Integration of Smart Sensors in Buildings to achieve Energy Efficiency in Hot and Humid Climate

"تكامل أجهزة الاستشعار الذكية لتحقيق كفاءة الطاقة في المباني في المناطق ذات المناخ الحار والرطب"

by

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Abstract

Relevant studies on the subject have revealed that a third of the global and primary energy in the world is being utilized in buildings and associated structures. It is also estimated that this utilization would grow to above 50% by 2030 because of the fast and consistent growth in economic activity and increase in population around the world. People tend to spend the greater part of their time in indoor spaces e.g., commercial and residential buildings. Improving energy efficiency and indoor environment comfort is necessary. Hence, the trend towards designing smart buildings that incorporate intelligent control systems has become the norm in the construction industry (Shaikh et al. 2016).

Most of the current buildings nowadays were built prior the evolution of significant technological advancements such as the internet of things (IoT). Relevant technologies have recently evolved at a vast pace, allowing for the possibility to introduce enhancement on the performance of various building control systems such as electrical, mechanical, electromechanical, automated control systems, renewable energy, building envelope and building insulation, and others. Therefore, it is important to assess the association between retrofitting old buildings and thereby turning them into Smart Buildings and the effect that this exercise may have on their energy efficiency through a holistic method. Of particular interest in this approach is to evaluate the impact on the HVAC and lighting systems in order to optimize the energy usage in those systems.

Based on the detailed literature review that has been carried out to complete this research, it was found that there are few researches that have been conducted in hot/humid climates especially in the gulf region or the United Arab Emirates related to the area of study. Therefore, the research aims to study how can retrofitting existing buildings in the UAE to become smart buildings save energy and reduce the energy demand. The findings of this research can be used to develop strategies that enhances the energy efficiency in existing buildings that have HVAC systems in the UAE and the gulf region.

This research assesses retrofitting the Lighting and the HVAC systems to an existing office building by implementing energy conservation strategies along with smart sensors to reduce the energy demand. An actual field measurement was done to an existing governmental office building in Dubai, and energy conservation measures are

discussed and analyzed to reduce the building energy demand, on the other hand, a computer simulation (IES VE) was used to build a model for an office building in Abu Dhabi and varies energy conservation strategies on the lighting system and the HVAC system were applied and simulated to understand the impact on the modelled building energy demand.

The results for the energy conservation measures that are proposed for the case study building in Dubai showed that upgrading the HVAC system controls could achieve about 17% savings in the HVAC power demand, installing a chiller plant manager would achieve savings of 14%, retrofitting existing conventional AC with invertor AC would achieve 38% savings, and installing adiabatic cooling would save about 11% of the HVAC power demand.

While applying different scenarios in the computer simulation of an office building in Abu Dhabi, the results showed that there is a potential of reducing the power consumption from the lighting system by 16% when replacing the fluorescent lights with LED, and 75% reduction in power consumption when using dimming system that is linked to the occupancy sensors, and 7% reduction when controlling the lights in the building via dimming system based on the external day lighting. The simulation also shows that controlling the cooling set point of the HVAC system can save up to 7% of the power demand, and when linking the HVAC operation with the building occupancy it can save up to 9%, also, using the VAV system can reduce 20% of the energy consumption of the HVAC system.

ملخص:

كشفت الدراسات ذات الصلة بأن ثلث الطاقة في العالم يتم استهلاكها في المباني والمرافق، ومن المتوقع أن يصل هذا الاستهلاك إلى ما يزيد عن 50٪ من الطاقة بحلول عام 2030، وذلك بسبب النمو المتسارع في النشاط الاقتصادي وزيادة عدد السكان في جميع أنحاء العالم. حيث يميل البشر إلى قضاء الجزء الأكبر من أوقاتهم في المساحات الداخلية مثل المباني التجارية والسكنية، وبالتالي فإنه من الضروري أن يتم تحسين كفاءة الطاقة وجودة البيئة داخل هذه المباني. كما أصبح التوجه نحو تصميم المباني الذكية التي تتضمن أنظمة تحكم ذكية من أساسيات البناء في الوقت الحالي.

تم بناء معظم المباني القائمة حالياً قبل حدوث الثورة التكنولوجية مثل إنترنت الأشياء، حيث تطورت التقنيات ذات الصلة بوتيرة كبيرة مؤخراً، مما يسمح بإمكانية إدخال تحسينات على أداء مختلف أنظمة التحكم في المباني مثل أنظمة التحكم الكهربائية والميكانيكية والكهروميكانيكية والآلية والطاقة المتجددة ومواد البناء والعزل وغيرها، لذلك، أصبح من المهم دراسة العلاقة بشكل متكامل بين إعادة تأهيل المباني القديمة بتحويلها إلى مبانٍ ذكية وأثرها على كفاءة استخدام الطاقة، وبخاصة الأثر على استهلاك أنظمة التدفئة والتهوية وتكييف الهواء والإضاءة من أجل تحسين استخدام الطاقة في هذه الأنظمة.

وبناءً على مراجعة الدراسة الأولية التي تم إجراؤها لاستكمال هذا البحث، فقد وجد أن هناك عدد محدود من الأبحاث التي أجريت في هذا المجال في مناخات المناطق الحارة والرطبة وبخاصة في منطقة الخليج العربي أو الإمارات العربية المتحدة، ولذلك يهدف هذا البحث إلى دراسة إمكانية إعادة تأهيل المباني القائمة في دولة الإمارات العربية المتحدة لتصبح مبانٍ ذكية وأثرها على توفير الطاقة في هذه المباني. مما يسمح باستخدام نتائج هذا البحث لتطوير استراتيجيات تعزز كفاءة استخدام الطاقة في المباني القائمة التي تحتوي على أنظمة التكييف في الإمارات العربية المتحدة ومنطقة الخليج بشكل عام.

تم من خلال هذا البحث تقييم لإعادة تأهيل أنظمة الإضاءة والتدفئة والتهوية وتكييف الهواء في المباني المكتبية من خلال تطبيق استراتيجيات مدعمة بأجهزة الاستشعار الذكية لتقليل الطلب على الطاقة، حيث تم إجراء تجربة ميدانية لمبنى إداري قائم لمكاتب حكومية في إمارة دبي، وتم طرح ومناقشة وتحليل تدابير لزيادة كفاءة استخدام الطاقة في هذا المبنى، بالإضافة إلى استخدام نظام محاكاة بالكمبيوتر (IES VE) لبناء نموذج لمبنى إداري مخصص للمكاتب في إمارة أبوظبي وتم طرح عدة استراتيجيات لزيادة كفاءة استخدام الطاقة في أنظمة الإضاءة والتدفئة والتهوية وتكييف الهواء في المبنى ومحاكات هذه الاستراتيجيات باستخدام نظام المحاكاة لفهم تأثير كل منها في تحسين أداء الطاقة في المبنى.

وعليه، فقد أظهرت نتائج السيناريوهات المقترحة لزيادة كفاءة استخدام الطاقة في المبنى الحكومي في إمارة دبي، بأن تحديث وحدات أنظمة التحكم في التدفئة والتهوية وتكييف الهواء يمكن أن يحقق وفورات في استهلاك الطاقة بنسبة 17٪، وتحقيق وفورات بنسبة 14٪ من خلال تركيب وحدات تحكم ذكية لنظام التبريد المركزي، وتوفير ما يقارب من 38٪ عند استبدال وحدات التكييف الحالية بوحدات تكييف مزودة بعاكس للتيار المتردد، كما أن تركيب نظام تبريد ثابت الحرارة سيوفر حوالي 11٪ من الطلب على الطاقة.

ويبين هذا البحث نتائج تطبيق سيناريوهات مختلفة لتحسين كفاءة استخدام الطاقة في نظام المحاكاة بالكمبيوتر لنموذج المبنى الإداري في إمارة أبو ظبي كالتالي؛ إمكانية تقليل استهلاك الطاقة من نظام الإضاءة بنسبة 16٪ عند استبدال مصابيح الفلورسنت بمصابيح الصمام الثنائي (LED)، وتحقيق خفض في استهلاك الطاقة بنسبة 75٪ عند استخدام نظام التحكم بشدة الضوء متصل بأجهزة استشعار الإشغال في المبنى، وتحقيق خفض بنسبة 7٪ عند التحكم في شدة الإضاءة الداخلية في المبنى

من خلال نظام مرتبط بضوء النهار الخارجي. كما تُظهر نتائج المحاكاة أيضًا أن التحكم بضبط درجة حرارة أنظمة التكييف يوفر ما يصل إلى نسبة 7٪ من الطاقة، وعند ربطها بالإشغال في المبنى يصل الوفر إلى نسبة 9٪، كما أن استخدام نظام حجم الهواء المتغير (VAV) يمكن أن يخفض استهلاك الطاقة لنظام التدفئة والتهوية وتكييف الهواء في المبنى بنسبة 20٪.

Dedication and Acknowledgements

I dedicate my research to the sake of Allah, my Lord and my creator, and to my family and friends who helped me and supported me during the entire journey. I also extend my appreciation to my supervisor, Professor Bassam Abu Hijleh who guided and motivated me step by step and has allocated his time and provided his valuable feedback continuously to complete the research.

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Abbreviations and Acronyms

˚C	Temperature scale in Celsius
AED	Arab Emirate Dirham
ANSI	American National Standards Institute
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	Building Automation System
BIM	Building Information Model
BEMS	Building Energy Management System
BMS	Building Management System
CDD	Cooling Degree-Days
CO2	Carbon Dioxide
DCV	Demand Controlled Ventilation
DeepRL	Deep Reinforcement Learning Algorithm
DQN	Deep Q-network Algorithm
DX	Direct Expansion Cooling
EEI	Energy Efficiency Indicators
EMS	Energy Management System
FCU	Fan Coil Units
FAHU	Fresh Air Handling Unit
HVAC	Heating Ventilation and Air Conditioning
IEQ	Indoor Environment Quality
IESVE	Integrated Environmental Solutions Virtual Environment
IoT	Internet Of Things
LEED	Leadership in Energy and Environmental Design
MPC	Model Predictive Control
MWh	Megawatt Hour
NAR	Nonlinear Autoregressive neural network
NZEB	Net Zero Emission Buildings
PM	Particulate Matter
PTI	Purification Time Inference
TR	Ton of Refrigeration
TVOC	Total Volatile Organic Compounds
U	Overall Heat Transfer Coefficient
UAE	United Arab Emirates
VOC	Volatile Organic Compounds

Chapter 1 Introduction

1 Introduction

1.1 Overview

Some of the typical smart control systems in smart building concept include: advanced integrated building management and automation system, HVAC control system, addressable fire alarm system, communication network, access control systems, security, monitoring, surveillance, energy efficient and smart lift system, lighting control digital addressable system, and computerized smart and predictive maintenance management systems (Arditi, Mangano & De Marco 2015).

The Internet of Things (IoT) has shifted the technology towards new type of smart buildings through automating the processes that controls various functions and technologies in the building. The sensor collected data is transferred to automated controllers who send signals to the technical systems following a logical order as for example to close or open the air vents or to switch the lights on or off (Mace et al. 2018).

King and Perry (2017) researched the use of interconnected communication technologies in smart buildings to automate the operation and controls; like; smart lighting control programs, performance monitoring and control of smart HVAC systems through sensors, smart windows to regulate the solar heat and the daylight into the building, smart plug loads to cut off power when devices are not in use, smart central computer consoles for building operators, smart energy resources to store and generate power on site, and smart real-time system optimization to gather and analyse data from the operation and create variations based on pre-set parameters. The study suggested using smart technologies may result in reducing the energy demand, e.g. smart lighting control systems can save 45% and additional 20% to 30% when web based lighting systems are used, smart thermostat save 5% to 10%, also, variable frequency drives (VFD) 15% to 50%, smart plugs save 60%, smart shadow glass up to 30%, building automation system (BAS) saves 10% to 25% from the total energy consumption in the building, in addition, cloud based information system can save between 5% to 10%.

Chenari, Carrilho, and Silva (2016) suggested that energy demand is increasing worldwide, with the building sector contributing considerably to the countries overall energy demand. Hence, it is imperative to study this phenomenon and promote energy efficient buildings. As we have seen, the significant contribution in buildings' energy demand is from the HVAC systems and particularly in office buildings amounting which amounts to 40% of the total demand. Ventilation systems play a vital role in the supply of satisfactory indoor air quality that offers comfort for occupants and reduces possible health issues through the employment of natural, mechanical and/or mix ventilation plans that incorporate the behaviour of the occupants, characteristics of the building, nature of indoor activity, and outdoor conditions.

Hutchins (2016) studied suggested that retro commissioning the existing buildings may be difficult, but it ultimately saves the energy that is otherwise wasted because of control systems' failure or change. Sensors with feedback to control systems are significant in controlling many operations in a building, for example; adjusting the building operations based on the demand and occupancy, scheduling HVAC systems operation hours, recovering wasted energy through the exhausted air, improving the load of the air conditioning based on the ambient temperature, precooling or preheating the ventilated air, in addition to using the daylight and occupancy to schedule and control the lighting hours.

What is a Smart Building? It is a building that offer safe, comfortable and productive environment to the occupants without conceding the energy and/or the operational performance. Those buildings can have diverse infrastructural elements to maintain the comfort levels for their occupants, like; efficient HVAC systems, occupancy monitoring systems, smart metering and others. Mullassery (2015) defined Smart Buildings as buildings which adaptably incorporate smart controls in the different systems and in the building construction material to achieve durability, comfort, and energy efficiency, and due to the usage of smart sensors and technologies it enables the buildings to be adaptable to predict and be prepared for the change over a timeline.

1.2 Energy Audits in Buildings

The energy audit in buildings is a periodic examination and a study and the energy systems to confirm that energy in these buildings is used as most efficiently as possible. It identifies the energy uses in the different systems and opportunities for energy conservation, as well as creating a programme for energy management to systematically apply strategies to control the buildings energy consumption patterns. It focuses to minimize the energy consumption based on the climate where the building is located, the building function and occupancy amongst other factors. It also establishes a balance between the buildings energy requirements as per their function and the actual energy consumption of these buildings (RSB for Electricity and water, 2020).

The energy audits are normally preformed on existing buildings, and the exercise include; evaluating the buildings' envelop, controls, mechanical and electrical equipment, and general overall operations. The usual proceeding step is to benchmark the evaluated results with the most relevant building efficiency standards, for example, in Abu Dhabi there is a programme for buildings and communities designs, construction, and operation called Estidama. While the more used program known as Leadership in Energy and Environmental Design (LEED) is used more widely and is established by the US Green Building Council (USGBC).

The Estidama programme was established by the Abu Dhabi government to support its 2030 strategic plan and vision to creating a sustainability framework aiming to increase the energy efficiency in the capital city. The government has applied Estidama requirements on new development and newly constructed buildings, however, the existing buildings in Abu Dhabi that were built before the introduction of the programme are consuming energy far more than what they should making the UAE amongst the top countries with the largest energy consumption and environmental footprints per capita worldwide.

There are many aspects contributing to the high consumption of energy in existing buildings. In the UAE, more than 70% of the power consumption in the buildings can be found as a result of using air conditioning for cooling purposes due to the hot weather climate and the high temperature in the region, also, the poor buildings' envelop contribute to the increase in the energy demand, including; external coating, infiltrations, insulation, materials, etc. while the poor design of the mechanical system in the buildings and over sizing of the cooling system also result in consuming more power, and waste more space and money for the buildings' owners. However, when designing the cooling systems in the buildings, the negligence of the external factors of the climate conditions like humidity may cause health issues to the building occupants, while operating the cooling system in full capacity when the building is not occupied, for example during night times or winter, can cause redundancy in energy consumption.

The electrical systems in the building, like appliances and lightings are other sources of high power consumption, excessive quantities of lighting and equipment and poor control of the use of the lights during unnecessary times of the day can lead to increasing the consumption.

ASHRAE defined 3 progressive types of audits for energy:

Firstly, ASHRAE Level I energy audit which includes mainly a walk-through and a preliminary analysis of data, it is also known as “screening audit” and it is considered as the starting point for the building energy efficiency optimization. It guides the energy auditors to evaluate the energy performance of the buildings in relations to other similar buildings, and creates a baseline for energy improvements, and where to focus to achieve the highest energy efficiency and potential financial savings. The audit can be performed through interviewing the site operating personnel, reviewing the utility bills of the building for a specific period, a walk-through of the building to identify energy improvements potentials and understand the building configuration and the type and nature of energy systems. The outcomes of this audit includes a high level energy analysis for the building, a short report with the detailed findings, and recommendations.

Secondly, ASHRAE Level II energy audit including assessment, energy survey, and analysis for the building from the previous audit. The assessment and analysis include lighting, HVAC, building envelope, domestic hot water, equipment loadings and plug. A detailed analysis is conducted at this stage for the energy consumption to quantify the base loads, effective energy costs, and seasonal variation. Followed by assessing the factors that affect the building energy performance and the occupants’ comfort including lighting, temperature, ventilation air quality, and humidity. More analysis can be done through detailed interviews with the building operators, management team and occupants to find potential issues areas and explain the financial and non-financial targets of the program. The audit outcomes are reported to the management team stating the various options for energy efficiency measures (EEMs) and their economic feasibility.

Thirdly, ASHRAE Level III energy audit is conducted to detail the capital severe modifications for the building. This stage achieves a thorough understanding of the costs, benefits, and performance expectations. Therefore, computer simulation for the entire building is used to accurately model the building and understand the impact from the proposed changes/modifications, which could be architectural modifications to the building or the HVAC retrofits. Monitoring of electrical equipment, lighting levels temperature, occupants' behaviour and other critical aspects is done via data loggers, the data is then used to calibrate the computer model and simulate the scenarios to check whether the model power consumption reflects the actual power and energy usage in the building.

1.3 Measurement & Verification of Energy Projects

Measurement and Verification is a critical element of any energy performance project. The core objective of the Measurement and Verification is to quantify and verify the energy and operational savings derived from the project measures. The values of the performance and operational parameters are needed to calculate energy savings associated with energy conservation measures (ECM) implementation. A brief description of each methodology is provided below.

- **Option A** is the preferred method for establishing an energy baseline, when it is determined that savings calculations will be achieved from the direct result of reductions in energy performance parameters, and the ECM is a constant load within the facility/building. Option A allows for spot measurement, use of empirical data, or performance parameter stipulation to assess baseline consumption. If performance parameters can be directly measured neither continuous metering nor modelling will be required.

- **Option B** is the preferred method for establishing energy baselines when it is determined that energy savings will be the result of reductions in energy performance parameters, but the equipment/end-use device affected by an ECM is not a constant load within the facility/building. Option B requires spot measurement, short term metering, or data logging to assess baseline consumption.

- **Option C** is the preferred method for establishing an energy baseline when savings calculations make it necessary to measure the interactive affects between variable load ECMs, to determine the impact of the interactive effects of several ECMs on energy savings. This option would typically be used if metered data were available. Option C requires verification of actual performance via whole facility or main-meter measurement.

- **Option D** is the preferred method for establishing an energy baseline when savings calculations will deem it necessary to measure the interactive effects between variable load ECMs, to determine the impact of the interactive effects of several ECMs on energy savings. Option D requires verification of actual performance via whole building/facility analysis using a recognized computerized analysis simulation.

1.4 Energy Subsidies

Historical energy consumption for the buildings energy demand in the Arab region for the period of 1990 to 2015 shows that the energy prices are highly subsidized especially for the oil exporting countries in the gulf region (GCC) which includes the UAE which is considered amongst the highest energy subsidies countries in the World. However, the electricity consumption in these countries have the highest electricity consumption per capita worldwide due to the significant use of the air conditioning loads in the buildings in particular in the summertime (Karti 2019).

Table 1 shows the energy subsidies for the Arab countries for 2015 in which the UAE has a total of energy subsidies equivalent to almost 29 Billion USD which constitutes about 6.6 of the total country GDP and is ranked the third highest amongst the Arab countries after Saudi Arabia and Egypt. The total energy subsidies in the UAE per capita mounts up to 3023 USD/capita, and for electricity it is 337 USD/capita.

Table 1 Energy subsidies in the Arab region 2015 - source (Karti 2019).

Country	Total Energy Subsidies [1] (Billions USD)	Percent GDP (%)	Subsidies of Total Energy Per Capita (USD/person)	Subsidies of Electricity per Capita (USD/person)
Algeria	23.870	10.0	604.70	59.83
Bahrain	3.940	11.2	3224.74	1179.72
Egypt	32.349	10.0	365.79	33.20
Iraq	0.495	0.2	13.37	0.00
Jordan	1.424	3.6	208.67	89.90
Kuwait	14.097	7.8	3429.95	409.78
Lebanon	5.246	10.3	1151.99	465.14
Libya	6.442	10.2	1021.64	0.00
Mauritania	0.058	1.3	15.53	15.53
Morocco	1.957	1.6	58.41	NA
Oman	7.267	8.9	1718.97	102.13
Qatar	14.471	6.4	5995.25	1041.12
Saudi Arabia	106.556	13.2	3395.03	352.54
Sudan	1.375	2.1	35.77	NA
Tunisia	2.004	4.0	180.37	115.28
United Arab Emirates	28.961	6.6	3022.85	337.03
Yemen	0.359	0.7	12.69	6.08
Arab region	250.868	8.3	715.65	85.31

The Arabic countries have electric power generating capacity of 232,675 MW with 6% only coming from renewable resources which is mainly the hydroelectric plants (equivalent to about 11,000 MW). Therefore, majority of the Arab countries including the UAE have set very ambitious targets to increase the usage of the renewable energy resources to meet the electricity demand. Table 2 shows the electricity prices in Arab region for the year 2015 where the UAE’s cost of electricity is about 0.08 USD/KWh and ranked 5th compared to other Arab countries and has a generation capacity of 29,348 MW while the consumption is about 12,916 KWh/capita and the total energy consumption per capita is 5.805 TOE/person, which is equivalent to 23.2 tons of CO2 emission / capita.

Table 2 Electricity prices, energy use, and carbon emissions indicators for Arab countries 20015 - (Karti 2019).

Country	Cost of Electricity (USD/kWh) [1]	Electricity Generation Capacity (MW) [2]	Electricity Consumption per Capita (kWh/person) [3]	Total Final Energy Consumption per Capita (TOE/person) [3]	CO_2 Emissions per Capita (tons/person) [4]
Algeria	0.051	13,000	1451	0.944	3.717
Bahrain	0.008	3889	20,190	4.568	23.450
Egypt	0.033	32,483	1754	0.604	2.199
Iraq	0.009	25,600	1218	0.496	4.812
Jordan	0.092	4882	2288	0.73	3.003
Kuwait	0.007	18,000	14,951	4.523	25.224
Lebanon	0.046	2710	2861	0.835	4.296
Libya	0.016	10,000	1656	1.322	9.187
Morocco	0.123	8202	892	0.435	1.744
Oman	0.026	8750	6588	4.548	15.443
Qatar	0.022	8900	17460	8.769	45.423
Saudi Arabia	0.013	46,400	9926	4.6	19.529
Sudan	0.049	3253	264	0.265	0.309
Syria	0.004	3154	811	0.357	1.599
Tunisia	0.127	4491	1458	0.7	2.587
UAE	0.080	29,348	12,916	5.805	23.202
Yemen	0.041	1500	147	0.095	0.865

The building sector contributes significantly to the national total energy consumption in the Arab region, although it varies from country to another. The consumption from residential buildings is higher than the commercial/public buildings. The overall residential consumption in the Arab region was 791 TWH in 2015 representing about 75% of the entire energy consumed by the building sector. The energy mix for the residential buildings and commercial buildings in the Arab countries is shown in figure 1 and in figure 2. In general the GCC countries uses electricity to meet their energy demand for the buildings stock while the other Arab countries uses combined electricity with fossil fuels, however, Sudan uses hydroelectric power to meet its building energy demand where 84% consumed by the household. The highest energy consumption in the buildings is seen in Saudi Arabia consumes representing third of the energy consumed by all the Arab countries by 260 TWh in 2015, while UAE consumed about 75 TWh in its overall building sector (Karti 2019).

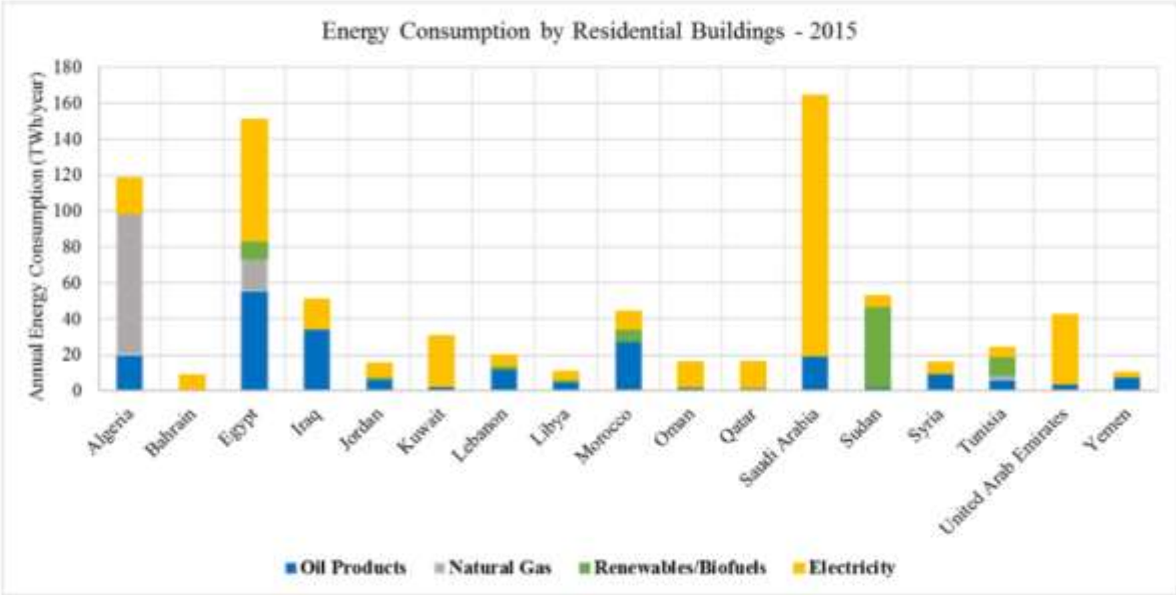


Figure 1 Energy consumption in Residential buildings in 2015 in the Arab countries -- source (Karti 2019).

