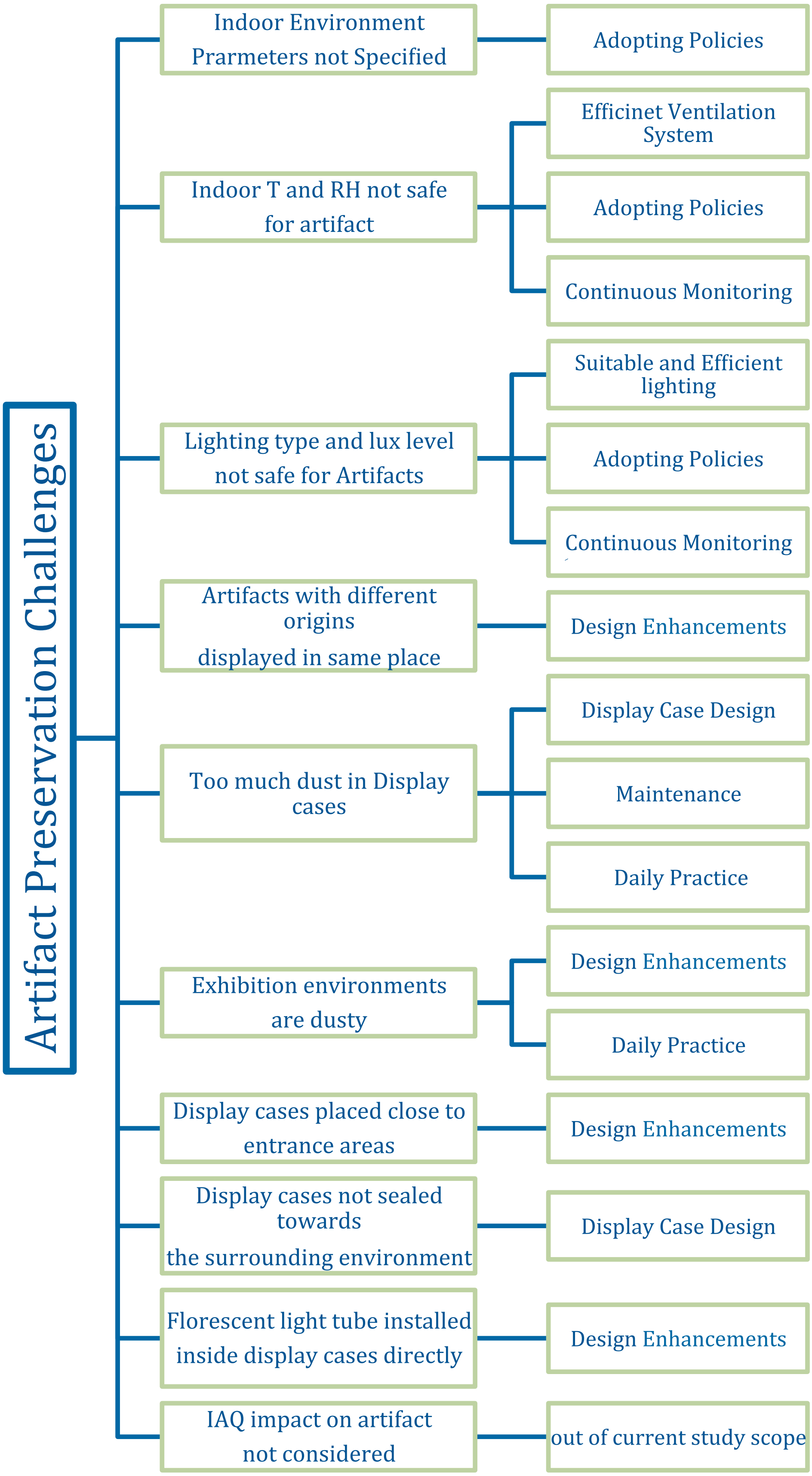


Figure. 5.21. CCM Proposals scopes in terms of artifact preservation in the exhibitions.

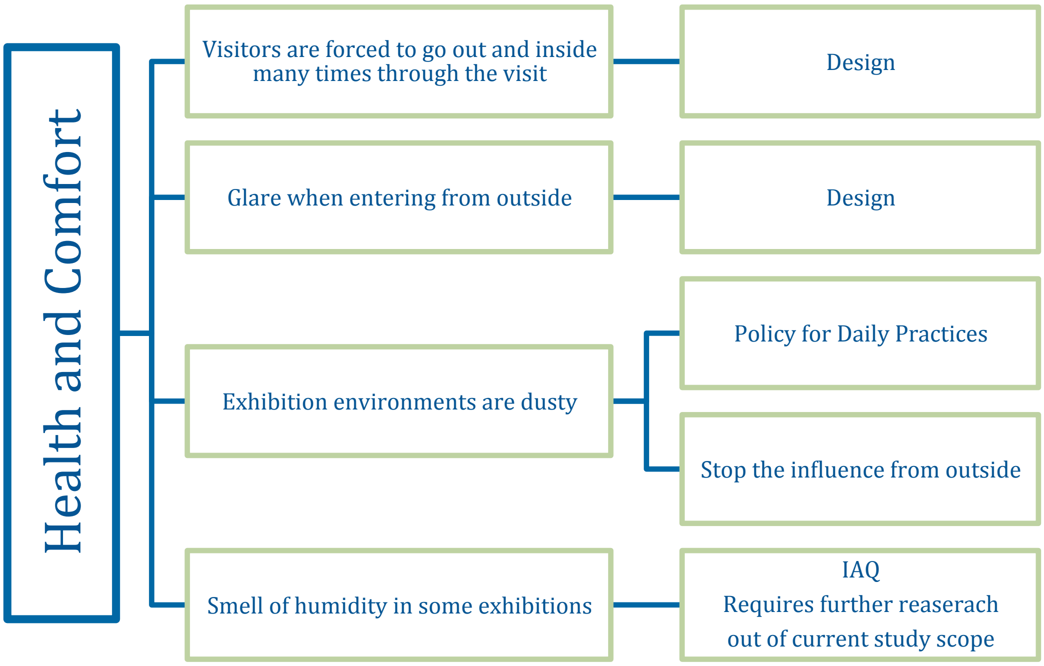


Figure. 5.22. Proposals scopes in terms of health and comfort in the exhibitions CCM

Since this case study requires many changes in different aspects, a separate section for the proposal assessment is dedicated.

Based on the concerned areas for the solutions, it is shown that the proposals fall under two main categories: 1- enhancements based on redesigning existing elements, and most importantly is to 2- adopt guidelines. The lack of guidelines and not having a clear policy for the museum practices is resulting in the poor conditions of the environment.

In the establishment stage of any museums, specifically museums with ancient artifacts it is very crucial to identify set of guidelines with clear objectives considering all artifact preservation requirements. Since this guideline is missing in this case study it should be set based on a clear plan with specifying timeline for achieving the different required goals.

Even though the author targeted the exhibition environments only as a focus point in evaluation, however, this lack was noted on a bigger scale in terms of the museum practices in general. Based on the evaluation made, radical enhancements are required for this case study museum.

This research contributes in providing the information needed for the requirements of the exhibition environment specially that the proposed solutions are targeting the concerned museum it self.

To make the proposals clear and to the point this section will present the solutions under the two main point of:

1- Policy and Guidelines
2- Design Enhancements

After presenting the solution under the two main factors, the discussion and assessment of each factor are presented based on the three targets of the study:

1- Artifact Preservation
2- Energy saving
3- Human Health and Comfort

Same sequence is followed in the 3 case study proposals.

5.2.1.1. Policy and Guidelines

Since the museums has no specified policy and guidelines, to enhance the current conditions it is crucial to clearly indicate the following points in terms of policies for the exhibitions:

- Quantitative indoor environment parameters targeting hygrothermal and luminance parameters.
- Determine daily practices in the museum
- Maintenance policy
- Continues monitoring for the indoor environment

Policy and Guidelines for Artifact Preservation: CCM

As for artifact preservation, since guidelines for museums indoor environment are lacking in this region, as a starting point adopting international guidelines will help the museum management to decide for the needed actions for the collections to reach to a stable condition.

Details for different guidelines for museums are presented in literature review section 2.2.1.1. The management can carry further focus into the different guidelines and standards and selection could be made based on them. The benefit of these guidelines is in their holistic approach towards the museums as a whole complex. They determine different policies towards all the activities take place in the museums. This includes the transportation of the collection, storage conditions, items for loan and many more that are not mentioned in this paper as they fall out of the focus of the study. However they are all crucial points that any museums with such activity have to assign clear information about the collections.

Guidelines will identify the detailed indoor environment parameters in terms of RH, T and illuminance levels by numbers and the allowance of fluctuations during the day as well as the different seasons. This point is one of the main missing points that made the exhibition environment not stable for the artifacts in CCM.

After considering a specified set of guidelines it is important to upgrade facilities to meet the conditions requirements. Based on the interview with the founder of the museum, the general qualitative knowledge about the artifacts needs was considered in the establishment stage. However, due to lack of detailed information and lack of access to guideline and specifications, the decision were made without full awareness on the impact and results on artifacts. Lighting, HVAC and display cases are not meeting the preservation requirements of the museums. Based on the guideline specifications, decisions could be made to select the proper systems that meet the requirements and provide the desired conditions.

After upgrading the systems, monitoring of the environment comes in. Having set of numbers showing safe range would not be effective unless they are applied and maintained. To ensure if the specified set points are being implemented correctly continues monitoring is required.

Having integrated building management system with monitoring and control possibility for the environment can interfere with the systems and make the needed action to maintain the parameters without problems.

On a very smaller scale, according to the guideline by London Museum (SHARE), if the museum does not have enough facility for monitoring and control, it was advised to use the data logger devices for the indoor monitoring of the environment. This will indicate the recorded fluctuation, however, control should be made manually that would be done late.

Also determining maintenance and service policy based on guidelines will limit the faults in different systems. Preventing the problems from happening is the best way to be done. Continues service and cleaning for the systems including HVAC, light etc,, will keep the efficiency of the systems before getting the damages. Daily cleaning for the environments will keep the dust and dirt away keeping the environment fresh and safe for the artifacts.

Policy and Guidelines for Energy Saving and Intelligence

When the organization set a clear goal to be achieved all the activities will follow the objectives to reach to the assigned goal. In order to have a sustainable and more energy efficient environment the first step is to identify the goal and the desire for achieving it. Based on the interview with the founder of the museum the motivation for energy reduction is mainly to cut down the monthly utility bills.

Addressing intelligence and energy efficiency as a key factor for selecting different systems in the museum will direct selection options for searching systems possible with these features. Thus it will eliminate options with no features of intelligence and energy saving.

Setting a policy for integrating daylight with intelligent features, LED light and integration sensors, will reduce energy consumption for lighting, increase the efficiency and make intelligence features in the environment.

Figure. 5.23 summarize the needed policies to be adopted in this case study.

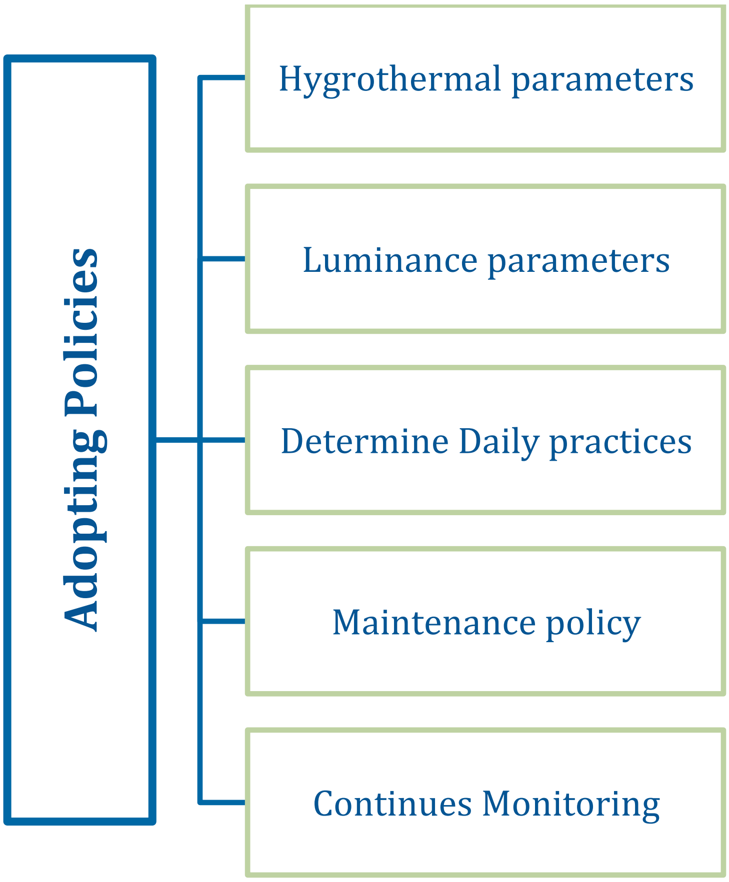


Figure. 5.23. Needed policies' scopes for CCM

5.2.1.2. Design Enhancements

After setting clear policy targeting all aspects of the activities and the different museum environments, design enhancement stage would follow. Design Enhancement should be considered within the policies and targets identified and any change would directly contribute in enhancing one of the three areas of the study (Artifact preservation, Intelligence and energy saving as well as human health and comfort). The important consideration in this part is to target only the concerned areas of the study, thus changing the aesthetic appearance of the exhibitions in not concerned in the proposals even though they contribute in the visitors satisfaction in general according to chapter 2. Based on the identified challenges for CCM the design enhancements should mainly target to:

- Limit the influence from outside to inside environment

- Limit the negative influence from the environment on the display cases
- Enhance methods of collections display
- Enhance lighting and the luminance parameters
- Proper selection for convenient ventilation system suitable for the indoor environment of the museums
- Limit Glare for visitors
- Enhance visitors circulation and reduce the interaction with outdoor

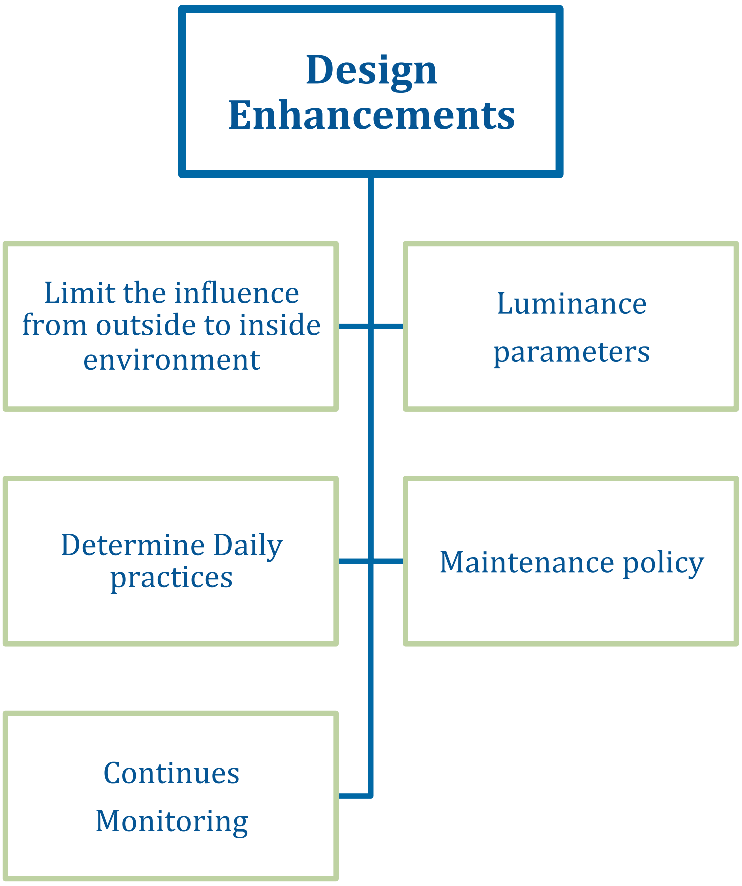


Figure. 5.24. Design enhancement scopes for CCM

Design Enhancements for Artifact Preservation

Visitor Circulation and Building Envelope

Having different small exhibition spaces that have the doors open and close without control make the indoor environment uncontrolled and influenced by outside result in poor building envelope.

Considering the current arrangement of the museum (Fig. 5.25), currently the door used for entering the exhibition is located in the middle of the exhibit. Changing the starting point of the exhibit, and closing the current entrance will make the entrance door limited to certain area and the visitors to start from the beginning of the room, thus less negative impact is resulted. There is existing door that is placed in beginning of the room, which can be utilized for this purpose.

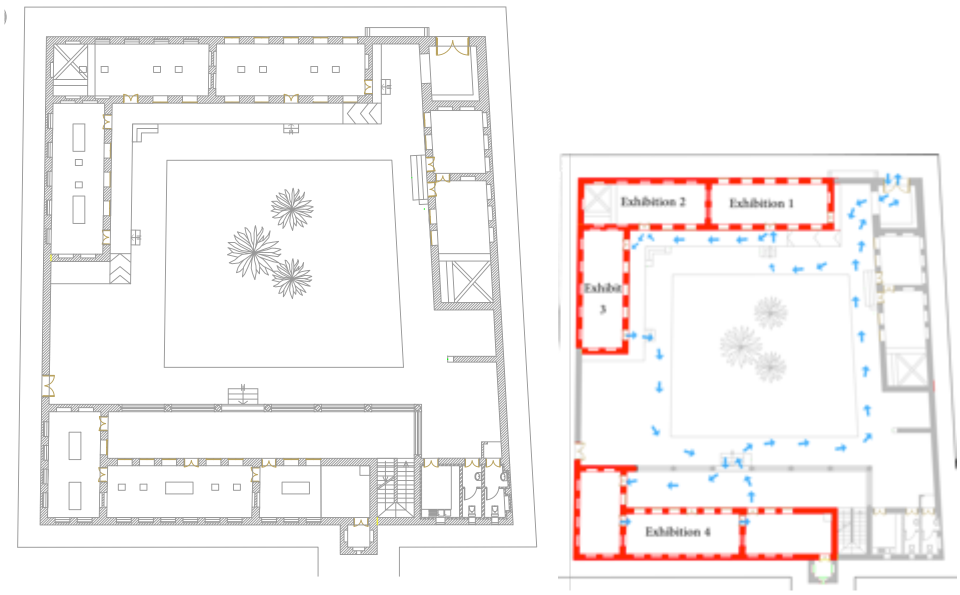


Figure. 5.25. CCM arrangements and circulation

Placing air curtain system above entrance door will act as a barrier for blocking the influence from outside as people enter the exhibition. Air curtain system will contribute on keeping the environment clean with much less dust entering the area.

Also, to make the environment properly sealed and increase efficiency of AC implementing the double door concept in the simplest way will keep all the heat entering the environment in that gap between first and second door. It is more convenient to be installed inside the current structure, so no major change will be required for it.

Figure 5.26 shows the proposal for the enhancements to be done in Exhibit 1,2 and 3 in CCM.

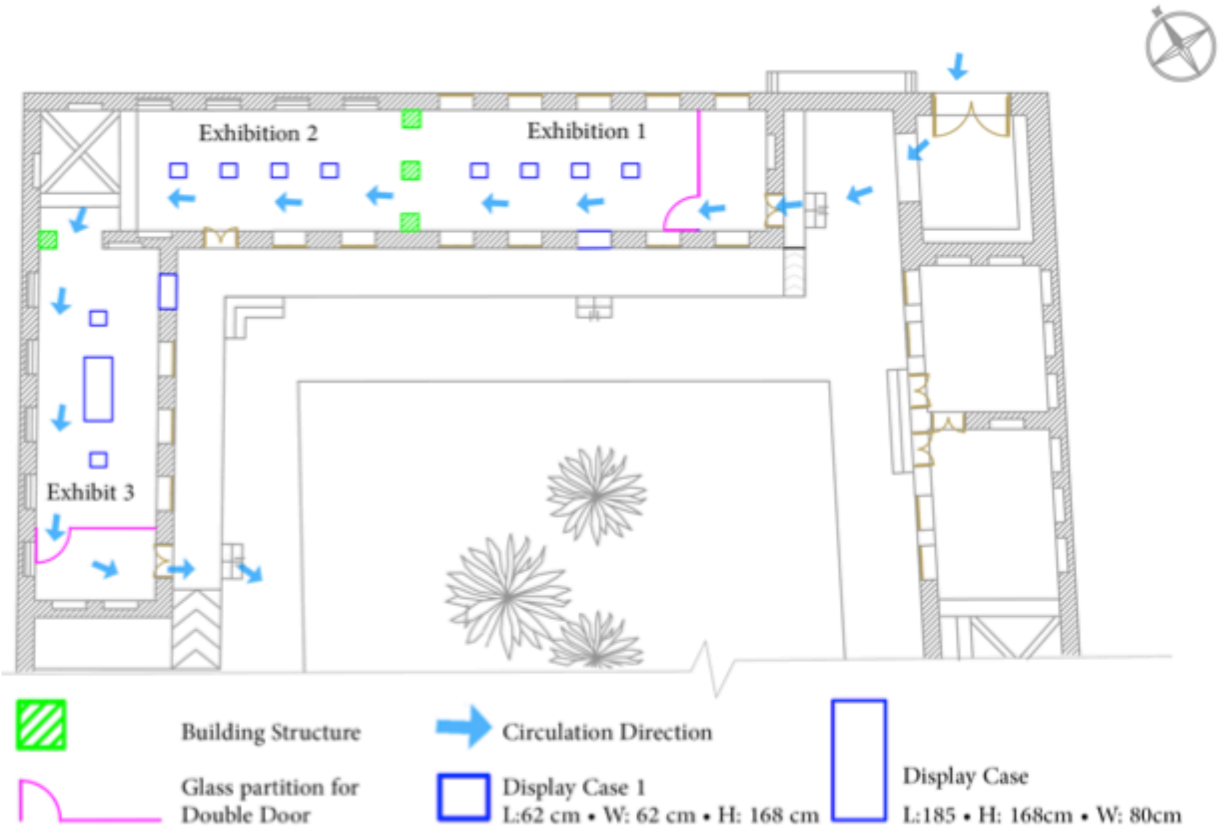


Figure. 5.26. Proposed design enhancements

The blue arrows indicate the circulation of visitors in the 3 exhibits. The allowance space for the firs and second door in exhibit 1 is 150 cm. Glass partition is assigned to be placed with a door. The arrangement of the display cases in the middle is re-arranged with a fair distance from the glass door.