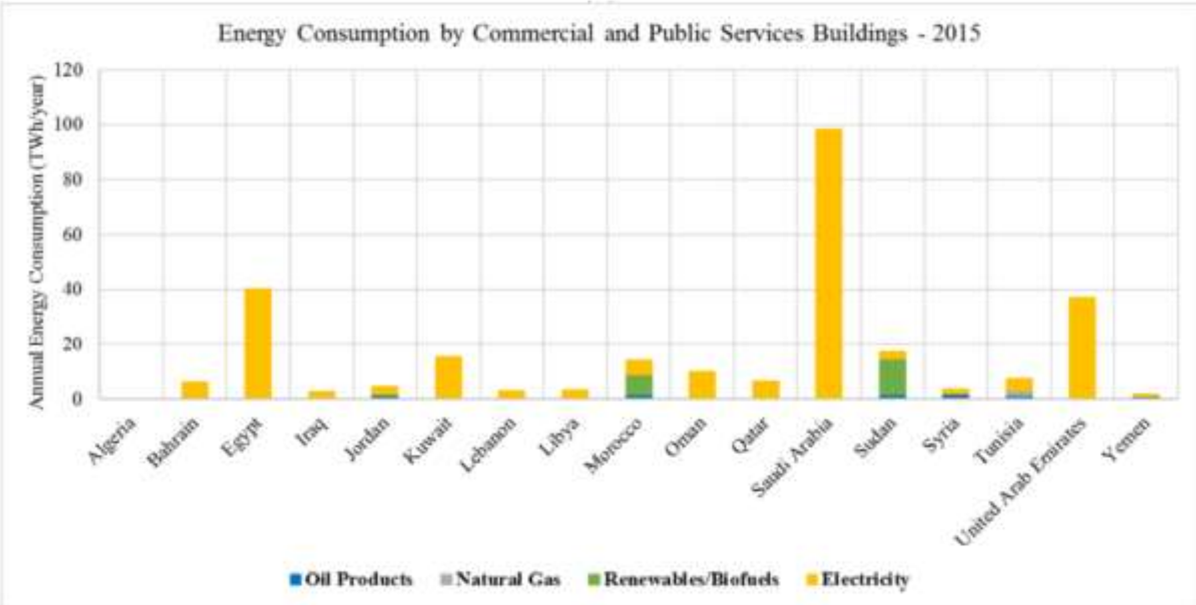


Figure 2 Energy consumption in Commercial & Public buildings in 2015 in the Arab countries - source (Karti 2019).

1.5 Energy Performance Contracting Business Model (EPCBM),

The selection of EPCBMs has become increasingly crucial. Different EPCBMs may impact the EPC project performance differently. This section discuss the three main kinds of EPCBM and their characteristics. However, there are other kind of EPCBMs (Shang et al. 2017).

- **Shared Savings model**: It is referred as a Full Service Energy Service Companies (ESCOs), they sign with the energy client a financing and performance contract that is responsible for the design, finance and implementing an energy performance contracting projects. These companies are required to prove the energy savings through the contractual period. A fixed share of the savings are paid to these companies within a specified period, meaning there is almost no risk to the clients. ESCOs companies bear the credit and the commercial risks, in addition, ESCOs and/ or the funding parties bear the performance risk (Patari and Sinkkonen 2014).

- **Guaranteed Savings model**: The ESCOs companies do not finance the EPC projects but design and implement them, however they could organize funding the project. In this model, ESCOs companies guarantee that the savings form energy to be enough to pay the liability payments. ESCOs companies bear the commercial risks and the client or the funding party bear the performance risk (Patari and Sinkkonen 2014).
- **Chaffee model**: ESCOs are required to operate and maintain the entire energy system for the clients and they carry the energy cost. In this model, ESCOs companies manage and handover the system to the client by self-funding based on agreed targets. ESCOs will get all the energy savings if they achieve the targets. Otherwise, they pay the remaining amount to the client. ESCOs take the funding risk at the same time (Shang et al. 2013). Also, Shang et al. 2017 compared the different kinds of EPCBMs as per table 3.

Table 3 Different kinds of EPCBMs – source (Shang et al. 2017).

		Shared Savings model	Guaranteed Savings model	Chaffee model	Financing Guarantee model	Finance Lease model
Application frequency		low	high	low	low	low
Financing way		ESCO financing/TPF (By ESCO)	Client financing/TPF (By client)	ESCO self-financing	Financing guarantee company financing	Financing lease company financing
Financing cost		high	low	low		
Project's Payback period		Less than 3years	Less than 5 years	Generally longer		Generally longer
Project scale		Generally small	Generally large	Generally large	Generally large	Generally large
Risk sharing	performance	ESCO (and client)	ESCO	ESCO	ESCO (or client)	client
	credit	ESCO/Financing institution	Client/Financing institution	ESCO	Client/ESCO	ESCO
	technique	ESCO	ESCO	ESCO	ESCO	ESCO

1.6 Retrofitting the Existing Buildings

Energy efficiency principles in buildings are used to manage of energy usage of the buildings in order to achieve the intended task while maintaining the minimal consumption of the energy without neglecting the individuals' comfort. There are several active and passive measures that could be used to existing buildings and new buildings. However, there are some aspects that to be considered i.e. reduction in energy consumption, minimizing emission levels in particular the CO2 emission, indoor air quality of the building, and the economic feasibility of the applied energy conservation measures.

Passive measures use minimal energy consumption post installation and in some cases no consumption at all. One of the passive techniques in buildings designs is deploying the sun's energy to heat or cool spaces, while considering the building orientation, shades, building thermal mass, etc. Passive measures in retrofitting existing buildings can aim to upgrade building envelope thermal performance, minimize air infiltration, improve thermal insulation, increase daylight penetration as well as optimizing the advantages of the shading elements.

Conversely, active retrofit measures aim to retrofit / upgrade the mechanical and the electrical systems in the buildings and to provide equipment with high energy efficiency. Those active measures require energy to run and operate. Therefore, active retrofit measures need to be selected carefully, considering their applicability, technical and commercial feasibility and the expected outcome of each measure, therefore, the systems and equipment in the building need to be commissioned properly, and the occupants' behaviour towards energy consumption and conservation lifestyle needs to be altered (WBDG, 2017).

1.7 Motivation

While UAE's increased development is a symbol of the country's growth, some challenges are presented along with progress. Buildings in UAE have been built in the past without taking into consideration the energy efficiency during the design. As such, UAE is ranked among the countries with highest per capita electricity consumption worldwide. For example, the Abu Dhabi Statistics Center reported that the electricity consumption is 66,810,821 MWh/year in the city which interprets to 22.97 MWh/year per capita. These statistics show that the consumption in the city increased significantly between the years 2014 and 2016 as seen in figure 3. Abu Dhabi Distribution Company explained that the electricity consumption in the city has been growing significantly and it will be challenging to manage if no active measures are effectively undertaken in the future (Statistical Yearbook of Abu Dhabi, 2017).

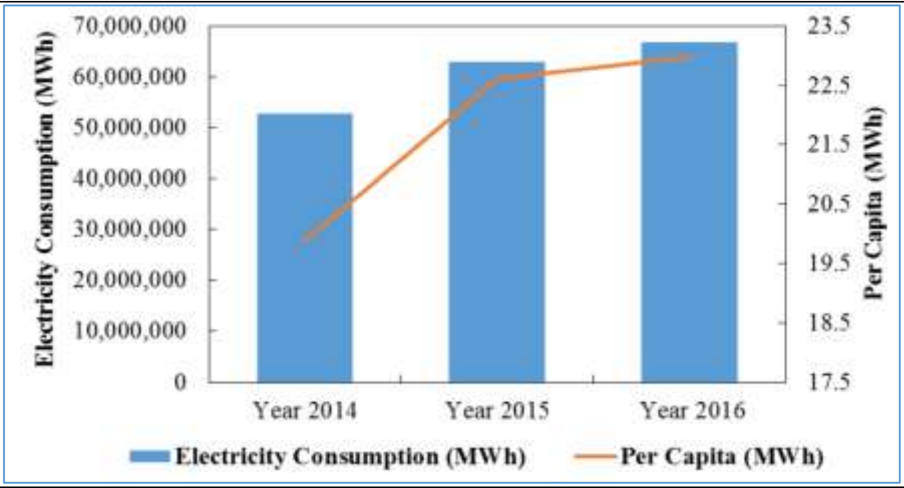


Figure 3 Abu Dhabi Electricity Consumption for Years 2014, 2015, & 2016 – source (Statistical Yearbook of Abu Dhabi, 2017)

Figure 4 shows the electricity consumption in Abu Dhabi from 2014 to 2016. It is noticed that the commercial building sectors contributes to the growing demand with accumulated percentage of 52.2%. Meaning there is a great demand on energy by the building sector and requires some serious actions for energy efficiency. Therefore, the city adopted new regulations to enhance environmental sustainability in this sector and other sectors through introducing a Pearl Rating System in 2011, directing all new buildings to achieve specific measures to minimize their energy consumption (Statistical Yearbook of Abu Dhabi, 2017).

Sector	Year 2014	Year 2015	Year 2016
Domestic	29.4	26.9	25.6
Commercial	**30.1**	**48.1**	**52.2**
Government	24.7	9.3	6.6
Agriculture	5.4	5.7	5.7
Industry	10	9.7	9.8
Other	0.4	0.3	0.1
Total (%)	**100**	**100**	**100**

Figure 4 Electricity Consumption in Abu Dhabi by Sector 2014, 2015 and 2016 – source (Statistical Yearbook of Abu Dhabi, 2017)

Another city in the UAE, The Emirate of Dubai has also established an Integrated Energy Strategy for the year 2030, considering Retrofitting existing buildings as one of the main pillars of the strategy with a potential of reducing the energy demand from the buildings by 9% in 2030, Dubai also, focuses on scaling up the use of renewable/solar energy, the Dubai Electricity and Water Authority (DEWA) started a large scale project for solar grid-connection distributed generation in the region in the year 2014 (State of Green Economy Report, 2015).

There have been numerous studies worldwide that discussed the possibility of retrofitting existing buildings and reducing their energy consumption, however, since the focus on energy demand have been lately (less than 10 years ago) introduced by the UAE government and in particular by Dubai and Abu Dhabi governments, there have been not many academic research papers done in the UAE and in the neighboring counties in the gulf region which has a similar climate to the UAE, to tackle the issue of high energy consumption of existing buildings and to reducing the consumption from those buildings by using smart technology.

In addition, retrofitting buildings in the UAE to be smart buildings will support the country's vision towards achieving sustainable development and will increase the UAE citizens and the residents' awareness on the importance of protecting the environment and the use of energy more efficiently while contributing to mitigating the Greenhouse Gas (GHG) emissions.

This dissertation intends to prove that significant savings can be achieved when retrofitting an existing building to be a more energy efficient building using different energy conservation measures and strategies, with the aim of extending this concept and applying it further to other similar buildings in the UAE while satisfying the local sustainability standard such as "Estidama" in Abu Dhabi.

Based on the detailed literature review on several studies that has been carried out to complete this dissertation, the most key research gaps in this area can be summarized as follows; the majority of previous studies that is done previously to understand how retrofitting existing buildings using smart technology can enhance energy efficiency is conducted in a cold climates where heating for the building is the main player and fewer studies have been conducted in hot/humid climates especially in the gulf region or the United Arab Emirates. Additionally, most of the studies have adopted one or two methods; such as; surveys or simulation.

The importance of this research could be simplified as the most effective way to represent to the buildings' owners in the UAE and in the gulf region (or any other region which have a similar climate to the UAE), where energy efficiency improvements can be made to start reducing the total utility bill of the building and save money. At the end of this research, a set of recommendations and energy efficient improvements are proposed with two detailed case studies, one actual governmental office building in Dubai, and another modelled office building in Abu Dhabi, which have been used to analyse and support the intended energy conservation measures and presenting the outcomes. The research clearly illustrates the current energy consumption of the buildings under study, and estimates the potential savings over the time. It also hopes to support stakeholders to enhance their operational efficiency and longevity of existing buildings while achieving energy savings which by default will be replicated to the overall cost savings of the building and reducing the emissions from the buildings in support of mitigating the climate change at the long run.

1.8 Research Aims and Objectives

The dissertation intends to study the practices and influential factors on the integration of sensors in smart buildings, and recommend strategies/scenarios to achieve energy efficiency. In addition, the research shall answer the following question; **How can retrofitting existing buildings to become smart buildings using integrated smart sensors save energy and reduce the energy demand.**

The dissertation objectives include, studying different research methodologies in the researched area, make comparison and choose the most appropriate methodology, conducting a field experiment on one of the office buildings in Dubai, extracting energy data sets from the historical records of the building, analyze the current state and propose energy retrofitting optimization scenarios and measure their expected impact on reducing the building energy demand, developing a model for an office building in Abu Dhabi using a simulation software, propose different energy retrofitting efficiency scenarios for the base case model and simulate these scenarios to examine their impact on reducing the base case model energy demand.

The outcomes of the research could be used for further strategies that enhances the energy efficiency in existing buildings. Also, the methodology of the research might be used to assess more buildings that have similar characteristics or buildings that have HVAC systems in general in the UAE and the gulf region.

1.9 Research Outlines

This research dissertation is presented in 6 chapters. The content for each chapter is explained below:

- The first chapter presents an introduction and an overview of the main topics in this research, and clarifies the background, the motivation, and the aim and the objective of the research.
- The second chapter highlights some previous literature reviews and studies in this area, it also provides details about smart sensors and cost savings of using smart sensors to retrofitting the buildings.
- The third chapter discusses the different research approaches and methodologies that were used in this area of study and the advantages and disadvantages of each one of them, as well as the preferred research methodology that has been used to complete this research.
- The fourth chapter discusses in details the case study from a government building in Dubai, it provides detailed analysis of the buildings status and suggests conservation scenarios for the building to improve its energy efficiency and presents their expected results.
- The fifth chapter discuss in details the case study of a modelled office building in Abu Dhabi, it provides details about the model and the results from the simulation software for the proposed energy improvement scenarios.
- The sixth chapter provides the conclusion summary of the research, and highlights the key recommendations.

Chapter 2 Literature Review

2 Literature Review

2.1 Previous Researches and Studies

Bin Masood et al. (2017), studied the energy performance of one of **Abu Dhabi's** Petroleum Institute buildings, the researchers applied the ASHRAE levels I, II, and III of energy audit. It was found that the building's energy consumption is 1,065,615 kWh/annum which is equivalent to 155,688 AED per year. The study produced a number of energy conservation measures and were classified based on their retrofit costs into low, medium, and high. A model of the building was created using a computer software and the proposed energy conservation measures were simulated to understand their results and impact on the overall energy consumption. The results showed that savings of 42% could be achieved throughout the building with a payback period of 6.7 years. The retrofits measures included, replacing the DX system with a variable refrigerant flow system while maintaining the same cooling capacity for the building 80 tons, this retrofit achieved about 63% of the total building energy consumption equivalent to 94,190 AED with a payback period of 8.7 years.

A research was done in 2015 to study the potential of efficiency improvement in water and energy in **Abu Dhabi's** building sector in relation to Estidama pearl rating programme. Results of simulation analysis showed a potential in reducing the electricity consumption by 31-38% and for water consumption by 22-26%, based on the type of the building other specific parameters. More results indicated that accumulated monetary savings could be achieved by about AED 19 Billion over ten years period (2011-2020) after implementing Estidama requirements, while the expected accumulated emission reduction for the same period to be 31 Million ton of CO2eq (Assaf and Nour 2015).

(Khouri et al. 2020) studied the energy consumption of an office building located in the **UAE / Sharjah**, the office building was constructed in 2017 and has a floor area of 2000 m2 with steel design and full height glazing structure surrounding the three sides of the building, the building occupants are 40 employees. The study was done via computer simulation under the UAE weather conditions. Several parameters were taken into consideration, including, HVAC system, building orientation, window-to-wall ratio, the U-values of the walls and the roof, and the external shading. These parameters were evaluated to be optimized to achieve the lowest energy consumption possible. The results from the simulation software showed that retrofitting the roof components with a new structure can achieve energy savings by 8.49% and decreasing the overall energy consumption by 38%, while retrofitting the AC system can achieve energy savings by 8.34 and decreasing the overall energy consumption by 37% decrease, in addition retrofitting the walls type with a higher insulating material can achieve 20% decrease in the energy consumption.

Ayoub et al. (2014) conducted a study to understand the energy consumption and conservation measures in commercial buildings in **Qatar**. Results showed a potential energy saving by 7.5% by using envelope design, and about 3-16% through occupants' behavioral changes. They also studied the use of renewable solar energy to save energy by utilizing green energies. The results showed that there is a potential of reducing the CO_2 emissions of the building from using these different scenarios in substantial amounts, in particular adopting 30% of the building energy supply to be from renewable resources, will reduce the emissions by about 27%.

Hassouneh et al. (2015) completed an energy audit for a department in the faculty of Engineering and Technology in the University of **Jordan**, aiming to applying the principles of green buildings to an existing building structure. The results showed that the building insulation resists the heat flow and keeps the building cooler during the summertime and warmer in wintertime. Also, the insulated buildings permit to choose the right size of the HVAC systems and reduce the initial cost from the HVAC system which will also save the costs at the long run as the system do not need work for long hours to maintain required comfortable temperature. They also found double glazed windows can reduce the heat loss from the building which already suffers from a loss of 60% of the heat from using windows that are standard single-pane. it was also found that installing occupancy sensors in the classrooms, facilities and offices within the department can achieve saving up to 20-50%. The also studied the impact of replacing the magnetic ballasts with electronic ballasts and found that it will reduce the heat losses and will eliminate the electric flicker and will save about 25-35%. In addition, the usage of dimmers within the classrooms, offices and facilities with variable luminance can save up to 10-60%. The estimated the annual payback period from electricity bills to be less than 3 years.

Tahsildoost and Zomorodian (2015) conducted a study to understand the energy retrofit meaures on two typical buildings in **Iran** that were built before and after 2000. The study included three main steps: preliminary building energy performance analysis and presenting retrofit potentials, optimizing and prioritizing different scenarios as per the energy simulation and payback period, and evaluation of the applied measures. Results from the simulation and payback period analysis showed that roof insulation, window replacement, and air tightening are the most efficient and suitable options to apply. The buildings were monitored and evaluated after applying those measures, and the savings in total energy consumption was about 30% in the old building and about 38% in the new building.

Sekki et al. (2015) conducted a case study to measure educational schools and universities buildings energy consumption in a **Finnish city**. Results showed that newer buildings consume less energy to heat the building than older ones. They found that there is a 16% less heating energy consumed in the schools that are built after the 1980s compared to the entire schools stock, and a 22% less energy consumed in the schools that are built after 2004. However, the trend of the schools electrical consumption was rising up, they found that the schools that are built in the 2000s have a higher consumption in the electricity by 5% compared to the entire school stock. The study showed that newer buildings have a lower energy consumption, although the Finnish climate is cold, electricity consumption was found to be higher than heating consumption in those buildings that were built in the 2000s.

Wang (2016) examined in his research the energy consumption of 51 universities, 11 middle schools, 5 elementary schools, and 7 high schools in **Taiwan**. Results showed that HVAC system and lighting were the key consumers in the overall building energy consumption. The researcher proposed several energy conservation measures to determining the optimal energy savings in which 9 for HVAC systems, like, variable refrigerant volume systems, variable air volume systems, and total heat recovery systems, which can reduce the chillers workload. Also, regulating the CO2 during summertime via CO2 control system to regulate the outside air intake and avoid placing hot outside air into the building, and other measures. it was found that the proposed measures can save up to 33% of the energy consumption with capital return within 5-7 years.

Aliberti et al. (2019) used internet of things (IoT) technology to predict the outcomes from a school building in Italy (14,5000m2 without air conditioning, district heating system and double glazed windows) via simulated and actual six years data (2010 to 2015). The model was established to measure the indoor air temperature in the school every fifteen (15) minutes through thirteen (13) IoT sensors and devises. The experiment was divided into two stages, testing stage using huge number of simulated data from EnergyPlus software, and exploitation stage using nonlinear auto regressive with smaller actual dataset from the systems performance. The correlation between the predicted and the observed values were analysed via time series analysis. At the end, the study results revealed that the nonlinear auto regressive model provided accurate prediction for the air temperature with a prospect of three (3) hours for the studied rooms/spaces and four (4) hours for the full building.

2.2 Overview of Smart Sensors

2.2.1 Occupancy sensing

2.2.1.1 Image-based sensors

They store information in a matrix and work with the electromagnetic radiation technique. They include luminance cameras, infrared (IR) cameras, and visible light cameras. Image-based sensors can be used to save energy and maintain better indoor environment conditions. The infrared sensors emit waves through the air and are reflected back once they hit an item/object, it analyses the distance from it, understand its shape, and helps to identify the occupancy presence, track the occupant location, count and activity. The main concerns from using camera sensors are limited coverage, higher cost, privacy breach, complexity of installation and its algorithm (Liu et al. 2013).

2.2.1.2 Motion sensors:

They are used to define the presence of occupants, commonly used sensors are, photo sensors, ultrasonic Dopplers, Passive infrared (PIR) sensors, and microwave Dopplers. The ultrasonic and Doppler sensors can measure the speed of the person movement from/to the sensor, and has a larger density than PIR sensors, therefore it might over count small objects movements in the space. Ultrasonic sensors analyses the distance from the object and can measure the occupancy moving through the doorway. The PIR motion sensor is used to identify the occupant presence, and if there is no occupants the lights are switched off, this can achieve efficient light energy usage.

Choi et al. (2016) used both photo sensors and PIR sensors in office space, results showed that saving of 26% of the energy when reducing the switch off period from 20 minutes to 1 minute in the PIR sensor, and 35% energy saving when integrated with

LED light. Motion sensors are usually used for occupancy detection for lights and HVAC controls. As such, false signals cause the system to work improperly and leads to occupants' discomfort. The main concerns in motion sensors is when the occupant does not move for a long time which will trigger the light to turn off, in addition, the timeout period when it is short it causes disturbances to the persons, and if it is long energy will be wasted when the space is not occupied, as such, the optimal timeout set point is important when using motion sensors (Choi et al. 2016).

2.2.1.3 Radio-based sensors:

Dong et al. (2019) clarified that these sensors use radio signals (electromagnetic waves range between 10 kHz and 300 GHz) to identify the occupant presence, location, identity, count, and movement. There are various radio-based sensors; radio frequency identification (RFID), global positioning system (GPS), ultra-wideband (UWB), and WIFI or Bluetooth. GPS is used to identify and monitor the occupants; occupants need to carry GPS-enabled devices to determine their position by wearable devices or smartphones. The accuracy of the GPS system ranges between 1 cm and 10 m, based on the technology used and the weather conditions. RFID uses tags with a unique code to identify people or objects and can measure their proximity. Active RFID tags have a longer range of sensitivity than Passive RFID tags and can be used in large office spaces. UWB is a wireless communication system that measure the person presence via transmitting short signals (its accuracy is between 10 cm and 50 cm). WIFI/Bluetooth devices have a low range of wireless sensitivity (their accuracy is between of 2 m and 10 m depending on the positioning technique). The WIFI access points identify the occupancy presence via WIFI signals. The Bluetooth is used as a low power solution for monitoring and controls applications.

2.2.1.4 Threshold and mechanical sensors:

They identify the occupant presence when interacting with the doors or windows. There are various types, like, door badges, reed contacts, IR beams, and piezoelectric mats. Door badges require occupants to swipe to access the indoor space and can count the occupants, it is expensive device and doesn't count if more than one occupant passes at a time. The reed contacts detect when a window or a door is opened or closed, it consumes a low amount of energy and is a low-cost sensor. The IR beam produces a signal that counts the occupant when it is blocked, however, it will not count more than one occupant if they pass through the beam at the same time.

Piezoelectric mats produce electrical signal when occupants pass on them or stand on them, it is cheaper, but, occupants need to walk or stand long enough on the mat to be detected (Yeom, Choi & Zhu 2017).

2.2.1.5 Chair sensors

Labeodan et al. (2015) explained that these sensors are used to identify the occupancy presence and can save energy through controlling the light and the HVAC system when the occupant is absent. The main concerns of using chair sensor or pressure mats, if the occupant is standing in the zone it doesn't count the occupant, the sensors send false signals if the pressure is not applied on the exact pressure pad or when occupant change seating position, and there is a minimum weight required to activate the sensor

2.2.2 Environmental sensors

2.2.2.1 Temperature and humidity sensor:

Temperature and humidity sensors measure the indoor environmental features in the building and should be calibrated regularly to maintain accuracy. Temperature sensors varies in price, quality, range and accuracy, the precision can vary from less than +/− 0.5 K to less than +/− 0.1 K. The thermo-fluidic sensor measure the temperature of the occupant, they are wireless sensor and measure the indoor environmental parameters like humidity, temperature, thermal radiation and air velocity (Cheng and Lee 2016). The integration between sensors and the building control system enhances the occupants' comfort and save energy. Kim et al (2018) used a heating coil and a cooling fan that are attached to the chair to analyze the occupant thermal comfort. The collected data from the humidity sensor and the temperature sensor attached to the cooling fan and the heating coil on the chair, assist to evaluate the energy use in the indoor space and the comfort levels.

2.2.2.2 Air velocity sensors:

They are utilized to sense the indoor airflow rate with a decent response to real-time changes in the environmental parameters. Choi and Moon (2017) discussed air quality in the indoor environment and its impact on occupant's satisfaction level, they used gender, age, and occupant location in the analysis. The result showed that women are satisfied more with air speed of 0.2m/s at 1.1m height which ties up with ASHRAE standard 55, though, men were dissatisfied with the air speed of 0.2m/s and were content at a lower air flow rate. Dong et al. 2019 explained that a study used a WSN to measure both air temperature and velocity, the sensor works without battery at air flow ratio of 3 m/s, that is sufficient to operate the circuit, the sensor is capable to analyze the temperature and the air velocity with this minor electricity consumption. The study also used a self-powered WSN to measure the air flow rate with sensor contains electromechanical generator and the air velocity is analysed based on the rotor frequency, it operated with a 433 MHz and recorded data every 2s, the system monitor the indoor air speed in real-time.

2.2.2.3 Photometric sensor:

It is a light level sensor that is used to regulate the intensity of the luminaire per the availability of the daylight. Its optimal control reduces the energy consumption while retaining the comfort. The main worry if the sensors is fixed next to a window which can reduce the light for occupants far from the window. The ASHRAE 90.1 average value for illuminance in the office spaces is 500 lx if the zone is occupied and 300 lx if the zone is not occupied (Gentile, Laike and Dubois 2016). Galasiu et al. (2013) implemented 3 different control scenarios to save energy from artificial lights; light sensors, occupant sensors, and dimming controls which were used collectively achieving saving in energy between 42– 47% in comparison to lights working without such controls. The light sensor saved 20% of the energy, the occupant sensor saved 35%, and the dimming control saved 11% of energy. Besides, more parameters to be taken into consideration for the lighting control scenarios, like, glare, the ratio of the color temperature, the light spectrum, and the illuminance vertical to horizontal ratio.

2.2.2.4 CO2 sensor:

Is used for identifying the presence of the occupant(s) and their counting by analysing the relationship between the presence and the level of the CO2 gas that is exhaled in the air parts per million (PPM) by the persons in the building and is used in HVAC manufacturing to control the ventilation demand based on the CO2 (Labeodan et al. 2015). However, the main concerns, like, the mix of air and CO2 concentration is affected by changing the HVAC system air flow rates and the opening and closing of the doors in the office space which leads to false data of occupants counts. A control scenario used to detect occupants' presence through CO2 concentration levels in the return duct, both the actual field case studies and the simulated ones showed that controlled ventilation based on the CO2 level can achieve energy savings up to a 60% in comparison to a constant ventilation rate systems (Lin and Lau 2014).

2.2.2.5 Volatile organic compounds (VOC):

Dong et al. (2019) explained in their study that VOC sensors measure the level of gaseous material in the indoor space, based on the response amongst the targeting gases concentration and the sensing material. They used Transducers to translate the changes in the environmental parameters into electrical signals to analyse the comfort of the indoor spaces, and they suggested that the VOC levels are between 5 and 50 µg/m3 in the building and much higher levels of total volatile organic compound (TVOC). They also indicated that Solid-state sensor measures VOC concentration based on the variations in the semiconducting material electrical properties. Micro-electro-mechanical system (MEMS) made up of optical or micro fabric or nanomaterial based reads the VOC level by a transducer linked to a microprocessor which generates electric pulses as a response to the environmental changes.