Most important aspect is to make the 3 rooms linked and connected together. By refereeing to the plan in figure 5.25 as shown the middle part can be opened (the green squares indicates the area of the new opening) to make pathways for visitors to enter the second exhibition. Similar method could be implemented to exhibition 3 as well. Exhibition 2 included the opening at the beginning and at the end of the room. Current entrance door can be kept as emergency exit. However, it should be sealed properly to avoid air leakage from outside. The display cases in exhibit 2 are distributed in a way to avoid placing items below the opening of the wind tower.

The entrance door of exhibit 3 is closed and it can be utilized as a display area after proper treatment towards outdoor influence. Same concept of double door is implemented at the end of exhibit 3 with the implementation of air curtain system.

One crucial point to be considered is properly closing the old entrances and making them sealed as currently there are a lot of gaps and air leakage that could influence the indoor environment as well.

Display Cases

Since the guidelines identify different RH conditions for artifacts with different origins, the arrangement of the collections and their placements should be redesigned with careful considerations.

As for the display cases, in figure 5.25 the blue boxes indicate the display cases and they are based on the current sizes. Currently 2 different sizes of display cases are being used in the middle areas:

1- Small display: 62 x 62 cm with the height of 128 cm
2- Big display 185 x 80 cm with the height of 168 cm

Current display cases have big opening in their joint areas that make them open to change and allow too much dust inside them.

The display areas in the gaps between the double doors should not be any of the sensitive items, it is recommended to keep the general information and the brochures of the museums in this place.

The current display cases should be replaced and redesigned, as they are suitable for museum purposes. Also, the artifacts in each display case should be carefully chosen to match same origins.

Display cases designed by specialists for museums will ensure to meet the requirements of the artifacts. Currently, there is lack for local suppliers of museums display cases. However, items can be imported from well-known companies across the world, that provide the options of UV filtered, air tight with minimum air exchange rate, RH controlled with different designs and storage flexibility. (Gaylord Archiva, 2016; Meyvaert Glass Engineering, 2016 ; Frank, 2016)

Ventilation

Based on the current conditions and the measurements, the current AC system is not suitable for the environment and can not be upgraded. Thus, replacement is required to control the indoor space of the galleries in terms of T and RH fluctuation.

Figure. 5.27. Damages impacted by current AC unit in CCM

For the safety of the collections it is important to provide a uniformed and stable conditions. Selecting an efficient HVAC system with the option of RH monitor and control in the environment is essential.

Also, enhancing the building envelope reduces the negative impact from outside and makes the environment more stable in terms of fluctuation in parameters.

Lighting

As of lighting levels, currently the high lux level, no UV filtration, long hours of light exposure to materials and not efficient lighting system are harmful for the collections. Incorporating the proper lighting system that addresses all the mentioned points is essential.

Replacing the current fluorescent lighting with LED lights is proposed. LED lights have no IR and UV radiation they have longer life expectancy with higher efficiency as mentioned in literature review section.

Lighting levels can be adjusted to the required lux levels and has the possibility for change in the future.

Simplest way to reduce the light exposure time of the artifacts is to turn off the lights when there are no visitors in the exhibitions. Currently lights are on based on the hours of the opening of the museum for 12 hours a day six days a week results in total 3,456 hours of light exposure for artifacts. Considering the summer period from May till end of August, number of tourists and museum visitors are much less, thus exhibitions are empty from visitors for relatively longer hours and sometime for some days. Closing the lights during these hours will result in significantly reducing the light exposure times without reducing the working hours of the museum.

Simplest way in order to achieve this with no cost is closing lights manually, since the museum is small in size and simple methods adopted inside it this is very easy to be done manually with the current resources.

Inserting occupancy detection sensors can control the lights automatically and lights can switch off or to be dimmed when there are no visitors in the exhibition. System can be on in the exhibition that has visitors and stay off in other exhibitions.

The purpose of the mentioned proposals are mainly to enhance artifact preservation aspect, which is missing currently. Moreover, they also contribute in energy saving in terms of enhancing the building envelope for limitation of outdoor influence and air infiltration, reducing energy consumption by reducing the lighting operating hours.

Also, human health and comfort will be enhanced in terms of keeping the body in similar conditions for longer time and avoid thermal shock, also to reduce the glare when limiting the number of times visitors enter and exit from the environment.

***Design Enhancements for* Energy Savings**

Daylight

Integrating daylight in the safest way by filtering the UV radiation and controlling the amount of light entering the building. This is possible to be implemented in CCM without making major changes in the museum, as the existing building has already window opening to the outdoor environment but is been closed with wooden panels as shown in fig 5.28. The size of the opening is 100 cm width by 120 cm height.

Figure. 5.28. Current windows at CCM

It is very crucial to integrate diffused daylight rather than direct sun light. As it has been proven previously in earlier study by Al–Sallal and Bin Dalmouk (2011) that the daylight entering the museums in such buildings are not safe for the collection (explained in details in in chapter 2). To get the safe daylight, it should be treated.

Examining different possibilities through IES software will show the best option to be implemented. Section 5.2.1.3 in this chapter is dedicated for this aspect to elaborate in details the proposals that can be assessed through IES.

However, since currently the museum is operating manually without integration of different building components the proposals made here are meant to be suiting the case studies best. Thus the intelligent aspect is not considered as been expressed in literature review chapter.

Ventilation

Based on the current conditions and the summer measurements, benefiting from natural ventilation is not possible to reduce the energy consumption, as the outdoor T is very high. To reduce energy consumption and benefitting from the lower T. Considering the winter conditions is essential. The winters in UAE are not very cold thus; there is no need for heating. However the T is cool to a point that stops the need for AC in some times. Allowing natural ventilation will reduce significant amount of cooling demand however in a museum environment it should treated and be studied well. To stop the direct air flow inside benefitting from mechanical ventilation through heat recovery integration in the HVAC units can help reduce energy consumption during winter. Since winter period is not measured and considered in this research and requires further study, in order to quantify the energy reduction.

Keeping the option of integrating heat recovery through mechanical means is considered for the HVAC selection.

Another point to be considered for lowering energy consumption is to make the set points of T one degree or more higher than the current one and check the impact on the environment. However the current AC unit is not being efficient in providing the proper T in the exhibition environment. Moreover, it does not provide the option of controlling RH that is crucial for artifact preservation. That can be a result of not sealing the exhibitions properly towards outdoors and also not selecting the appropriate HVAC systems for the requirements of the museums.

As mentioned previously, the current conditions are based on manual methods with no integration in the building, however, by considering the

intelligence level, it will make the building components integrated. It will ease the control over the building. And will make the museum as a whole united place that provide the artifacts requirements, understands the needs of visitors and personnel, and also reduces energy consumption based on predicting the changes happening and interacting to them. Having the discussed elements of HVAC, light integrated into a BMS system will provide this type of interactive environment. BMS systems help increase efficiency of the components if properly installed and also contribute to reduce energy consumption rate in the building.
Connecting the firefighting systems with HVAC to stop operation in case of fires will limit the fire zone and keep it away from spreading.

Design Enhancements for Health and Comfort
Considering human health and comfort in the exhibitions, in Visitor Circulation and Building Envelope section of this chapter the indoor exhibition distribution has been discussed in order to limit the number of times people have to go outdoor and indoor to avoid the thermal shock to body. Also, enhancing building envelope, dust and other elements not enter the exhibits that will benefit to human health and comfort a well as artifact preservation.
Limiting the number of times visitors have to go inside and outside for going to the different part of the museum are reduced. However, based on the exhibition distribution, visitors still have to walk fair distance in order to move to exhibition 4 area. Furthermore, shading element can be considered to be utilized for the outdoor area for the comfort of visitors from one exhibition to another, however, since it is not in the current study focus, has not been considered.

Also, daily practice and cleaning routine should be enhanced to keep the exhibitions clean for the comfort of the visitors and most importantly for the safety of artifacts.

5.2.1.3. Assessment of proposals for Case Study 1:CCM

As shown in the previous part, this case study requires mandatory major changes in terms of some the systems in the exhibition environment in order to maintain the artifacts. This part is dedicated for assessing some of the proposals that can contribute in the energy consumption aspect. Since currently the adopted systems are not appropriate for exhibitions, applying changes will result in different energy consumption patterns that might be higher than the existing.

This section is dedicated for details about:

- Building the base case model
- Validation of Base Case Model in IESVE
- Experiments of different options for each proposed area
- Comparisons of the results in terms of energy and electricity consumption.

Base Case Model

Based on the site specification and information mentioned in details in case study chapter 4, for the modelling process in IES the location and site detail in IESVE has been assigned to Dubai with the selection of the exact location from the APlocate tool which is directly linked in IESVE.

Abu Dhabi weather data file from ASHRAE design weather database is selected, as it is the closest location to the case study. The site orientation of the existing building is 45 degrees of north and has been assigned to the model accordingly. The max dry bulb temperature recorded based on the design weather data file is 44.60 C in July. Screen shots from location details and weather information are included in Appendix C.

Construction materials and thermal properties of the different areas of the model are very crucial in IESVE as they are directly linked to the energy consumption and other factors as well. As mentioned earlier the building is old and built based on the old traditional methods using local materials. Since not all the building materials (coral stones, sarooj, chandal wood) are available in the IESVE materials database to ensure the best selection of materials and specification author has referred to a dissertation study by Faraj conducted in 2015 using UAE historical structures in IESVE simulation. Since the building materials and specification of the research are relevantly similar to the current study and the base case model was validated in the study, the information was used in the current study for the similar conditions. Limestone and a layer of plaster were assigned as the wall construction with assigning the exact thickness of the wall for the current study. Screen shots from the construction layers of the walls and ceiling are included in Appendix C.

Building Template Manager

Museum building template was assigned for the model from IESVE building template database. As this template will provide the standard options for museums in terms of internal gains of different elements.

Thermal Conditions

Since building regulations tab is only applied for UK buildings nothing was assigned for this part.

As of room conditions, heating was set off continuously with DHW (district hot water system) set to 0 and off all the time.

Cooling set point was assigned to 18 degree as the current practice. A yearly operation profile was defined for cooling by assigning different operation hours for AC in different seasons and months. According to the current practice during summer AC is on 24 hours. As of other months, various operation hours was defined approximately as there is no fixed practice done. Plant Auxiliary Energy is set to the same yearly cooling profile as well.

Model setting followed the ASHRAE standards of 0.05 solar reflected fraction with 1 furniture mass factor.

Humidity is not controlled thus t kept as default of 0 to 100 % saturation.

Cooling system specification was defined by Apache system tool, following the current specification of the AC split units used in the museum.
The SSEER kw/kw is the COP (coefficient of performance) and is related to the efficiency of the system and its power consumption. As the COP increases the system get more efficient and consumes less power. (Shekarchian et al, 2011) Following ASHRAE standards in IES 3.8 is defined as the COP and implemented in this project.

Internal Gains
Lighting internal gain was assigned in the model based on the current fluorescent lights. 13.200 W/m2 assigned for max sensible gain in display areas selected from the museum template database. Lighting profile is set based on the hours of the museum operation from 8am to 8pm continuously on and off only on Fridays.

The second type of internal gain was assigned to people with 78 W/person for max sensible gain with 6.68 m2/ person occupancy density following ASHRAE standards. Since there was no records for visitors numbers by the museum management, ready occupancy templates for museums was adopted from the database for the internal gains part.
Infiltration was added for the air exchange tab, with specifying 0.45 ach of max flow. The standard is 0.25 to 0.35 ach however since the museum is not well sealed towards the external air, 0.45 ach was assigned by the author.

Validation of Base Case Model in IESVE
Following the details mentioned in the previous part, apache dynamic simulation was run for the entire year. Figure 5.29 is showing the results for the modeled building in terms of energy for one year in MWh. The blue bar shows the lights electricity; green bars system electricity and total electricity are indicated in red.

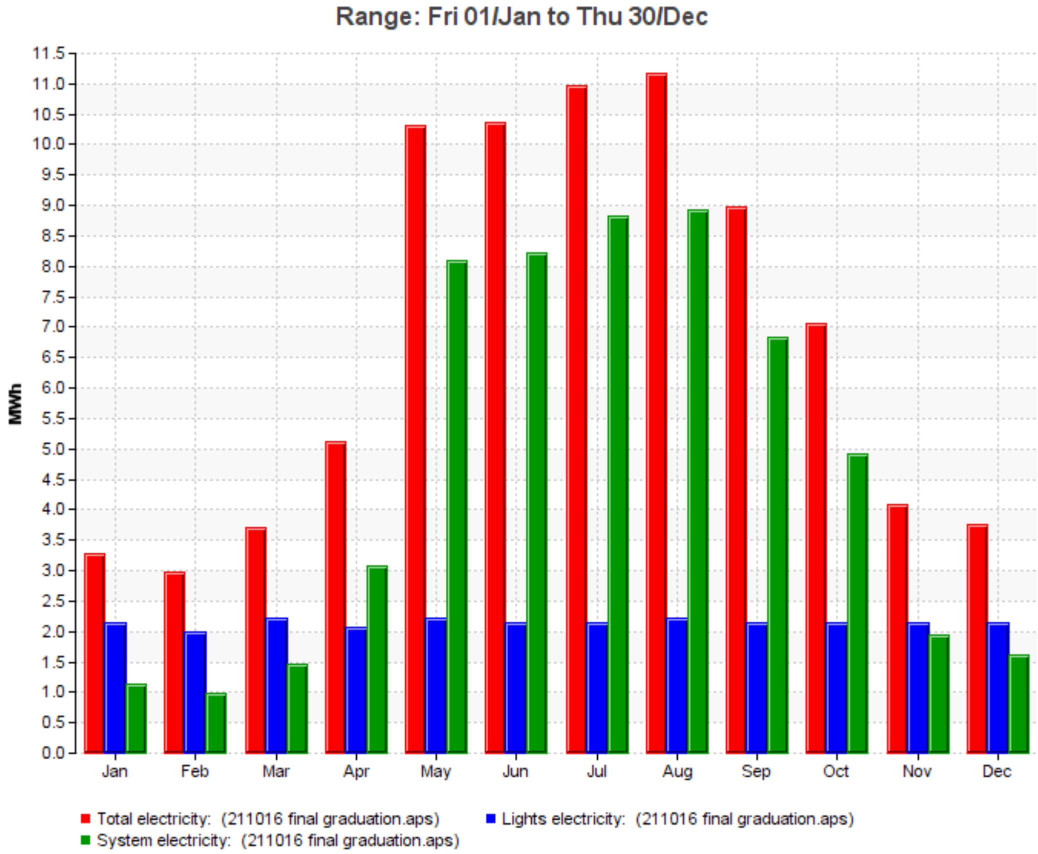


Figure. 5.29. Electricity consumption for base case model. (IESVE, 2016)

In order to check the accuracy of the modeled building in IESVE and compare the results to reality, utility bills for 7 months could be obtained from the museum management (scans of bills available in Appendix C). Comparing the total electricity amounts from the simulation results with the utility bills gives clear indication of the accuracy and the ability of the author for modeling and running simulations.

Table 5.32 is comparing the total electricity amounts for the seven months based on the utility bills.

Table 5.32. CCM total electricity figures in IES vs reality.

Month	IES model (MWh)	Existing (MWh)	% of accuracy
Jan	3.281	3.28	100.03%
Feb	2.9702	2.942	100.95%
March	3.7006	3.68	100.55%
April	5.1292	4.92	104.25%
May	10.3211	10.64	97.00%
June	10.356	10.32	100.34%
December	3.756	3.88	96.80%
Total	**39.5141**	**39.662**	**99.62%**

As shown in the table, the IES simulation shows less than 0.1% extra consumption in comparison to the bills in 4 months. Since there is no fixed operation schedule for AC in the winter in the museum, this small difference could be due to having less total hours of operation in a month that could not be defined in the cooling profile as a regular routine. This could go for the month of April as well. There is 4% difference, the reason here also could be for the hours of operation, total hours of AC operation in a week or in the month could be less in reality by little difference.

As for the case that the IES model is showing lower percentage in comparison to the utility bills by 3% and 3.2% (May and December), this could be based on the current practice of having the doors open while AC is operating. Having doors and windows open during the AC operation results in consuming more electricity than normal. Even though author has considered higher rate for infiltration because of this, however, during these two months infiltration could be more than the assigned (0.45) in the model.

By comparing the total electricity consumption of the 7 months the IES model is 99.62% close to reality. By referring to IESVE, achieving an error percentage of ±5% from existing buildings is enough to have very solid information and results to depend on for researches. Based on the methodology chapter 3 section 3.1.3 Having error percentage of ± 4% is considered acceptable as well. These results are only for 7 months, however, the obtained bills included summer and winter months, so the indication is quite accurate for the different seasons as well.
Since the model is valid, the information obtained from the simulation and presented figure 5.29. in terms of lighting and system electricity can be depended on and considered as well. The following section is dedicated for the experiments of different options for each proposed solution of the museum.

Experiments Results for Proposals

Considering the exhibition environments, and the simulation results obtained from the current conditions, this section will be showing different experiments in terms of lighting and cooling system. Each is presented in a separate section in order to clarify the contributing changes. Different scenarios for lighting is presented by experimenting step by step change in order to quantify the best practice and how much change each could have.

Experiments Results for Proposals: Light Electricity

The different lighting scenarios for the museum are starting from very simple methods and each scenario will include a different change. The following diagram is showing the different scenarios that are examined here. The scenarios are based on two different options; 1- using the current lighting 2- Changing light to LED lights

As mentioned in the proposals, daylight is examined here as well. As mentioned earlier in chapter 2, since introducing light without treating is not safe for the collections the option of different types of glazing is based on implementing a layer of solar film reflection UV and IR radiation is implemented in all experiments.

Scenario 1: Current Lighting to Operate Only During Occupancy

Since the exhibitions of the museum are very small, and all are having simple systems, this scenario can be implemented with no cost and no changes. As mentioned previously, light is on from the opening till the closing of the museum. If the museum staff keep the lights off and turn them on manually only when visitors are there, could have huge difference in the electricity specifically during summer periods, where the numbers of visitors are very small. This way is very simple and does not need any extra effort from the staff, as staff are around the exhibitions during different visits. This method could be also implemented by applying sensors to the exhibition environment. Sensors will detect the presence of human and automatically turn the lights on.

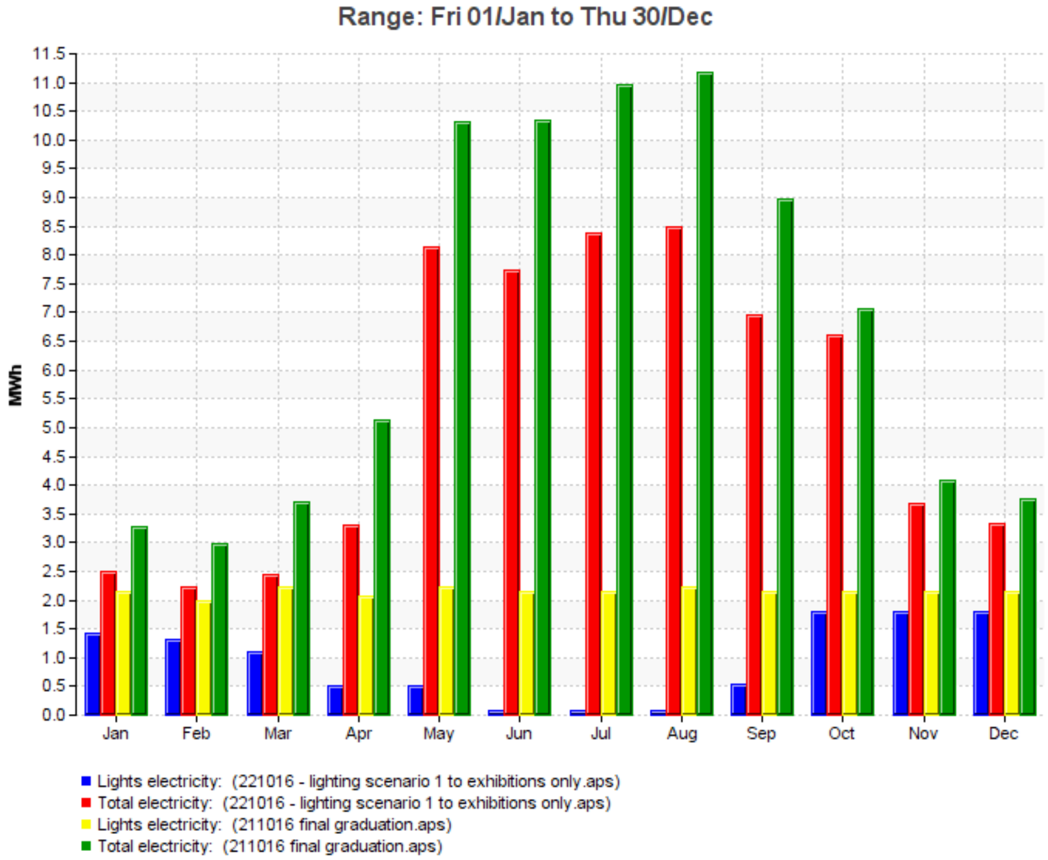
Since the museum management did not have any record for the visitor numbers during different months. Author had made different profiles for the year based on the experience and the knowledge of working in private museum over 4 years. Over all, number of visitors are not big and the exhibitions stay empty for long times. Also, some museums change their working hours during summer period to open only on some days of the week, as there are no visitors.

Profiles were created based on the assumption of significant drop in number of visitors during summer months, and more visitors during winter. Considering the time duration and group visits were taken into account as well. Table 5.33. shows the lighting profiles assigned for every month of the year. Fridays are considered continuously off through the entire year.

Table 5.33. Lighting annual operation profiles for IESVE.

Month	Hours of Light Operation
Jan- Feb	Daily: 2 hour on 1 hour off
March	Daily: 1 hour on 1 hour off
April	Daily: 1 hour on 3 hours off
May- June- July	Weekly: Total 8 hours
August	Weekly: Total 2:30 hours
September	Daily: 1 hour on 3 hours off
Dec- Oct - Nov	Daily: 5 hours on 1 hour off

This profile shows the reduction of annual exposure of items towards light. Considering the current condition of 12 hours per day (3756 hours per year), this profile will reduce the annual exposure to (1498 hours per year). Figure 5.30 shows the result obtained from implementing this profile. As shown, the yellow bars are the existing light electricity with approximately 2.1 MWh per month. The blue bars are showing the light electricity with the implemented profile. Green bars and red bars are the total electricity for before and after. As shown during all the months of the year total electricity of the museum has dropped. Summer periods had the most reduction as the lighting operation hours were much less in comparisons to the winter months.



5.30. Light electricity and total electricity base case model vs scenario 1.(IESVE, 2016)

Total light electricity in the base case model is 25.7618 MWh, and it dropped to 11.0437 MWh in this experiment which is 57% annually. This drop in percentage is excellent as there is no cost associated with it. And it was based on no change s implemented to the system at all.

Considering this change to the total electricity consumption of one year, the current one year total electricity is 81.7712 MWh. The change in lighting operation hours resulted in having 63.8313 MWh, this contributed in 22% reduction for total electricity that is also a noticeable reduction.

When the operation hours of light reduce, the change results in two ways. Reduction of light electricity impacts directly the total electricity. Moreover by reducing the lighting hours, cooling load of the system reduces thus, it results in reducing the total electricity indirectly as well.

By considering the cooling loads in the base case model and this experiment presented in figure 5.31 without applying any changes to the hours of ac operation or the settings, the cooling loads were reduced as well. This is noted more in the summer time, where the ac is operation contiguously. The annual cooling load dropped from 144.1652 MWh to 131. 9221 MWh, which is 8.49% reduction in overall cooling loads.

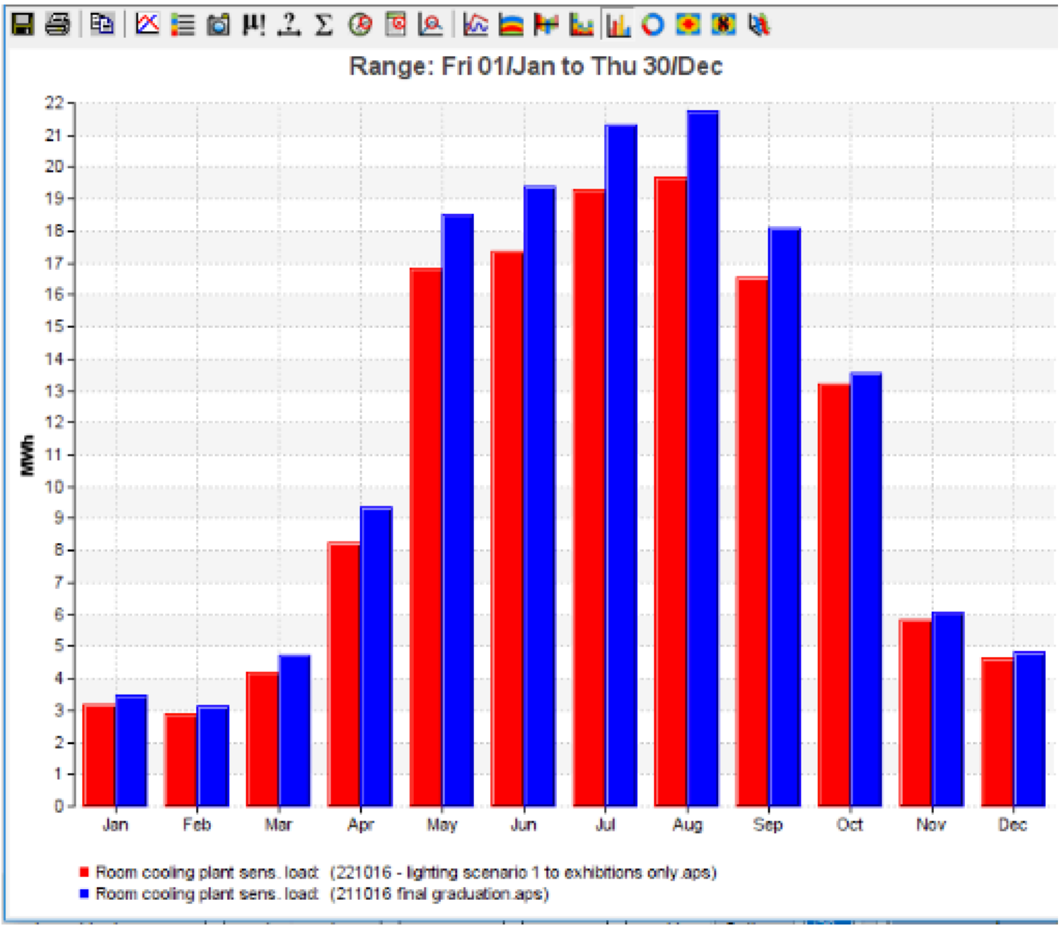


Figure 5.31. Cooling load decrease by implementing scenario 1. (IESVE, 2016)

Scenario 2: Daylight + Current Lighting to Operate Continuously at Evening Times

Since the current exhibition halls already have windows and they are not utilized, this experiment includes opening the existing windows and allowing treated daylight inside. Lighting will be off during the day and in the evening times from 5:30 pm to 8pm lights will be consciously on in this scenario. This is done based on the assumption of manual control to the artificial lighting. As well as considering enough daylight is available for the space. Only changing the operation hours of the lights without the implementation of the window to the simulation model is tested in this scenario. As implementation of windows with different glazing options contribute in heat gain and result in higher energy consumption of AC units. This aspect is already taken into account and implemented in the cooling system section. Therefore, only light electricity is considered here. Fig 5.32. shows the light electricity based on the assigned profile as shown the operation of 2:30 hours every day through the entire year has significant drop in energy consumption.

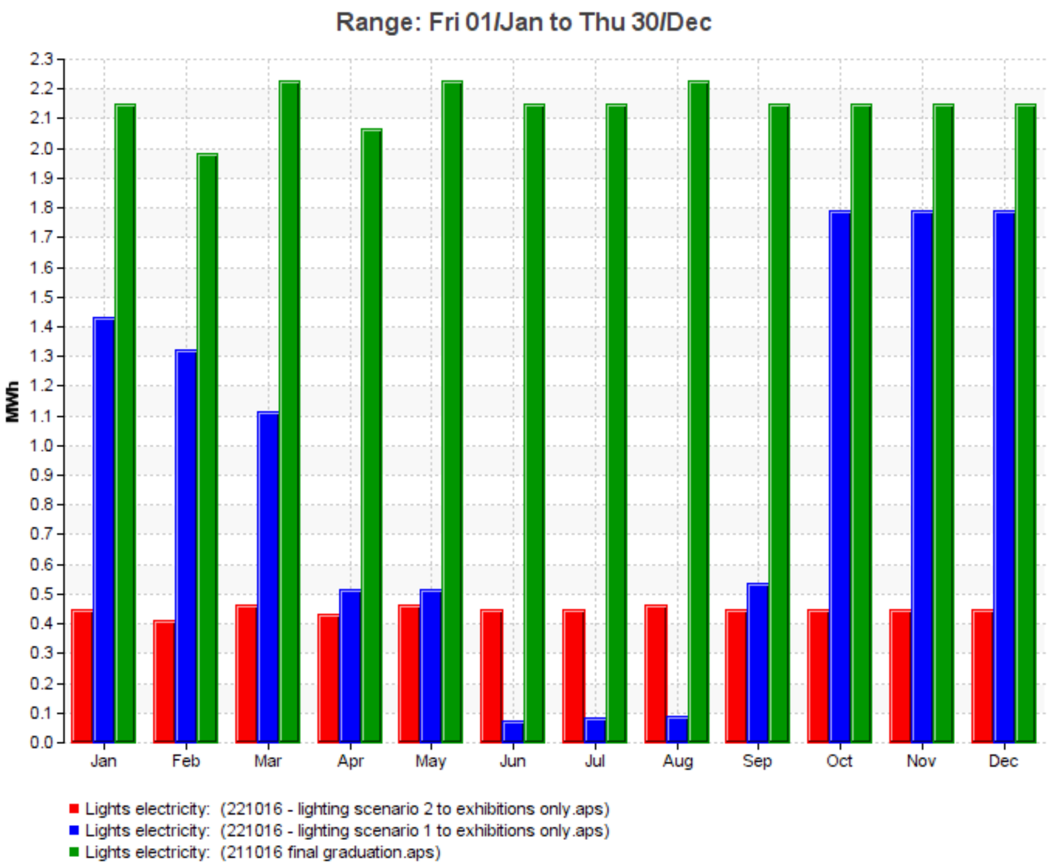


Figure 5.32. Light electricity reduction base case model green bars vs scenario 1 blue bars vs scenario 2 red bars (IESVE, 2016)

In comparison to the existing situation (green bars), the current solution reduces light electricity from the current condition (25.7618 MWh) to total of 5.367 MWh per year making with the percentage of 79% reduction. In comparison to scenario 1,(11.0437 MWh) 51% light electricity is reduced.

In terms of cooling loads reduction caused by changing the lighting operation, it was reduced to annual 128.4847 MWh which is 10.87% percent reduction.

Decision for selecting this scenario cannot be done based on this result only. As, it is necessary to consider the heat gain and the additional energy consumption resulted by using the different types of windows as well.

Scenario 3: Daylight + Current Lighting to Operate Only During Occupancy at Evening Times

This experiment includes benefitting from daylight in the mentioned way for scenario 2 in combination with lighting operation only during visitors occupancy in the evening times where daylight is not there. Profile is created based on the assumption of having evening visitors during winter season. So lights are on from 5:30 pm to 8 pm every day except Fridays. As for summer, evening visitors are expected, as weather is better during this time. However, the consideration is made based on the assumption of having visitors for 2 or 3 days of a week and the rest of the days lights will be off. Figure 5.33 is showing the result of implementing this profile in comparison to the other scenarios. The yellow bars are indicating the current on going practice and the red bars are the indication of light electricity for scenario 3. As shown, light electricity in scenario 3 is the least in comparison to the other scenarios.

The reduction in cooling loads were the most in this case as well by a percentage of 11.79%.

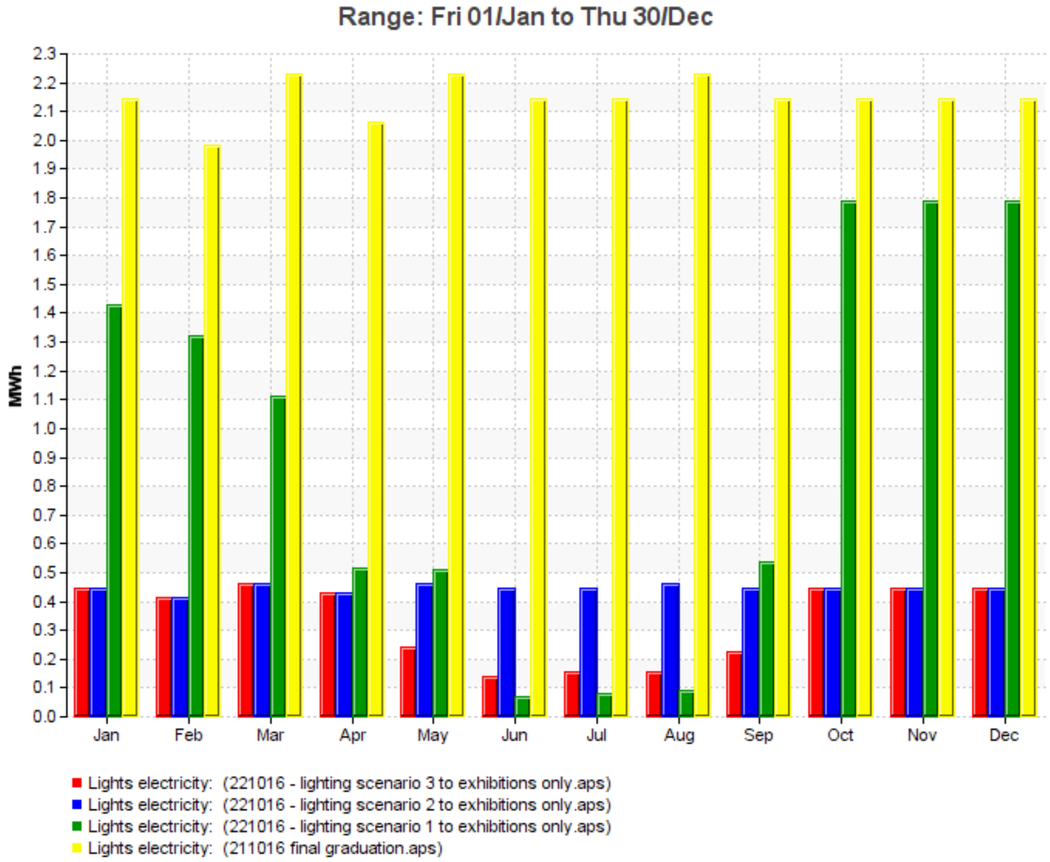


Figure 5.33. Light electricity base case model 3 scenarios (IESVE, 2016)

Table 5.34. is showing the total light electricity for each scenario as well as the percentage of reduction in comparison to base case model (current condition).

Table 5.34. Total light electricity and percentage of reduction for 3 examined scenarios

	Scenario 1	Scenario 2	Scenario 3
One year Light Electricity (MWh)	11.0437	5.3670	4.0081
% of reduction from base case	57%	79%	84.45%

As shown in table 5.34, scenario 3 contributed the most percentage of light electricity reduction in comparison to others. However, to make the final decision of implementation the system electricity changes should be considered in regards to making windows in the model.

The previous 3 scenarios of experiments did not include any changes in the lighting system itself. The experiments were done based on changing the hours of operation according to the presence of visitors. Next set of experiments will be about changing the current fluorescent lights to adaptation of LED lighting. The experiments will be done based on examining the same previously assigned profiles, in addition to the profile of having the current practice of 12 hours operation through the working days of the museum. This will give clear indication of the change in electricity for all the conditions examined on the existing lighting

Scenario 4: LED Lighting to Operate During the Operation Hours of the Museum

For replacements of light and the appropriate choice for museum practices, iGuzzini lighting manufacturer company was approached in their Dubai office. The company has delivered successful lighting projects for different existing and upcoming museums in UAE. Based on the case study conditions and exhibition specifications, iN30 LED type of light was proposed by the manufacturer. Lighting simulation within the museum exhibition spaces was provided by the manufacturer through Relux software simulation (lighting specification as well as the simulation are available in Appendix C). From the simulation results the information needed for calculating the heat gain based on the lighting type was obtained and embodied in the thermal template of the project. (Appendix C) Also, the current existing lighting heat gain properties was removed from the thermal template as well. The lux levels assigned for the exhibition by this type of light was to achieve max of 300 lux for the type of the collections.

This calculation included removing all the fluorescent lights in the display cases, as they were very strong and harmful. The proposal was made to make the exhibitions lightened and provide enough safe light in the whole environment rather than making spot lights pointed at each display case. As this option of making dramatic lighting with different contrasts could be added later on after the proper rearrangements of the items in the display cases based on their type and choosing appropriate light for them incase it was needed.

The profile in this scenario was assigned to the existing practice of 12 hours operation from 8am to 8pm and lights off on Fridays. Figure 5.34 shows the results of lights electricity for the proposed option (LED lights indicated in red) along with the existing lightings in indicated in blue.

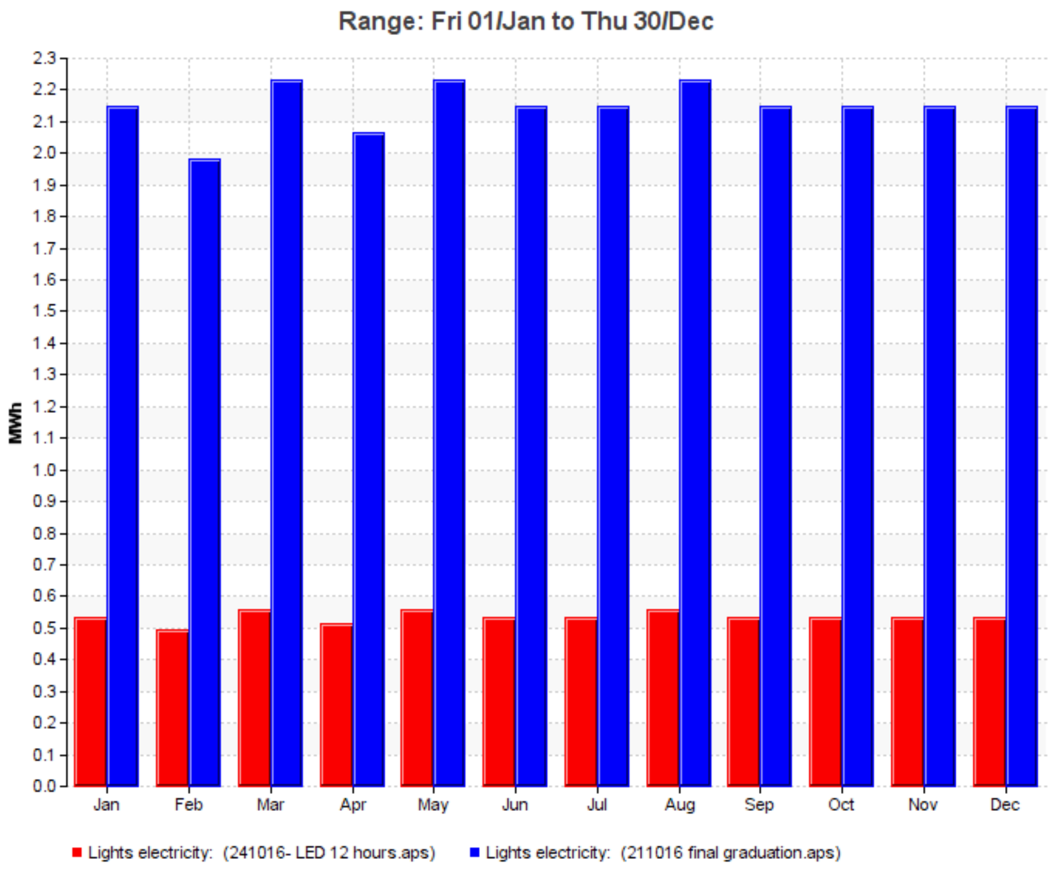


Figure 5.34. Light electricity LED light in red vs existing light blue. (IESVE, 2016)

As shown significant reduction in light electricity is achieved by incorporating LED lights. Comparing 0.5 MWh the average of light electricity per month for LED lights to the current 2.1 MWh, resulted in 75% light electricity reduction for the whole year in the museum.

As of total electricity, figure 5.35. shows the current total electricity for existing conditions in yellow and the blue is for showing the results after changing the lights.

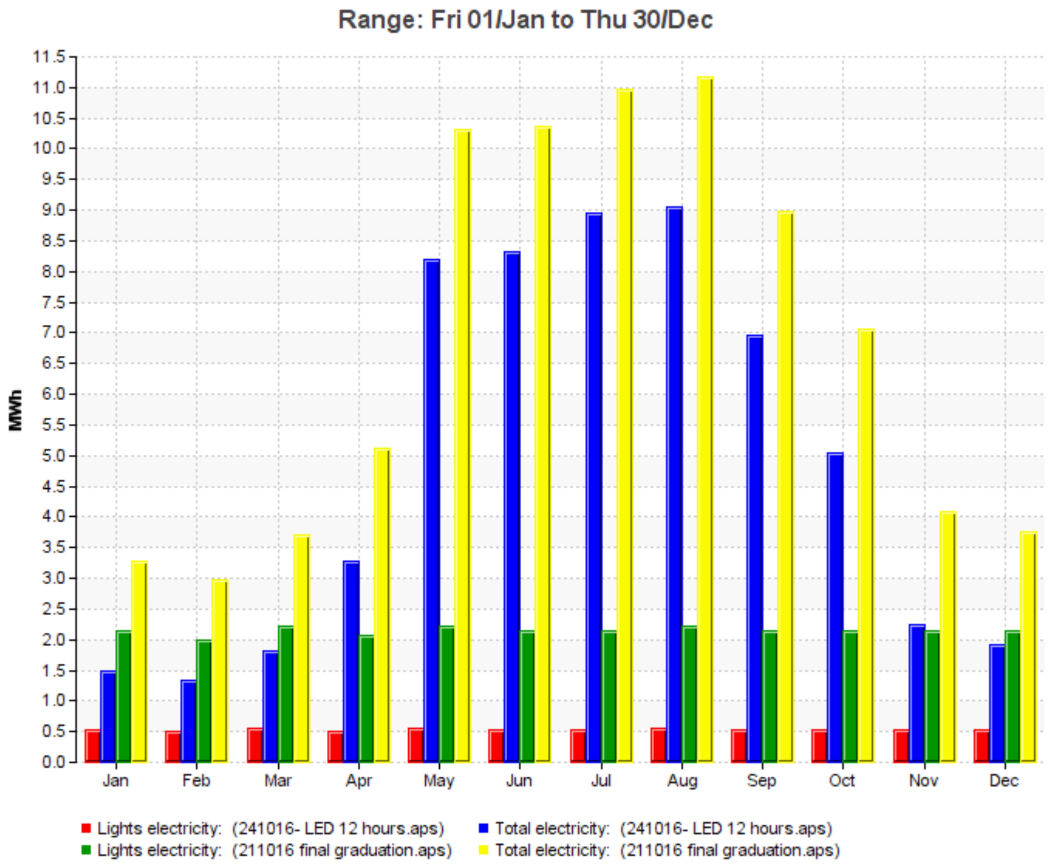


Figure 5.35. Total electricity, light electricity LED vs existing lights. (IESVE, 2016)

As shown in Table 5.35 the over all electricity reduction for the entire year is 28.3%. This reduction is based on continues operation of light. The other scenarios for different operation profiles are examined in the following parts.

Table 5.35. Total electricity, light electricity LED vs existing lights. (IESVE, 2016)

	Lights electricity (MWh)	Total electricity (MWh)	Lights electricity (MWh)	Total electricity (MWh)
Date	241016- LED 12 hours.aps	241016- LED 12 hours.aps	211016 final graduation.aps	211016 final graduation.aps
Jan 01-31	0.5353	1.4813	2.1468	3.2810
Feb 01-28	0.4941	1.3341	1.9817	2.9702
Mar 01-31	0.5559	1.8267	2.2294	3.7006
Apr 01-30	0.5147	3.2873	2.0642	5.1292
May 01-31	0.5559	8.2079	2.2294	10.3211
Jun 01-30	0.5353	8.3323	2.1468	10.3560
Jul 01-31	0.5353	8.9453	2.1468	10.9697
Aug 01-31	0.5559	9.0642	2.2294	11.1653
Sep 01-30	0.5353	6.9577	2.1468	8.9772
Oct 01-31	0.5353	5.0529	2.1468	7.0633
Nov 01-30	0.5353	2.2479	2.1468	4.0817
Dec 01-30	0.5353	1.9110	2.1468	3.7560
Summed total	6.4232	58.6487	25.7618	81.7712

Since the reduction of electricity is significant, cooling loads reduction was more in comparisons to the same scenario for exiting lighting.