2.2.2.6 Particulate matter (PM) sensor:

It is used to detect the indoor air particles levels below 2µ. Some PM detectors use a piezoelectric crystal to detect the indoor air particles, the sensor vibrates when the particles are placed on it and the result shows the quality of indoor air. The concern is the PM sensor ability to detect the low concentration level of pollutants (Snyder et al. 2013). White et al. (2013) utilized a micro fabric piezoelectric film bulk acoustic resonator (FBAR) technique to analyse the PM level in the indoor air. The oscillation frequency varies when the particle accumulate on the surface where the usual frequency is 600 MHz. Because its weight is light, smaller size and low cost, the micro fabric technique is used in the indoor environment. Also, indoor environmental air quality sensors can be connected to smartphone to analyse the measured readings.

2.2.3 Other sensors

2.2.3.1 Wearable sensors, Smartphones and Internet of things based sensors:

Sim et al. (2016) explained in their paper about Wearable devices like watches and bracelets that can be used to sense human data, the location, human temperature, heart rate, air temperature, relative humidity, sleep patterns, and perspiration rate. Smart devices that have innovative technology for communication are called IoT. It is a non-direct sensing method for occupancy. Wearable devices like watches and bracelets and smartphones could be used to collect information about the occupants identity, presence, location, and other information in the building. Also, special Apps collect data from the occupants' feedback based on their comfort level, and can be used to provide better comfort levels and control the thermostat and lights to save energy, it also directly affects the occupant productivity. Cheng and Lee (2014) used wearable devices, smartphones, motion and temperature sensors for comfort levels management and energy efficiency, they obtained information aiming to maintain the desired occupants' temperature while providing feedback to the HVAC smart controllers, and this saved 46.9% of the energy consumption.

2.2.4 Comparison between Smart sensors, their accuracy and costs

Dong et al. (2019) summarized in the figure below the major existing occupancy sensors and compared it to the U.S. Department of Energy ARPA- E SENSOR program goal which aims to have a system that accurately counts the presence of the occupants to enhance the energy performance in commercial building. The study showed that most sensors uses external power source to function which requires wiring and additional costs for large buildings, the sources can be the sensor boards or the sensor element itself. The sensor boards/processors consume power and a sensor that are cloud based needs a high level of data security. they suggested that smart sensors collect and analyse data in a smart way while consuming the minimum power i.e. data collection is not required if the space is vacant for a specific time. They also indicated that Communication usually contributes to more than 60% of the whole sensor unit. Figure 5 represents some of the occupancy sensors technologies and their accuracy vs the costs.

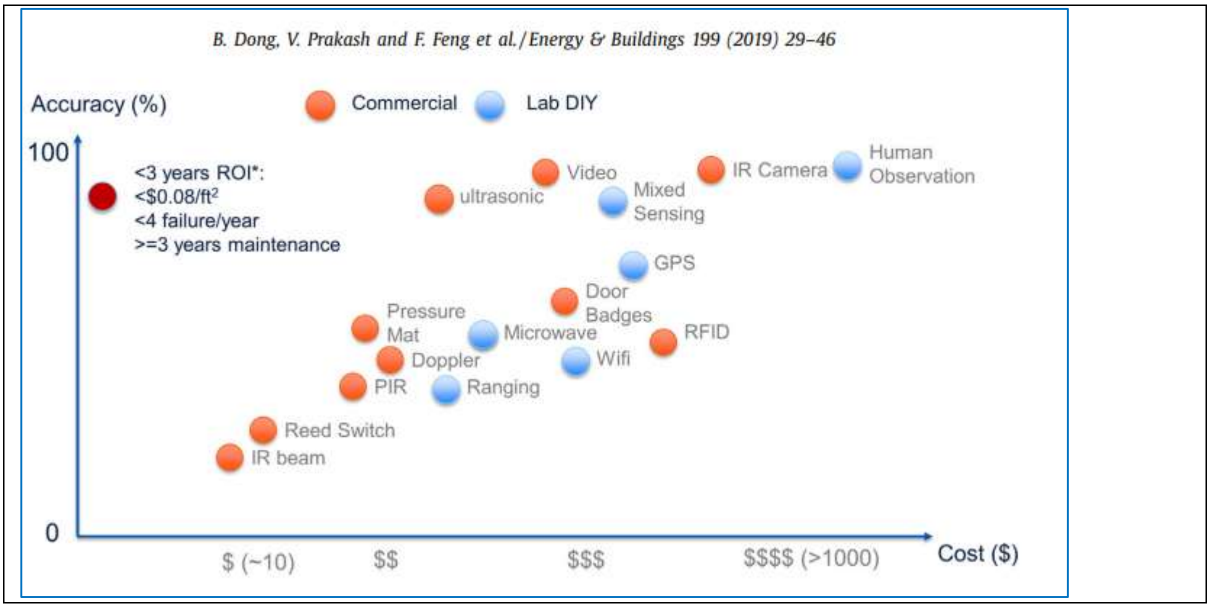


Figure 5 Summary of current occupancy sensing technologies and ARPA-E SENSOR Goal – Source Dong et al. (2019)

2.3 Using Smart Integrated Sensors to Save Energy in Existing Buildings

2.3.1 Energy Savings from smart technologies

King and Perry reported at the American Council for an Energy-Efficient Economy in 2017, the smart building technology is the future through sensors integration to control and monitor the temperature, consumption of the power and the water usage and other parameters in the building in real-time. This has changed the buildings management approaches, to provide the assets' real-time performance, foresees future issues by prediction, and provides sufficient data to rely and act upon accordingly. They also studied and reported the potential savings from individual smart technologies, as listed in table 4.

Table 4 potential savings from individual smart technologies – source (King & Perry 2017)

System	Technology	Energy Saving
HVAC	Variable Frequency Drive	15-50% of pump/motor energy
HVAC	Smart Thermostat	5-10% HVAC
Plug load	Smart Plug	50-60%
Plug Load	Advanced power strip	25-50%
Lighting	Advanced lighting control	45%
Lighting	Web-based lighting management system	20-30% above controls savings
Window Shading	Automated share system	21-38%
Window Shading	Switchable film	32-43%
Window Shading	Smart glass	20-30%
Building Automation	BAS	10-25% whole building
Analytics	Cloud based energy information system	5-10% whole building

They also reported that, smart buildings can reduce energy consumption and achieve saving up to 2.37 KWh/sq.ft and reduce the energy demand by 30–50% from integrating the smart technologies together in the building.

In the same report the researches showed a range of energy savings in a number of commercial buildings from the different smart technologies as listed in the table 5.

Table 5 energy savings in a number of commercial buildings from the different smart technologies - – source (King & Perry 2017)

Building type	Floor area (sq.ft.)	Smart Building technology	Average Energy consumption (kWh/year)	Percentage savings	Average Savings (kWh/year)
Education	100,000	Occupancy sensors Web-based lighting control management system	190,000	11%	20,900
Office	50,000	Lighting controls Remote HVAC control system	850,000	23%	200,000
Hotel	200,000	Lighting controls Remote HVAC control system	4,200,000	6%	260,000
Laboratory	70,000	Air quality sensors Occupancy sensors Real-time ventilation controllers	980,000	40%	390,000
Hospital	120,000	Lighting controls + LED upgrade Data analytics software package	7,900,000	18%	1,400,000

2.3.2 Smart technologies Cost vs Energy savings vs Payback

King and Perry (2017) stated that the purchase cost, payback and energy savings of smart technologies differs across technologies. Technologies that control the building in one application, like a building automation system, are more cost effective in large buildings than smaller buildings due to the square footage covered by the application. However, technologies that are applied excessively all over a building, like smart thermostats, are more cost effective in smaller buildings. Sensors and advanced smart controls have reduced in price because they have become smaller and embeddable, and their wireless capability made them retrofit friendly; they have also less installation and commissioning costs than wired devices. The researchers compared the costs and the energy-saving potential of smart technologies, as seen in table 6, the prices in AED are based on the market prices in the UAE (Honeywell, Johnson Control, etc.).

Table 6 costs and the energy-saving potential of smart technologies - – source (King & Perry 2017)

Category	**Technology**	**Component**	**Cost in** $	**Energy Saving**	**Simple Payback**	**Life span**
HVAC	Wired sensor	Energy, temperature, flow, pressure, humidity sensors	140-385 AED/sensor	N/A	N/A	15-30 years
HVAC	Wireless sensor	Energy, temperature, flow, pressure, humidity sensors	140-385 AED/sensor	N/A	N/A	15–30 years
HAVC	Wireless sensor	Variable frequency drive (pumps and motors)	750-1850 AED	15–50% pump or motor energy	1–2 years	7–10 years
HVAC	Smart thermostat	Smart thermostat	140-385 AED	5–10% HVAC	3-5 years	10 years
HVAC & Lighting	Hotel guest room occupancy controls	Door switches, occupancy sensors	100-500 AED/sensor	12–24% HVAC, 16-22% lighting	2.5–3.0 years	10 years
Plug load	Smart plug	120v 220v	200-500 AED	50–60%	4-12 months	9 years
Plug load	Advanced power strip	Tier One types	$45–50 each	25–50%	8–18 months	10–20 years
Lighting	Advanced lighting controls	Occupancy/vacancy, delighting, task tuning, lumen maintenance, dimming, delighting	$2–4/sf	45%	3–6 years	10–20 years
Lighting	Web-based lighting managemen t system	Software and hardware	$1.15/sf	20–30% above controls savings	1–4 years	10–15 years
DER	Smart inverter	Smart inverter	$0.16/watt	12%	4–5 years	10 years
Window shading	Automated shade system	Shades w/ automatic controls	1110-1850 AED	21–38%	4 years	10-20 years
Window shading	Switchable film	Self-adhered	$15–20/sf	32–43%	2-3 years	10 years
Window shading	Smart glass	Thermochromic Electrochromic	300-350 AED	20–30%	21 years 33 years	30 years 50 years
Building automation	Traditional BAS	Sensors, controllers, automation software	$1.50–7.00/ sf	10–25% whole building	3–5 years	10–12 years
Analytics	Cloud-based EIS	Sensors, communication systems, web-based software	$0.01–0.77/ sf + service contract	5–10% whole building	1–2 years	Length of contract

Building automation system is considered the most expensive technology in this area. The cost of a traditional BAS varies from $1.50 to $7.00/sq.ft., with 10% to 25% average whole-building energy savings. The wireless cloud-based require less hardware than a typical BAS and cost less 30% to install, however, it requires additional costs for subscription service which should be considered. If the building has a traditional BAS, adding a cloud-based remote monitoring will involve a small additional cost. However, if there is no control nor monitoring systems in the building, installing sensors and controls will require higher costs (Tracy 2016).

Chapter 3 Research Approaches and Methodologies

3 Different research approaches that were used in the area of study

In this research over 45 studies were thoroughly reviewed during the literature review, the studies/researches were selected from international journals that are peer-reviewed, based on the research methodology, objective, research structure, data analysis, measurement type, outcomes, model development. It was found that, the key methods used in the researched area are; Literature Review, Modelling, Simulation & Modelling, and Field Experiment, hence, the section below represent some of the examples from each research methods:

3.1 Literature Review Approach

Guyot, Sherman and Walker (2018) studied 38 case studies on residential buildings focused on smart ventilation systems, considering the indoor air quality and the energy demand. After evaluating the studies, they established that energy saving of 60% could be achieved by using smart ventilation systems. They also used the readings of the CO2 concentration level, humidity, ambient temperature, occupancy, and Total Volatile Organic Compounds (TVOC). In addition, the researches used a subgroup of smart ventilation systems that is known as Demand Controlled Ventilation (DCV), this DCV's uses sensors to adjust and control the rates of ventilation in the building continuously and automatically in relation to the concentration level of the indoor pollutants.

Feng et al. (2019) studied 34 case studies on net zero emission buildings (NZEBs). The researches took into consideration the technology, energy performance, and the design strategies in those buildings to evaluate the data. It was found that passive design technologies are adopted in hot and humid climate countries, like; day lighting, natural ventilation, and renewable resources of energy. They classified the technologies into five (5) different groups i.e. lighting, plug loads, HVAC systems, renewable energy, and building design and envelop. As a result, they found that some buildings were not energy efficient despite applying energy efficient technologies in the NZEBs, still some cases were not energy efficient and that there were additional benefits of implementing NZEBs like increasing productivity of the occupants in the building and improving its indoor air quality.

3.2 Modelling Approach

Heo et al. (2019) studied a confined public facility in Seoul (subway station), the researchers recommended to design intelligent ventilation control systems with artificial intelligence (AI) method that manages the indoor air quality (PM10 concentration levels) automatically through deep reinforcement learning algorithm (DeepRL). The DeepRL was trained to decrease the energy demand from the smart ventilation system. The considered three (3) key methods; creating DeepRL control system, evaluating the performance of the ventilation system, and indoor air-quality system environment. The energy performance in the subway was assessed for complete three (3) weeks with respect to various measures of the ambient air and the indoor air quality. The research outcomes revealed that energy demand was reduced by 14% in the subway station and the indoor air quality increased due to using ventilation systems with DeepRL algorithm.

Chen et al. (2014) collect data from 4 buildings in china for PM2.5 level and PM10 level via an indoor air quality monitoring system, the readings from the system were received every minute by a local server that computes every ten (10) minutes the average of the received readings, and sends it to a cloud server which collects data about ambient air quality each one hour. Artificial neural network model was created to assess the efficiency of air pollutants filtration by the buildings' HVAC systems to suggest improvements to optimize the running hours of the HVAC systems, this model identify the faults, and provide information when the filtration system of the HVAC is to be replaced. The researchers used artificial neural network and suggested a three layer model of Purification time Inference (PTI). They found that although using two (2) hours default period attained an exceptional accuracy, but it took long time for purification meaning there is waste of energy, therefore, the default time was reduced.

3.3 Simulation & Modelling Method

Aliberti et al. (2018) studied forecasting the indoor air temperature in smart buildings using nonlinear autoregressive neural network model to improve the energy efficiency, six (6) years dataset was used to train and validate the model, weather data and Building Information Model (BIM) established simulated dataset, the EnergyPlus simulation software apprehended the data. In addition, a multilayer network compared the predicted data and the outputs from the model. Researches recommended some control strategies to reach an energy efficient system consideration the predicted thermal behaviors of the smart buildings.

Plageras et al. (2017) studied Internet of Things (IoT) in smart buildings, they collected data from those buildings via wirelessly connected sensing devices. A smart building model was designed and simulated, the data was collected from the sensors, including; light, temperature, occupant movements, and humidity. Due to using cloud based solution, the building operators can have access remotely and take decisions according to actual and real time data. Network was simulated and the data was gathered using an operating system, however, simulation software was used to simulate real time date. The study concluded that energy demand can be reduced by using smart wireless sensors to collect data and provide real time readings in smart buildings.

Mace et al. (2018) studied smart buildings with a focus on cyber security matters, as the smart buildings send and receive data through internet networks with many integrated systems involved, such as, lighting, HVAC, access control, and many others, therefore, those buildings and their systems could be under cyber security threats. The researchers discussed a methodology using simulation and modelling to evaluate the security of those systems within the smart buildings, and they demonstrated a fan coil unit as a case study.

3.4 Field Experimental Approach

Granderson et al. (2018) talked about a methodology for model predictive control (MPC) to expand the HVAC effectiveness in buildings, the model considered information from a BAS to define the optimum set point, this two way correspondence permitted to assess the real time information and give signals to the BAS to make improvements in the operation and decreasing the energy usage and expenses. Field assessment was done on 4 buildings over 7-15 months, the energy saving was estimated before and after the meters. The outcomes concluded savings of 9% particularly from reset scenarios on the temperature and static pressure of the Air handling unit supply air, yet the new technology of the HVAC system didn't influence the comfort levels, albeit the model presented great outcomes, though, if the building is practicing sequencing and resetting strategies efficiently already it may not be helpful.

Shen et al. (2017) studied 4 Smart Buildings in Canada, they used one to two years data, and installed energy management system in all Buildings; including job requests to deal with the inconsistencies in the HVAC activities, improvement of the HVAC controls dependent on the climate conditions, the synchronization between lighting and HVAC systems, defects, and the occupancy. They suggested that the greater part of the buildings in the United State that have BAS are not working according to the desired plan because of the faults of the sensors and actuators in the BAS. They utilized building energy management system in their experiment to find these deficiencies and fix them along with optimizing the operation of the HVAC leading to saving 15% of the energy consumption equivalent to $818K.

Peña et al. (2016) studied data mining solution in an office building by utilizing the data from sensors to set up some rules to improve the energy performance in the building and identify faults in the intelligent buildings in Spain. Data was gathered from various indoor and outdoor sensors, for example, indoor temperature, occupancy, humidity, daylight, wind, and ambient temperature. They fixed energy analyzers to read the meters in the electrical panels every five minutes and linked them to various systems in the building, like; power, HVAC and lighting to find out how much energy each system consume in the building. They evaluated the collected information via data mining approaches to improve the performance of the building energy management system.

3.5 Advantages and disadvantages of the different Methods:

Advantages and disadvantages of the Surveys and Literature Review research Method: the pros include; it is versatile and could be done by any kind of professionals, it has a wide reach and low cost of collecting large number of data from various sources, besides, it is easy for preparation and has trustworthy outcomes if the survey questions are defined properly along with clear criteria. In contrast, the cons include; potential partiality of the results, having poorly defined questions may result in improper data and information collection, also, there is a potential of misunderstanding the survey questions by the participants which could cause obtaining insufficient and inadequate data.

Advantages and disadvantages of the Field Investigation research Method: the pros include; having direct and hands on involvement by the persons studying the subject as it is conducted in a real environment which minimizes the intervention in the collected data, also, it open the doors to learn different facts that could not be obtained from the survey or the literature review method for example. In reverse, it could be time consuming and costly, people conducting the studying could manipulate the data, influenced by external factors which may affect the results, and it is not easy to replicate.

Advantages and disadvantages of the Modelling and Simulation research Method: The pros include; adaptability by assessing various strategies through varying the main factors, has a solid predicting capability which supports minimizing the risks when taking actions and decisions in the actual investigations, supports assessing difficult situations that are unfeasible to be analyzed through calculations, at the same time it requires less resources that are compared to those needed for the actual investigations, moreover, it does not interrupt the actual system. The cons include; long time is required to prepare the theories that has efficient prediction abilities for the best results which can be costly, also, any faults in the programming of the simulation could lead to improper and inaccurate results.

3.6 Preferred Research Methodology

Researches with effective and accurate results require following the most adequate methods to study the topic, thus, choosing the research methodology is imperative. In this research a **mixed model approach** is selected to achieve the aims and objectives of this research, including, Literature Review, Field Measurement, and computer modelling and simulation. The chosen method is based on the pros and cons of the different methods that have been discussed earlier.

This research integrated more than one approach together, including: (i) A literature review, (ii) A detailed case study including field measurement, and (iii) Modeling and Simulation.

i) The literature review; in this research many previous research papers that have been conducted in the area of retrofitting buildings to be smarter and energy efficient have been studied, some criteria were set to selecting those studies, for example; relevance to the topic, date of publication, authentic publisher, number of citation, climate of the country, buildings characteristics to be similar to those in the UAE, and other factors,

ii) Field measurement and detailed case study; in order to acquire reliable data, interact with experts and observe the systems in a real world scenario a field measurement approach was selected to support the literature review in this research, which enabled bulky historical and real data gathering from the BMS system and the utility bills for the case study that is selected to be a governmental office building in Dubai, the empirical and historical data from the building aided conducting quantitative and qualitative data analysis of the building HVAC system, lighting system, indoor air quality, ambient temperature, inputs from the ASHRAE level 2 energy audit, and enabled proposing set of energy efficiency scenarios that is specific to the building and understate their impact on the building energy performance, the analysis and the results are discussed further in this research.

Modeling and Simulation: following the field experiment and the actual case study, the integrated environmental solutions virtual environment software (IESVE) is used in this research to model an office building in Abu Dhabi, different scenarios were simulated to apply different retrofitting energy conservation measures; including; replacing fluorescent lights with LED lights, using dimming control systems based on occupancy and based on the day lighting, controlling the cooling set point of the HVAC system, and controlling the set point based on the occupancy and based on the wintertime. The outcomes of the simulation is discussed and analyzed in this research.

3.7 Data Analysis in the Research

From the outcomes of the Literature review, the Case study and The model simulation, Qualitative and Quantitative comparisons is made; Analysis is conducted for the building energy consumption during a defined period, such as, HVAC system, lighting system, wintertime, summertime, occupancy. From the observations, measurements, the empirical and historical data analysis, the research assessed the correlation between using integrated sensors and intelligent controllers by converting an ordinary building into a smart building while achieving & enhancing the energy efficiency and comfort in the building. Cooling degree-days (CDD) and building energy consumption were analyzed using regression analysis. Power analyzers are utilized to acquire data from the electrical power systems in the building, like; the HVAC and lighting power profiles. Inventory of the lighting system and lux measurement were recorded, and energy baseline was developed.

Based on the data analysis, energy optimization scenarios using smart controllers and smart sensors for the HVAC and lighting systems are proposed and their results are discussed. Different results were obtained from the simulation software IES VE and presented in graphs and tables. Comparisons were made against the data set obtained from the simulation for the proposed energy conservation measures and the date set of the base case model.

Chapter 4 Case Study for a Government Building in Dubai

4 Case Study from Dubai / UAE

This section will discuss the actual case study that has been done for this research. A Governmental Office building has been selected for this case study in the emirate of Dubai, United Arab Emirates. The study was conducted over 5 months, to consider both the summertime and the wintertime. The sources of Electricity and water in the building is from Dubai Electricity and Water Authority (DEWA).

4.1 Methodology

The primary objective of this case study is to identify the existing energy consumption profile and assess the feasibility of implementing cost effective smart energy technologies and integrating sensors in the facility with a comprehensive analysis, measurements, monitoring, analysis and calculations.

4.2 Building Overview

The building is G+10 floors and 2 basement parking governmental offices that comprises 3 blocks (A, B and C,). Its floor area is 82,194 m2 and was constructed in 2011. The building structure is Glass Fiber Reinforced Cement Cladding (G R C), and Double Glaze Curtain Walls (U-Value = 1.8 W/m^2K) with Vent Gaskets and the Air permeability for the air infiltration is (7 m3/h/m2), and the deflections in Wind Loading is less than (1/250) of the height of the frame. The building has a BMS system and its HVAC system consist of:

- Two (2) air cooled screw chiller plants on the rooftop includes ten chillers (four (4) chillers of 250 tons capacity and six (6) chillers of 273 tons).
- Twelve (12) primary pumps, 10 operational and 2 on standby, and all of them are constant speed, and nine (9) secondary pumps (7 operational and 2 on standby) and all of them are variable speed.
- Eight (8) Air Handling Units (AHU)
- Six (6) fresh air handling units (FAHU).
- Four (4) fresh air units.
- Fifty two (52) Variable Refrigerant Volume (VRV) systems
- Fifty (50) split ducted direct expansion cooling (DX) units.
- Thousand and fifty (1050) Fan Coil Units (FCUs)
- Twelve (12) exhaust fans.

Sun Path Analysis: Sun path demonstrate the arc path that the Sun follows when the earth rotates and tracks the Sun in the different seasons and in the day. It impacts the daytime length and the amount of daylight received in different seasons. The position of the sun has a significant impact on the heat gain of buildings. Considering Dubai's geographic position, building heat gains often peak during the afternoon and for the façade that is oriented to the West direction. The building consists of three blocks having several entrances oriented towards different directions. Considering the location & partial shade from adjacent structures, there is a possibility of maximum solar gain perceived on the eastern façade during the mornings with a possibility of a significant heat gain on the western façade due to afternoon & evening sun. Since part of Block A windows are partially shaded, heat gains during the afternoon sun would be far lesser compared to the rest of the glazed windows on the west facade. The northern walls would receive very limited sunshine throughout the year due to sun's path. Figure 6 shows the sun path for the building.

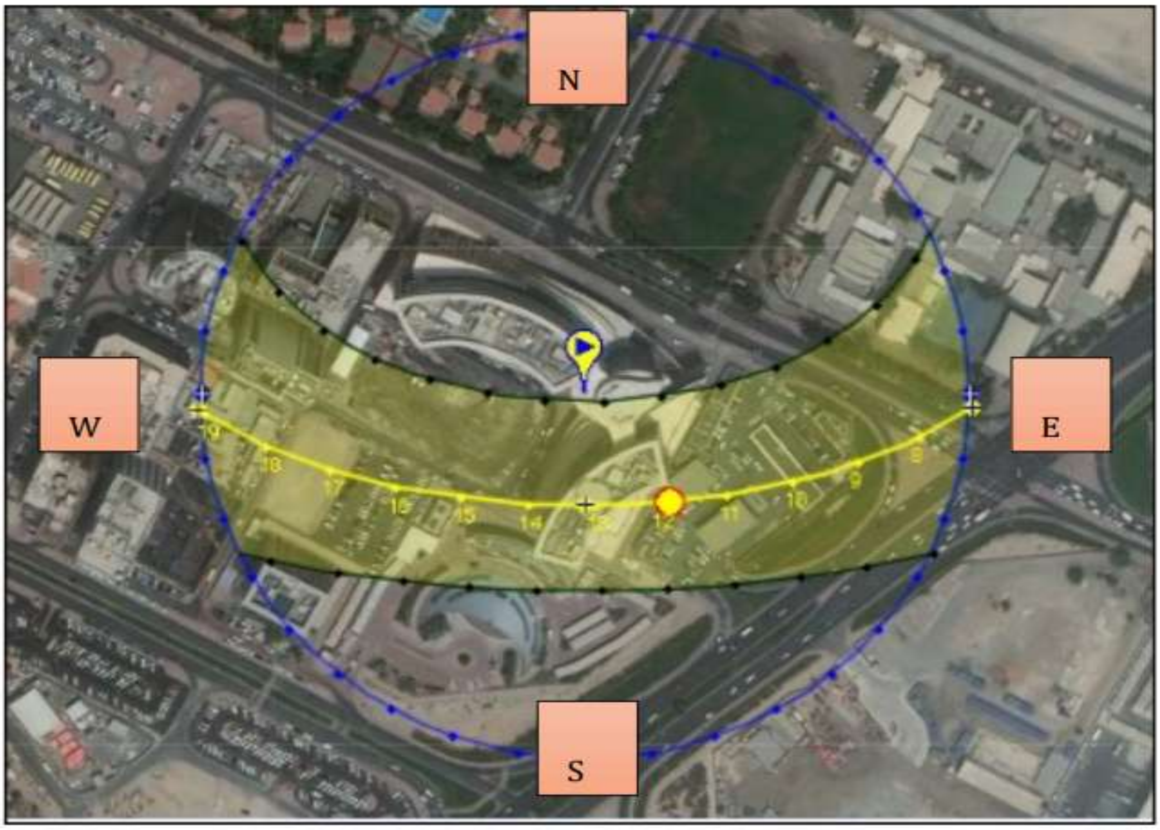


Figure 6 Sun Path Analysis

4.3 Measurements Activities

Various instruments were used for measurements in the case study as per table 7.

Table 7 measurements and instruments

#	Measurement	Instrument Used
1	Building power at MDBs	BMS data/ Power analyzer
2	Chiller plant cooling and power profile	BTU meter & Power Analyzer
3	Pumps power profile	Power analyzer
4	FAHU measurements: • Air flow • Temperatures & Relative Humidity • Power	 • Anemometer, • Thermo hydrometer, • Power analyzer
5	CO2	CO2 meter
6	Lux levels	Lux meter
7	Water Measurements	Water jar/ clock
8	FCU	Power analyzer/ temperature logger
9	Instantaneous Power Measurements	Power analyzer

4.4 Building Services

The major elements of energy consumption in each block in the building are described in detail as below:

HVAC System: The building is conditioned by two air-cooled screw chiller Plants, one located in Block A and the other in Block C. The chilled water is then distributed to the building via a secondary pump to the AHU/ FAHU/FCUs.

Chillers: The facility has its own on-site chiller plants; 4 chillers are located in Block A having a capacity of 250 TR and 6 chillers sited in Block C with a capacity of 273 TR respectively. The chilled water set point temperature for all chillers is maintained between of 6-7 °C. Table 8 includes the make and the capacity of the chillers.

Table 8 Chillers capacity

Chiller Plant location	Make	Chiller model	Capacity TR	Qty	Serving block
Block A	Carrier	30XA902	250	4	Block A
Block C	Carrier	30XA1002	280	6	Block B and C

Primary and Secondary Pumps: The chilled water system configuration is constant primary and variable secondary flow, where both primary and secondary chilled water network are present. The primary circuit consists of primary pumps (One for each chiller) and associated pipework, supplying a constant flow across each chiller. The secondary circuit consists of variable speed pumps, which operate based on differential pressure set point across the index line of the chilled water network. Each chiller designed with one primary pump and secondary pump works with differential pressure setting. Table 9 includes the power rating of the pumps.

Table 9 Primary and Secondary pumps capacity

Location (Block)	Pumps	Rated Power (kWh)	Qty
Block A	Primary Pump	15	5
	Secondary Pump	22	4
Block C	Primary Pump	15	7
	Secondary Pump	30	5

Fresh Air Handling Units (FAHUs) / Air Handling Units (AHUs): Total of 6 fresh air handling units (FAHU) supply fresh air into the building with different power rating as listed in the table 10 below. Except FAHU-4, all other FAHU installed with heat recovery units. Operation varies from 13 to 24 hours.

Table 10 Fresh Air Handling Units (FAHUs) / Air Handling Units (AHUs) capacity

Sr. No.	Airflow (m3/hr.)	Supply Fan Power (kW)	Return Fan Power (kW)	Heat Recovery Unit	Quantity
1.	33656	37	11	Yes	1
2.	42448	30	7.5	Yes	1
3.	46897	37	15	Yes	1
4.	15296	10	NA	No	1
5.	50119	37	17	Yes	1
6.	44176	37	15	Yes	1

DX Units: All DX units mainly serving the different locations such as UPS, IDF room, mechanical rooms, electrical rooms and some offices as listed in Table 11 below.

Table 11 DX Units capacity

Equipment	Capacity	Rated Power (KW)	Qty
Decorative Type Split	1.54	2.45	11
	2.6	3.59	2
	2.7	3.7	2
	1.43	2.04	2
	2.52	4.25	3
	2.54	4.82	1
	2.0	2.69	1
	0.83	1.46	1
	2.0	3.1	1
	2.82	3.6	1
	2.59	3.5	1
	2.0	2.69	1
	2.0	3.0	1
	2.0	3.0	1
Split Ducted	4.5	5.0	6
	6.4	9.0	1
	3.78	5.47	3
	3.0	4.0	2
	3.5	5.0	5
	3.12	4.11	2
	3.2	4.27	1

Variable Refrigerant Volume (VRV) Systems: In addition to a chiller plant, the facility is also equipped with multiple VRV. Table 12 shows their models, capacity and the rated power of the VRV system used in the facility.

Table 12 Variable Refrigerant Volume (VRV) Systems capacity

Equipment Location	Make	Model	Capacity (TR)	Rated Power (KW)	Qty
VRV -Block A	DAIKIN	RXYQ8P	6.4	5.22	2
		RXYQ10P	8.0	7.42	8
		RXYQ12P	9.5	9.62	6
VRV -Block C	DAIKIN	RXYQ10P	8.0	7.42	18
		RXYQ12P	9.5	9.62	18

Lighting Systems: The facility is fitted out with a combination of LEDs, FTL and Compact Fluorescent lamps. Corridors lamps fitted with motion sensor and partially lamps are scheduled through Clipsal lighting control. Generally, Lights switched ON/OFF from 6:30 am to 04:30pm. The facility has already taken initiatives to replace the existing conventional lamps with LED.

Building management system: There is Honeywell BMS and Niagara based iBMS for the monitor and control of all major equipment in the facility, FCUs, FAHU, AHUs are scheduled through the iBMS.

4.5 Baseline Energy Summary

The facilities annual electricity consumption is around 7,546,600 AED. The electricity (from DEWA) is supplied to the facility by 14 Low-Voltage panels. Monthly electricity consumption data was obtained for the years 2017, 2018 and 2019. The total energy consumed by the facility during the time from July 2018-June 2019 is taken into consideration for the baseline analysis as shown in figure 7:

- Annual Electricity consumption: 17,151 MWh
- Annual Electricity cost: 7,546,600 AED
- Average Electricity cost: Approx. 0.44 AED/kWh (2018-2019)
- Maximum electricity cost: 861,974 AED in August
- Minimum electricity cost: 425,092 AED in March
- For the same period from July-2017 to June 2018, the electricity consumption is higher by 5.95%.

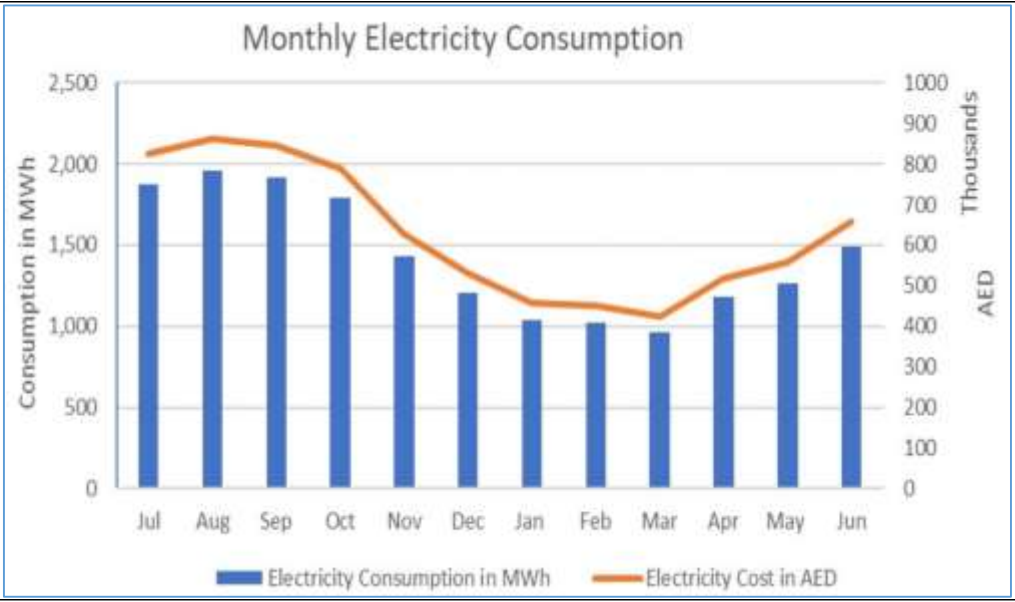


Figure 7 Monthly Electricity Consumption

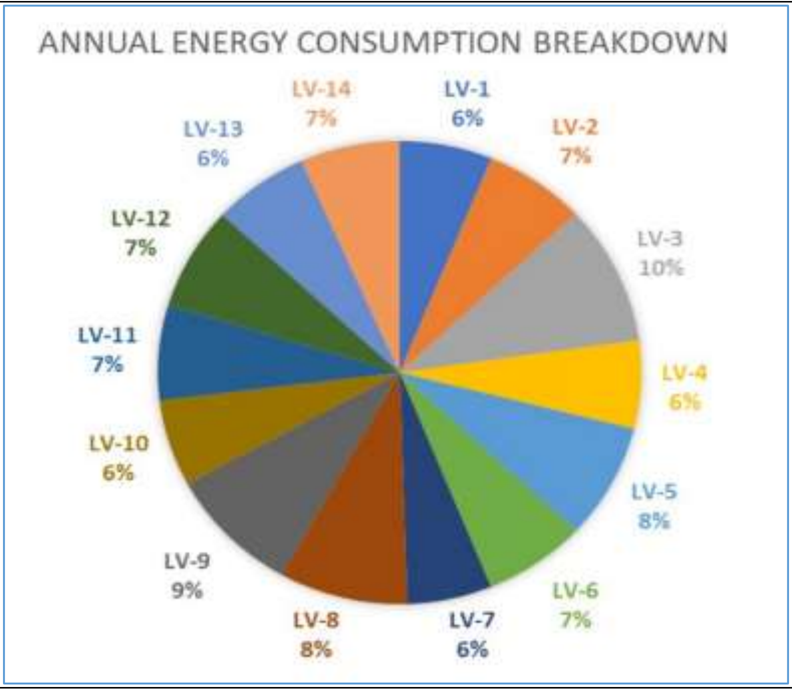


Figure 8 Annual Energy Consumption Breakdown

Figure 8 depicts that LV panel 3 consumes the most at 10% on an annual basis in which the Block C chillers number 5 and 6 is connected, followed by other LV panels consuming in between 6%-9% respectively. Table 13 shows the load covered by each one of the LV panels in the building.

Table 13 Total Annual consumption and the load

LV No.	Total Annual Consumption (kWh)	Load covered
LV 1	1,163,434	Block- C Chiller 1,2; SMDB-F10C1
LV 2	1,320,799	Block C Chiller 3,4; SMDB-F10C2; SMDB-F1C
LV 3	1,829,466	Block C Chiller 5,6 ;SMDB-B2
LV 4	1,152,715	SMDB-F5C1, F8B, F4C1, F3C1, F3C2, F1C1, F6C1,SMDB-FAHU
LV 5	1,503,928	SMDB-GC2, F2C2, F1C2, F4B, F6C2, ESMDB-G2
LV 6	1,275,003	SMDB-GC1, F2C1, FB, F2B, F3B, F7B, F5C2, F9C2
LV 7	1,063,558	SMDB-F4C2, RF, F7C1, F8C1, F9C1, F8C2, F7C2, F6B, F5B
LV 8	1,626,274	Block A Chiller 7 & 8, SMDB-F1A1
LV 9	1,627,070	Block A Chiller 9 & 10, SMDB-F3A1
LV 11	1,125,432	ESMDB-G1, SMDB-SHA2, F4A1, F5A1, F5A2, F8A1, F3A2, F10A1
LV 11	1,231,642	SMDB-POF, F2A1, F10A2, F2A2, GA2, GA1
LV 12	1,338,826	SMDB-F7A1, F7A2, F8A1, F8A2, F9A1, F9A2, LIFTS, RF(A)
LV 13	1,193,153	SMDB-BASE A, UPS-(1), UPS-1A, SMDB-RA1, RA2, R3, UPS-2A, UPS-(2), SMDB-BASE B
LV 14	1,238,950	SMDB-RC1, RC2, RC3, GC, BASE C, ESMDB-F8B

Breakdown analysis End-user breakdown analysis is carried out using measured power, operating hour and % loading based on constant load and variable load. Constant load includes: lighting, AHU, FCU, office loads, chilled water pumps. Variable loads includes, chiller, secondary pumps, DX units. The baseline energy consumption of the building for its different equipment like AHUs, Air Conditioners, Chillers, Pumps & Lighting fixtures are given in figure 9 and figure 10. The analysis shows that, HVAC accounts for about 57% of the energy consumption in which chiller consumes about 34%. Energy Performance index is 210 kWh/m2/year.

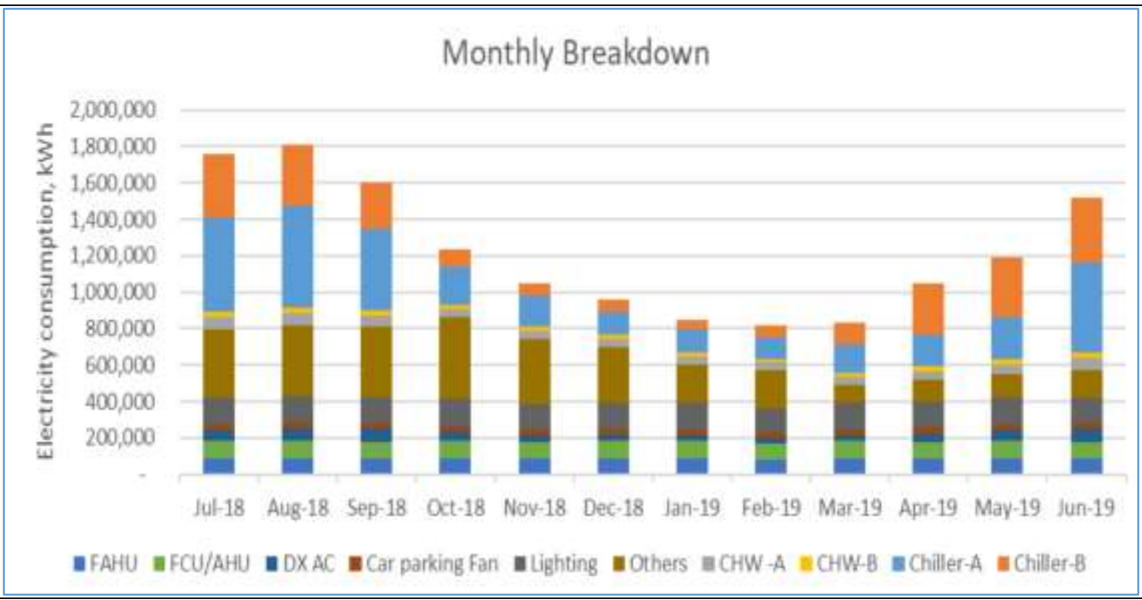


Figure 9 Monthly breakdown – Load analysis

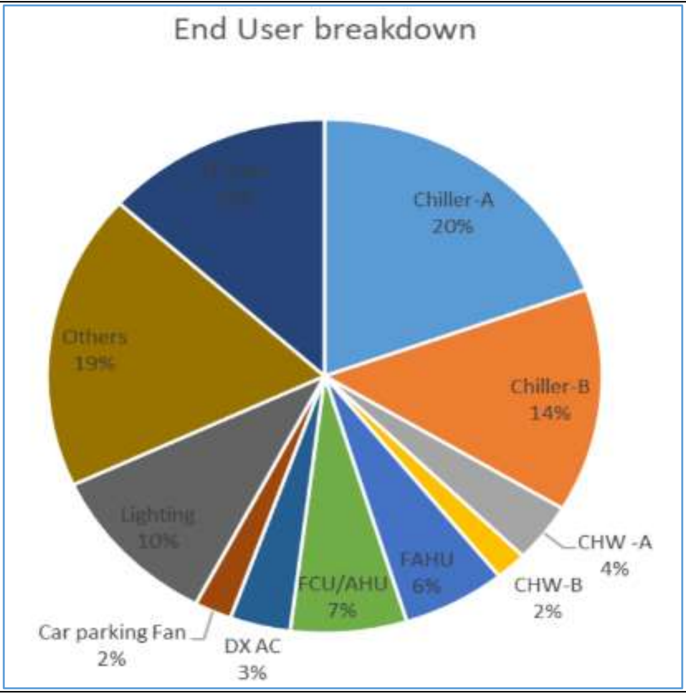


Figure 10 Load Balance - End User

4.6 Regression Analysis

Heating and Cooling degree days (HDD/CDD) are used to understand the impact of the ambient air temperature on the energy consumption of the building over a particular time. HDD/CDD symbolise the number of days and the number of degrees that the ambient air temperature at a particular location is lower or higher than a particular reference temperature. Since the building is air-conditioned and no heating is involved, only CDD have been considered as independent variables.

The relationship between these two variables is represented by the equation (y=mx + c), alphabet ‘y’ represents energy consumption plotted on the y axes and ‘x’ represents cooling degree days plotted on the x axes. Slope of the line ‘m’ represents degree by which energy consumption varies corresponding to a rise of ‘x’ degree days. Constant ‘C is known as base load, which is considered to occur as a constant load and is independent of the amount of degree days. R2 is the co-efficient of determination of the model and if its value is above 0.75, then the model is considered to correlate considerably with the independent variable.

Monthly data for cooling degree days (CDD @ 20C) from Dubai International Airport and the electricity consumption from the building were analysed for the year July 2018-June 2019 as shown in Figure 11. Similarly, regression analysis was performed for individual LV panels 1 to 14 combined and are plotted in the sections below; Historical total annual electricity consumption for the months (July 2018- June 2019) was analysed for its dependency with monthly cooling degree days. The R2 (co-efficient of determination) value for regression model is apparently 0.73, this signifies that the weather (CDD) does not show any strong correlation with the electricity consumption of the facility.

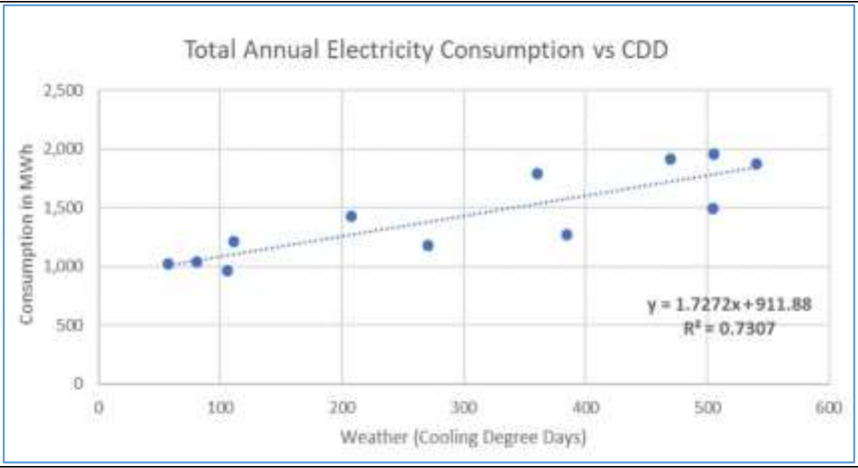


Figure 11 Linear Regression Analysis – Total Annual Electricity Consumption vs CDD (July 2018-June 2019)

4.7 Field Assessment and Analysis

Extensive measurements were carried out at the facility to identify existing equipment performance, operational philosophy and energy losses. In addition to the above historical data from the iBMS was collected and analysed. The following sections provide a summary of the measurement and analysis performed;

Electricity Consumption: The building power consumption was collected from iBMS for all 14 incomers in order to understand the consumption pattern of the facility. Power consumption was analysed for four days covering normal working days (Sunday to Thursday) and weekends (Friday and Saturday) to understand the building operating patterns during both summer and winter seasons. Observations are as follows:

- Day and night consumption is almost 55% and 45% in summer time & winter time. (Night hours are considered from 6 PM to 6 AM).
- Day consumption between working and non-working day is almost same in summer and observed some difference in winter periods.
- Base load in summer and winter is about 1800 kW and 1000kW respectively.

Summer Season

Summer Season Weekend vs Weekday Consumption Comparison

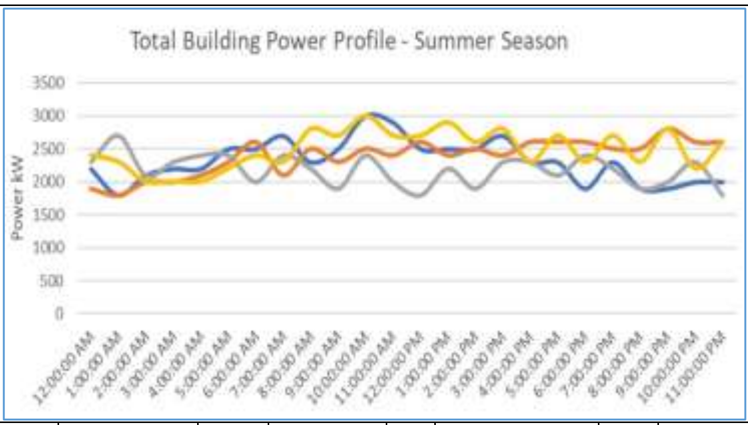
Table 14 shows that the total power consumption in the working days (Sunday to Thursday between 7am – 4pm), during summer season is higher than the weekends, this is due to having less occupants working in the building during the weekends, however the difference between the consumption in the working days and non-working days is not significant as the HVAC system is kept on in most common areas in the building, and the HVAC ventilation system runs 24 hours due to the hot and humid weather during this period.

Table 14 Summer Season Weekend vs Weekday Consumption Comparison

Date (August)	**Working day 1**	**Weekend 1**	**Weekend 2**	**Working day 2**
Average (kW)	2,321	2,838	2,179	2,487
Maximum (kW)	3,000	2,800	2,700	3,000
Minimum (kW)	1,800	1,800	1,800	2,000
Total Consumption (kWh)	55,700	57,200	52,300	59,700
Day Consumption (kWh)	30,700	29,500	25,500	31,900
Night Consumption (kWh)	25,000	27,700	26,800	27,800

Also, the building power profile for the summer season as seen in figure 14 shows that the energy consumption correlates with the official duty hours of the employees (Sunday to Thursday between 7am – 4pm), however, there is still an ongoing operation in the building before and after the mentioned time like, call centre, GYM, other operations which runs 24 hours a day, as well as the routine maintenance activities that is scheduled out of official duty hours.

It is also noted from figure 13 that MDB 1 which serves Block C chillers no1 and no.2 contributes to the highest energy consumption during the summer season by 14% and the least consumption is in MDB 9 with 1% which serves Block A chillers no.9 and no.10.



Thursday Friday Saturday Sunday

Figure 13 Total Building Energy Consumption Profile during Summer Season

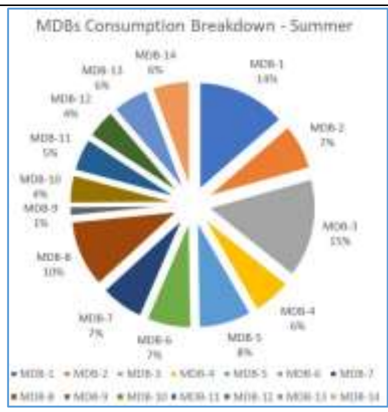


Figure 12 MDBs Total Consumption Breakdown – summer

Winter Season

Winter Season Weekend vs Weekday Consumption Comparison.

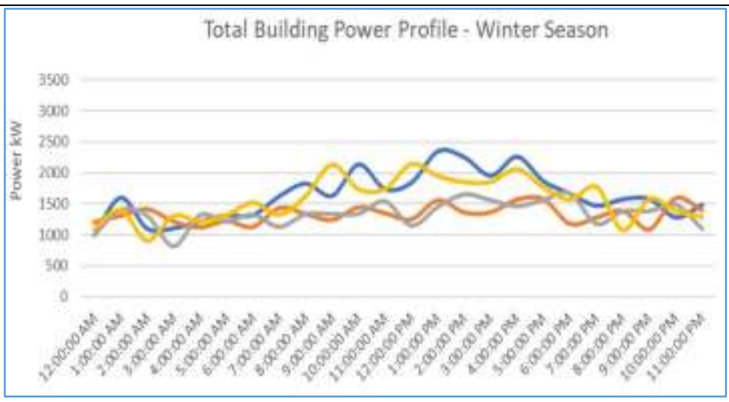
Table 15 shows that the total power consumption in the working days during winter season is higher than the weekends, this is due to having less occupants working in the building during the weekends.

Table 15 Winter Season Weekend vs Weekday Consumption Comparison

Date (December)	Working day 1	Weekend 1	Weekend 2	Working day 2
Average (kW)	1638	1329	1338	1571
Maximum (kW)	2352	1588	1672	2148
Minimum (kW)	1000	1084	812	908
Total Consumption (kWh)	39304	31904	32104	37704
Day Consumption (kWh)	22852	16552	16852	21752
Night Consumption (kWh)	16452	15352	15252	15952

Also, the building power profile for the winter season as seen in figure 15 shows that the energy consumption correlates with the official duty hours of the employees (Sunday to Thursday between 7am – 4pm), however, there is still an ongoing operation in the building before and after the mentioned time like, call centre, GYM, other operations which runs 24 hours a day, as well as the routine maintenance activities that is scheduled out of official duty hours.

It is also noted from figure 16 that MDB 8 which serves Block A chillers no.7 and no.8 contributes to the highest energy consumption during the winter season by 12% and the least consumption is in MDB 9 with 1% which serves Block A chillers no.9 and no.10.



Thursday | Friday | Saturday | Sunday

Figure 14 Total Building Energy Consumption Profile during winter Season

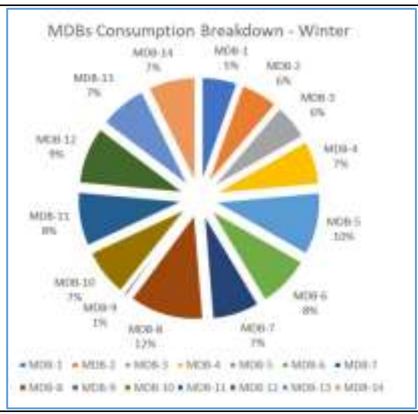


Figure 15 MDBs Total Consumption Breakdown – Winter Season

Comparison: Summer Vs Winter - Total Building Power Profile: Analysis was done to compare the total building power profile in the winter season and the summer season for two official working days (Thursday and Sunday) and two official non-working days

(Friday and Saturday). It is found that the building power profile correlates in terms of the increase and decrease of the power consumption in the weekdays and weekends as seen in Figure 16. Also, as expected the energy consumption during the summer time is higher than winter time due to the more usage of the cooling system in the building as the outside temperature and the humidity in Dubai increases during summer time.