By referring to table 5.36 cooling load reached to 129.7862 MWh, which is 10% reduction from current situation.

Table 5.36. Cooling load LED vs existing lights. (IESVE, 2016)

	Room cooling plant sens. load (MWh)	Room cooling plant sens. load (MWh)
Date	241016- LED 12 hours.aps	211016 final graduation.aps
Jan 01-31	2.7415	3.4564
Feb 01-28	2.5793	3.1437
Mar 01-31	3.9428	4.7043
Apr 01-30	8.2377	9.3485
May 01-31	16.8647	18.5354
Jun 01-30	17.8097	19.3759
Jul 01-31	19.7453	21.3138
Aug 01-31	20.1186	21.7436
Sep 01-30	16.5261	18.0760
Oct 01-31	12.0453	13.5610
Nov 01-30	5.2278	6.0721
Dec 01-30	3.9474	4.8344
Summed total	129.7862	144.1652

Scenario 1: LED Lighting to Operate Only During Occupancy

Following same profiles assigned for lighting operation only during occupancy, mentioned in the existing light experiment section. By the adaptation of this profile with LED lights reduces the lights to achieve 2.7535 MWh for the entire year, this number is very close to the current monthly light electricity (2.1 MWh) which is considered significant drop from the yearly 25.7618 MWh light electricity.

Table 5.37. light electricity LED Scenario 1 and current scenario vs base case lights. (IESVE, 2016)

	Lights electricity (MWh)	Lights electricity (MWh)	Lights electricity (MWh)
Date	241016- LED - scenario 1.aps	241016- LED 12 hours.aps	211016 final graduation.aps
Jan 01-31	0.3568	0.5353	2.1468
Feb 01-28	0.3294	0.4941	1.9817
Mar 01-31	0.2779	0.5559	2.2294
Apr 01-30	0.1287	0.5147	2.0642
May 01-31	0.1278	0.5559	2.2294
Jun 01-30	0.0180	0.5353	2.1468
Jul 01-31	0.0206	0.5353	2.1468
Aug 01-31	0.0223	0.5559	2.2294
Sep 01-30	0.1338	0.5353	2.1468
Oct 01-31	0.4461	0.5353	2.1468
Nov 01-30	0.4461	0.5353	2.1468
Dec 01-30	0.4461	0.5353	2.1468
Summed total	2.7535	6.4232	25.7618

Comparing the results, this scenario contributed in 90% reduction from existing lighting with 12 hours operation. And 42.8% reduction in comparison to continues 12 hours operation of LED lights.

Figure 5.36 shows indicates the light electricity changes, green bars for base case model, blue bars LED light operating 12 hours a day, and red bars for LED lights operating based on scenario 1 profile.

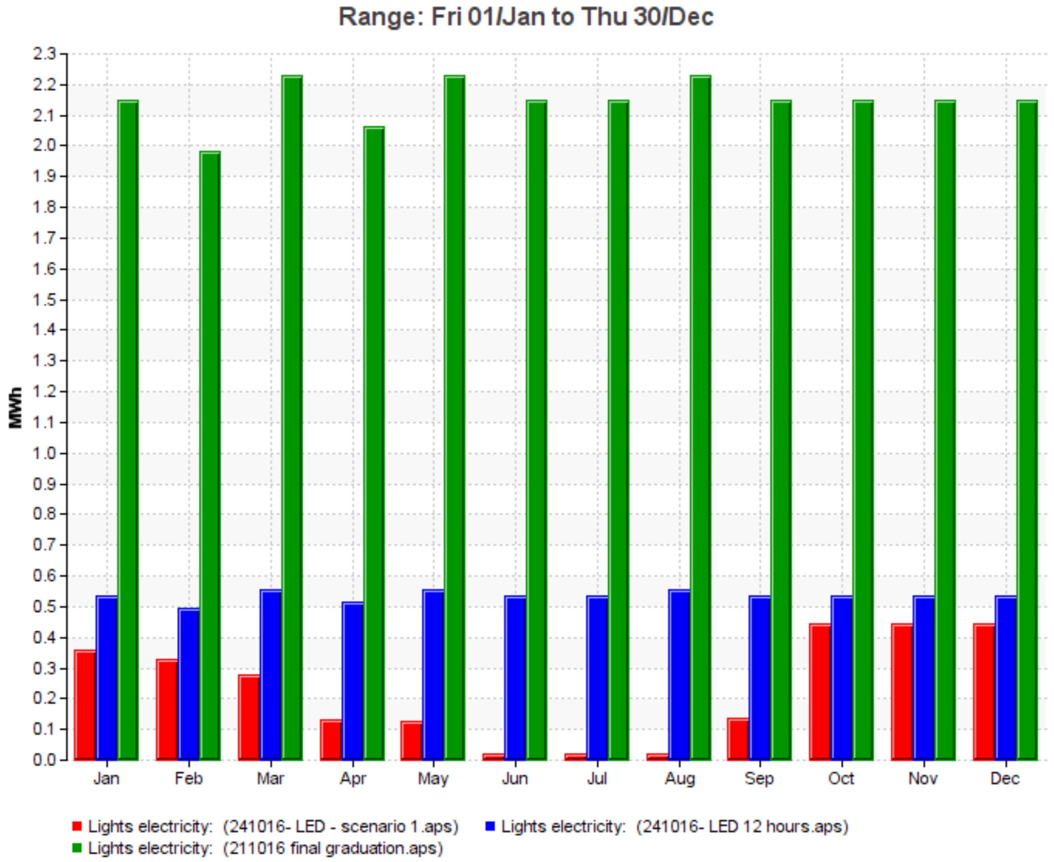


Figure 5.36. Light electricity base case, LED lights operating 12 hours a day and LED light scenario 1. (IESVE, 2016)

Moving to Cooling load reduction, shown in table 5.38, 126.7334 MWh was achieved which is 12.09 % reduction from base case model.

Table 5.38. cooling loads LED Scenario 1 vs base case model. (IESVE, 2016)

	Room cooling plant sens. load (MWh)	Room cooling plant sens. load (MWh)
Date	241016- LED - scenario 1.aps	211016 final graduation.aps
Jan 01-31	2.6766	3.4564
Feb 01-28	2.5158	3.1437
Mar 01-31	3.8163	4.7043
Apr 01-30	7.9661	9.3485
May 01-31	16.4381	18.5354
Jun 01-30	17.3072	19.3759
Jul 01-31	19.2441	21.3138
Aug 01-31	19.6004	21.7436
Sep 01-30	16.1399	18.0760
Oct 01-31	11.9619	13.5610
Nov 01-30	5.1746	6.0721
Dec 01-30	3.8923	4.8344
Summed total	126.7334	144.1652

Scenario 2: Daylight + LED Lighting to Operate Continuously at Evening Times

Light electricity is presented in Figure 5.37 with the assumption of having daylight, artificial lights to operate continuously during evening times. As mentioned earlier it is mandatory to consider the heat gain caused by utilizing windows in the space and the contribution they have in the electricity before making the decision of implementation for this and the coming scenario.

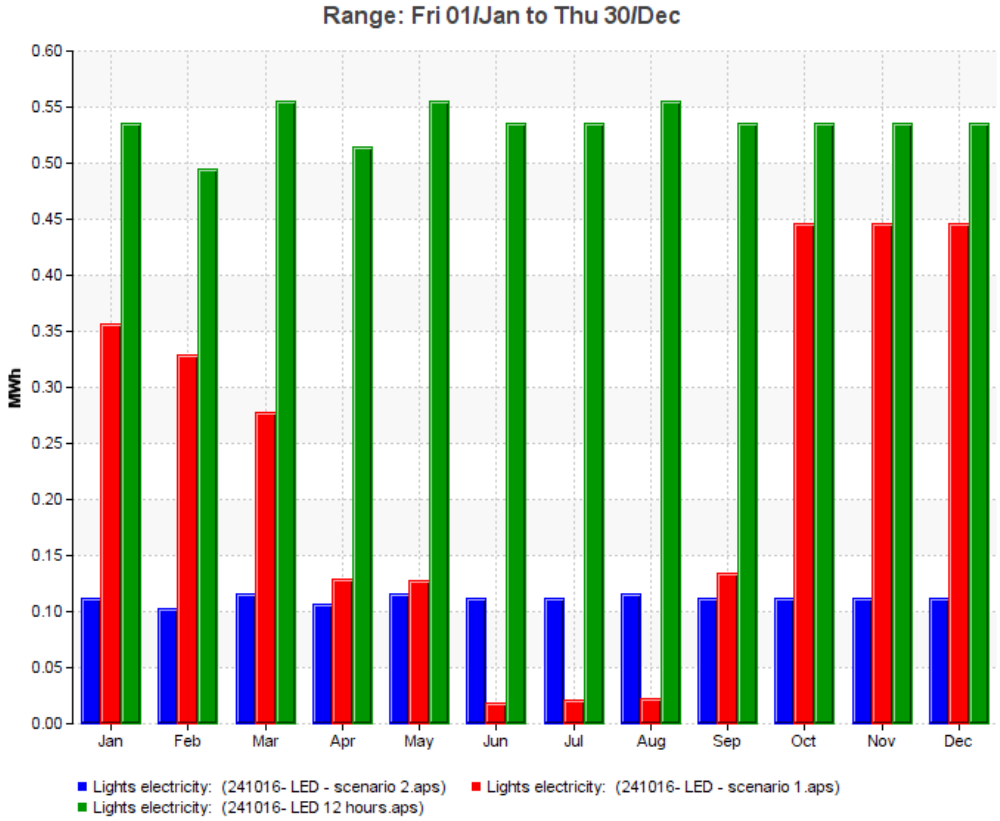


Figure 5.37. Light electricity for scenario 1, 2 and 12 hours daily operation of LED lights. (IESVE, 2016)

Table 5.39. Light electricity for scenario 1, 2 and 12 hours daily operation of LED lights

	Lights electricity (MWh)	Lights electricity (MWh)	Lights electricity (MWh)
Date	241016- LED - scenario 2.aps	241016- LED - scenario 1.aps	241016- LED 12 hours.aps
Jan 01-31	0.1115	0.3568	0.5353
Feb 01-28	0.1029	0.3294	0.4941
Mar 01-31	0.1158	0.2779	0.5559
Apr 01-30	0.1072	0.1287	0.5147
May 01-31	0.1158	0.1278	0.5559
Jun 01-30	0.1115	0.0180	0.5353
Jul 01-31	0.1115	0.0206	0.5353
Aug 01-31	0.1158	0.0223	0.5559
Sep 01-30	0.1115	0.1338	0.5353
Oct 01-31	0.1115	0.4461	0.5353
Nov 01-30	0.1115	0.4461	0.5353
Dec 01-30	0.1115	0.4461	0.5353
Summed total	1.3382	2.7535	6.4232

As shown 51.4 % reduction in comparison to LED scenario 1, 79% reduction in comparison to LED 12 hours operation, and 95% reduction in comparison to base case.

As of cooling demand 12.68 % is the reduction happened in the cooling load by applying this scenario in comparison to the base case model. From table 5.47, 18.289 MWh cooling load was reduced in this experiment.

Table 5.40. Cooling load for LED lights scenario 2, and base case model. (IESVE, 2016)

	Room cooling plant sens. load (MWh)	Room cooling plant sens. load (MWh)
Date	241016- LED - scenario 2.aps	211016 final graduation.aps
Jan 01-31	2.5336	3.4564
Feb 01-28	2.4177	3.1437
Mar 01-31	3.7217	4.7043
Apr 01-30	7.9206	9.3485
May 01-31	16.4281	18.5354
Jun 01-30	17.3979	19.3759
Jul 01-31	19.3329	21.3138
Aug 01-31	19.6912	21.7436
Sep 01-30	16.1179	18.0760
Oct 01-31	11.6436	13.5610
Nov 01-30	4.9805	6.0721
Dec 01-30	3.6904	4.8344
Summed total	125.8762	144.1652

Scenario 3: Daylight + LED Lighting to Operate Only During Occupancy at Evening Times

By implementing the profile of night operation during occupancy Table 5.41 was obtained. Yearly light electricity for was reduced to 0.9993 MWh. 24% reduction in yearly light electricity is achieved by this method in comparison to scenario 2. And 94.13% could be reduced in comparisons to the base case model.

Table 5.41. Light electricity for scenario 1, 2 and 3 of LED lights

	Lights electricity (MWh)	Lights electricity (MWh)	Lights electricity (MWh)
Date	241016- LED - scenario 3.aps	241016- LED - scenario 2.aps	241016- LED - scenario 1.aps
Jan 01-31	0.1115	0.1115	0.3568
Feb 01-28	0.1029	0.1029	0.3294
Mar 01-31	0.1158	0.1158	0.2779
Apr 01-30	0.1072	0.1072	0.1287
May 01-31	0.0600	0.1158	0.1278
Jun 01-30	0.0343	0.1115	0.0180
Jul 01-31	0.0386	0.1115	0.0206
Aug 01-31	0.0386	0.1158	0.0223
Sep 01-30	0.0558	0.1115	0.1338
Oct 01-31	0.1115	0.1115	0.4461
Nov 01-30	0.1115	0.1115	0.4461
Dec 01-30	0.1115	0.1115	0.4461
Summed total	0.9993	1.3382	2.7535

Figure 5.38 is showing the light electricity for the 4 different options of LED lights in comparisons to the base case model. As shown huge difference is resulted from the implementation of LED and the best option was the third scenario in terms of light electricity.

Figure 5.38. Light electricity for LED lights scenario 1, 2,3 vs base case model. (IESVE, 2016)

Considering the total electricity figures and the experiments done, figure 5.39 shows the annual total electricity for the base case model along with scenario 3 of LED light implementation as it contributed the most in comparisons to the other scenarios. As shown this reduction is reflected for every month of the year almost by same value. The 94.13% reduction of light electricity of scenario 3 contributed in overall 36.29% annual reduction in total electricity.

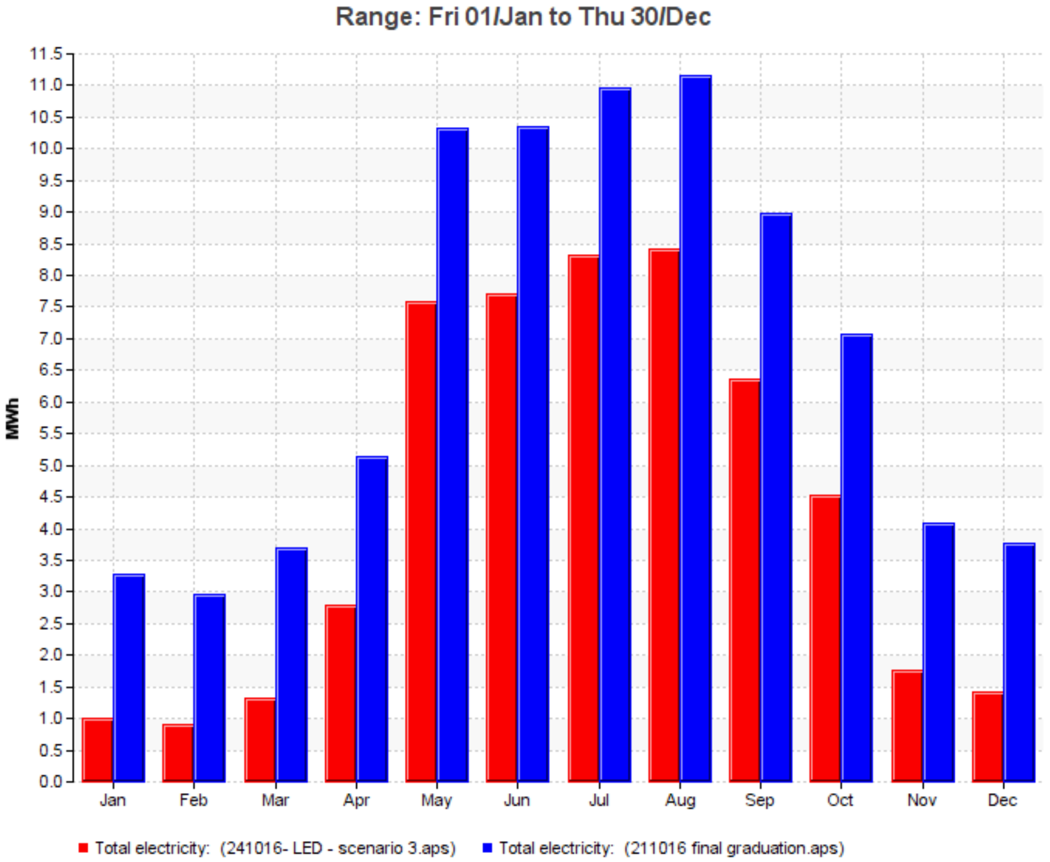


Figure 5.39. Total electricity for LED lights scenario 3 vs base case model. (IESVE, 2016)

Table 5.42 shows the yearly lights electricity for the 4 different LED lighting profiles examined scenarios as well as the base case model. As shown best situation is scenario 3 with the reduction of 96.12%, however it should be studied with the factors related to daylight in order to ensure the possibility of implementing this scenario.

Table 5.42. Yearly light electricity, percentage of reduction in comparison to base case model

	LED 12 hours a day operation (MWh)	Scenario 1 (MWh)	Scenario 2 (MWh)	Scenario 3 (MWh)	Base Case Model (MWh)
One year Light Electricity	6.4232	2.7535	1.3382	0.9993	25.7618
% of reduction to base case	75.06%	89.31%	94.80%	96.12%	

In terms of cooling demand reduced by the implementation of scenario3, with LED lights are shown in table 5.43. The reduction made to the cooling load by implementing scenario 3 with LED lights was 12.9%, which is a good reduction as well.

Table 5.43. Cooling demand result for LED lights scenario 3 vs base case model. (IESVE, 2016)

	Room cooling plant sens. load (MWh)	Room cooling plant sens. load (MWh)
Date	241016- LED - scenario 3.aps	211016 final graduation.aps
Jan 01-31	2.5336	3.4564
Feb 01-28	2.4177	3.1437
Mar 01-31	3.7217	4.7043
Apr 01-30	7.9206	9.3485
May 01-31	16.3741	18.5354
Jun 01-30	17.3233	19.3759
Jul 01-31	19.2615	21.3138
Aug 01-31	19.6166	21.7436
Sep 01-30	16.0646	18.0760
Oct 01-31	11.6432	13.5610
Nov 01-30	4.9805	6.0721
Dec 01-30	3.6904	4.8344
Summed total	125.5478	144.1652

In order to be able to make the decision for the best option from the proposed scenarios, the amount of daylight entering to the environment should be studied. The following part includes analysis for daylight incase of opening the windows.

Experiments Results for Proposals: Daylight Distribution

When considering the daylight for museums, most importantly is to block the harmful radiation before entering the environment. Applying a layer of appropriate solar film could do this. High reflectance and lower transmittance would also benefit in reducing the heat gain in the environment. Vista Dual Reflective Series Celeste Solar Control Film (V18SRCDF) was chosen. (specification available in Appendix C).

As mentioned earlier, the current opening are having decorative elements covering the surface that includes almost 85% of the surface area. For studying the daylight inside the exhibition, the assumption was done based on having the full surface of the window without the decorative element, but with the implementation of light.

Daylight analysis was done in IESVE Flux Pro, figures 5.40-5.42 show the daylight distribution for the three galleries that is exposed to sun. Simulation is run for three times at 21st of August. First one was for the morning hour at 10 am (figure 5.40), second was at 12pm (figure 5.41) and the third one was at 3pm (figure 5.42). These lux levels are generated based on not considering the decorative element.