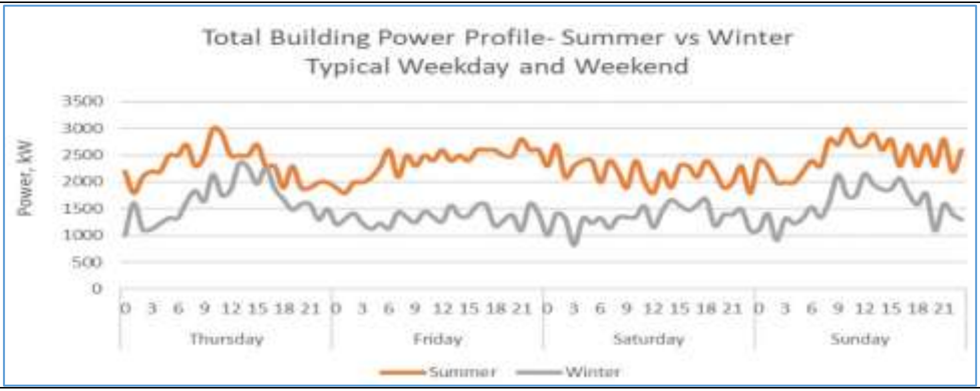
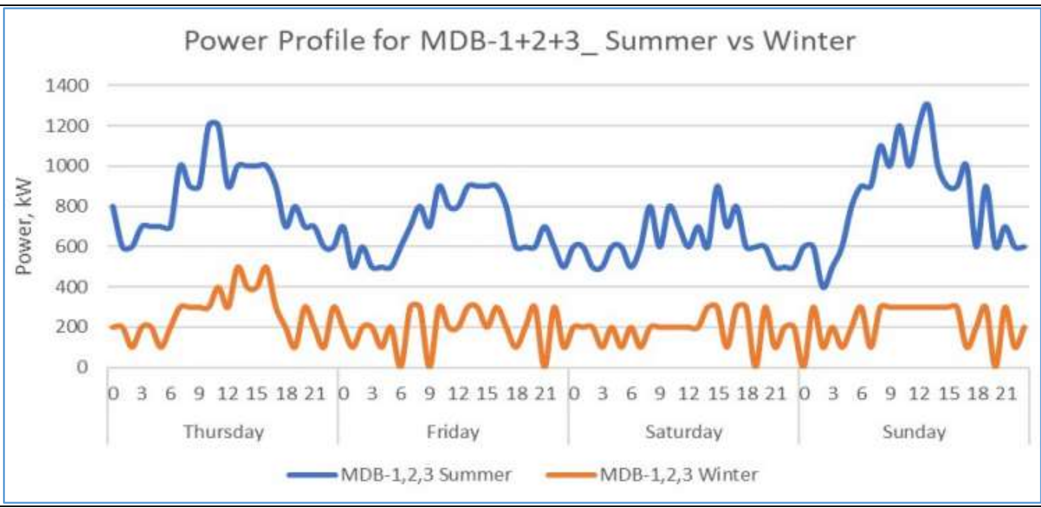


Figure 16 Comparison Summer Vs Winter Total Building Power Profile

Comparison: Summer Vs Winter for the MDBs (LV 1 to LV 14). Further analysis was done for each one of the MDB panels to understand the relation between the consumption in the summer time and the winter time for each MDB and their related load. It was found that the major changes happen with the MDBs that are serving the chillers in the building i.e. MDB 1,2, 3, 8, and 9 in which the power consumption increases significantly in the summer time compared to the winter time especially during the working days (Thursday and Sunday) as seen in figure 18. However, it was also noted that there is an abnormal increase in the energy consumption during the weekend days in MDB 8 and 9 which could not be justified at this stage. The comparisons results for the rest of MDBs are available in *Appendix A*.



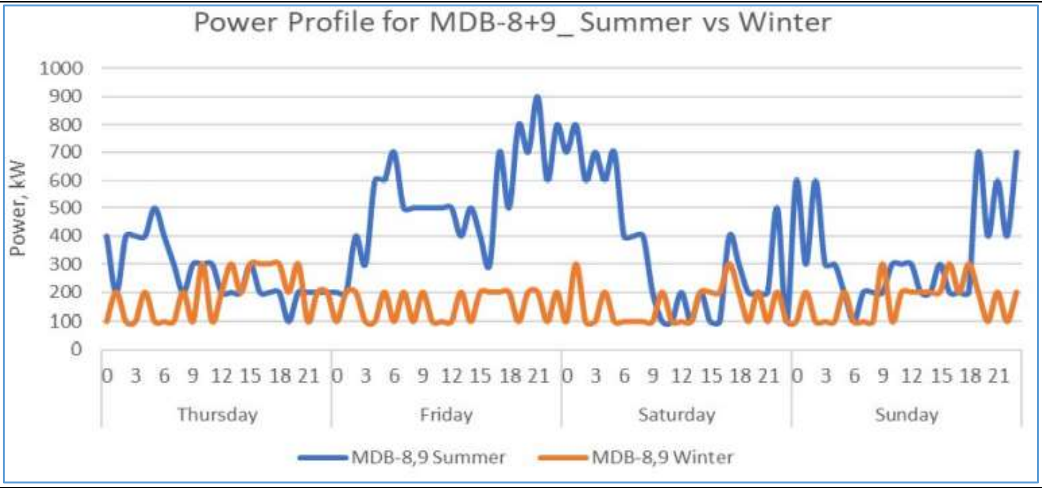


Figure 17 Summer Vs Winter MDBs

HVAC Systems:

Chillers: The buildings cooling demand was recorded for a period of 4 days covering workdays and weekend (Thursday to Sunday). Simultaneously, a power analyser was installed to record the chiller power consumption. Chiller profiles provides chiller performances, hours of operation and operating pattern as seen in figures 19 and 20 which represents the chillers power profile and the Chilled water flow rate for Block A,

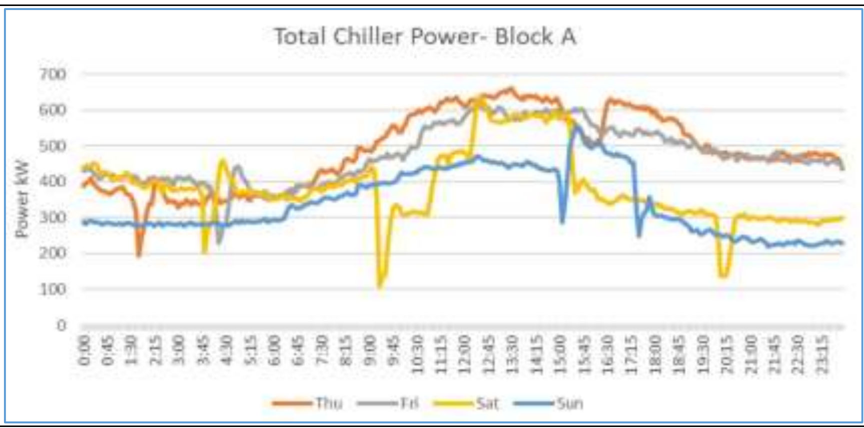
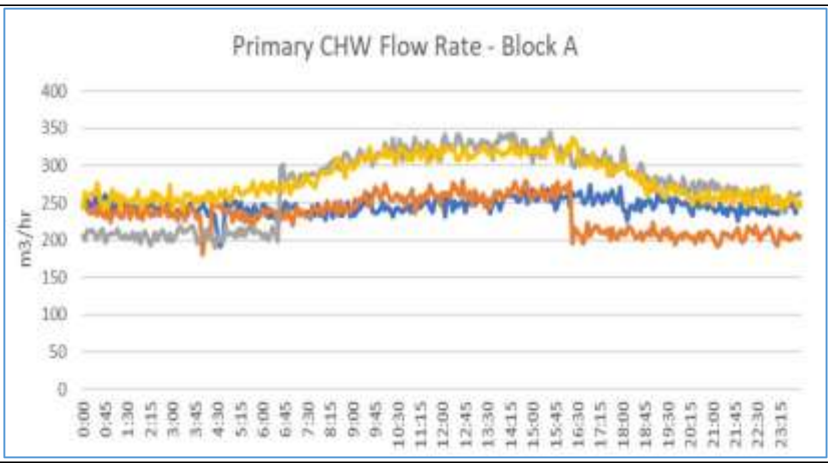


Figure 18 Total Chiller Power Profile for Block A



	Thu		Fri		Sat		Sun

Figure 19 Primary CHW Flow Rate – Block A

Total Chiller Power Profile and Chilled water Flow Rate for Block C are represented in figures 21 and 22.

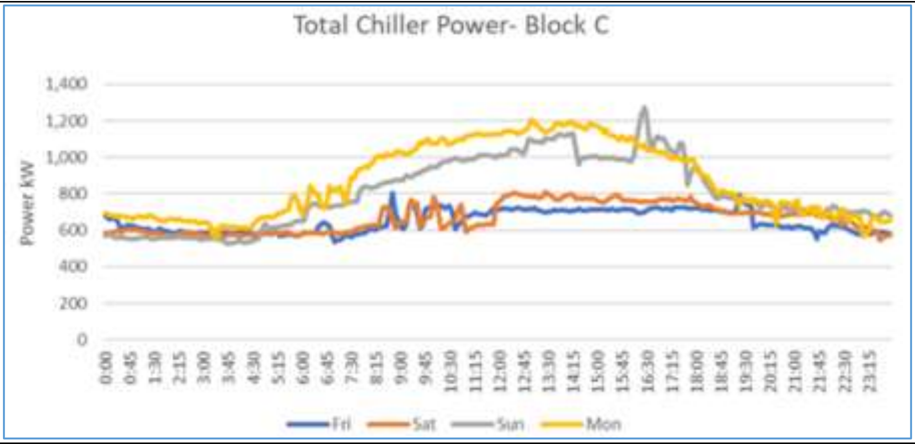
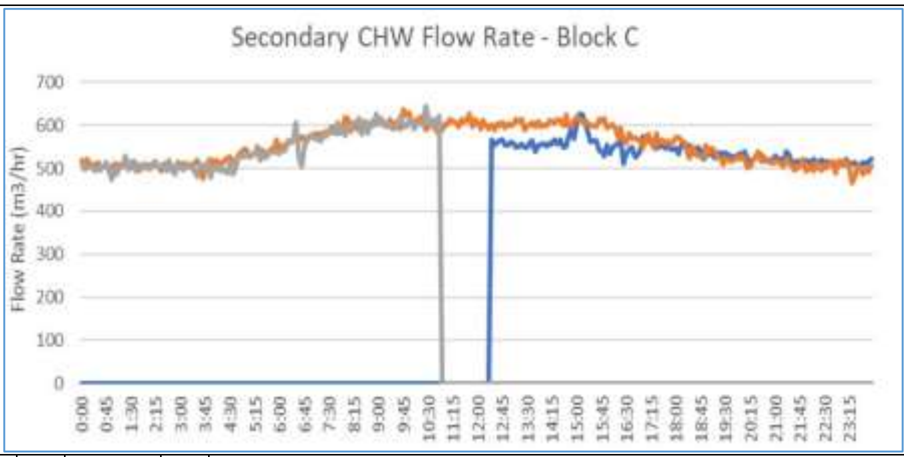


Figure 20 Total Chiller Power Profile for Block C



	Thu		Fri		Sat

Figure 21 Primary CHW Flow Rate – Block C

Key **observations** from the chillers performance during the studied period are listed below for Chillers in Block A and Block C:

- Chiller operations are not consistent.
- Chiller supply temperatures are about 6 degC.
- Chiller efficiencies are at acceptable level for the age of the system.
- Each chiller runs with one primary pump combination.
- Secondary pump installed with VFD and operating based on the DP setting.
- DP setting is fixed for both summertime and wintertime.

Chiller Plant Efficiency: Also, sample chiller efficiencies are evaluated by measuring the temperature across the evaporator, the chiller flow and the power input. Figures 23 and 24 shows the chillers efficiency profile for the chillers in Block A and Block C respectively. It is noticed that the efficiency of the chillers in both Blocks A and C has a similar profile, in which the Kilowatt per ton of cooling (KW/TR) is above one and increases during the day between 10:00am and 5:00pm to above 1.5 KW/TR.

The cooling load which is defined as a ratio between the energy consumption in (kW) to the rate of heat removal in (tons), whereas, the lower the kW/TR indicates that the system is more efficient. Noting that KW/ton = 12 / (COP x 3.412). Therefore, both sets of chillers in Block A and Block B requires improvements to enhance their efficiency and in return improve their energy performance.

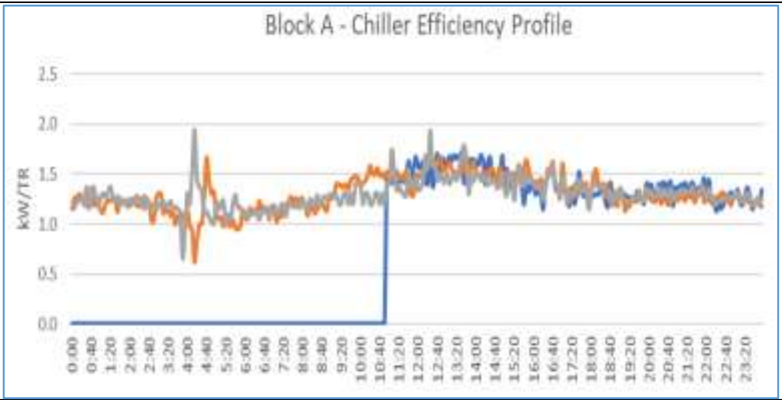


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Figure 22 Chiller Efficiency Profile - Block A

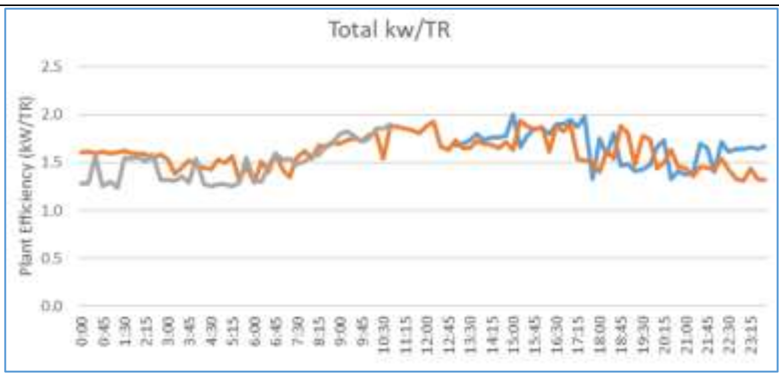

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Figure 23 Chiller Efficiency Profile - Block C

Some Chiller measurements were taken instantaneously for chiller no.5, no.6, no.7, and no.10, the sample chiller efficiencies are evaluated by measuring temperature across evaporator, chiller flow and power input. Table 16 shows the results of the measurements were the following was found, the set point for all chillers are fixed at 6 degrees despite the changes in the outdoor temperature, the flow of the chilled water was the highest in chiller no.10 due to the area that the chillers covers in Block which have more occupants and requires more cooling, the chilled water temperature before and after the evaporator is known as Delta-T which is a function of the chilled water flow rate and the cooling load found to be 4.7, 3.7, 2.9, and 4 for the chillers 5,6,7, and

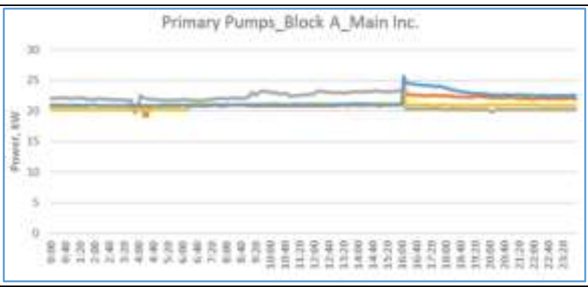
10 respectively, and all the chillers efficiency performance KW/TR was about or above 1.5 which indicates that the chillers are not running at their optimal performance.

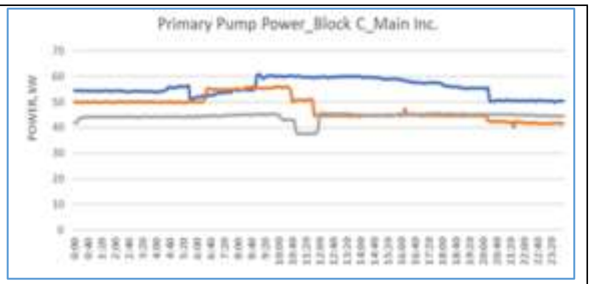
Table 16 Chillers measurements

Description	Chiller 5	Chiller 6	Chiller 7	Chiller 10
Time	10:40 am	6:10 pm	4:40 pm	4:10 pm
Ambient Temperature C	37	36	38	38.4
Set point C	6.0	6.0	6.0	6.0
Evaporator side				
Chilled water temperature C	5.8	5.9	7.9	7.8
Chilled water temperature inlet C	10.5	9.2	10.8	11.8
Chilled water flow m3/hr	93.45	9.4	100.91	121.45
Delta T C	4.7	3.7	2.9	4
Compressor side				
Compressor suction pressure kPa	252	172	NA	NA
Compressor Discharge kPa	1350	1403	NA	NA
Compressor Power KW	256	146	147	268.5
TR produced TR	161	97.4	95.9	160
Chiller performance KW/TR	1.59	1.49	1.53	1.67

Chilled water Pumps: In addition to the chiller plant performance, the power profile for the primary and secondary pumps were also measured and analysed.

Primary Pumps: All primary chilled water pumps are designed to operate at constant speed with a rated power of 15 kW each. Block A consists of 4 operational + 1 standby pumps whereas Block C has 6 operational + 1 standby pumps, which supply a constant flow of chilled water over the operational chillers. Figure 25 shows the chilled water primary pumps power profile for both Block A and Block C. It is noticed that the power profile shows increase of the primary pumps power in Block C in the normal working days compared to the weekend days (Friday and Saturday), however, the power profile for the primary pumps in Block A shows increase in the power during Saturday which is a weekend day and there is a jump in the power at 4:00pm in all the other days except for Saturday where the power is decreased.

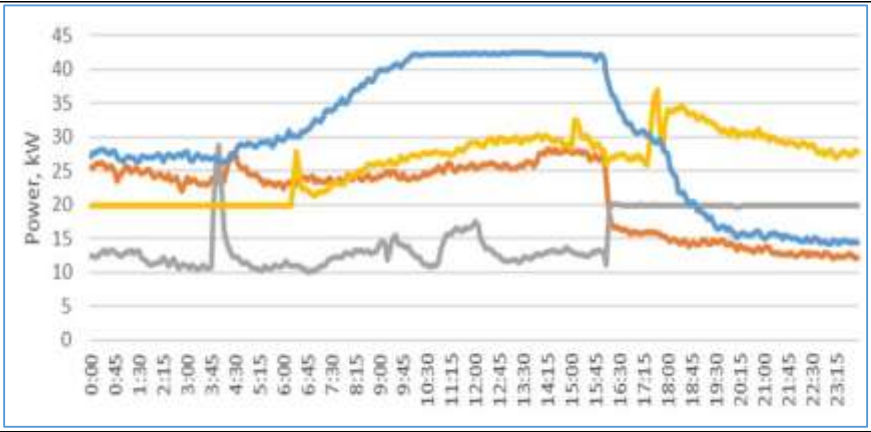




Fri Sat Sun Mon | Thu Fri Sat

Figure 24 Primary Pump Power Summary for Block A and Block C

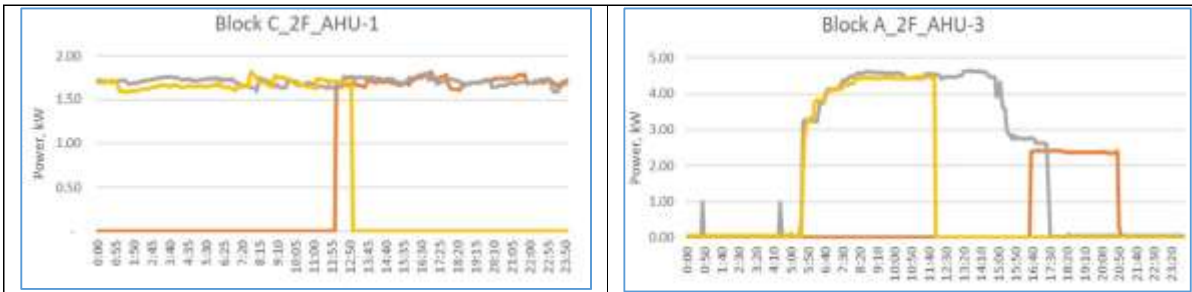
Secondary Pumps: Chilled water is supplied to the building via variable speed secondary chilled water pumps catering to Block A, B and C where Block A consists of 3 operational +1 standby pumps of 22 kW each and Block C comprises of 4 operational + 1 standby pumps of 30 kW each, responsible for chilled water circulation in the entire building. The power profile of the secondary pumps in Block A is presented in figure 26. It is noticed that the power increases in the working days (Sunday and Monday) compared to the non-working days Friday and Saturday) and it increases with the start of duty hours at about 7:00am and decreases again after duty hours at about 4:30pm, where the demand on the cooling system will be less due to lesser number of occupants in the building.



	Fri		Sat		Sun		Mon

Figure 25 Secondary Pump Power Summary for Block A

Air Handling Units (AHUs): A total of 8 AHUs are installed, serving the 1st and 2nd floors. To understand the power profile for the same, AHU 1 and 3 were logged on for continuously 3 days each during working days. Figure 27 depicts the power measurement summary and profiles for each sampled AHU. The measurements shows that the power profile for AHU 1 in Block C has almost a consistent average power of 1.7 KW, and it was running continuously on Monday and for almost half a day on both Sunday and Tuesday. However, the AHU no.3 in Block A power profile shows that the machine is operating in a different schedule from one day to another with a maximum power of about 4.5 KW.



	Sun		Mon		Tue		Tue		Wed		Thu

Figure 26 AHU-1 Block C and AHU-3 Block A

Fan Coil Units (FCUs) and Space Temperature profile: The building is equipped with over 1050 FCU units where 583 of them is connected to the Building Management System (BMS) and rest are standalone units. The FCUs that are connected with the BMS runs with pre-set schedule and temperature which varies from 18.8 to 30 degC. Figure xx shows samples of the temperature profile of two sets of the FCUs in the Building. The first set samples are (Block A: 2nd floor FCU no. 10, basement 2 FCU no. 03, and ground floor FCU no.10) and the second set samples are (Block A: 7th floor FCU no. 33, Block B: 8th floor FCU in the pantry, and 4th floor FCU no.07). It is noticed that the FCUs in the common areas like Ground Floor and the Pantry are has a higher temperature than the other FCUs located in the offices. Figure 28 shows the temperature profile for the two sets of the fan coil units.

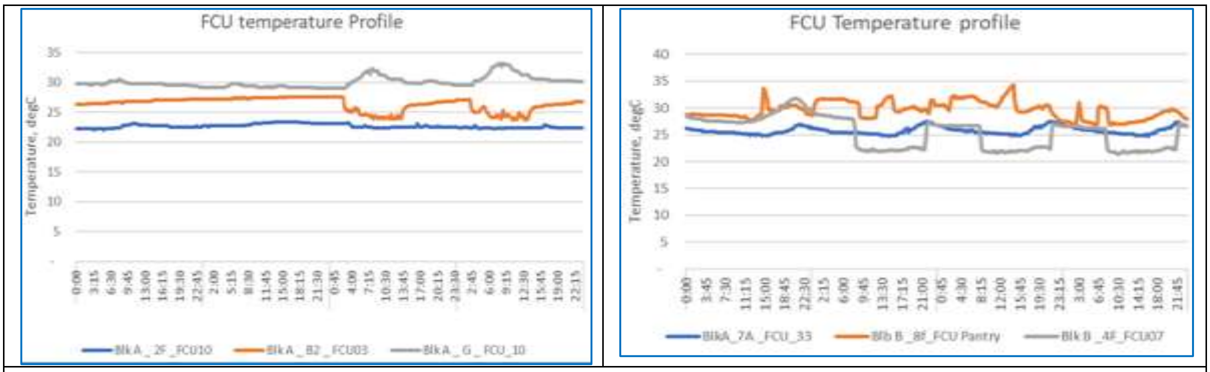


Figure 27 FCU temperature profile – set 1 and Set 2

Space temperatures:

The building space temperature was measured in different sampled locations (7 locations), as seen in Table 17. The locations were chosen to cover the biggest two blocks in the Building Block A and C, and the measurements were taken for 24 hours in the offices area and in the common areas i.e. the corridors. Results shows that there is not much difference in the average temperature readings between the night time and the day time in the building, meaning that the cooling system was running 24 hours at almost the same set point which can be linked to the occupants behaviour leaving the AC units on in the offices and for the lack of scheduling the AC cooling set point in the common areas to match with the cooling demand that is required during duty hours and after duty hours.

Table 17 Space temperature

Location	B-A, 2F Offices	B-C, 6F Corridor	B-C, 2F Offices	B-C, 6F Offices 1	B-C, 6F Offices 2	B-A, 5F Offices	B-A, 7F Offices
24 Average	22.2	21.3	21.9	21.8	19.28	22.2	22.4
Night Average	22.18	21.2	21.6	21.5	19.2	22	22.2
Day Average	22.24	21.3	21.8	22.13	19.2	22.4	22.6
Min	22	21.2	21.4	21.3	18.4	21.3	21.4
Max	22.24	21.7	22.8	22.5	20	23.1	23.7

Fans Power Profile

Exhaust Fan: Fans Measurements were carried out to understand the power consumptions of the extract and fresh air fans sited in the car park area. The data was logged for a period of 3 days one extract fan power profile is shown in figure 29. The power profile represent different days over a period of 24 hours. Car parking fans runs for 24 hours at low speed. It is noticed that that the extract fan number 4 was running continuously on Sunday and was scheduled to switch off for half a day on Monday and Saturday. The power of the fan is almost constant during the day with about 5.3 KW.

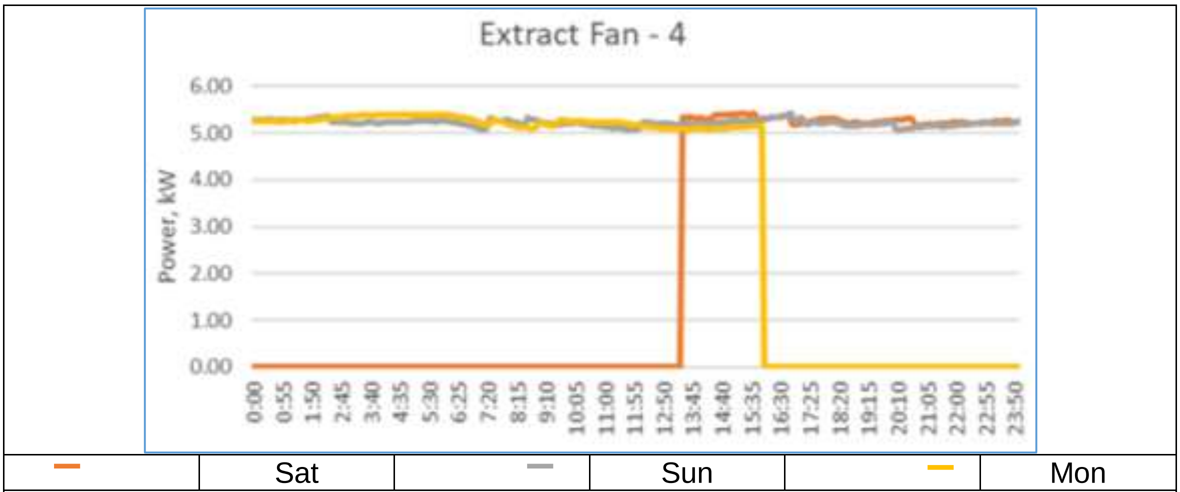


Figure 28 Extract Fan- 4 Power Profile

DX Units: The facility is equipped with decorative type split and split-ducted DX units with power rating ranging from 4-9 KW depending on the type of DX unit. Two DX units serving basement UPS rooms were logged for a period of 2 days to analyse the power profile as depicted in figure 30. Each power profiles for DX unit 1 and DX unit 2 shows individual lines representing different days over a period of 24 hours, where the power for each unit is almost constant during the day and is about 5 KW.

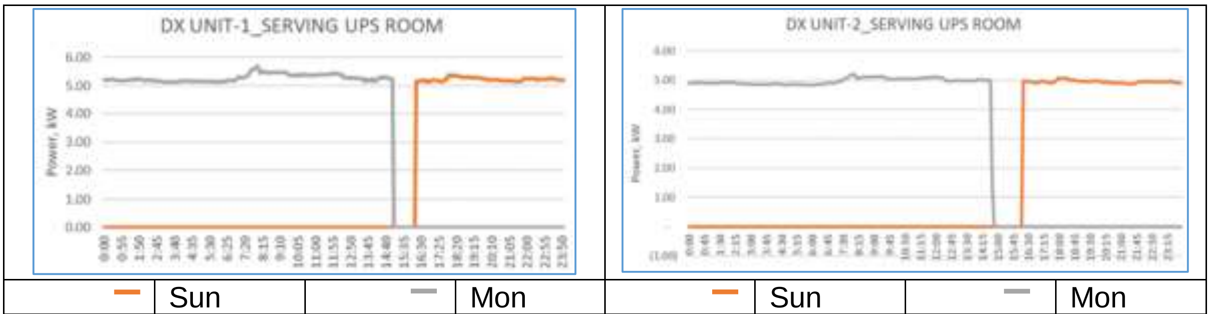
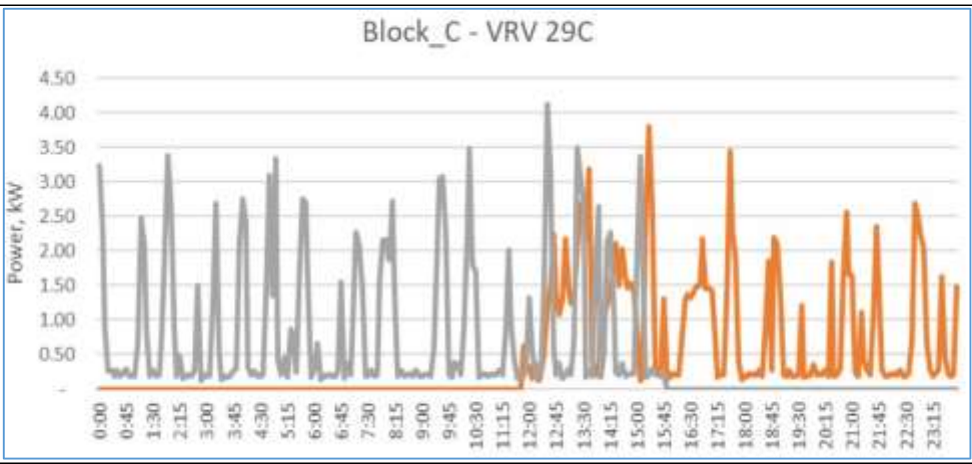


Figure 29 DX Unit 1 and Unit 2 - Serving UPS Rooms

Variable Refrigerant Volume (VRV) Units: The VRV units are installed in the building to provide cooling to intermediate distribution frame (IDF) rooms in the floors. VRV consumes significantly lesser than normal conventional DX AC units. The difference between the VRV unit and the conventional split unit is that a single outdoor VRV unit can cater to more than one indoor unit, while one outdoor split unit can cater to one indoor unit. The VRV enables to control the amount of refrigerant flowing to the various evaporators (indoor units) that are connected with it, therefore, the temperature inside the rooms can be controlled via changing the flow of the refrigerant flowing to the indoor units. Figure 30 shows the power profile of the sample VRV unit in the building at temperature value of 29 C that has been measured over two days. It is noticed that power demand varies between 0 KW to 4 KW, and the total consumption of the sampled units during the two days varied between12 KWh and 14 KWh with a higher consumption in the day than the night time because of the increase of the outdoor temperature during the day which then would require more cooling to the rooms inside the building. *Appendix B* shows the measurements for the other VRV systems.



—	Wed	—	Thu

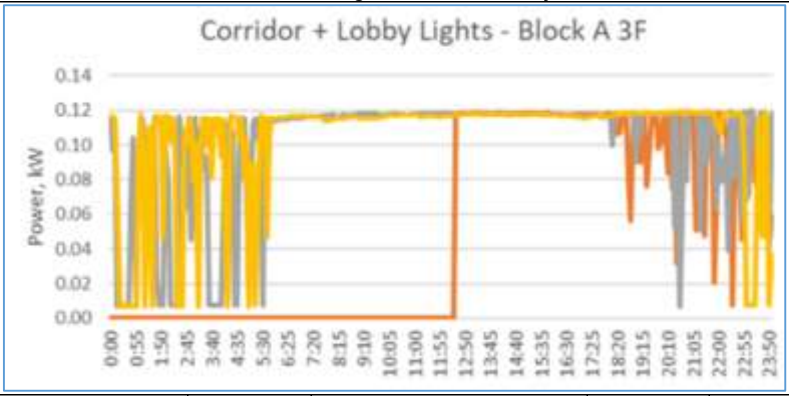
Figure 30 Block C VRV at 29 C

Lighting Systems:

Lighting Profile: The facility is equipped with different types of light fittings such as LEDs, Fluorescent Tubular Lamps and Compact Fluorescent Lamps. The following graph below summarises the lighting power profiles recorded at various locations within the facility for 3 days in the 2nd and 3rd floors respectively. Corridors installed with motion sensors and wash rooms lights are kept ON continuously.

Tue Wed Thu

Lighting Power Profile Block A 2nd floor: Corridor Lights and Lift Lobby



Sun Mon Tue

Lighting Power Profile Block A 3rd floor: Corridor and Lobby Lights

Figure 30 Lighting Power profile

Figure 31 shows the measured lighting power profile for the 2nd floor and 3rd floor in the corridor are and in the lift lobby areas, the pattern of the lights consumption is different in each floor, however, in both floors the lights are kept on during working hours where the building is mainly occupied between 6.0am and 6.0pm, and the consumption of the 3rd floor is far less than the 2nd floor due to using LED lights with motion sensors in the 3rd floor while compact fluorescent lamps are used in the 2nd floor. Also, the lights in the 3rd floor was on and off continuously after duty hours due to the activation of motion sensor by the movement of the maintenance team who is located in the 3rd floor. *Appendix C* shows the measurements for the lighting profile for other measured areas.

Lux Measurements The lighting fixture types installed inside the facility comprises of mostly Fluorescent Tube Lights (FTL) in corridors and open offices whereas common areas such as washrooms and prayer rooms are equipped with Compact Fluorescent Lamps (CFL). Similarly, LEDs were installed in corridors across 3rd floors. Instantaneous measurements for lux levels were recorded in various areas like corridor, lobby and open offices at a height of around 1m from ground level recorded the lux levels ranging between 100 – 950. *Appendix D* shows the measurements.

Indoor Environment Quality (IEQ): Indoor Environment Quality (IEQ) refers to the quality of the environment within and around buildings and structures. Poor environment quality can affect health and comfort of building occupants/environment. If, taken into consideration, reducing such common pollutants indoors can help reduce the risk of indoor health concerns, CO2 being one of them. The acceptable indoor CO2 levels as per ANSI/ASHRAE Standards 62.1 and 62.2 is (800 - 1000ppm) for indoor spaces, above which is harmful & becomes hazardous to humans with increments. Instantaneous measurements were carried out within facility blocks A and C. For instance the CO2 level in the 3rd floor Block A was 866ppm, and in 7^{th} floor Block A was 783ppm, while in 7^{th} floor Block C was 698ppm, and it was 723ppm in the 9^{th} floor of Block C. Therefore, the sampled area measurements for the CO2 levels were within the acceptable levels.

4.8 Recommendations based on the case study analysis:

Based on the detailed field assessment, the proposed smart solution aims to the merge data obtained from additional smart sensors in the building environment that to be connected through the network and the existing BMS system. The measurements are recorded and visualized via a cloud based software and a mobile application, the time and location can be determined in real time if certain environmental influences are exceeded or deviated from its set point. The data in the cloud networks goes to the Internet and then to the BMS onsite. In this network the data endures more processing and analytics, adding a level of intelligence that is unavailable in the existing BMS. Also, the cloud-based software can combine the old data from the BMS with real time data from sensor and can be displayed in a dashboard. This can avoid extra expenses due to upgrading the existing BMS while achieving comparable functions.

A machine learning technology (digital platform) would be implemented to monitor and control the key parameter to track the energy, equipment health and comfort in the facility and maintain comfort conditions during occupied period, the materials used for the technologies to comply with local standard and industry standards. Major savings coming from HVAC optimization and retrofits, while the International Performance Measurement and Verification Protocol (IPMVP standard) is followed to set robust measurement & verification plan. Also, these measures will have lifetime more than 10 years and will support in reducing the maintenance cost as well as the CO_2 emission.

Therefore, the following four proposed smart integration of technologies and sensors in the case study building is studied to understand its impact on the overall energy consumption in the building:

- HVAC Controls Upgrade along with Cloud Analytics.
- Installation of Chiller Plant Manager (CPM) along with Cloud Analytics.
- Retrofitting existing conventional AC with invertor AC.
- Installation of Adiabatic Cooling System for Air Cooled Chiller.

Note: The formulas that are used to calculate the expected savings from each of the proposed strategy are obtained from Honeywell Company.

4.8.1 HVAC Controls Upgrade along with Cloud Analytics

From the site survey and the field assessment, the following was observed:

Fresh air handling unit: 5 units with heat recovery and 1 without heat recovery, operating for 13 to 24 hours. Different schedule maintained for different units. Supply temperature varies from 10 to 24 degC, CO_2 varies from 600 to 900 ppm. **Fan Coil and Air handling unit**: There are about 1000+ units across the facility; almost 600 units connected in BMS and rest are standalone, FCUs are scheduled through BMS and most of the units are running 24 hours, there are 8 AHUs and runs from 13 to 24 hours. **Car parking exhaust fan**: There are 4 fresh air fans and 12 exhaust fans, all fans are fitted with 2 speed and mostly run at low speed.

Therefore, adding a cloud-based Software (machine learning solutions) As A Service (SAAS) that uses edge connectivity where data is aggregated in the cloud, with runtime and predictive analytics and notifications, to improve the overall performance of the equipment to automatically and continuously optimize the HVAC system based on changing weather and occupancy condition, besides adding intelligence to the BMS, such as; VFD control for FAHU based on CO_2 levels, converting the standalone FCU to communicating type FCU control, changing the programs for the FCU/FAHU/AHU/ car parking system and connecting the VFD and controllers with field devices and networking and integrating them with the existing BMS while integrating the BMS points with the Enterprise Building Integrator. The real time data can be shown on dashboards that are secure and centrally accessible by all stakeholders.

The cooling demand in the facility is not static, but varies, depending upon weather and occupancy. Also, the operation of HVAC plants is not coordinated, chiller plants don't track demand of downstream zones, however, temperature and comfort can be maintained without any wasted energy, for example the cooling system can generate the same temperature by using colder water and moving air fast, that can be determined by the intelligent cloud based system which computes the optimum set point settings to minimize energy spend while maintaining occupant comfort, being closed loop it can automatically reset the HVAC main set points continuously (24x7) and send the optimum values to the BMS without having a human interface in the loop.

Requirements include, installation of Variable Frequency Drives (VFDs), installation of CO_2 sensor and additional temperature sensors in the FAHU, installation of FCU thermostat, Connecting the sensors and controllers and integrating with the BMS system and the cloud based software, programming the required changes to the operation and scheduling of the FCU/FAHU/AHU and the temperature set point.

Estimated Energy Saving and Calculation Formula:

Energy savings = (FAHU + AHU + FCU) kWh savings + Associated cooling savings + Cloud analytics savings

- FAHU kWh savings = Baseline consumption X (1- Combined OA reduction%^3) x (1- safety factor)
- FAHU cooling savings = Cooling Savings = m3/hr x (Coil Dh) x 1.2 x Cooling Efficiency x Actual operating hour x % savings run hour optimisation % flow reduction x (1-safety factor) /3.516/3600
- FCU/ AHU kWh savings = Baseline consumption x % run hour reduction
- FCU/ AHU = (night hour chiller consumption – chiller savings) x % run hour consumption
- Cloud analytics savings taken as 8%.

Table 18 shows the expected savings from upgrading the HVAC system and using cloud software, where a total saving of 17 % (which is equivalent to 684,554 KWh) from the FHAU, AHU, FCU, and Car parking system energy consumption could be achieved.

Table 18 Energy Savings from HVAC Controls Upgrade

Equipment	Adjusted Baseline consumption	Estimated kWh	Savings kWh	Cooling savings kWh	Cost savings AED	% savings on system
FAHU	1,019,662	420,046	599,616	327,673	408,007	59%
AHU	74,371	62,477	11,893	10,183	9,713	16%
FCU	862,987	692,711	170,276	346,689	227,465	20%
Car parking system	367,920	229,950	137,970	-	60,707	38%
Cloud analytics	5,670,651	5,216,999	453,652	-	199,607	8%
Total	7,995,590	6,622,183	1,373,407	684,544	905,499	17%

The installation and modulation of the BMS upgrade will save about 905,499AED which is 12% on the total electricity bill. The proposed upgrade can have other benefits such as increasing the visibility across the portfolio of the building, improving the response times and operational performance, reducing energy demand and energy spend, maximizing the equipment lifecycle and uptime while reducing the operational and maintenance costs, and providing improved planning for preventative maintenance.

4.8.2 Installation of Chiller Plant Manager (CPM) along with Cloud Analytics:

During the field assessment and the site survey in both Air-cooled chiller plants, the following operations are observed: Chiller plants are connected with iBMS, constant set point temperature throughout the year is maintained, supply temperature is between 5.8 - 7 degC and the return temperature varies from 8 degC (wintertime) to 12 degC (summertime), the number of primary pumps based on the number of chillers and run at constant flow, secondary pumps installed with VFD and operating between 30-40Hz, the chiller loadings are not balanced to operate at optimum setting, the chiller plant operated for 24 hours, and the day hour consumption and night hour consumption is about 55-60% & 40-45% respectively.

It is observed that there is an opportunity to optimize the operation of chillers & auxiliary equipment, & implement the set-point reset strategies to achieve energy savings, through installing advanced Chiller Plant Manager to improve the operational efficiency thereby achieves the energy savings, also, Cloud Analytics could be implemented to monitor and control the chiller system, the following options can achieve the savings: chilled water temperature reset, chiller loading to meet the best operating point, variable frequency drive for primary pump, secondary pump operation optimisation, installing differential sensor in the chiller evaporator and ambient air sensors, installing BTU meters, controllers, gateways, & enclosures, connecting the field devices with the network networking, and integrating the existing BMS system with the Enterprise Building Integrator (EBI) and the Chiller Plant Manager to track the chiller plant efficiency in Real-time. Chiller Analytics can provide the feedback on the system operation which can be used to plan the maintenance reducing downtime & sudden equipment breakdowns, and increase the equipment life.

Estimated Energy Saving: The proposed installation & implementation of Chiller Plant Manager & Cloud Analytics will save about 408,438 AED annually in both plants which is equivalent to 5.4% on total electricity bill. Savings in AED are calculated by using the rate of 0.44 AED per kWh. Following rationale is used in the savings analysis. Monthly analysis is carried out for savings quantification.

- 2-3% savings for 1 degC set point change based on the ambient conditions.
- 2-3% savings for 10% loading change.
- 10% flow change will save 27% based on affinity. One additional primary pumps runs at low frequency and 1 degC temperature difference improvement for secondary pumps.
- Recovery/Safety Factor: 15%

Calculation Formula: Energy savings = Chiller savings + Pump savings

- Chiller savings = Day Baseline consumption x % savings due to set point change + night baseline consumption x % savings due to set point change + Total baseline consumption x % savings due to loading

- Pump savings = Pump baseline consumption x % savings due to flow reduction

Table 19 represents the expected savings due to installing the proposed Chiller Plant Manager, where a total savings of 14% from the energy consumption of the chillers could be achieved, which is equivalent to 928,269 KWh and AED 408,438 per year.

Table 19 Savings from Installation of Chiller Plant Manager

System	**Building**	**Current Consumption kWh**	**Estimated Consumption kWh**	**Savings kWh**	**Cost savings AED**	**% Savings**
Air Cooled Chiller	Block C	3,934,172	3,330,422	603,750	265,650	15.35%
Air Cooled Chiller	Block A	2,693,837	2,369,318	324,519	142,788	12.05%
Total		6,628,010	5,699,741	928,269	408,438	14.01%

4.8.3 Retrofitting existing conventional AC with invertor AC

From the site survey and the field assessment, it was observed that, there are 49 Split Air Conditioning (AC) units installed at different locations in the facility serving server room, UPS rooms etc. These units are conventional AC which runs based on the set point temperature. Typically, these unit compressor switch ON/OFF based on the space temperatures. The design ratings of the conventional split AC efficiency performance (KW/TR) is between 1.2 - 1.3 KW/TR.

The existing conventional air-conditioner's operating parameters like air flow (m3/s), Dry Bulb Temperature and Wet Bulb temperature, compressor power (kW) are measured and weighted power consumption is calculated as 1.7 KW/TR. Figure 32 compares the energy consumption from the inverter AC and the non-inverter AC.

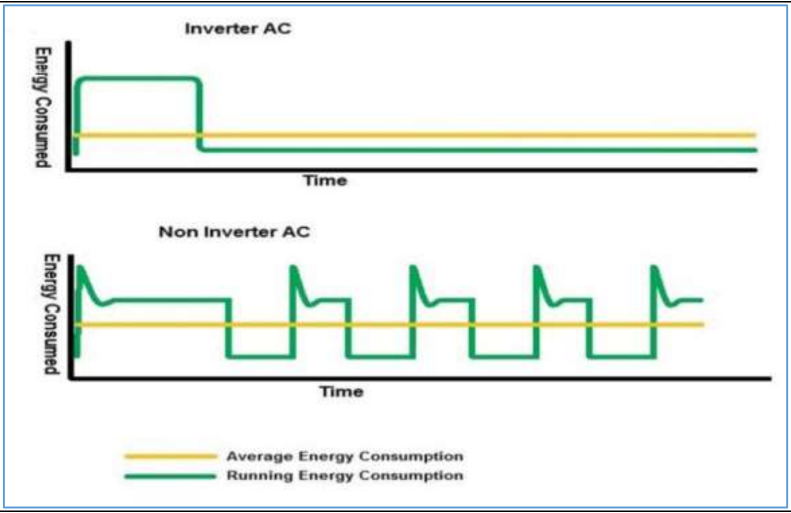


Figure 31 Inverter AC vs Non-Inverter AC – source from the internet

Specific power consumption increases with the increase in ambient temperature and continued usage. In an optimally designed inverter compressor, the energy consumption will be proportional to cooling demand, variable speed compressors help achieving the cooling faster thereby providing faster comfort. Also, this will reduce the strain on the electrical system due to reduction in frequent start/stop of the compressor, and reduce the maintenance costs due to reduced wear & tear.

Replacing the existing air conditioning units with energy efficient inverter based air conditioning units with higher efficiency (kW/TR) will achieve energy savings, and due to the use of environment friendly refrigerant, the AC units will not contribute to the harmful effects to the climate like CO2 emissions.

Estimated Energy saving: Following formula is used to calculate the energy savings:

- Existing kW/TR (A) = Measured kW/TR
- Proposed kW/TR (B) = Design kW/TR
- Baseline energy calculation (C) = Power rating of DX AC unit x running hour/day x no of days per year x % actual loading (measurement) x (1 - factor loading)
- Energy savings D = C x (1- B/A) x (1 - safety factor).
- Safety factor: 10%

Table 20 represents the expected savings from implementing the proposed Retrofitting existing conventional AC with invertor AC, where a total saving of 38% of the energy consumption from DX units could be achieved, which is equivalent to 225,750 KWH and AED 99,330.

Table 20 Savings from Retrofitting existing conventional AC with invertor AC

Equipment	Baseline consumption (kWh)	Proposed DX (kWh)	DX savings (KWh)	Cost savings (AED)	% savings on system
All Units	596,671	370,921	225,750	99,330	38%

4.8.4 Installation of Adiabatic Cooling System for Air Cooled Chiller

From the site observation, the cooling performance of the air cooled system highly depends on the conditions of the outside air. Air cooled chiller performance drops when the inlet air temperature rises. Installation of wet wall system at the air inlet to the condenser coil of chiller will decrease the entering air temperature and improve the performance of condenser coil of the air-cooled chillers to achieve energy savings. This will facilitate condenser cooling at much lower temperature than Dry Bulb Temperature (close to Wet Bulb Temperature).

When the dry and hot air goes through a wet surface, the water evaporates and the energy that is required for the evaporation is taken from the surrounding air, hence reducing its air temperature. This reduction in condensing temperature will reduce the operating specific power consumption of chiller and save energy. The closer the air temperature entering the condenser coil to the Wet Bulb Temperature, the better the condenser coil performance and more energy saved. As well, it is required to install water piping, accessories for water circulation, water meter, and temperature sensor. The system to be integrated with the EBI. Also, reduction on condensing pressure reduces compressor load, and less dirt reaches condensing coil fins as air passes through the wet wall, thereby keeping the fins cleaner & more efficient for heat transfer.

Estimated Energy saving: Installation of wet wall system could save about 223,925 AED which is equivalent to 3% of total electricity baseline bill, savings in AED are calculated by using the rate of 0.44 AED per kWh for electricity (*Appendix E* shows the Rates from Dubai Water and Electricity Authority) and 0.046 AED/IMG for water.

Calculation Formula: Chiller kWh Saved = Chiller adjusted Baseline Consumption x (1- kW/TR Proposed / kW/TR Existing) x (1 - Safety factor)

- Chiller adjusted baseline= Chiller baseline – chiller savings in CPM - Cooling load savings in HVAC controls.
- Net Savings = Chiller Savings – Water Cost
- % Recovery factor taken as 15%

Table 21 presents the expected savings due to the installation of the Adiabatic Cooling System where a total of 11% savings in energy consumption from the chillers could be achieved that is equivalent to 740,473 KWh and AED 223,925.

Table 21 Savings from Installation of Adiabatic Cooling System

System	Building	Existing Consumption kWh	Estimated Consumption kWh	Savings kWh	Cost savings AED	% kWh Savings	% net Savings
Air Cooled Chiller	Block C	2,617,015	2,209,121	407,894	129,301	15.59%	11.2%
Air Cooled Chiller	Block A	1,944,835	1,612,256	332,579	94,624	17.1%	11.1%
Total		4,561,850	3,821,377	740,473	223,925	16.23%	11.16%

Summary of the expected Savings from four proposed strategies:

Table 22 shows a summary of the expected Energy, financial, and Emission savings due to implementing the proposed strategies with estimated execution timeline to be between 6 - 8 months. Figure 32 represents the annual base case electricity consumption vs annual electricity savings and the annual base case electricity cost vs the annual electricity cost saving.

Table 22 Summary of Energy, Monetary and CO2 emission Savings

#	Summary	Amount	Unit
Baseline Data			
1	Annual baseline electricity consumption	17,151,331	kWh
2	Annual baseline electricity cost	7,546,586	AED
Savings after implementing the proposed strategies			
3	Annual electricity consumption savings	3,952,444	kWh
4	Annual electricity cost savings	1,637,192	AED
5	% savings on baseline consumption	23.0%	%
6	% savings on baseline cost	21.7%	%
7	Equivalent CO2 reduction annually	1,976	Tonne

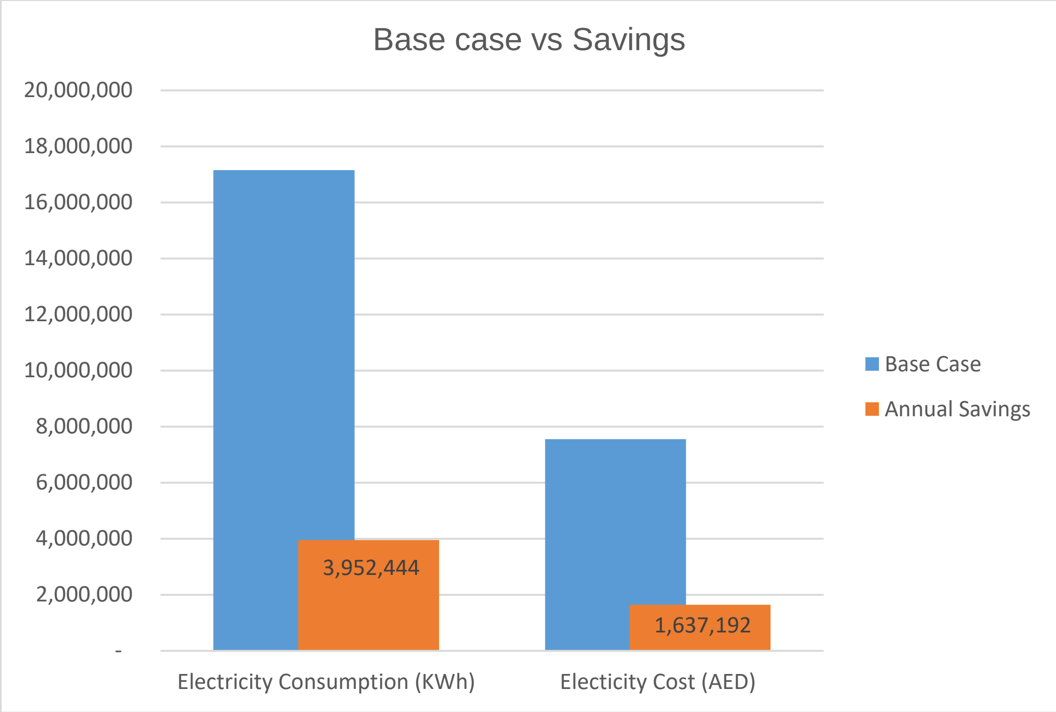


Figure 32 Base case vs Savings for Electricity consumption and costs

Chapter 5 Modelling and Simulation - Case Study from Abu Dhabi

5 Simulation using the (IES VE) Software – Case Study

Simulation software (Integrated Environmental Solution Virtual Environment - IES VE) has been applied in this research to understand the impact of the energy conservation measures and the usage of smart sensors to convert the building into a smart building on its energy consumption through quantitative analysis, and to support the outcomes of the proposed strategies that have been proposed earlier in this research for case study of the government building in Dubai. This section will discuss and analyse the outcomes.

Variable sets of simulation have been conducted using the IES VE software, one for the base case building without any changes or modification and other simulations for the same building after applying the energy conservation measures and sensors. The simulation has tackled different scenarios mainly for lighting and HVAC systems as explained hereafter.

The First part assessed and analysed the impact on the energy demand when upgrading the controls of the Lighting system in the building and installing energy efficient lights, which includes:

A. Replacing Fluorescent lights with Light Emitting Diode (LED) Lights.
B. Controlling the lights through Dimming Controls based on Occupancy Sensors.
C. Control the Lights through Dimming Control based on External Day Lighting.
D. Changing the Ballast Factor.

The Second part assessed and analysed the impact on the energy demand when upgrading the controls of the HVAC System, which includes:

E. Adjusting and controlling the Cooling Set point for the HVAC system in Winter Season.
F. Adjusting and controlling the operation of the HVAC system based on Occupancy.
G. Using Variable Air Volume (VAV) systems.