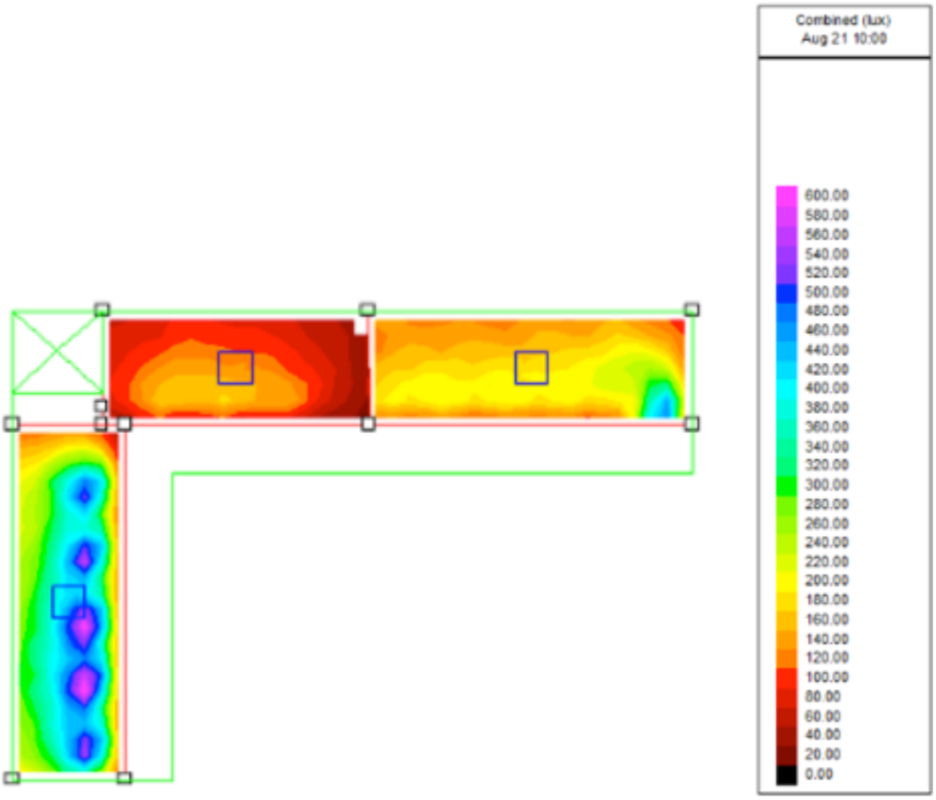


Figure 5.40. daylight analysis for 3 exhibitions on Aug 21st, at 10 am. (IESVE, 2016)

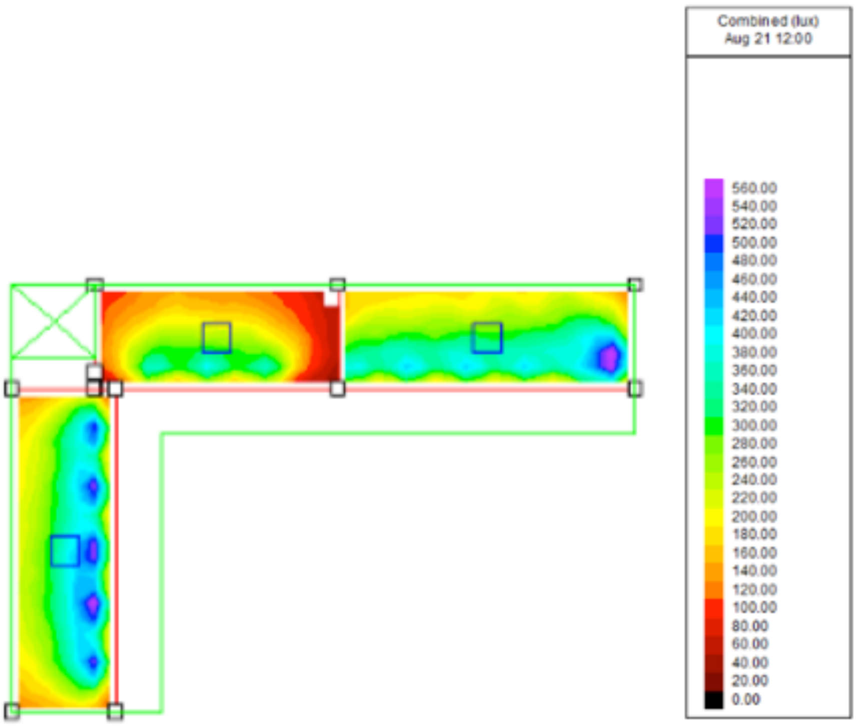


Figure 5.41. daylight analysis for 3 exhibitions on Aug 21st, at 12 pm. (IESVE, 2016)

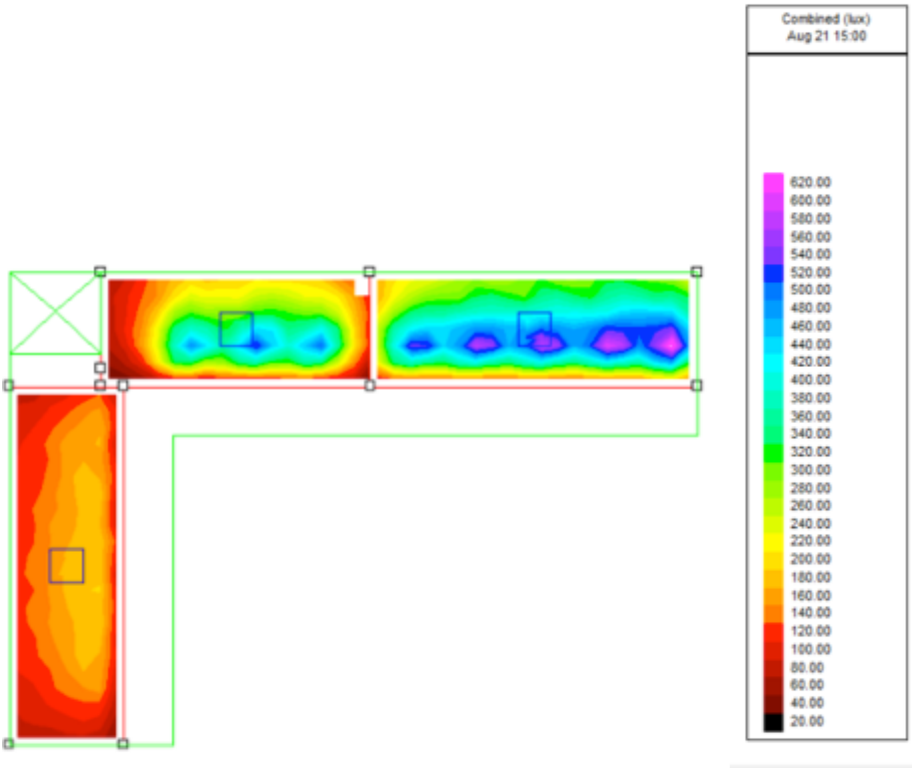


Figure 5.42. daylight analysis for 3 exhibitions on Aug 21st, at 3 pm. (IESVE, 2016)

As shown, the windows are distributed along one side of the exhibition environment as the opposite side, are closed and there is no current window. Based on the daylight simulation the lux levels are changing significantly through out the day in each exhibition. And it is not providing uniformed conditions in the exhibitions. Considering this throughout different times of the day daylight should be blocked at some time or even to be integrated with artificial light. As shown in figure 5.42, with the consideration of no decorative elements blocking light the third exhibition is having max 180 lux. (According to IESNA, safe range for museums is from 50-300 lux). While this in reality could be much less as most of it would be blocked. However in the earlier hours it is brighter. These elements could be controlled based on automatic blinders integrated with sensors, to open and close based on the lux levels of the environment. Nevertheless, Since this museum is operating on basic manual methods proposals should be adoptable for the type of museums as well.

Sometime daylight would be strong that should be blocked and other times artificial light should be operating alongside to increase the light. Having these options will require automation, and integration of sensors for lights, blinders to operate according the needs. Since the museum is having very basic components it will be complicated to implement all at this stage. This could be done at another stage when upgrading all systems.
Since this is not the case, the option of integrating daylight was excluded from this study. Additionally, since windows always are accompanied with heat gain, the heat gain through different type of glazing should be considered as well. However, since daylight integration is eliminated, heat gain through glazing is excluded as well. Nevertheless, the current available glass is single glazing, which is always known to be having high heat gain in the environment. Integrating windows would also require the consideration of changing the glass type accordingly.

The following experiments are dedicated for changes related to enhance the building envelope to reduce infiltration.

Enhancing Building Envelope: Standard Infiltration

By linking the three exhibitions together, closing extra doors and sealing them properly, infiltration rate will enhance. This experiment included setting the infiltration to the standard rate (0.25 ach) and checking the enhancements it causes.
Figure 5.43. indicates very slight increase in system electricity during the winter months. In contrary, a noted decrease is achieved during the summer months in the system electricity. This is due to hot air entering the environment and causing more energy consumption to keep the environment at the desired temperature. Total reduction in annual system electricity was 1.8298 MWh.
By referring to table 5.44 total electricity decreased by 1.8298 MWh annually, which shows infiltration has direct and equal impact to total electricity. This contributed by 2.23% decrease in annual total electricity.

The reduction might not be noticeable, however, it is important for stabilizing the exhibition environments for the collections and limit the dust and other elements entering the exhibitions.

Table 5.44. Total electricity base case vs enhanced infiltration. (IESVE, 2016)

	Total electricity (MWh)	Total electricity (MWh)
Date	281016-Graduation-infiltration alone on all	281016-Graduation 99% base case .aps
Jan 01-31	3.3116	3.2810
Feb 01-28	2.9959	2.9702
Mar 01-31	3.7193	3.7006
Apr 01-30	5.0754	5.1292
May 01-31	10.0218	10.3211
Jun 01-30	10.0206	10.3560
Jul 01-31	10.5849	10.9697
Aug 01-31	10.7722	11.1653
Sep 01-30	8.6910	8.9772
Oct 01-31	6.9033	7.0633
Nov 01-30	4.0722	4.0817
Dec 01-30	3.7731	3.7560
Summed total	79.9414	81.7712

Moreover, adding air curtain systems in the exhibition environments will result in further enhancement as proved by earlier researches Luo et.al, 2015). By assigning the infiltration to 0.15 ach as a result of enhancement, figure 5.44 shows further reduction in system electricity following the same pattern. The over annual system electricity reduction was 2.7351 MWh this is 49% more reduction in comparison to having standard infiltration. The over all reduction in total electricity was 3.34% from the base case model. As mentioned earlier this change is needed for the safety of the exhibitions for the collections. Their small contribution in energy reduction is an extra benefit as well.

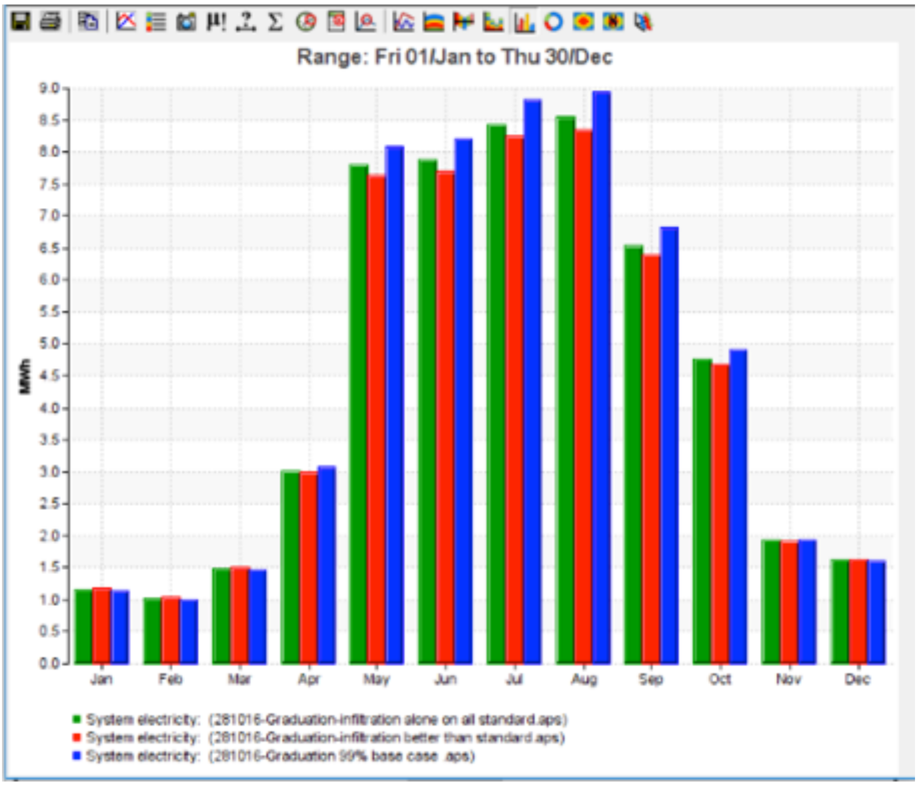


Figure 5.43. System electricity results, base case model in blue, infiltration 0.25 ach green, infiltration 0.15 ach red. (IESVE, 2016)

Experiments Results for Proposals: Relative Humidity Control

As shown in the evaluation section for this case study, RH was not safe and not controlled in the exhibition environments. This experiment included adding the limit of the variation to the thermal condition in Apache. According to UK standards having 10% of daily fluctuation is safe for the collections and the assigned range was 45% to 55% not to exceed that in the environment. Figure 5.44 shows the results of system electricity by implementing two options for the humidity control in comparison to the base case model. Red bars indicate humidity control for the entire building. Blue bars indicate implementation of RH control for only the exhibition environments, which is needed.

The point to be considered here is that the relative humidity control was implimented on the same exisiting system specification, this might vary little in reality in adopting a different system. However, humidity control could be done by separate humidifiers or dehumidifiers, which their energy consumption is not taken into consideration here.

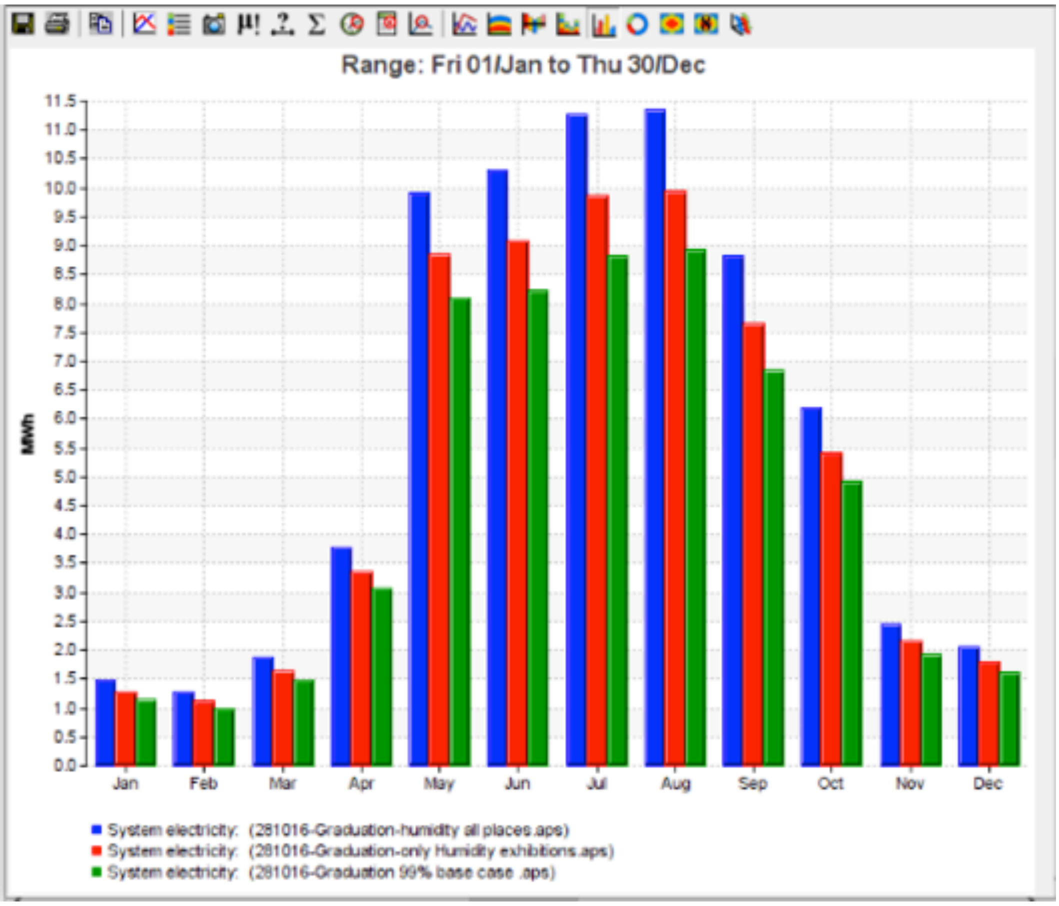


Figure 5.44. System electricity results, base case model in green, humidity control for exhibitions only in red, humidity control all building in blue. (IESVE, 2016)

As shown, by controlling the humidity in the environment energy consumption is increased in both options. Since this change in the environment is mandatory for the safety of the collections, it has to be considered even if it is increasing the energy consumption.

Table 5.45 shows the annual system electricity for these options. Implementing the humidity control in the entire building is leading the system electricity to be 70.7812MWh annually which is almost 26.37% increase from the base case model. However, by only controlling the exhibition environments rather than the whole building, the increase in energy consumption is less. In this case the system electricity will rise by 10.9% only.

Table 5.45. System electricity results, base case model, humidity control for exhibitions, humidity control all building. (IESVE, 2016)

	System electricity (MWh)	System electricity (MWh)	System electricity (MWh)
Date	281016 Graduation-humidity all	281016 Graduation-only Humidity	281016 Graduation 99% base case
Jan 01-31	1.4747	1.2799	1.1342
Feb 01-28	1.2764	1.1134	0.9886
Mar 01-31	1.8769	1.6437	1.4712
Apr 01-30	3.7723	3.3447	3.0649
May 01-31	9.9214	8.8341	8.0917
Jun 01-30	10.3067	9.0801	8.2092
Jul 01-31	11.2760	9.8560	8.8229
Aug 01-31	11.3492	9.9498	8.9360
Sep 01-30	8.8136	7.6464	6.8303
Oct 01-31	6.2048	5.4235	4.9165
Nov 01-30	2.4539	2.1517	1.9349
Dec 01-30	2.0554	1.7975	1.6092
Summed total	70.7812	62.1208	56.0094

Since the mandatory part is the exhibition environments, control of RH will be done only in them rather than having other unnecessary parts controlled.

Figure 5.45 is showing the chart for total electricity. By referring to table 5.46 the annual total electricity increased by 18.06% in the case of humidity control for all the building. While this percentage for RH control in exhibition environments, led to only 7.4% increase which is much more acceptable.

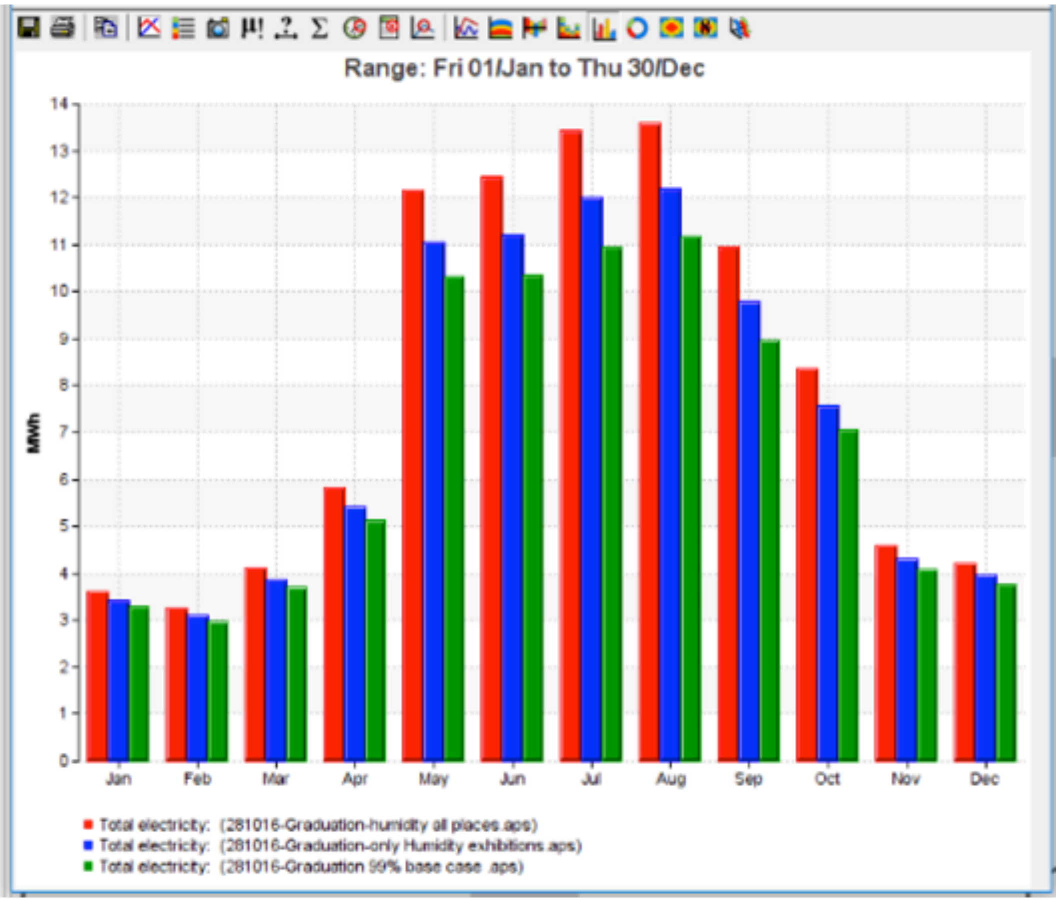


Figure 5.45. Total electricity results, base case model in green, humidity control for exhibitions only in blue, humidity control all building in red. (IESVE, 2016)

Table 5.46. Total electricity results, base case model, humidity control for exhibitions, humidity control all building. (IESVE, 2016)

	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)
Date	281016-Graduation-humidity all	281016-Graduation-only Humidity	281016-Graduation 99% base case
Jan 01-31	3.6215	3.4267	3.2810
Feb 01-28	3.2581	3.0951	2.9702
Mar 01-31	4.1062	3.8731	3.7006
Apr 01-30	5.8365	5.4089	5.1292
May 01-31	12.1508	11.0635	10.3211
Jun 01-30	12.4535	11.2270	10.3560
Jul 01-31	13.4228	12.0028	10.9697
Aug 01-31	13.5785	12.1792	11.1653
Sep 01-30	10.9604	9.7932	8.9772
Oct 01-31	8.3516	7.5703	7.0633
Nov 01-30	4.6007	4.2985	4.0817
Dec 01-30	4.2022	3.9444	3.7560
Summed total	96.5429	87.8826	81.7712

Moreover the pervious experiments for humidity control were based on considering the same condition f the current situation for having 0.45 ach infiltration. Reducing the infiltration will reduce the system electricity consumption associated with humidity control. As humidity will not change as frequent when there is less leakage to outside environment. The following experiment result is based on making the infiltration to the standard and below standard (in the case of air curtain system) and will implement the humidity control only to the exhibition environments. Rooms other than exhibition environments kept at standard infiltration (0.25) on the different experiments.

Figure 5.46 is showing the system electricity of the base case model (yellow bars), the blue bars indicate the humidity control for exhibitions only with having the same existing infiltration (0.45 ach). Red bars are for the best infiltration rate (0.15 ach) with humidity control in the exhibitions. And green bars are for the standard infiltration rate (0.25) with humidity control in exhibitions only. As shown reducing infiltration caused less increase in system electricity in comparison to the increase associated with humidity control alone.