5.1 Base Case Building Characteristics without any modifications:

The simulated building for this research is a commercial office building which consist of 10 floors for offices and 2 floors for car parking in which all the floors are above the ground level. The location of the Building is in the Emirate of Abu Dhabi which has almost identical climate to the Emirate of Dubai. Therefore, to simulate the building with the most relevant climate conditions the Abu Dhabi International Airport was chosen in the IES software as seen the figure 33 below:

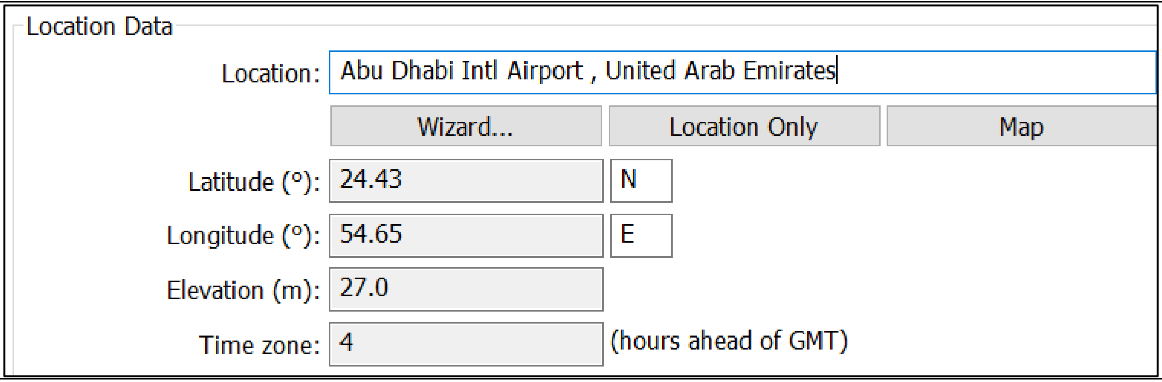
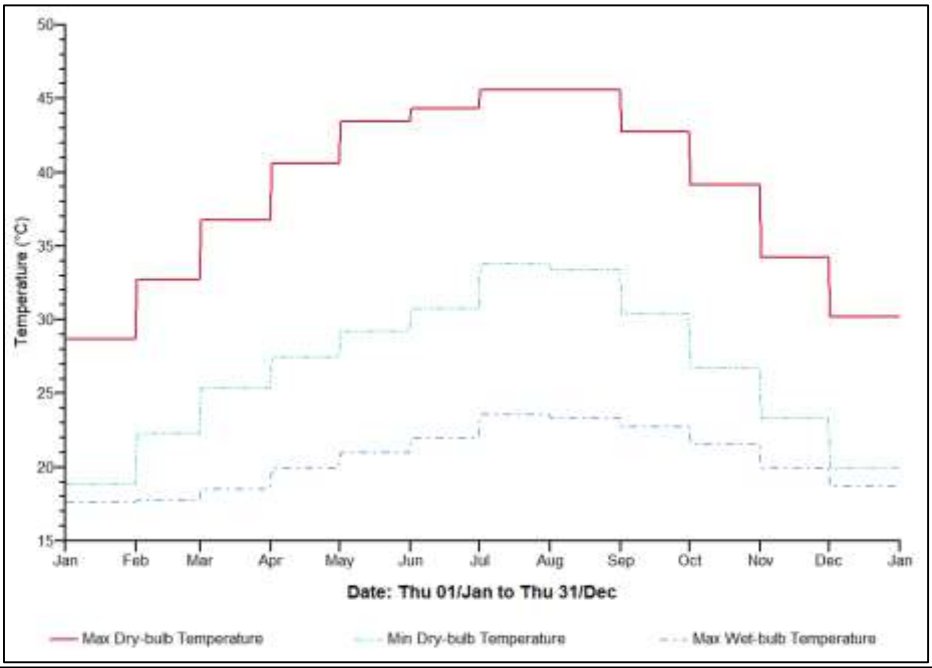


Figure 33 Location of Abu Dhabi

The design weather data of Abu Dhabi city from the IES software which uses the ASHRAE design weather data base v6.0 shows that the peak dry bulb temperature is recorded in Abu Dhabi on the 23rd of July as seen in figure 34. The same figure also shows the dry bulb and wet bulb variables month by month, where the highest is in July and the lowest is in January.

Design Weather Data

Source	ASHRAE design weather database
Monthly percentile:	
For heating loads design weather	99.60 %
For cooling loads design weather	1.00 %
Barometric pressure	101,008.3 Pa
Air density	1.200 kg/m³
Air specific heat	1.019 kJ/kg·K
Density-specific heat product	1.223 kJ/m³·K
Summer ground reflectance	0.2
Winter ground reflectance	0.2
Carbon dioxide (ambient)	400.00 ppm



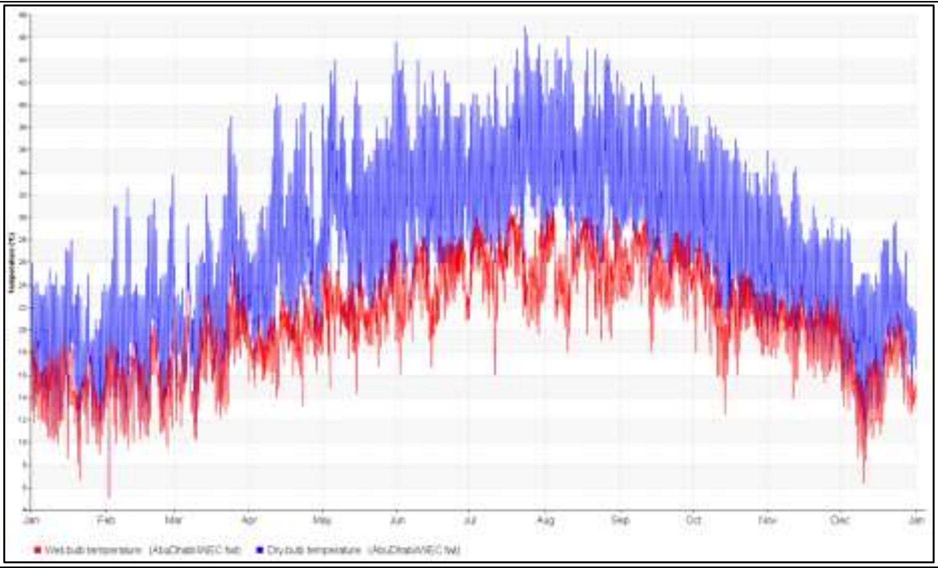
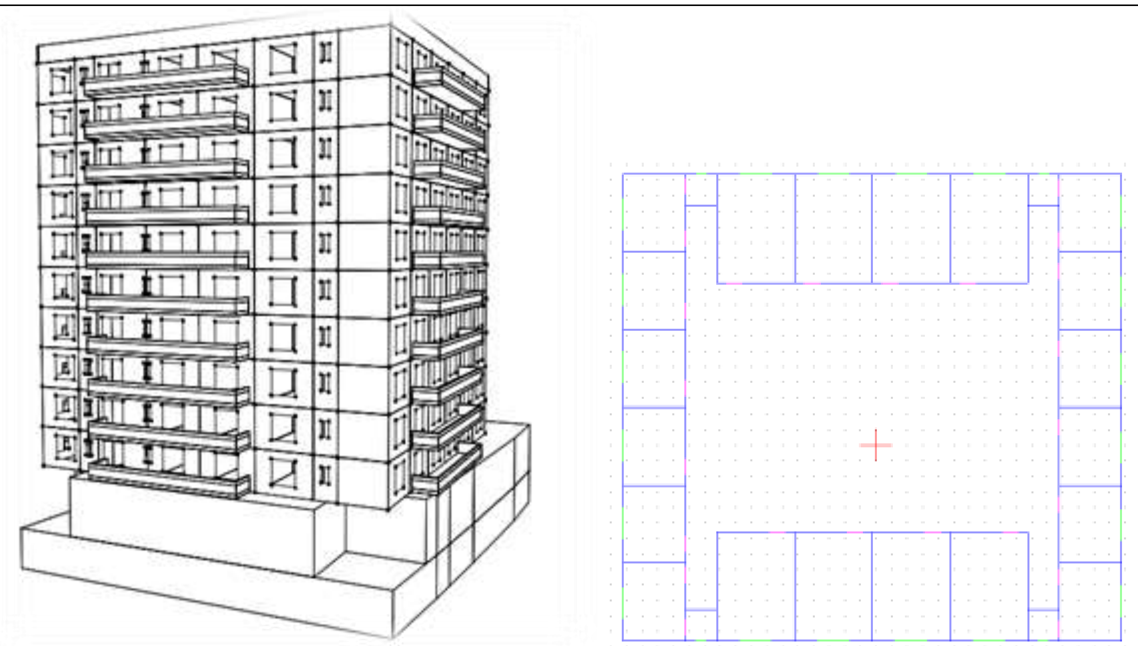


Figure 34 Weather Data for Abu Dhabi (Abu Dhabi International Airport) from IES VE

Floor Area: The building has a total gross floor area of 9,600 m2, and the conditioned floor area is 9,600 m2, the building conditioned volume is 34,014 m3, and the number of conditioned rooms are 251. There are 10 floors that are symmetric in design and consist of 20 offices in each floor, each office has one external window that is 4 m2 each, the offices are separated by walls (8 offices with a floor area of 35 m2 each and have external wall area of 31.5 m2, 12 offices with a floor area of 20 m2 each and have external wall area of 17.5 m2). The floors in the building also have 4 bathrooms distributed in the floor (4 m2 each), and a hallway with a floor area of 424 m2. The building has external balconies one balcony in each side of the building (total four balconies in each one of the floors), the balconies floor area is 29.885 m2 each. The building model is shown in figure 35.



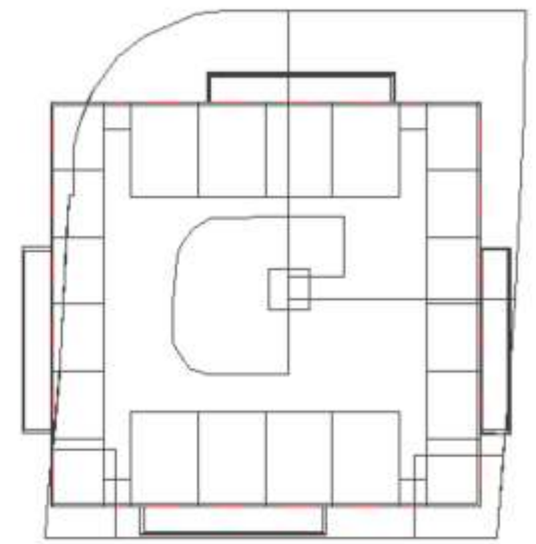


Figure 35 The Simulated Building Model and one Office Floor Layout

Sun Path Analysis: The building orientation is shown in figure 36. Due to sun's rotation, the maximum solar gain is perceived on the eastern side of the building in the mornings, and on the southern side of the building in the afternoons and the evenings. The northern and western walls would receive limited sunshine throughout the year due to sun's path.

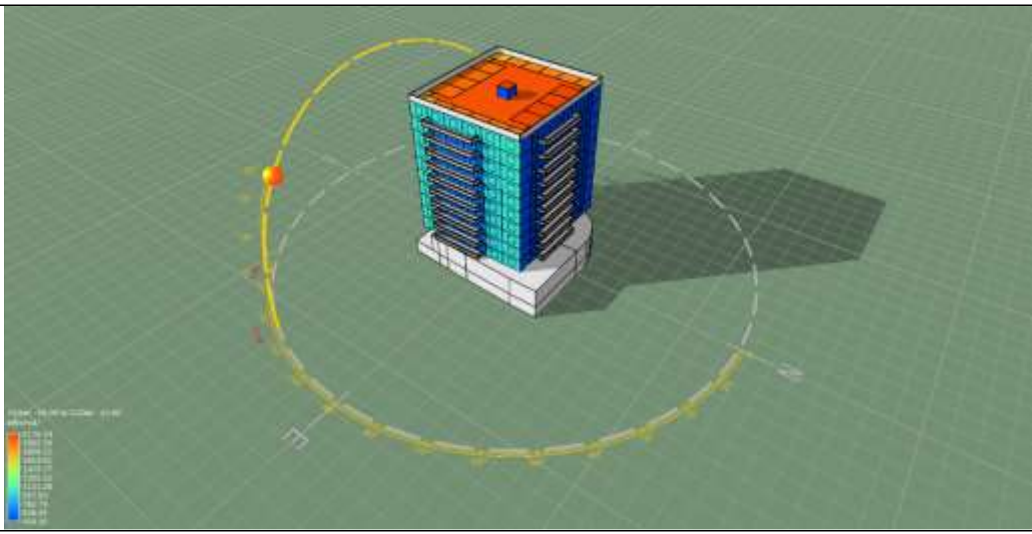


Figure 36 The Simulated Sun Path

U-Value: The thermal transmittance which is known as U-value represents the rate of heat transfer through the building structure divided by temperature difference across this building structure, and is measured with a unit (W/m2K). The better insulation of the building structure means a lower U-value, therefore, thermal transmittance and heat loss from radiation, convection, and conduction is taken into consideration, while a poor insulation and gaps can make the thermal transmittance higher than desired.

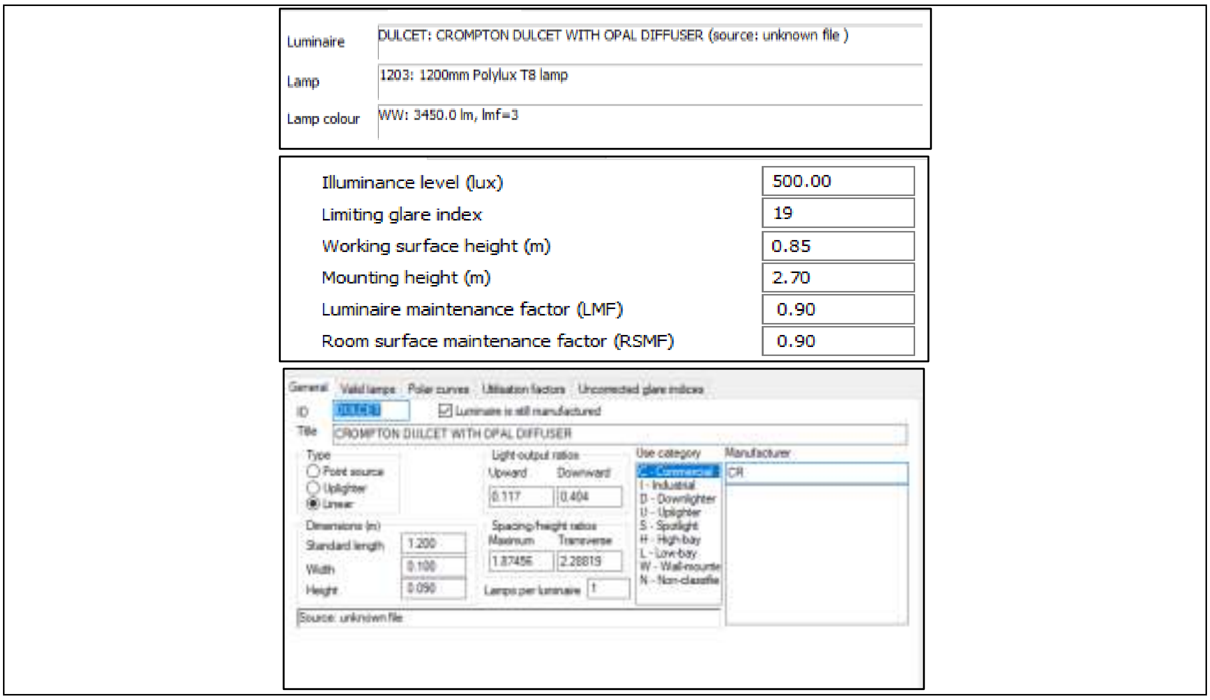
Also, the ambient temperature and the type of the material and the insulation used in the building structure affects this thermal transmittance.

The simulated building model has the following U-values; for the external walls 0.276 W/m²K, for the external glazing 1.619 W/m²K, for the roof 0.174 W/m²K, and for the internal walls and ceiling is 1.087 W/m²K.

Lighting System: The building model is equipped with Fluorescent lights, 1200mm Polylux T8 lamp (3,450 Lumens) and have Luminance level of 500 lux and are mounted at a height of 2.7 meter. The working surface height in the offices is 0.85 meter.

The lights in the base case building model run continuously for 24 hours a day and 7 days a week, and they are not controlled via dimming controls systems, also the radiant fraction for the lights which is used to calculate the long wave length radiation gain is (0.45). Therefore, the due to the continuous ON status of the lights and the non-availability of any controls in place, the building energy consumption is expected to be inefficient.

Figure 37 shows the details of building light template from the IES VE software, and Figure 38 presents the Base Case Luminaire photometric values.



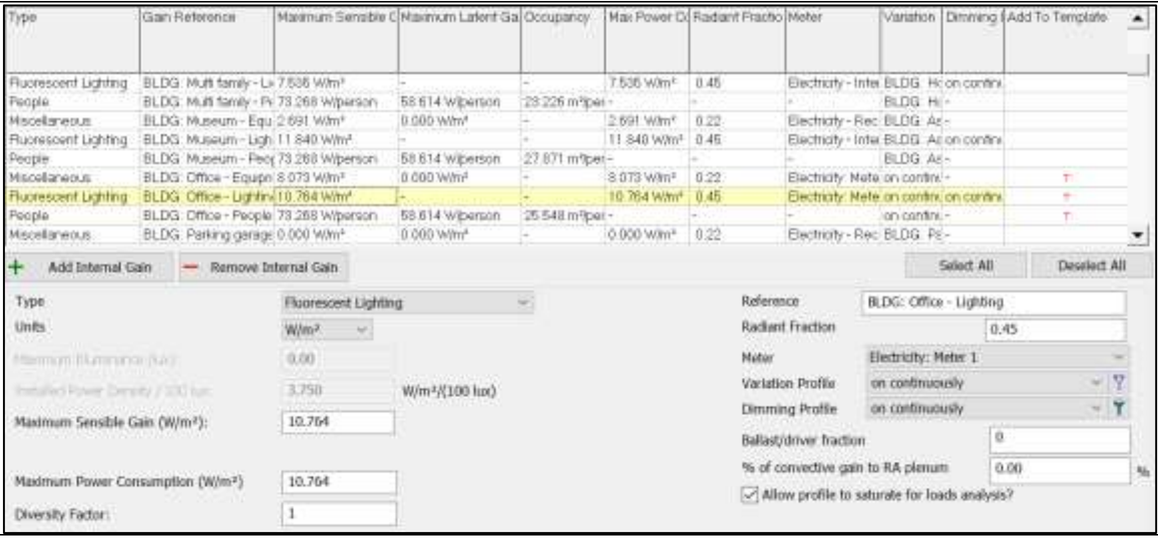


Figure 37 Base Case Building Lighting Template (IES VE)

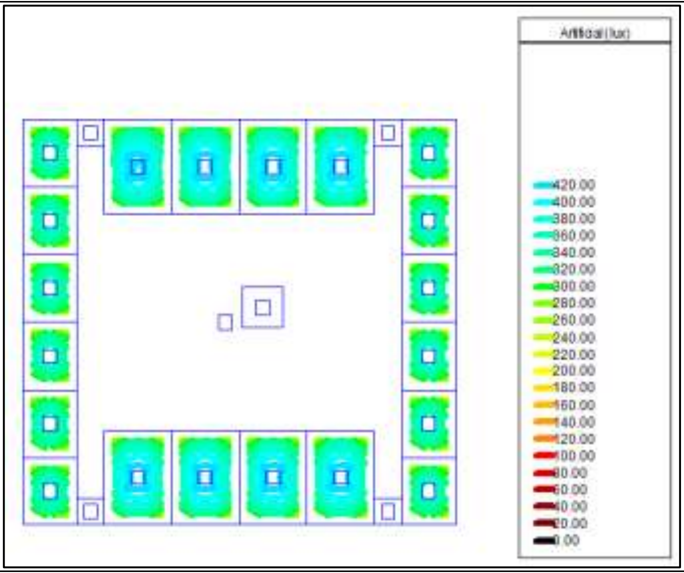


Figure 38 Base Case Luminaire photometric values (IES VE)

The total electricity consumption from the lights in the building is showing in figure 39, where the total electricity consumption per year is 905.2155 MWh. It is noticed that there is an abnormal reading in the month of February which could not be justified at this stage as it could be linked to other variables in the model.

HVAC: the HVAC system in the base case simulated model of the building is a single room cooling system DX with a combination of outdoor and indoor units connected by a refrigerant pipework. This HVAC system does not provide ventilation or heating. The cooling system in the building runs continuously for 24 hours a day and 7 days a week. The cooling set point is fixed at 23 C at all times. The occupancy density of the building is 25.55 m2/person. ASHRAE Heat balance method is used in the IES VE software for the load analysis methodology. Figure 40 shows the details of the HVAC system used in the base case model.

	Lights - Base case
Date	**MWh**
Jan	76.8813
Feb	69.4412
Mar	76.8813
Apr	74.4013
May	76.8813
Jun	74.4013
Jul	76.8813
Aug	76.8813
Sep	74.4013
Oct	76.8813
Nov	74.4013
Dec	76.8813
Total	905.2155

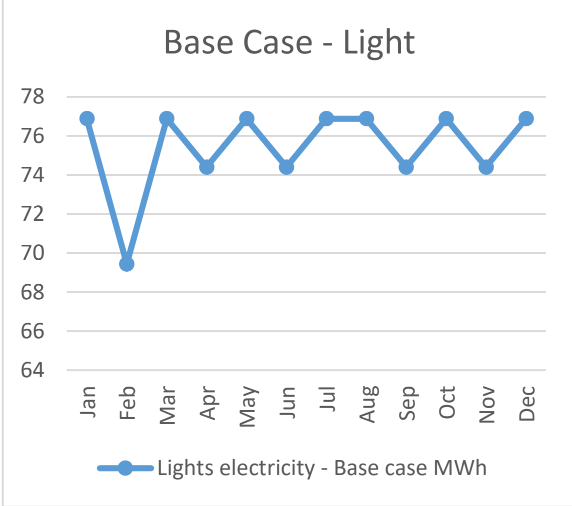
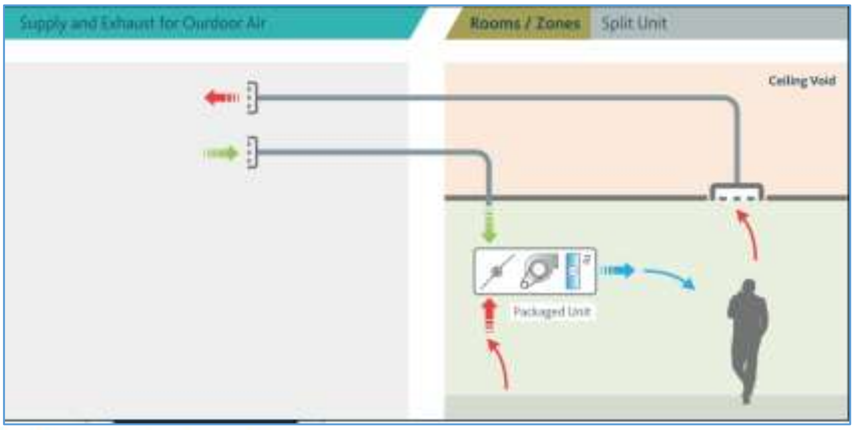


Figure 39 Lights Base case (IES VE)

Cooling

Operation profile	on continuously	
Setpoint (°C)	Constant	23.0



Project Loads Summary

	kW	W/m²
Cooling loads:		
Coincident peak space load	97.86	10.19
Heating loads:		
Coincident peak space load	22.88	2.38

Cooling Calculation Data

Results file	Re-modeled.clg
Calculated	2021/05/30 12:16
Profile Month	May - Sep
Max outdoor temp. dry bulb	45.6 °C
Max outdoor temp. wet bulb	23.5 °C

Figure 40 Base Case Building Air side HVAC system

The overall electricity consumption from the HVAC system in the base case building is equal to 937.4194 MWh a year. As the system in the model runs continuously and the set point is fixed at all times and during the winter and the summer time, it is expected that the energy consumption from the HVAC system in the model is not at its optimal state, and there is a potential for energy performance improvement. Figure 41 shows the HVAC electricity consumption in the base case modeled building.

	HVAC Electricity - Base Case
Date	**MWh**
Jan	70.1914
Feb	65.0076
Mar	73.4208
Apr	74.902
May	83.0538
Jun	83.6778
Jul	89.3171
Aug	90.1366
Sep	83.2554
Oct	79.9607
Nov	72.6272
Dec	71.869
Total	**937.4194**

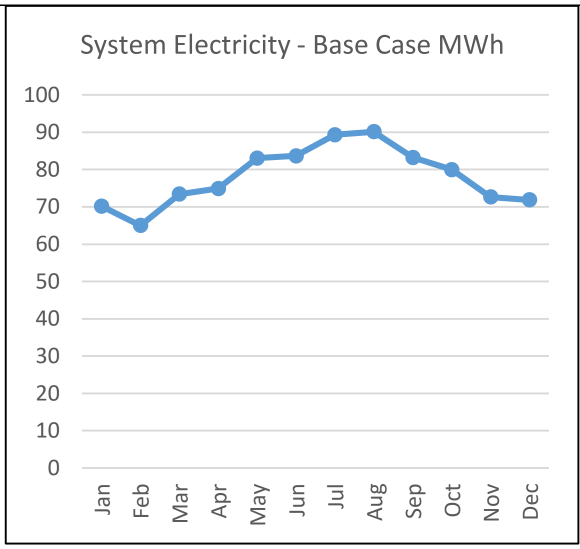


Figure 41 HVAC Electricity Base case (IES VE)

5.2 Validation of the Energy Consumption in the Modeled Building

The building model is designed with the energy demand from the lighting system and the HVAC system mainly, and there is no energy consumption from the equipment or hot water systems as these systems were not considered in the design and no data was entered into the software as such. Therefore, the base model building intensity is calculated considering the energy consumption of the Lighting system and the HVAC system divided by the total conditioned floor area, as follows: Total energy consumption is 1842.6349 MWh/year which is a combination of (905.2155 MWh from the lighting system + 937.4194 MWh from the HVAC system), and is equivalent to 1,842,634.9 KWh/year. The building conditioned floor area is 9,600 m2, hence, by dividing the total consumption of the building over the total conditioned floor area, the base building model energy intensity is 191.94 kWh/m2/year.

In the US there is a database for thousands of commercial buildings through the Commercial Buildings Energy Consumption Survey (CBECS) and is used for benchmarking purposes. However, with the absence of such database in the UAE and in order to validate the value of the energy intensity of the modeled building and due to unavailability of the modeled building monthly energy bills, the energy intensity of the modeled building was compared to the energy intensity of other office buildings in

Abu Dhabi. Judkoff et al. (2008) describes in their technical report the different methodologies for validating building energy analysis simulations in details.

Al Amoodi and Azar (2018) conducted a study comparing the average energy intensity of different types of buildings in Abu Dhabi. The study results concluded that the average energy intensity in the Office buildings in Abu Dhabi is 182.325 KWh/m2/year (not including the energy consumption of the equipment and the domestic hot water). While keeping in mind that the building model used in this research also does not include the energy from equipment and the domestic hot water, therefore, when comparing the average energy intensity of the Office buildings in Abu Dhabi from the mentioned study (182.325 KWh/m2/year) with the energy intensity of the modeled building used in this research (191.94 kWh/m2/year), the difference do not exceed 5% and is within the acceptable error range as per ASHRAE guideline 14-2014.

Also, Al Abbar the Chairman of the Emirates Green Building Council in Dubai stated in the Emirates Energy Efficiency Summit 2016 that the regulations put in place by the Emirate of Dubai contributes to the buildings to have a range of energy intensity between 160-260 KWh/m2/year (khaleej times website, 2016).

Therefore, the obtained result for the energy intensity of the modeled building is here again within the expected range and re-confirms the reliability of the model and its suitability to conducting further analysis.