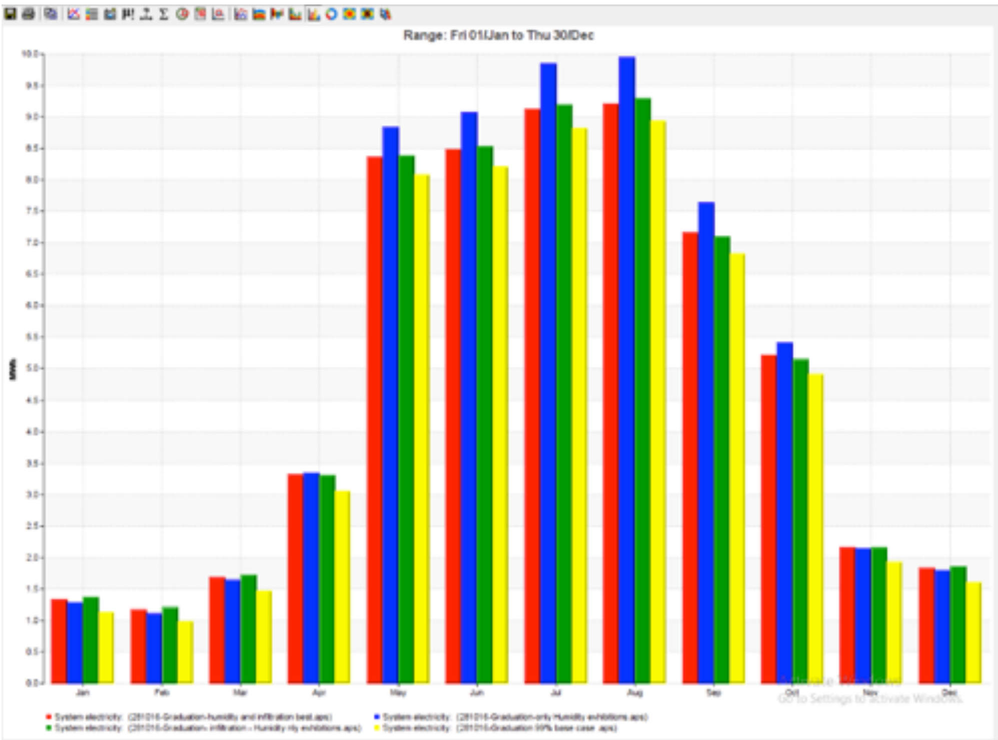


Figure 5.46. System electricity yellow bars base case model, blue bars humidity control 0.45 ach infiltration, red bars humidity control infiltration rate 0.15 ach, green bars humidity control infiltration rate 0.25 ach (IESVE, 2016)

Table 5.47 shows the figures for the examined situations across the year.

10.9% is the annual increase in system electricity when infiltration is not enhanced. While, 5.93% is the annual increase when infiltration is on the standard level. Moreover when infiltration is at best rate, the annual increase in system electricity is 5.48%. This contributed in reducing the increase by half of the percentage, which is a good contribution as well.

Since infiltration alone contributed by 2% and 3% reduction in system electricity, the contribution of infiltration in reducing energy consumption in humidity control is approximately more than 2 % which is noticeable as well.

Table 5.47. System electricity base case model, humidity control with 0.45 ach infiltration, humidity control infiltration rate 0.25 ach, humidity control infiltration rate 0.15 ach (IESVE, 2016)

	System electricity (MWh)	System electricity (MWh)	System electricity (MWh)	System electricity (MWh)
Date	281016-Graduation-humidity and infiltration best.aps	281016-Graduation only Humidity exhibitions.aps	281016-Graduation- infiltration - Humidity nly	281016-Graduation 99% base case .aps
Jan 01-31	1.3338	1.2799	1.3739	1.1342
Feb 01-28	1.1693	1.1134	1.2090	0.9886
Mar 01-31	1.6900	1.6437	1.7252	1.4712
Apr 01-30	3.3264	3.3447	3.3137	3.0649
May 01-31	8.3640	8.8341	8.3939	8.0917
Jun 01-30	8.4852	9.0801	8.5396	8.2082
Jul 01-31	9.1217	9.8560	9.2008	8.8229
Aug 01-31	9.2185	9.9490	9.2950	8.9360
Sep 01-30	7.1677	7.6464	7.1010	6.8303
Oct 01-31	5.2199	5.4235	5.1566	4.9165
Nov 01-30	2.1542	2.1517	2.1647	1.9349
Dec 01-30	1.8317	1.7975	1.8623	1.6092
Summed total	59.0812	62.1208	59.3357	56.0094

Considering the impact on total electricity, figure 5.47 shows the total electricity for having infiltration and humidity together in the mentioned ways.

Yellow bars indicate base case model. Red bars indicate the humidity control for exhibitions only with having the same existing infiltration (0.45 ach). Green bars for the best infiltration rate (0.15 ach) with humidity control in the exhibitions. And blue bars for the standard infiltration rate (0.25) with humidity control in exhibitions only. The change happens during summer months, while winter months stay almost near to the base case model.

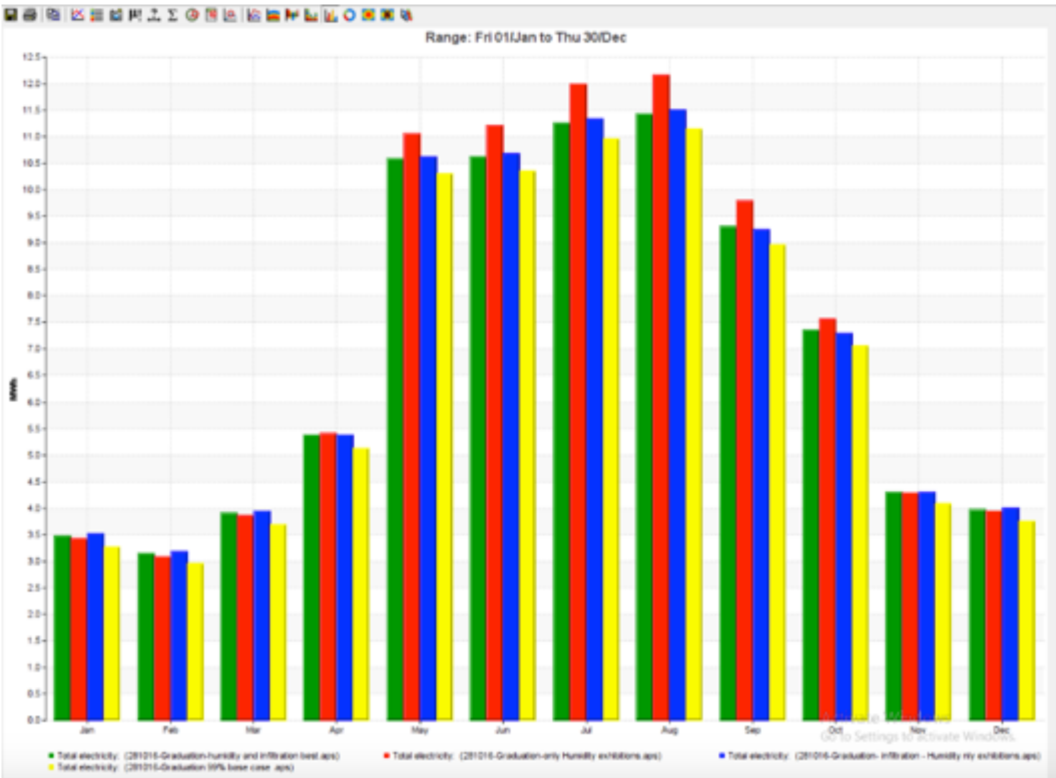


Figure 5.47. Total electricity yellow bars base case model, red bars humidity control for exhibitions only with infiltration 0.45 ach. Green bars infiltration rate 0.15 ach with humidity control for exhibitions, blue bars for standard infiltration rate (0.25) with humidity control in exhibitions. (IESVE, 2016)

Table 5.48 shows the figures for total electricity for the different conditions, of humidity control and infiltration. As shown the total percentage of increase is 3.75% in the case of having best infiltration with the humidity. Standard infiltration with humidity control contributed in 4.06% increase in total electricity of one year.

Table 5.48. Total electricity base case model, humidity control for exhibitions only with infiltration 0.45 ach, infiltration rate 0.15 ach with humidity control for exhibitions, standard infiltration rate (0.25) with humidity control in exhibitions. (IESVE, 2016)

	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)
Date	281016 Graduation humidity and infiltration best.aps	281016 Graduation only Humidity exhibitions.aps	281016 Graduation- infiltration - Humidity nly	281016 Graduation 99% base case .aps
Jan 01-31	3.4807	3.4267	3.5307	3.2810
Feb 01-28	3.1509	3.0851	3.1906	2.9702
Mar 01-31	3.9194	3.8731	3.9546	3.7006
Apr 01-30	5.3907	5.4089	5.3780	5.1292
May 01-31	10.5941	11.0635	10.6233	10.3211
Jun 01-30	10.6321	11.2270	10.6864	10.3560
Jul 01-31	11.2685	12.0028	11.3476	10.9697
Aug 01-31	11.4458	12.1792	11.5243	11.1653
Sep 01-30	9.3145	9.7932	9.2470	8.9772
Oct 01-31	7.3667	7.5703	7.3034	7.0633
Nov 01-30	4.3011	4.2585	4.3115	4.0817
Dec 01-30	3.9795	3.9444	4.0092	3.7560
Summed total	84.8429	87.8826	85.0974	81.7712

As shown considering the infiltration with the humidity control as figures linked together shows more realistic contribution made in the increase/decrease in the total electricity of one year.

Experiments Results for Proposals: Cooling Set Points

Considering the current practice done in the museum, the set points were set to 18 degrees. However, according to the onsite measurements results the exhibition room conditions were not close to this temperature at all. This indicates AC units are not working properly. Therefore, changing set points were not mentioned in proposals section. However, if Ac units were operating normal and maintaining the temperature to the set points, the environments would be much colder than needed. Set point of 23°C degrees according to ASHRAE standards, is suitable to be assigned for public spaces. As of the exhibition environments, to have safe conditions suitable for artifacts, the practice followed by Sharjah museums will be considered to follow the UK standards. In Sharjah museums the cooling set point are set to 21°C degrees, accordingly having fluctuation of 2°C degrees in temperature (UK standards) will keep the conditions save as well.

Increasing the temperature set points for the environments will result in reduction in energy.

Figure 5.48 shows the reduction resulted in system electricity by assigning the set point temperature to 21°C degrees in the exhibition environments and 23°C in the other remaining spaces. Red bars in the chart indicate the base case model and the blue bars are indicating the new set points. As noted the decrease in energy was done in all the months across the year.

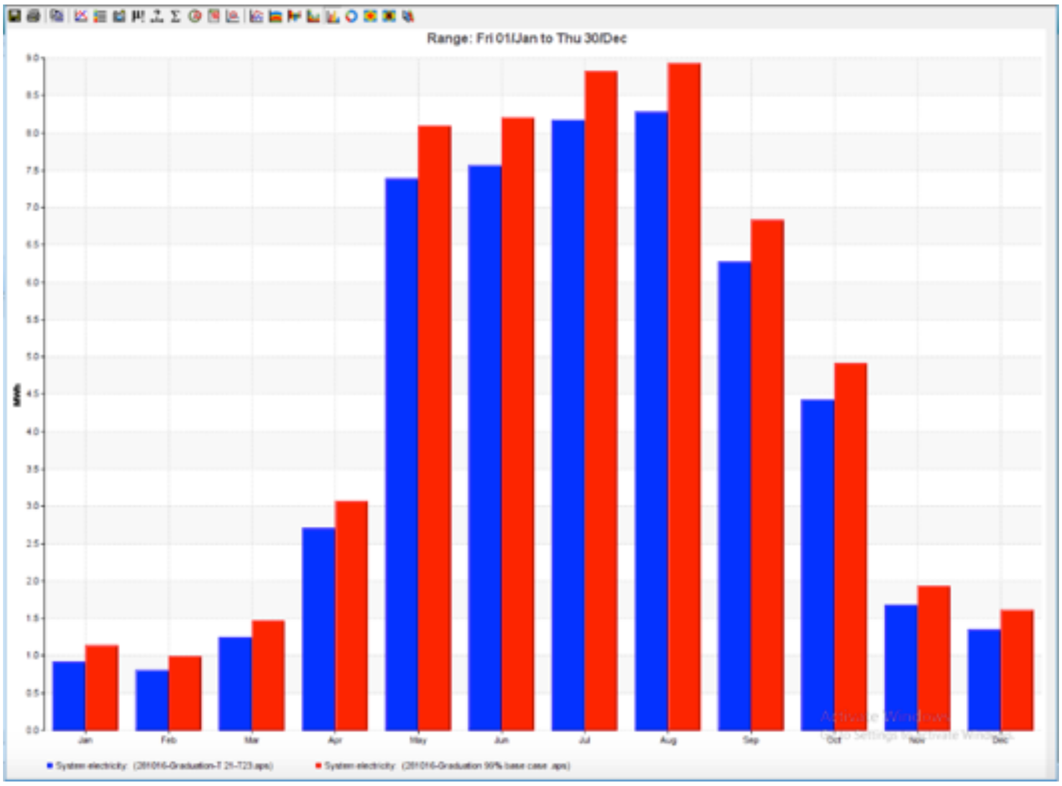


Figure 5.48. System electricity, base case model in red bars, new temperature set points of 21°C and 23°C shown in blue. (IESVE, 2016)

Table 5.49 shows the figures for system electricity. As shown system electricity dropped to 50.8193 MWh when set points were changed in comparison to the base case (56.0094 MWh), which is 9.26% reduction.

Table 5.49. System electricity base case vs temperature set points changed. (IESVE, 2016)

	System electricity (MWh)	System electricity (MWh)
Date	281016-Graduation-T 21-T23.aps	281016-Graduation 99% base case .aps
Jan 01-31	0.9194	1.1342
Feb 01-28	0.8101	0.9886
Mar 01-31	1.2521	1.4712
Apr 01-30	2.7020	3.0649
May 01-31	7.3848	8.0917
Jun 01-30	7.5650	8.2092
Jul 01-31	8.1741	8.8229
Aug 01-31	8.2847	8.9360
Sep 01-30	6.2717	6.8303
Oct 01-31	4.4298	4.9165
Nov 01-30	1.6825	1.9349
Dec 01-30	1.3436	1.6092
Summed total	50.8198	56.0094

Considering the total electricity, table 5.50 show figures for total electricity for the base case as well as the experiment of changing the temperature set points. As shown, the total electricity for one year dropped to 76.5816 MWh which is 6.34% overall. Which is a good reduction as well.

Table 5.50. Total electricity base case vs temperature set points changed. (IESVE, 2016)

	Total electricity (MWh)	Total electricity (MWh)
Date	281016-Graduation-T 21-T23.aps	281016-Graduation 99% base case .aps
Jan 01-31	3.0662	3.2810
Feb 01-28	2.7918	2.9702
Mar 01-31	3.4815	3.7006
Apr 01-30	4.7663	5.1292
May 01-31	9.6142	10.3211
Jun 01-30	9.7118	10.3560
Jul 01-31	10.3209	10.9697
Aug 01-31	10.5141	11.1653
Sep 01-30	8.4185	8.9772
Oct 01-31	6.5766	7.0633
Nov 01-30	3.8293	4.0817
Dec 01-30	3.4904	3.7560
Summed total	76.5816	81.7712

The important consideration for this situation is to ensure systems are maintained and fixed properly to operate correctly, otherwise this reduction is set point will result in increasing the indoor temperature more than what is it now and will not be safe for the collections.

Best Case Scenario

After having the different experiments for different options, forming the best case scenario by selecting the most practical options in each category should be made to evaluate the overall changes in total electricity.

Considering the fact that daylight will not be implemented for the exhibition environments, the options of scenario 2 and 3 LED/ existing lighting to operate along with daylight as well as the different glazing options for windows are excluded.

The remaining two options for light include:

1- Existing lighting to operate based on visitors availability in the space.
2- LED lighting to operate based on visitors availability in the space.

Since this section is dedicated for the best case, the implementation of LED is considered with the mentioned condition.

As of Relative Humidity, the option of only controlling exhibition environments rather than all spaces is selected. Additionally, the infiltration rate will be assigned to best condition of 0.15 ach.

In terms of temperature set points, the exhibition environments are set to 21 and the other rooms set to 23 degrees.

Table 5.51 summurizes the impact of each change happened to the base case model and the contribution each had in their concerened areas. The impact on the total electricity are shown. As well as meantioning the reson of implimentation of the propsal. It also includes the results for the option of keeping exisiting type of light, when operating during occupancy only, as this option had good impact without the need of any change and could be followed until different methods would be implimented.

As shown in the table, LED lighting contributed significantly in reducing the annual light electricity by 89%. This reduction in light electricity impacted the annual total electricity by almost 34% which is a noticeable reduction. As mentioned in the literature review chapter, LED lights, provide safer light in terms of IR and UV radiation, their life expectancy is higher. They are associated with higher cost in terms of upfront payment, but with the consideration of the safety of collection and their priceless values this is considered an investment for their durability.

Figure 5.49 shows the total electricity obtained by implementation of the best case scenario without the control of relative humidity. As shown all months had very good reduction in energy consumption which reflects the appropriate selection of proposals based on the case study. In comparison to the base case model, the reduction of energy consumption in the summer months was much higher and moderately lower during winter months. Maximum electricity is in August and it is above 8 MWh. While the total electricity in the base case model exceeded 11 MWh.

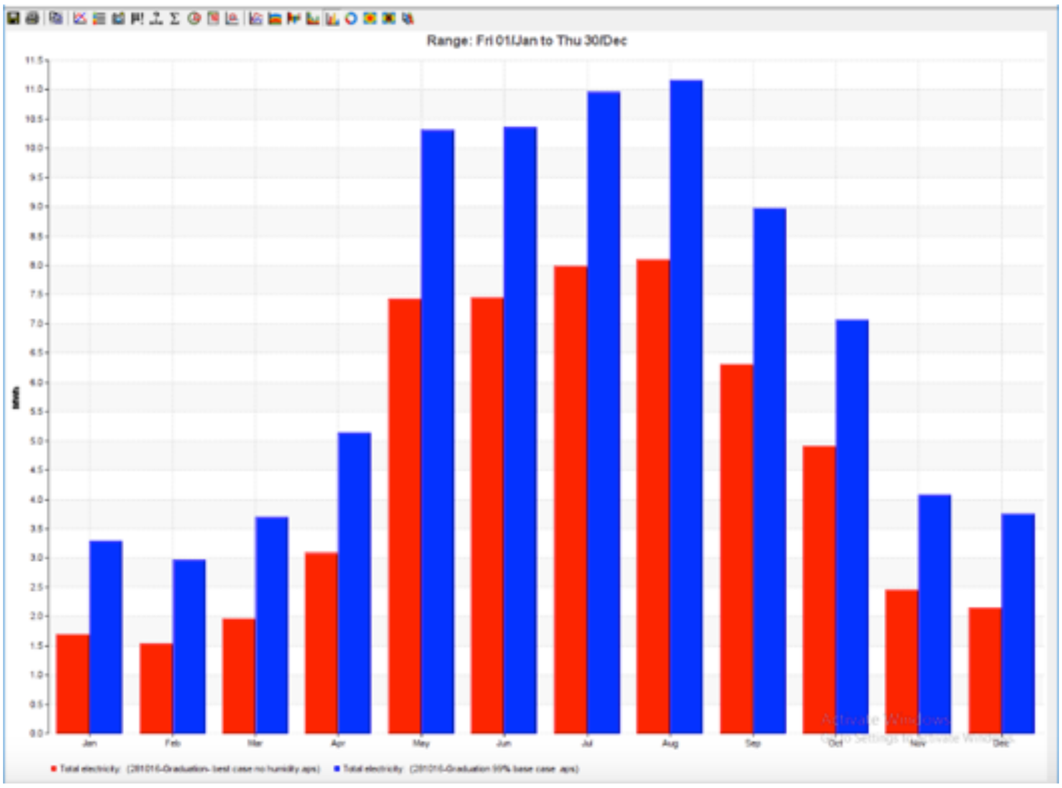


Figure 5.49. Total electricity of the best case scenario without the control of relative humidity in red vs base case model in blue. (IESVE, 2016)

Table 5.51 shows the exact numbers for total elextrictiy for the best case scenario as well as the base case model.

Table 5.51. Total electricity best case scenario without the control of relative humidity and base case model in blue. (IESVE, 2016)

	Total electricity (MWh)	Total electricity (MWh)
Date	281016-Graduation- best case no humidity.aps	281016-Graduation 99% base case .aps
Jan 01-31	1.6942	3.2810
Feb 01-28	1.5360	2.9702
Mar 01-31	1.9561	3.7006
Apr 01-30	3.0886	5.1292
May 01-31	7.4261	10.3211
Jun 01-30	7.4486	10.3560
Jul 01-31	7.9935	10.9697
Aug 01-31	8.1028	11.1653
Sep 01-30	6.3115	8.9772
Oct 01-31	4.9122	7.0633
Nov 01-30	2.4519	4.0817
Dec 01-30	2.1433	3.7560
Summed total	55.0648	81.7712

As shown in the table, the annual electricity for the best case scenario dropped from 81.7712 MWh to 55.0648 MWh resulted in 26.7064 MWh over all reduction. This is 32.65% reduction in total electricity.

With having the 32.65% reduction in mind some percentage should be compermized. As mentioned earlier the artifact conservation is a priority. And since relative humidity is a top priority in artifact conservation this compermize of increase should be done. However, as expressed earlier, the increase in energy consumption is already coverd by the implimentation of other energy reducing proposals. Figure 5.50 shows the total electricity after implimentation of relative humidity control in the exhibition environments. Green bars indicate the base case model. Blue bars is the best case scenario without humidity control and the red bars is the implimentation of humidity control in the exhibition spaces in the best case scenario model.

As shown, there was little increas in total electricity every month across the year, nevertheless this increase, still kept the total electricity remarkably below the base case model.

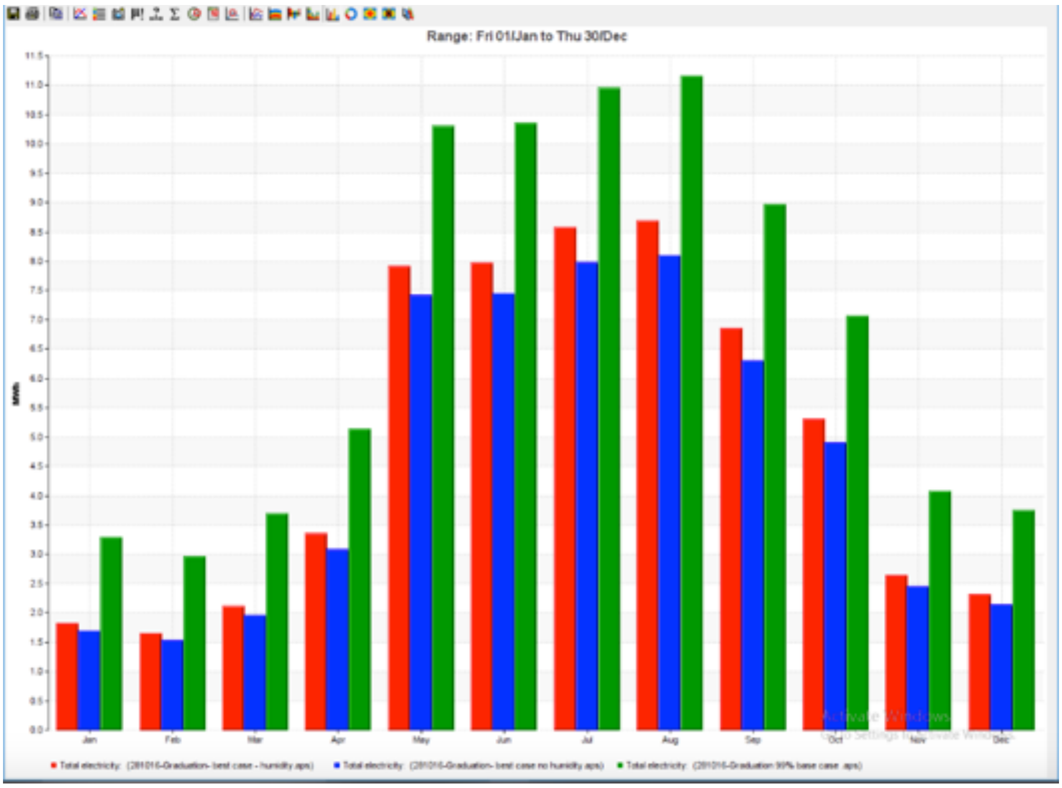


Figure 5.50. Total electricity, best case scenario with humidity control in exhibition environments in red, best case scenario no control of relative humidity blue, base case model green. (IESVE, 2016)

Table 5.52 show the figures of total electricity for each month as well as the total annual electricity. As shown total electricity increased from the previous case of 55.0648 MWh to reach to 59.2402 MWh humidity control resulted in 4.1754 MWh. This condition is still below the base case model with overall 22.531 MWh. Consideraing the overall total electricity reduction in best case scenario with the implimentation of relative humidity control, the over all annual total electrcity reduction was 27.55% reduction, for the best case scenario. This is more than quarter amount of the entire year from the base case model.

Table 5.52. Total electricity, best case scenario without relative humidity control, best case scenario with relative humidity control, and base case model. (IESVE, 2016)

	Total electricity (MWh)	Total electricity (MWh)	Total electricity (MWh)
Date	281016-Graduation- best case -	281016-Graduation- best case no	281016-Graduation 99% base case
Jan 01-31	1.8256	1.6942	3.2810
Feb 01-28	1.6562	1.5360	2.9702
Mar 01-31	2.1149	1.9561	3.7006
Apr 01-30	3.3596	3.0886	5.1292
May 01-31	7.9201	7.4261	10.3211
Jun 01-30	7.9763	7.4486	10.3560
Jul 01-31	8.5830	7.9935	10.9697
Aug 01-31	8.6861	8.1028	11.1653
Sep 01-30	6.8538	6.3115	8.9772
Oct 01-31	5.3125	4.9122	7.0633
Nov 01-30	2.6422	2.4519	4.0817
Dec 01-30	2.3099	2.1433	3.7560
Summed total	59.2402	55.0648	81.7712

Since the contribution of changing each element of the indoor environemnt has been discussed in details in the relevent section, the charts and tables of system electricity, cooling loads and light electrcicity are all provided in Appendix C.

Over all, the examined propsals rather than having only energy reduction concerns, targeted the artifact preservation as the priority, and examined their change in temrs of energy performance.

Each experiment provided clear quantitavie information about the impact of each propsal with the different possiblity of implimentation in terms of energy consumption. Moreover, having the best case scenario indicated clearly the overall energy performance when all the best options where integrated together and resulter in total of 27. 55% reduction annually.

Table 5.53 summurizes the applicable experiments and their contribution in terms of reducing orincreasing electricity demand in their concerned areas as well as the contribution in total annual electriciy.

Table 5.53. Summury of applicable experiments for CCM.

	Concerned Area	Annual Electricity Difference in the concerned area (MWh)	change occurred in the concerned area (MWh)	Difference in total electricity (MWh)	Percentage of change occurred in total electricity	Reason of Implementation
LED lighting operating during occupancy	Light Electricity	- 23.0083	-89.31%	-27.5955	-33.74%	1. Reducing light exposure 2. Safe lighting for artifacts 3. Saving Energy
Existing Lighting operating during occupancy	Light Electricity	- 14.7181	-57.13%	-17.9399	-21.93%	1. Reducing Light Exposure 2. Saving Energy
Standard infiltration	System Electricity	- 1.6552	- 2.95%	- 1. 6553	-2.02 %	Safety of artifacts Energy Reduction
Best infiltration	System Electricity	- 2.7351	- 4.88%	- 2.7351	-3.34 %	Safety of artifacts Energy Reduction
Relative Humidity Control With best infiltration	System Electricity	+ 3.0718	+ 5.48%	+ 3.0717	+ 3.75%	Safety of artifacts

5.2.2. Proposal and Assessment for Case Study 2: SHAM

Based on the identified conditions in the evaluation section figures 5.51 to 5.53

determine the areas that the proposed solutions would fall under.

By referring to the diagrams, most of the solutions would fall under the guidelines and adopting policies. Design enhancement would only address part of energy saving as well as the human health and comfort.

While, Design enhancement is targeting a particular concerned area, most important aspect is upgrading the systems to meet the requirements for artifact preservation.

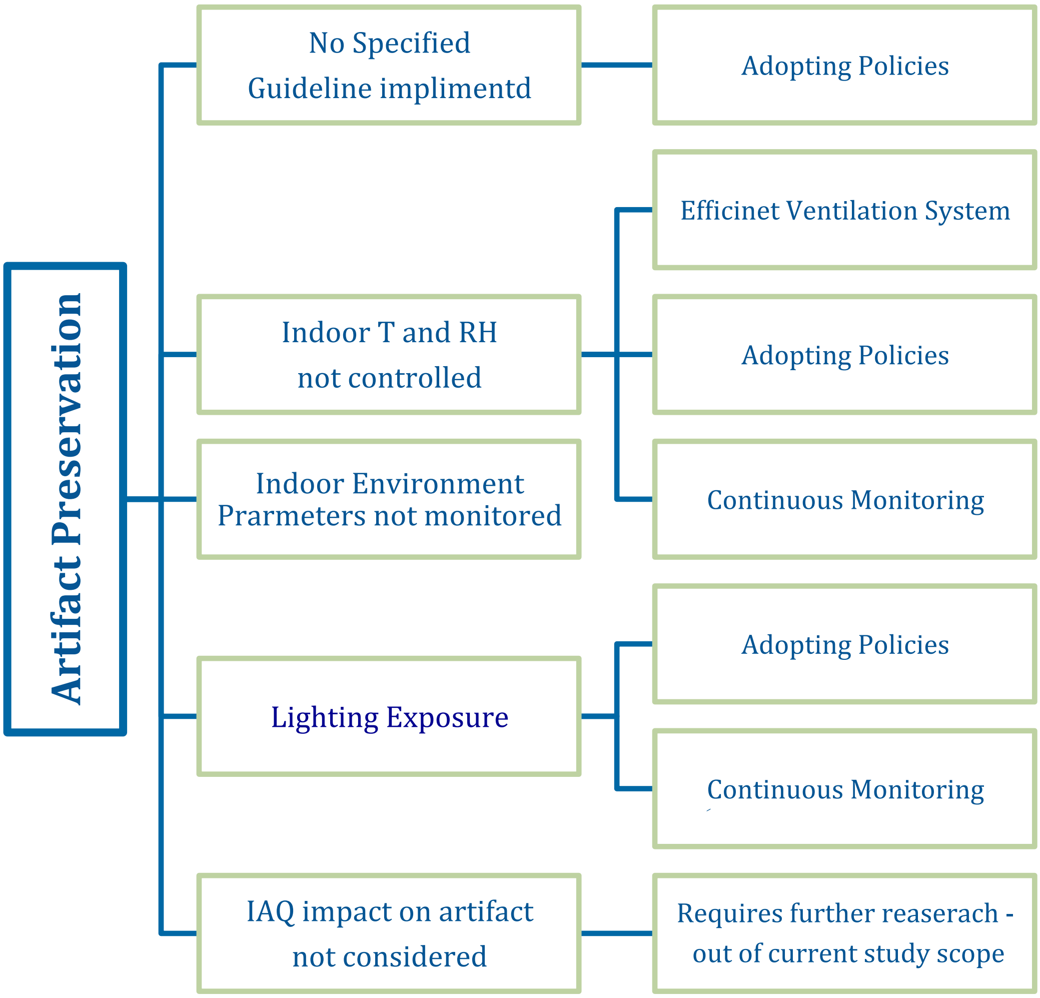


Figure. 5.51. SHAM identified challenges in terms of artifact preservation.

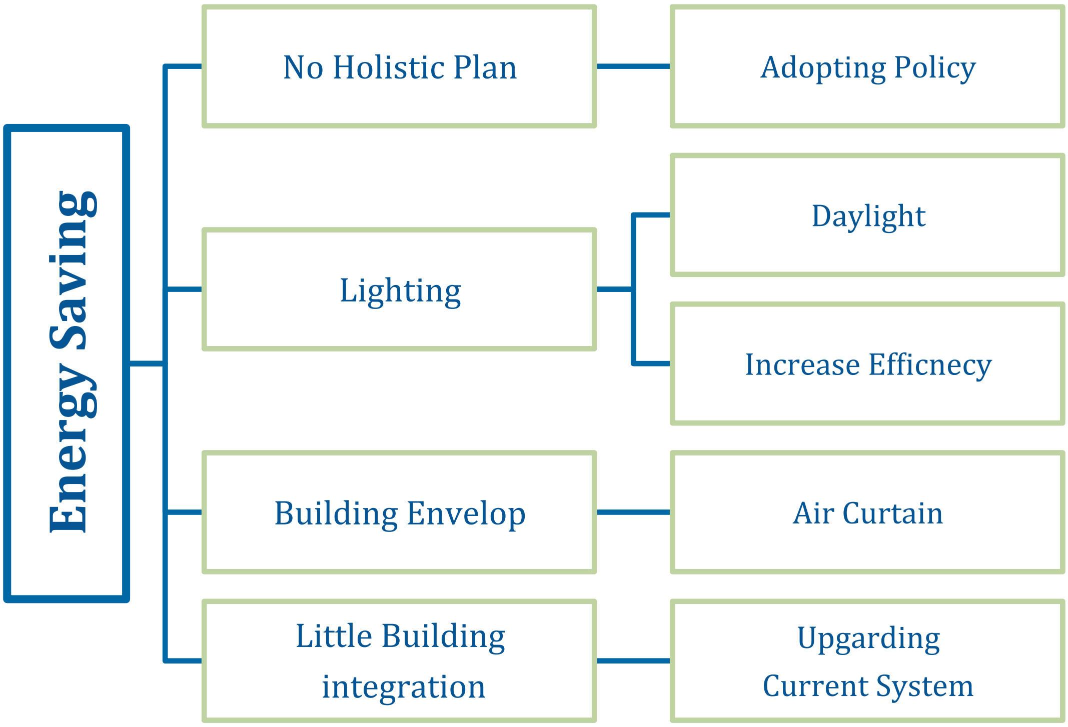


Figure. 5.52. SHAM identified challenges in terms of Energy saving.

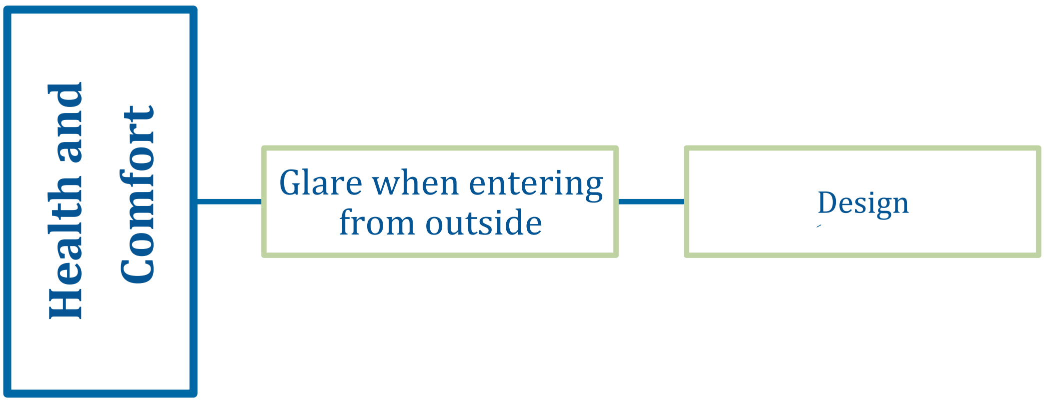


Figure. 5.53. SHAM identified challenges in terms of human health and comfort.

5.2.2.1.Policy and Guidelines

Policy and Guidelines for Artifact Preservation: SHAM

No exact indoor guideline followed and implemented

With the considerations taken in account for the artifacts of the museum there was no clear regulations and guidelines in general. That might be due to specifying special conditions for each peace. However, it is very crucial to have clear systematic guidelines identifies precisely the range and the fluctuation allowance for daily changes as well as the seasonal variations.

Monitoring Indoor environment

Having HVAC systems with assigned set points are not enough to have properly controlled environment. This would help the practice of short term without the prediction and analysis for the future as well as comparisons for the changes in the past. Continues monitoring to the environment will make it possible to study and track down the seasonal and the gradual changes happens over longer time periods on the artifacts.

Having monitoring systems will help configuring the areas that are not being controlled properly over time. So it will make it possible to take a decision for changing some components or enhancing the system or changing the display cases in sometimes to provide and meet the required conditions.

HAVC units do not control RH

Even though, the display cases are sealed to stop the surrounding influence, however they are not separated in terms of having separate cooling systems. Thus it can be predicted that over time the change and the environmental fluctuations would impact the indoor environment of the display cases negatively, therefore controlling T and RH in the same time is required. This requires the integration of humidifiers to the current system.

Policy and Guidelines for Energy Saving

No holistic Strategy for Energy Saving

In the establishment stage the concern towards the energy saving and energy efficiency was not having holistic approaches. With the availability of system that also serves energy savings was integrated. However since energy saving was not considered as a main target. Even with integrating systems that are more energy efficient they have not been utilized well.

Lightings on when not needed

As mentioned in the pervious part, the integration of energy efficient systems did not result in efficient practice. Even with the DALI systems, the museum lights are on during non-occupancy time. To make all serve the goal of energy saving, the aims should be identified and indicated, thus daily practices and activities will follow to reach the goal.

Little integration between building components

Having the building components integrated will increase the efficiency in the exhibition environments. If the lighting and HVAC all get connected via BMS according to occupancy detection lights will be on. Also since occupants will enter the exhibition and doors will open, T set point can be adjusted to be at lower temperature, in the entrance area for certain time thus the environment will be better managed. Accordingly, video projections start during the presence of the visitors in the exhibitions to save the energy.

5.2.2.2.Upgrading Current Systems for Artifact Preservation: SHAM HVAC

HVAC system be upgraded for RH mentoring and control

Having sealed display cases serve a lot in preserving the artifacts, however, to keep the environment safer for them it is essential to consider the surroundings. As conditions inside display cases might change over time or the inside conditions and outside conditions will be contrasting.

Currently only T is controlled in the exhibitions, while the RH changes play more important role in the collections conditions.

It is essential to upgrade the system in the exhibition environments to have humidifiers and dehumidifiers to make the environment more stable and suitable. According to the temperature conditions.

By adding the relative humidity control to exhibitions, as shown in the case study 1 (CCM) the energy consumption will increase by approximately 4%. However, if infiltration is controlled this percentage will be less.

Air Curtain

Even though currently the entrances of the museums are having additional sliding doors after the traditional doors, however by referring to the measurements obtained for the exhibition hall, the area in front of the entrance is heavily influenced by the outdoor conditions and T. because currently the sliding door is not acting as a double door concept by being a barrier. As visitors enter both doors are open thus influence to the environment is already done.

Considering the sliding door it self it can act as an enhancement when there is not visitors, the door would be sealing the envelop and stop the air leakage through the traditional door.

Applying air curtain to the entrance will enhance this feature and isolate the outdoor towards the indoor in a more efficient way.

Lighting

DALI system is already installed, however, not integrated and utilized. Currently the lighting system has all the requirements for being responsive, according to the drawings, the sensors also have been installed for occupancy detection. However it has not been integrated to work in the desired way. Since the system is already installed it should be programmed for interaction and occupancy pattern.

Since LED lights have been installed in this museum, big portion of energy has been saved through this type of light. As shown in case study 1 (CCM) adaptation of LED light contributed in 75% reduction in light electricity for one year.

Author had made manual calculation based on the lights specification and each fixture's wattage to estimate the current light consumption. As these details were not available by the management. Considering the exhibition environments only 5.1237 MWh is the total light electricity for one year by considering the current operation of 6 hours per day and to be closed during Saturdays and Fridays. This will be more when the operation hours of the museum will be extended till 8 pm and to open during weekends.

In order to simulate and assess the change in light electricity based on activating the occupancy detecting sensors in the environment, it is crucial to have a representative occupancy profile. Since the museum is very new the visitor's log was created only for the first month from the opening. First month of the opening could not be considered as a representative pattern for generating profiles for the entire year. And since the project is governmental, frequency of visitors are different from the private museum, thus author could not make an assumption for that as well.

However, since all the systems and the required components have been installed in the museum, knowing the exact reduction will not impact the decision making for willingness to invest in this strategy, whether it worth it to bare the upfront cost since it has been already done.

Nonetheless, rough estimate to have some idea about the reduction in light electricity for operating based on visitor availability is made in the following.

The result from case study 1 was considered with the assumption of having double visitors. Reduction in light electricity from 12 hours operation to operation based on visitors resulted in 42% reduction. Doubling this percentage will result in 21% reduction in light electricity.

If the current operation hours of the museum should be considered, for this case this percentage will be only half resulting in 10.5%.

Even though the percentage is low in comparison to case study 1, however, all the components are installed and the investment is done for them. This will help to optimize the system and contribute in reducing the return on investment time. Moreover, as proved in case study1, light electricity reduction will have impact on reducing the cooling loads in the museum as well.

To have accurate percentage in reduction monitoring and record of visitor frequently in the exhibitions should be made to generate profile and by the activation of sensor option in IESVE different simulations could show the results.

5.2.3. Proposal and Assessment for Case Study3: SMIC

Diagrams presented in figure 5.54 to 5. 56 are derived from the identified challenges in the evaluations made for this case study. Over all SMIC showed best conditions in comparison to the other 2 case studies and the identified challenges can be addressed with less efforts in comparison to case study 1.

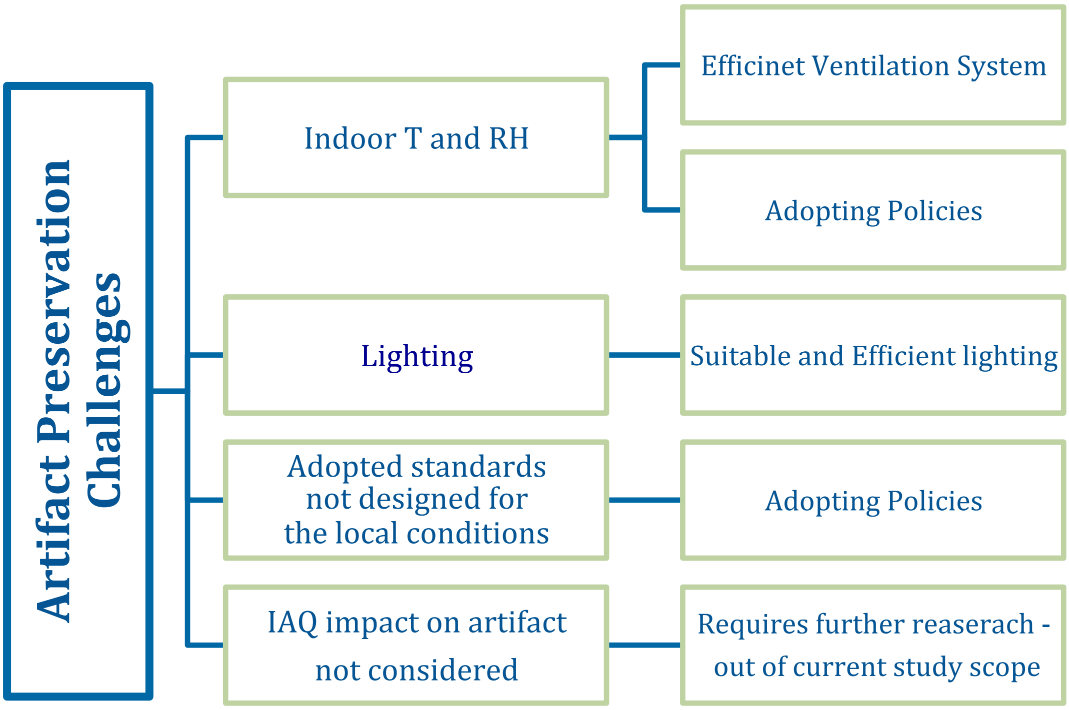


Figure. 5.54. SMIC identified challenges in terms of artifact preservation.

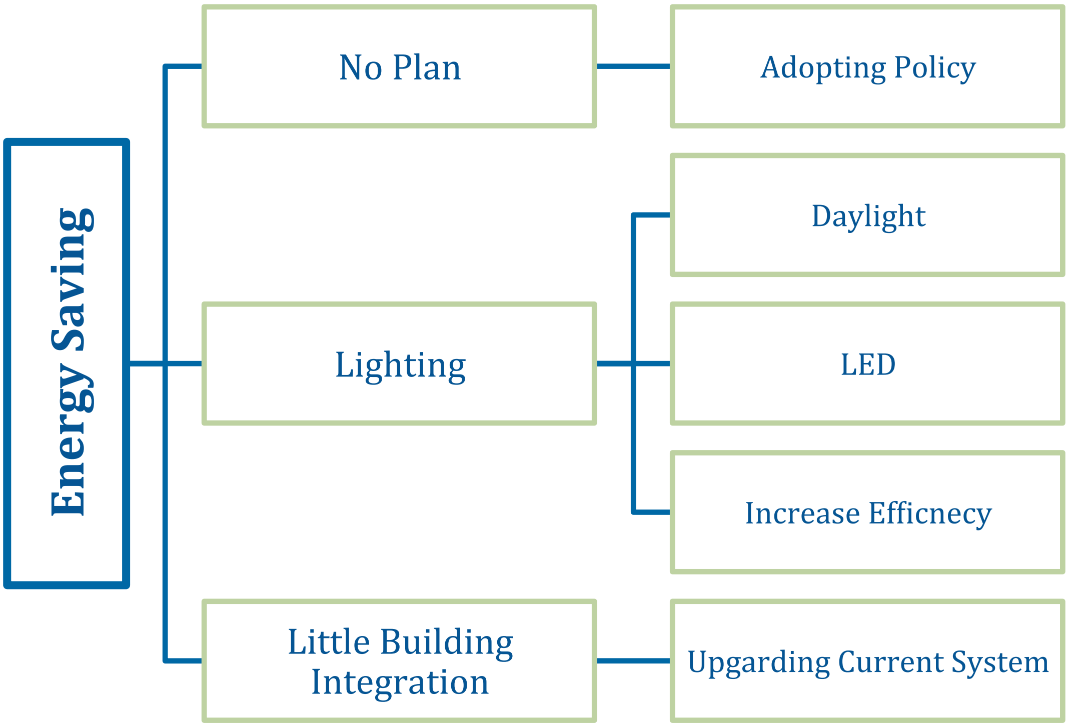


Figure. 5.55. SMIC identified challenges in terms of intelligence level and energy savings.

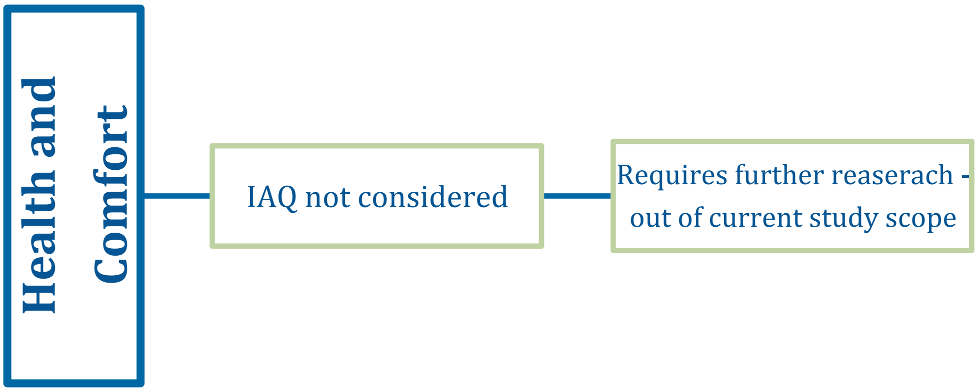


Figure. 5.56. SMIC identified challenges in terms of health and comfort.

As shown in the diagrams the consideration could be done for human health and comfort in this case study is related to indoor air quality which is not within this study scope thus it is not discussed in the following section. Following is the proposed solutions for the addressed challenges.

5.2.3.1. Policy and Guidelines

Policy and Guidelines *for Artifacts Preservation: SMIC*

As mentioned in evaluation section, the museum has very clear policy and guideline for preserving the artifacts based on following the UK standards. By referring to the evaluation made, all aspect related to artifacts preservations and practices are considered and taken into account. However, the adopted standards are not designed for the local conditions, as the seasonal variation and extreme weather conditions of this region is different than UK and other parts. Thus, it is crucial to have guidelines specifically designed targeting this region to be followed and implemented in the museums of the region.

Policy and Guideline for Intelligence and Energy Saving

Artifacts preservations and practices are considered as a baseline of practice in any museum in the world. However, as discussed in the literature review chapter the current concerns of museums is beyond keeping the artifact preservation practice. They are moving towards the energy saving and energy efficiency aspect to save the resources. While this concern is not been taken into account in SMIC. The museums needs to orient its concerns towards the current practices and concerns and integrates policies for energy saving and energy efficient systems to increase the intelligence of the building components. This considerations is more possible to be designed and implemented in this museums as, currently there is different departments within the Sharjah Museums Departments that have highly skilled and professionals of the field with rich experiences.

5.2.3.2. Upgrading Current Systems for Intelligence and Energy Saving

Replacing the current Halogen lamp lighting system to LED system will reduce energy consumption rate and add more durability to the system. Occupancy detection will eliminate the need of the keeping the light on during the operation hours. Lights will be switched on only when there are visitors in the exhibition and switch off when no visitors are in the place. Current system is capable of such feature however it is not currently integrated. Also, having lighting system connected with Building management system will increase the efficiency of the system. The current system has the ability of integrating to BMS however, its not been done.

The current Building Management systems is only integrating the HVAC and the fire fighting systems together. Having lighting systems integrated will increase the efficiency of the building and

Upgrading the lighting system in this way will also serve in reducing the annual exposure level to the artifact which also serves the artifact preservation positively.

5.2.3.3. Assessment of Energy Reduction in IES VE

The assessments in this case study will be only targeting the change associated in changing the type of lighting.

Also, since only artificial light are being assessed with no daylight, or change in the system as well as the orientation. IES model was created by only modelling the targeted exhibitions in this study to add the internal gains for light only.

Since the information of light electricity consumption for the museum was not available by the management, manual calculation was done in order to calculate the light electricity of the base case situation. According to the management 35 W halogen lamps are distributed in the exhibition halls. Operating daily from 8 am to 8pm and Fridays from 4pm to 8pm. By multiplying the number of lights, to the wattage of each light, to the operation hours during the year, 32.67 MWh was obtained for the 4 exhibition halls and the internal gains were adjusted to the type of light to be as close as possible to this figure accordingly.

By referring to the information obtained from the museum management about the number of visitors, it was noted that the number of visitors are high even during summer months.

Since data was not available for the approximate duration for having empty halls during the working hours of the museum in a day. As well as having high number of monthly visitors (average of 124 visitor per day during one month in summer) it is most probably that the halls would be occupied for most of the times during the operation hours. Therefore, the option of assessing dimming the light based on visitor occupancy was not examined for this particular case study based on the assumption of having continues visitors in all the halls. For this case study the assessed option included the evaluation for changing the light to LED with only adopting the current lighting operation profile (continuously on during the operation hours of the museum).

For the data needed in IES to simulate the impact of LED light for internal gain, based on the advise from the lighting manufacturer company, iN30 LED lights by iGuzzini were also simulated in Relux software for this case study based on the exhibition room specification (available in appendix C). In this case, the lighting installed in some of the showcases were not considered, and the proposal is made based on providing enough lighting for the environment according to the manufacturer.

Results obtained from IESVE by incorporating LED light led to reduction in light electricity are shown in figure 5.54.

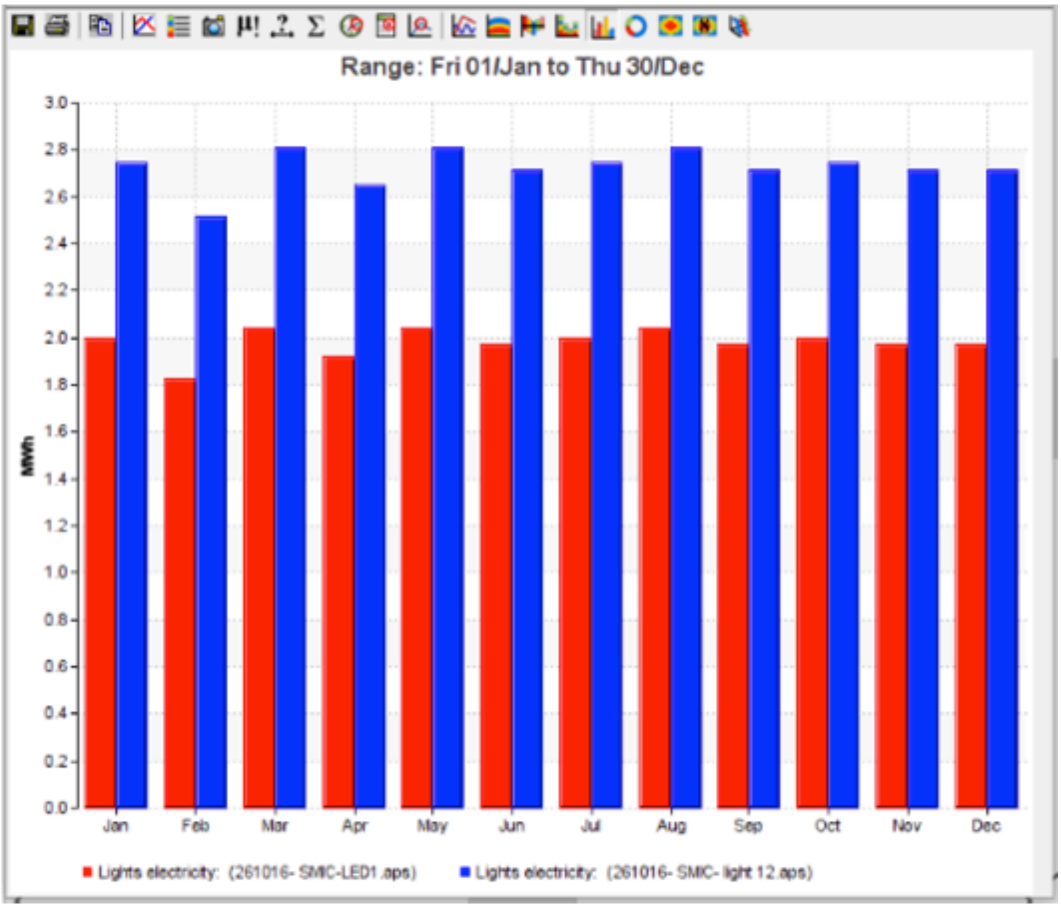


Figure. 5.57. Light electricity for targeted exhibitions at SMIC, blue bars base case, red bars proposed LED lights. (IESVE, 2016)

Red bars in figure 5.57 are showing the monthly LED light electricity based on following the current operation profile. And blue bars are the current light electricity consumption pattern. As shown light electricity consumption dropped from approximately 2.8 MWh to less than 2 MWh per month. Total annual light electricity was reduced from 32.6783 MWh 23.7564 MWh (8.9219 MWh reduction), as shown in table

As shown here the percentage in comparison to Case study 1 is less. And it is mainly because this case study assessment was don only on 4 exhibition halls and did not examine the whole building. Having all the building lights replaced with LED would contribute significantly in the drop of light electricity, cooling loads as well ass the total electricity.

Table 5.54. Light electricity for targeted exhibitions at SMIC base case and proposed LED lights. (IESVE, 2016)

	Lights electricity (MWh)	Lights electricity (MWh)
Date	261016- SMIC-LED1.aps	261016- SMIC- light 12.aps
Jan 01-31	1.9957	2.7452
Feb 01-28	1.8274	2.5137
Mar 01-31	2.0438	2.8114
Apr 01-30	1.9236	2.6460
May 01-31	2.0438	2.8114
Jun 01-30	1.9717	2.7122
Jul 01-31	1.9957	2.7452
Aug 01-31	2.0438	2.8114
Sep 01-30	1.9717	2.7122
Oct 01-31	1.9957	2.7452
Nov 01-30	1.9717	2.7122
Dec 01-30	1.9717	2.7122
Summed total	23.7564	32.6783

Overall 27.30% reduction in annual light electricity is achieved by adopting LED lights. Considering the 27% reduction of light electricity will result in 6.49% (7.6725 MWh) reduction in cooling load and over all (12.7582MWh) 4.41 reduction of total electricity annually.

Having detailed and accurate visitors occupancy patterns that could contribute in making profiles for occupancy patterns in the exhibition halls could drop this percentage little more. Therefore, lights could be dimmed during non occupancy patterns. However, since numbers of visitors are very high, it is expected the total time of having empty exhibits could be a sort period.

5.3. Brief Overview of Results and Findings

Generally, this chapter is the core of the study. It included two different sections; 1- evaluation results of the selected case studies. 2- proposals and assessment for proposals.

Chapter 6

Conclusion and Recommendations

6

6.1. Conclusion

With the important role of museums in preserving the history for future generations of different societies, this study targeted UAE historical museums. Even though museum practices in UAE is considered a relatively new practice comparing to other parts of the world, however, due to the attention paid to cultural activities, number of museums across the country is growing in the recent years.

This study considered different factors of indoor environment quality in the exhibition spaces of selected case studies in UAE.

As for this region, studies evaluating indoor environment quality of museums are very limited in the first place. Additionally guidelines and regulations specialized for indoor environments of museums are not publicized. Moreover, upgrading museums with the consideration of local climatic condition has not been thought of.

Since this study aimed at enhancing the current museums indoor environments into more sustainable environments, knowing the current conditions is a must in able to move forward with enhancements.

The adopted methodology for this research was combination of different methods following the SOBANE strategy of: screening, observation, analysis and expertise, developed by D'agostino et al. (2015) and Lucchi (2016a,b).

Evaluation of UAE museums indoor environments considered the three main aspects:

1- Artifact Preservation
2- Human Health and Comfort
3- Intelligence level and Energy Saving Approaches

The current conditions of the case studies were qualitatively evaluated based on the conducted surveys with the different departments in the museums as well as site visits. Quantitative evaluation of indoor parameters of exhibitions were done by conducting on site measurements, and recording: temperature, relative humidity and lux levels of the environments on three times of a day in each case study. This was the screening and observation stage of SOBANE strategy.

Based on the evaluation made, it was found that depending on the ownership of the museums (whether it is governmental or private) the knowledge level, resulted in having different policies for museum practices.

Major challenges were identified for case study 1 (CCM) in terms of practices, artefact preservation and human health and comfort. There were no policies for sustainable adaptation, but there was willingness of adaptation. The museums did not have any intelligence, all building components were very basic manually operation with no integration to each other. As of onsite measurements, it did not have stable environmental conditions in terms of Temperature (T) level and variation was above standards and it was within the danger zone, similar un safe conditions with relative humidity (RH) as well as lighting levels.

The specification of the display cases, lighting system and cooling systems was not suitable for the function of museum.

While, case study 2 (SHAM) in terms of intelligence had benefitted from having advanced technologies and automation for the space, suitable for museums with possibility of integration, however, not all installed features were utilized at this stage. Operations of different components are programmed to turn on and off from a control panel. Nevertheless continues monitoring was not implemented for the museum indoor environment. This case study was new, but represents the practice of a more advanced technology in comparison to case study 1, as both almost have same building features in terms of utilizing historical houses for museums. In SHAM, the policy was to have sealed and specially designed display cases for artefacts, rather than continuously monitoring and controlling the indoor parameters. As for lighting systems energy efficient type of light was utilized, but the concern of energy savings, was not a top priority.

In terms of on site measurements, T and RH fluctuations exceeded standards, however, unlike case study 1, they were still within the safe zone. This also lowers the risk for artefact preservation as the display cases are designed specially to block the surrounding environmental changes.

Moving to the third case study, (SMIC) very clear adaptation of international standards (followed UK standards) in terms of museum practices. Better environmental conditions were recorded, fluctuations were more stable in comparison to the other two case studies. T and RH is controlled and monitored continually in the different galleries by the building management system. The Air Handling Units (AHU) for the exhibition environments are equipped with humidifiers and dehumidifiers in order to have full control and provide the most uniformed indoor environment for artifact preservation. While in SHAM only T was controlled in the environment without the consideration of RH. Whereas, in CCM with the existence of AC units did not help in maintaining the proper T in the exhibits.

As noted in the results SMIC had the lowest visible light (lux) level numbers in comparison to the other two museums as well.

In terms of intelligence level, case study 3 had the integration and building management system with control possibility, however, when it was not a mandatory element for artifacts, upgrades were not made to lower energy consumption. (like integrating lighting systems to utilize the dimming options) over all, energy saving was not considered as a priority in this museum.

After the evaluation the selected case studies, based on the identified situation in terms of good conditions and current challenges, the question of “what are the possibilities for enhancing the current conditions?” were studied. This stage was the Expertize stage in SOBANE strategy that identifies solutions and assessment for the identified problems

Different proposals for enhancing the current conditions based on the targeted: 1- Artifact Preservation 2- Human Health and Comfort 3- Intelligence level and Energy Saving Approaches.

The proposals were framed based on the good practices implemented by the other case studies, as well as extracting information from literature review and most importantly through the conducted surveys with the professionals in the local market dealing with different museum projects. For the proposals, the option of most energy saving approach was considered within the safety of the collections in a way that suits the nature of each project.

Case study 1 (CCM) required major enhancements and proposals targeted the areas of:

1- Policy and Guidelines
   - Hygrothermal parameters
   - Luminance parameters
   - Determine Daily practices
   - Maintenance policy
   - Continues Monitoring

2- Design Enhancements
   - Limit the influence from outside to inside environment
   - Limit the negative influence from the environment on the display cases
   - Replacing cooling system suitable for the indoor environment of the museums
   - Enhance visitors circulation and reduce the interaction with outdoor

Case study 2 (SHAM) required some considerations in the followings:

1- Policy and Guidelines
   - No holistic Strategy for Energy Saving
   - No exact indoor guideline followed and implemented

- HAVC units do not control RH
- Define guidelines for artificat preservations
- Adopt policy for continues monitoring of indoor environment
- Lightings on when not needed
- Little integration between building components

2- Upgrading current systems
  - HVAC system be upgraded for RH mentoring and control
  - Air Curtain to block influence from outside
  - Lighting system to be utilized to be dimmed when not needed

Case study 3 (SMIC) recommendations were for:

1- Policy and Guidelines
  - Strategy for Energy Saving
  - To design guidelines based on the local conditions

2- Upgrading current systems
  - Lighting system

To assess the impact of energy performance of the proposals, reduction or assessments through software simulation have been carried out to quantify the enhancement as well as to identify the best practice from each proposal. The assessment stage was carried out through IES VE simulation, accuracy of results were validated at 99.62% by comparing the base case model energy performance and the utility bills for 7 months.

Experiments for case study 1 (CCM) examined types of light, profiles of operation, enhancements of infiltration as well as controlling the relative humidity in the environment along with the possibility for temperature set points.

Changing the existing lighting operating hours resulted in 57.13% reduction in light electricity by 14.7181 MWh at no cost. This contributed by 21.93% reduction in total electricity over a year.

Replacing current light with LED lights with the adaptation of the same assigned profile resulted in 89.31% reduction in light electricity. Which is significant reduction. This contributed in 33.74% in total electricity in which almost 11% was reduced from the cooling demands of the system yearly.
By making the infiltration rate standard 2.02% annually was reduced in total electricity. By further enhancement and the adoption of air curtain system total electricity could reduce to 3.34%.
Best case scenario was formed based on:

- The adaptation of LED light to operate during occupancy,
- Enhancing infiltration rate to reach to 0.15 ach
- Temperature set points, set to 21°C for exhibition environments and the other environments set to 23°C degrees.

Annual total electricity for the best case scenario dropped from 81.7712 MWh to 55.0648 MWh resulted in 26.7064 MWh over all reduction. This is 32.65% reduction in total electricity.
However, for the safety of the colletions relative humidity had to be controlled. Thus there was little increas in total electricity every month across the year, nevertheless this increase, still kept the total electricity remarkably below the base case model.
Consideraing the overall total electricity reduction in best case scenario with the implimentation of relative humidity control, the over all annual total electrcity reduction was 27.55% reduction over all for case study 1 (CCM).

For the lack of accurate representative infomration for case study 2 (SHAM) light electricity reduction was assumed to be 10.5% by utilizing the current sensors installed in the environments.

As of the assessments for case study 3 (SMIC) implimented only on adopting LED lights for continues operation dur to high number of visitors. Total annual light electricity was calculated to be reduced from 32.6783 MWh 23.7564 MWh (8.9219 MWh reduction), which is overall 27.30 % reduction in annual light electricity.

Overall, through this research, by considering the three case studies as representative models for private and governmental museums in the UAE, it can be concluded that the governmental museums have better conditions in terms of considering museum practices. However, generally museums in the UAE need to enhance their policy and upgrade their current indoor environment conditions to meet the baseline of artifact preservation.

Most important aspect of this study is showing the need for making policies and regulations in the region for museums indoor environment. Official guideline and regulation targeting museum practices, collection preservation in terms of indoor environment of the exhibition areas that considers the climatic conditions are lacking for the region.

As shown in the literature review chapter the indoor environment of the museums is a mandatory factor for preservation and is not a complimentary aspect for increasing the efficiency. Thus, with the growing number of museums in the recent years it is very crucial to identify clear regulations for historical museums specially the ones having ancient artifacts.

Moreover, since the knowledge and experience of governmental authorities are resulting in better practice for museums, private sector should benefit from these available resources. Governments, specially Sharjah museum departments can provide the opportunity for the private sector to benefit from the experts in the department and learn how to solve the challenges facing them. This could be made through different practical workshops or by consultations as well.

A main aspect in this region is that energy saving, intelligence aspect and sustainability are not thought of for existing museums and on going practices. As stated by Sharjah museums department as well as the founder of CCM; enhancements are done only by adaptation in newer projects, while the existing projects stay with the same conditions.

This is also noted on a bigger scale in terms of the regulations of the municipality for different buildings in general. The green building regulation system as well as Al Sa'afat Green building rating systems are only implemented for new buildings that are going to be built. While this would be a practical aspect for building industry in general as there are many new buildings and structures going on in the country, however, it is not efficient for museums in any means. As the buildings of the existing museums are historical, and the aim for them is to preserve them. Also, Al Sa'afat rating system is considering the museums as public buildings category in general and does not have any specification for it. Where as museums with ancient artifacts cannot follow the public building specifications and require special conditions for their artifacts. For the mentioned reasons, having regulation system for museums and artifacts will enhance the current conditions and force the implementation and provide the lacking knowledge of the requirements by the private museums.

6.2. Study Limitation

The study limitation was mainly for the limited time frame of the project. As continues monitoring and measurements for around one year is advised for indoor environment studies as shown in the methodology chapter.

Moreover, even though many researchers, including the author, have tested the intelligence evaluation questionnaire; it was not as efficient for the evaluations of the museums. This could be mainly due to the very technical questions, and the target of highly intelligent buildings. While the case study buildings were much simpler in terms of integration of building components.

6.3. Future Research Recommendation:

- A further stage of this research can be similar study but with continues monitoring that lasts for the different seasons in order to make proposals for energy reduction in terms of season variations.

- Since each museum had different results, considering bigger number of museums to be studied individually is advised for the next stage.

- Study for evaluation of the indoor environment quality of different museums in the UAE. By considering seasonal changes and measurements carried on annual basis.

- A study evaluating the Indoor Air Quality of UAE museums, as currently this aspect is not considered in any local existing museum.

- A study focused only on making case study 1 (CCM) as intelligent museum by proposing complete details of system integration and intelligent building components.

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