5.3 Results from applying the Different Scenarios:

This section will discuss the results obtained from the IES VE software when the different scenarios have been applied to the base case modelled building and have been simulated to understand their impact on the building energy performance.

5.3.1 Replacing Fluorescent lights with Light Emitting Diode (LED) Lights:

In this scenario the Fluorescent lights (1200mm Polylux T8 lamp, 3,450 Lumens, and 500 lux level) in the modelled building which run continuously for 24 hours a day continuously, and are not controlled via dimming controls systems, were replaced with Light Emitting Diode (LED) lights (LZ158: LZ 158, 5200 Lumens, and 500 lux level). The properties of the LED light is shown in figure 42.

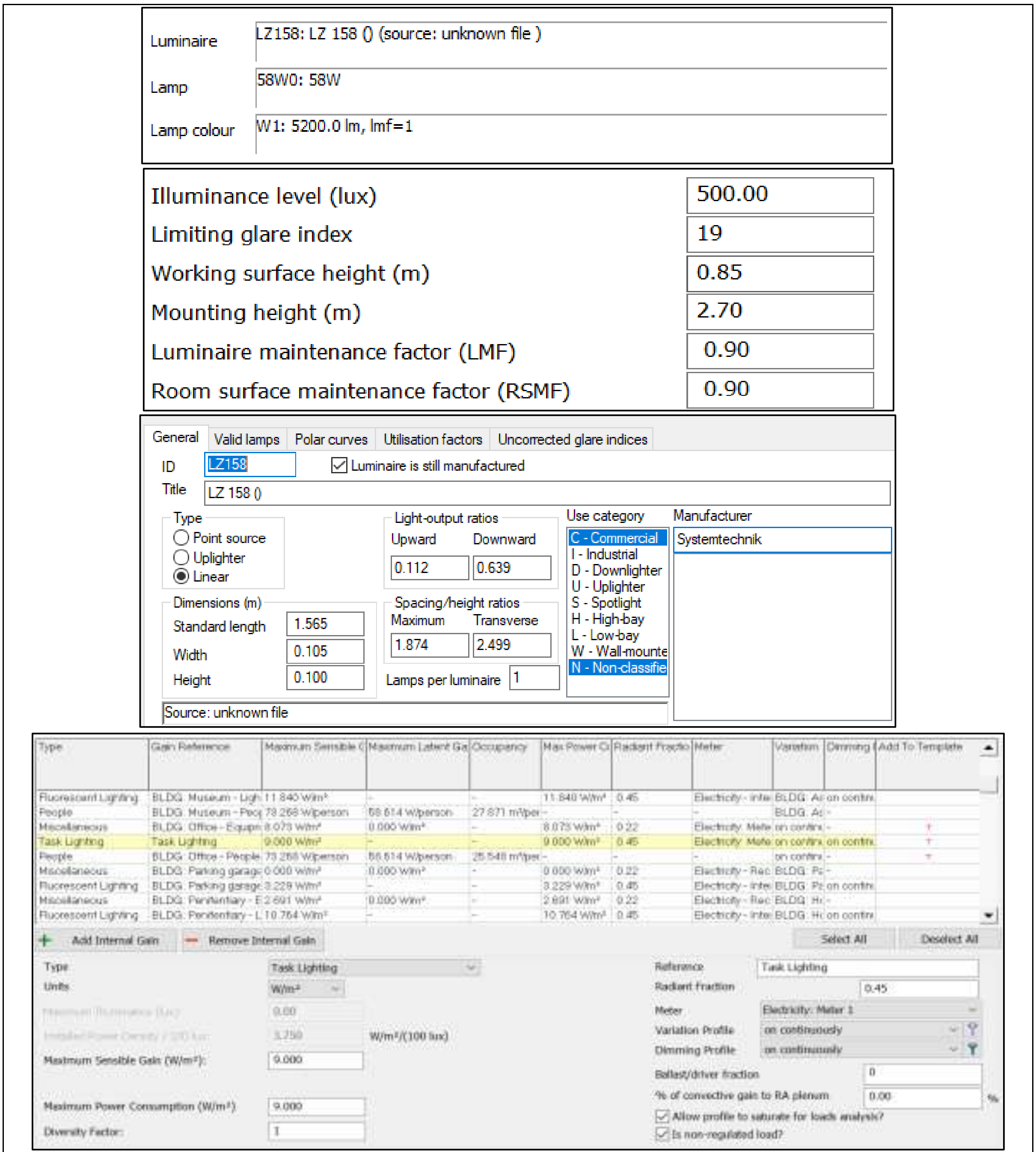


Figure 42 LED lights properties

From the simulation, it was found that replacement of the lights has achieved savings of 148 MWh over a year which counts to about 16% of the total light electricity consumption, where the base case fluorescent light total consumption for the year is 905.2155 MWH and the new LED lights consumption over the year is 756.8585 MWh. using the electricity cost of 0.44 AED/KWh, the monetary savings is estimated to be AED 65,277 per year. The drop in the power consumption was due to lesser power consumption per square meter (W/m2), where in the base case model the fluorescent lights power consumption per square meter is 10.764 W/m2, while the power consumption per square meter is 9.0 W/m2 for the LED lights.

Figure 43 compares the consumption month by month, this is while taking into consideration that the lights are kept ON continuously similar to the base case, and the lux level was also maintained at 500 lux.

Date	Base case MWh	LED Lights MWh
Jan	76.8813	64.2811
Feb	69.4412	58.0604
Mar	76.8813	64.2811
Apr	74.4013	62.2076
May	76.8813	64.2811
Jun	74.4013	62.2076
Jul	76.8813	64.2811
Aug	76.8813	64.2811
Sep	74.4013	62.2076
Oct	76.8813	64.2811
Nov	74.4013	62.2076
Dec	76.8813	64.2811
Total	**905.2155**	**756.8585**

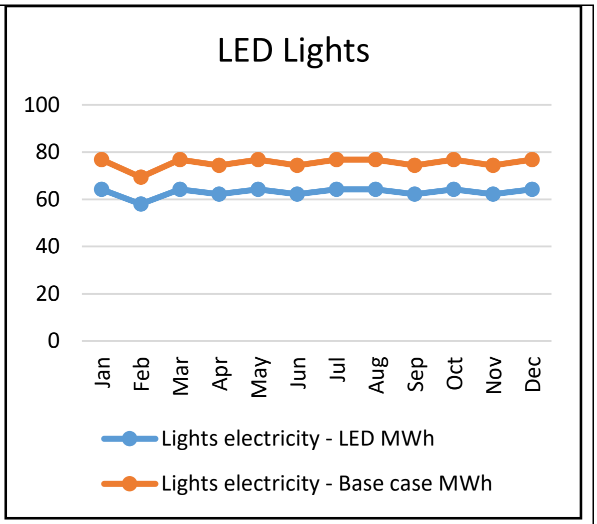


Figure 43 LED Lighting Results compared to Base case (IES VE)

5.3.2 Controlling the lights via Dimming Controls with Occupancy Sensors:

The lights in the base case modelled building runs continuously for 24 hours a day, therefore, Occupancy sensors were applied to the building to study the energy demand behaviour during the duty hours in the weekdays between 8.0am and 6.0pm in which the building will be occupied. Figure 44 shows the profile for the occupancy sensors where the building is mainly occupied during this period, a dimming system (Retail/Gym/ Office profile) is selected from the IES VE software to switch on the lights only when the space in the building is occupied as a signal from the occupancy sensors, and to keep the lights off when the building is not occupied, as shown in figure 45. The same luminaires i.e. Fluorescent lights (1200mm Polylux T8 lamp, 3,450 Lumens) from the base model were used in this scenario and were connected to the occupancy sensors.

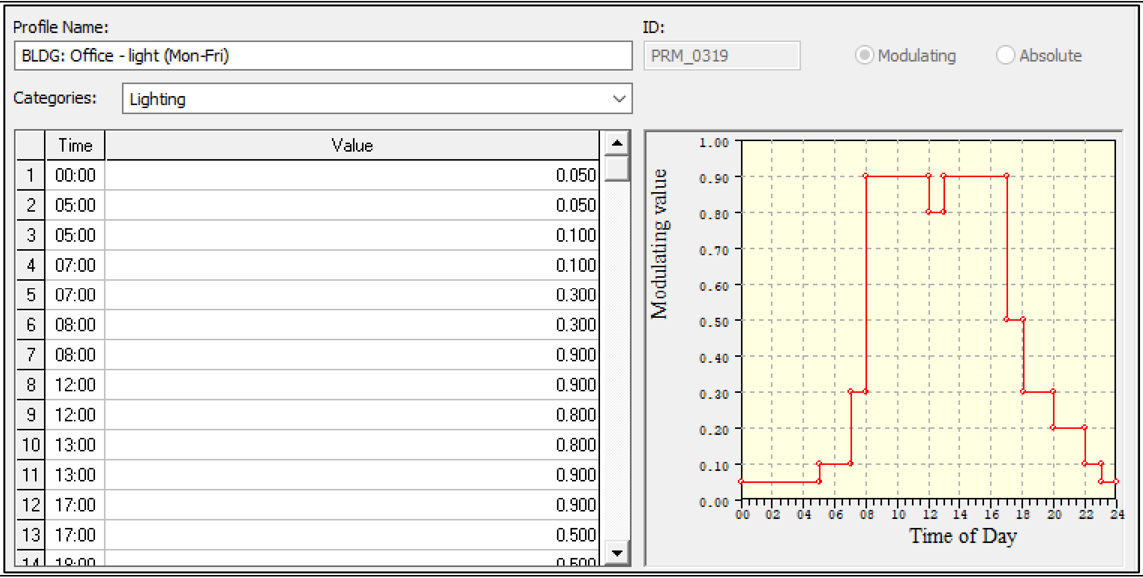


Figure 44 Occupancy Sensors (IES VE)

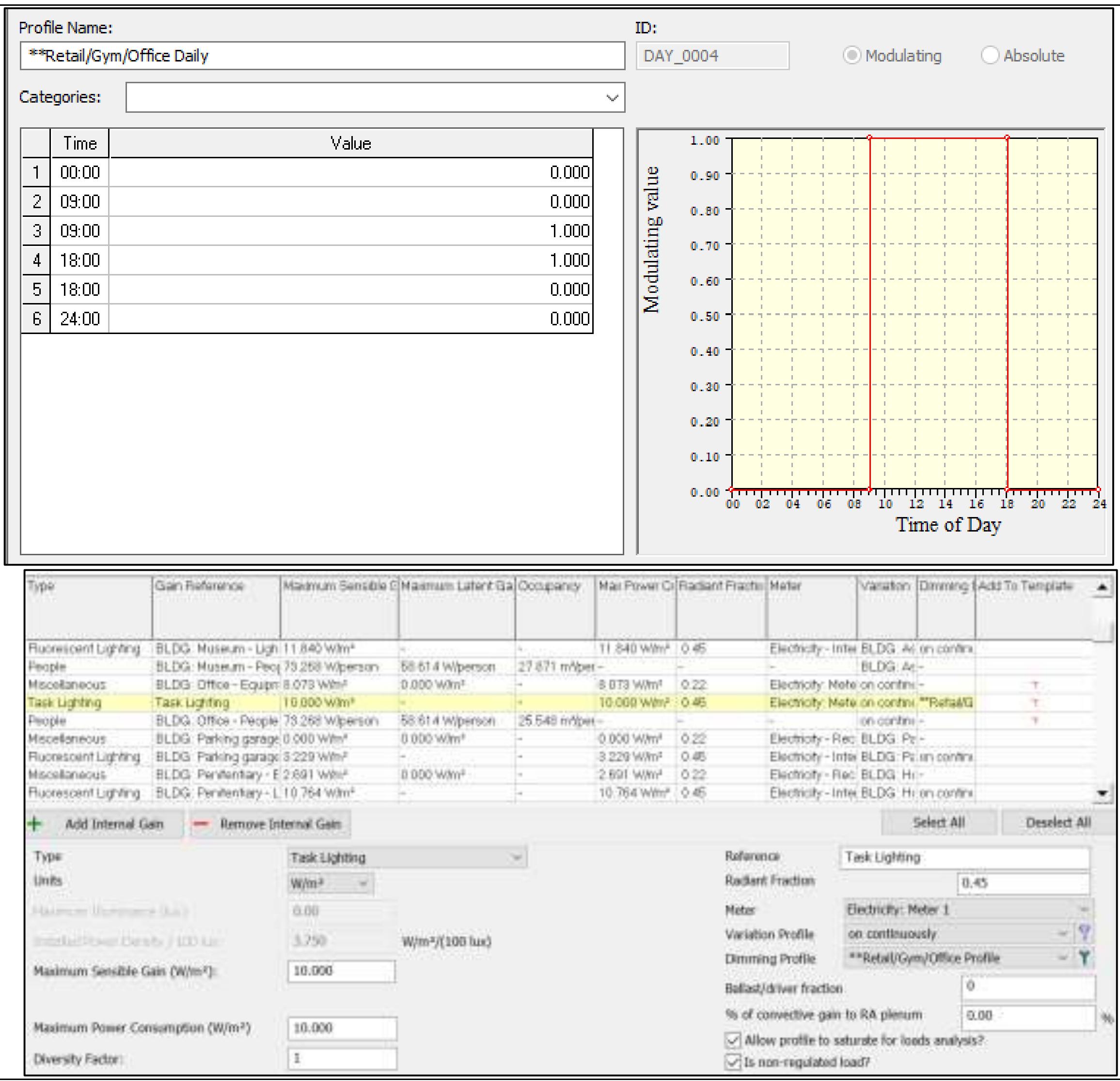


Figure 45 Dimming Control (IES VE)

The results from using dimming system that is linked to the occupancy sensors showed a significant reduction in the light electricity consumption in the building by 75%, where the consumption in the base case building is 905.2155 MWh and the consumption after applying the dimming controls and the occupancy sensors is 224.64 MWh, savings of 680.58 MWh as seen in figure 46, this is equivalent to monetary savings of AED 299,453 per year. The reduction of the consumption was due to less working hours of the lights due to being switched off when the offices are not occupied i.e. outside the main duty hours and when there are no occupants in the building.

	Base case	**Occupancy Sensors and Dimming Control**
Date	**MWh**	**MWh**
Jan	76.8813	18.144
Feb	69.4412	17.28
Mar	76.8813	19.872
Apr	74.4013	18.144
May	76.8813	19.008
Jun	74.4013	19.008
Jul	76.8813	18.144
Aug	76.8813	19.872
Sep	74.4013	19.008
Oct	76.8813	18.144
Nov	74.4013	19.008
Dec	76.8813	19.008
Total	**905.2155**	**224.64**

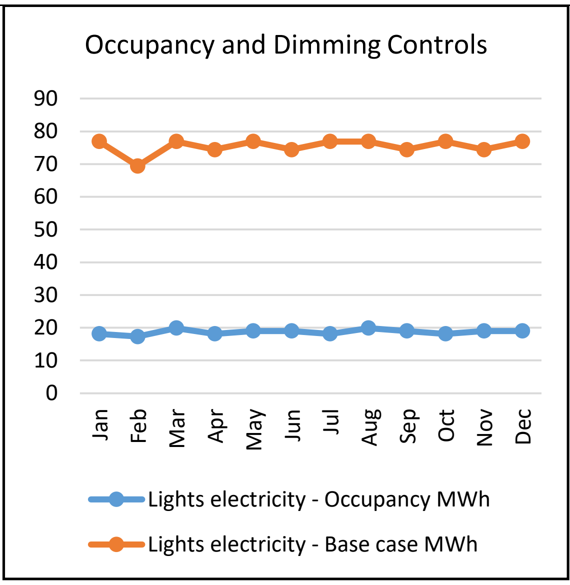


Figure 46 Occupancy Sensors and Dimming Results compared to Base case (IES VE)

5.3.3 Using lights Dimming Control based on External Day Lighting:

Another strategy is applied to consider dimming the lights in the building based on the external day light coming through into the building during the day. The profile is setup for continuous dimming to 10% of the light and a power of 50 foot candle during the day time, while keeping the overall lumen per square metre in the building at 500 lux level. The selected option in IES VE software is Daylight Dimming – continuous to 10% light; 20% min power at 50 fc. The same luminaires i.e. Fluorescent lights (1200mm Polylux T8 lamp, 3,450 Lumens) from the base model were used in this scenario and were connected to the dimming panels. Figure 47 shows the dimming system control profile.

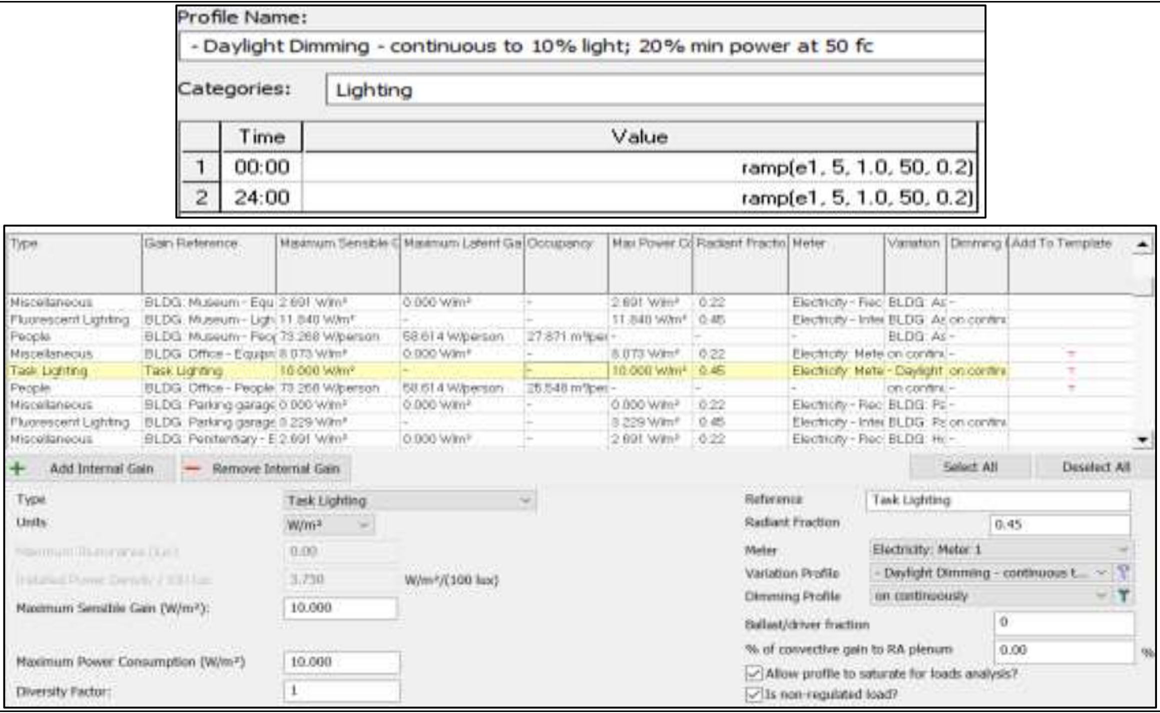


Figure 47 Day Light Dimming Control (IES VE)

The results from dimming the lights based on the intensity of the external day lighting coming through into the building shows that the electricity consumption from the lights in the building dropped from 905.2155 MWh as per the base case model to be 839.115 MWh in this simulated scenario, which is equivalent to saving 7% (66.1 MWH) of the yearly lights electricity consumption in the building, as seen in figure 48, which is equivalent to AED 29,084 per year. The drop in the consumption was due to lesser energy used while the lights are dimmed during the day, as the dimmed lights were controlled to run at 10% of their power only during this period while providing the same overall lumen per square metre in the building at 500 lux level.

	Base case	Day Light Dimming Control
Date	**MWh**	**MWh**
Jan	76.8813	71.2503
Feb	69.4412	64.3481
Mar	76.8813	71.2593
Apr	74.4013	68.9778
May	76.8813	71.2995
Jun	74.4013	69.0039
Jul	76.8813	71.2901
Aug	76.8813	71.2872
Sep	74.4013	68.956
Oct	76.8813	71.2492
Nov	74.4013	68.9446
Dec	76.8813	71.2492
Total	**905.2155**	**839.1152**

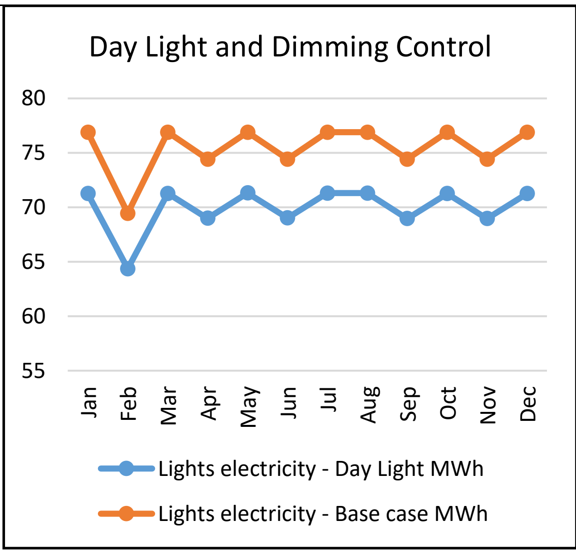


Figure 48 Day Light and Dimming Results compared to Base case (IES VE)

5.3.4 Changing the Ballast Factor:

The estimated system wattage of a fluorescent fixture = Lamp wattage x number of lamps x ballast factor, a ballast factor gives an indication on how much light a lamp can emit using that ballast, and its value ranges usually between 0.7 and 1.2. It is calculated by dividing the lumen output by lumen output of the same lights on a reference ballast, where a ballast factor that is less than 1 indicates that the fluorescent system produces less light than the reference ballast, and a factor that is above 1 indicates that it will produce more light.

In this simulation the ballast factor for the Fluorescent lights (1200mm Polylux T8 lamp, 3,450 Lumens,) is changed from 1.0 as in the base case model to become 1.2 to understand if there will be any impact on the lights energy consumption, however, the results from the simulation showed that there is no impact occurred on the fluorescent light electricity consumption from changing the ballast factor from 1.0 to 1.2. Figure 49 shows the results before and after changing the ballast factor which are found identical.

Date	Base case MWh	Ballast MWh
Jan	76.8813	76.8813
Feb	69.4412	69.4412
Mar	76.8813	76.8813
Apr	74.4013	74.4013
May	76.8813	76.8813
Jun	74.4013	74.4013
Jul	76.8813	76.8813
Aug	76.8813	76.8813
Sep	74.4013	74.4013
Oct	76.8813	76.8813
Nov	74.4013	74.4013
Dec	76.8813	76.8813
Total	905.2155	905.2155

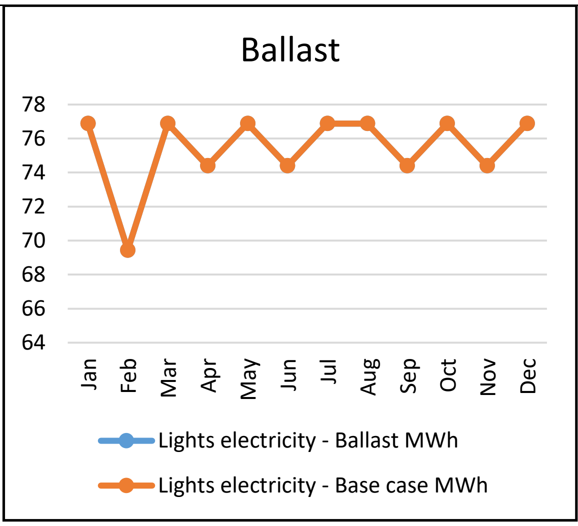


Figure 49 Ballast Factor Results compared to Base case (IES VE)

5.3.5 Controlling the Cooling Set point for the HVAC system in Winter Season:

The cooling set point in the base case modelled building is 23 C, therefore, in this scenario, the thermostat cooling set point for the HVAC system is adjusted to be 26C in the winter season (December to February where the average ambient temperature in the Emirate of Abu Dhabi is about 20 C) instead of 23 C as per the case base model to observe the difference that it could make on the electricity consumption from the

HVAC system, similar to the base case model the HVAC system is kept running continuously for 24 hours a day throughout the year, as shown in figure 50.

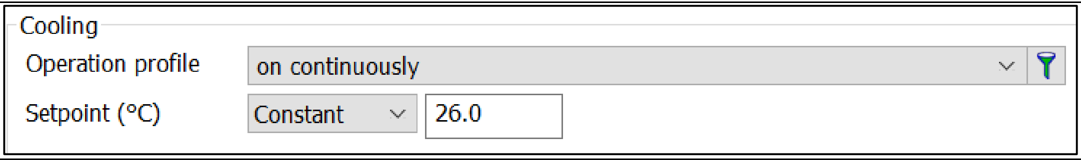


Figure 50 Adjusting the Set point in winter season (IES VE)

The results show that adjusting the thermostat cooling set point to 26 C instead of 23 C in the winter season (December to February) reduces the yearly electricity consumption of the HVAC system by 7% (63.59 MWh), from 973.4194 MWh in the base case model to 873.8256 MWh in the simulated scenario, which is equivalent to AED 27,981 per year. The changes in the power consumption only occurred during the three months from December, January, and February and the rest of the months consumption remained the same as there was no change in the thermostat set point on these months, as seen in figure 51. The reduction of the energy consumption is due to lesser working time of the AC compressors in the HVAC system which means consuming less power consumption.

Date	Base case Set point 23C MWh	Set point 26C MWh
Jan	***70.1914***	***65.4839***
Feb	***65.0076***	***60.5863***
Mar	73.4208	73.4208
Apr	74.902	74.902
May	83.0538	83.0538
Jun	83.6778	83.6778
Jul	89.3171	89.3171
Aug	90.1366	90.1366
Sep	83.2554	83.2554
Oct	79.9607	79.9607
Nov	72.6272	72.6272
Dec	***71.869***	***66.9993***
Total	937.4194	873.8256

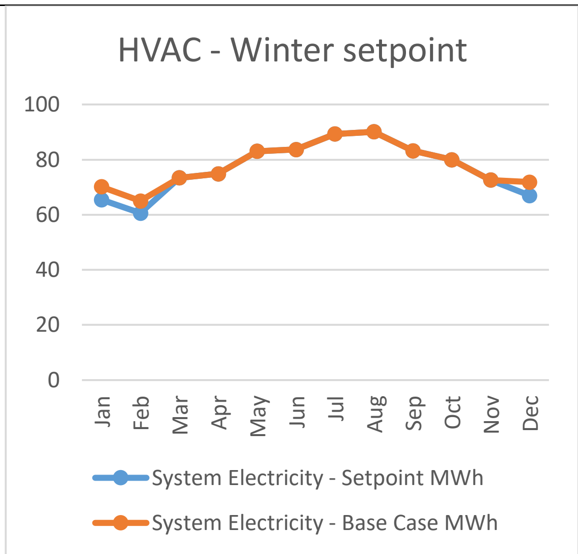


Figure 51 Set Point Results compared to Base case (IES VE)

5.3.6 Adjusting and controlling the HAVC system operation with Occupancy:

The base case model set point is fixed at 23 C throughout the year. Hence, the thermostat set point for the HVAC system is adjusted to be 23 C when the building is occupied which is mainly during weekdays’ duty hours (6.30am to 6.30pm) and at 26 C after duty hours in order to detect the impact that could be made on the total electricity consumption from the HVAC system. The occupancy sensors is used to detect the presence of the occupants in the building and the Retail/GYM/Office Profile is selected from the IES VE to simulate this change, as shown in figure 52.

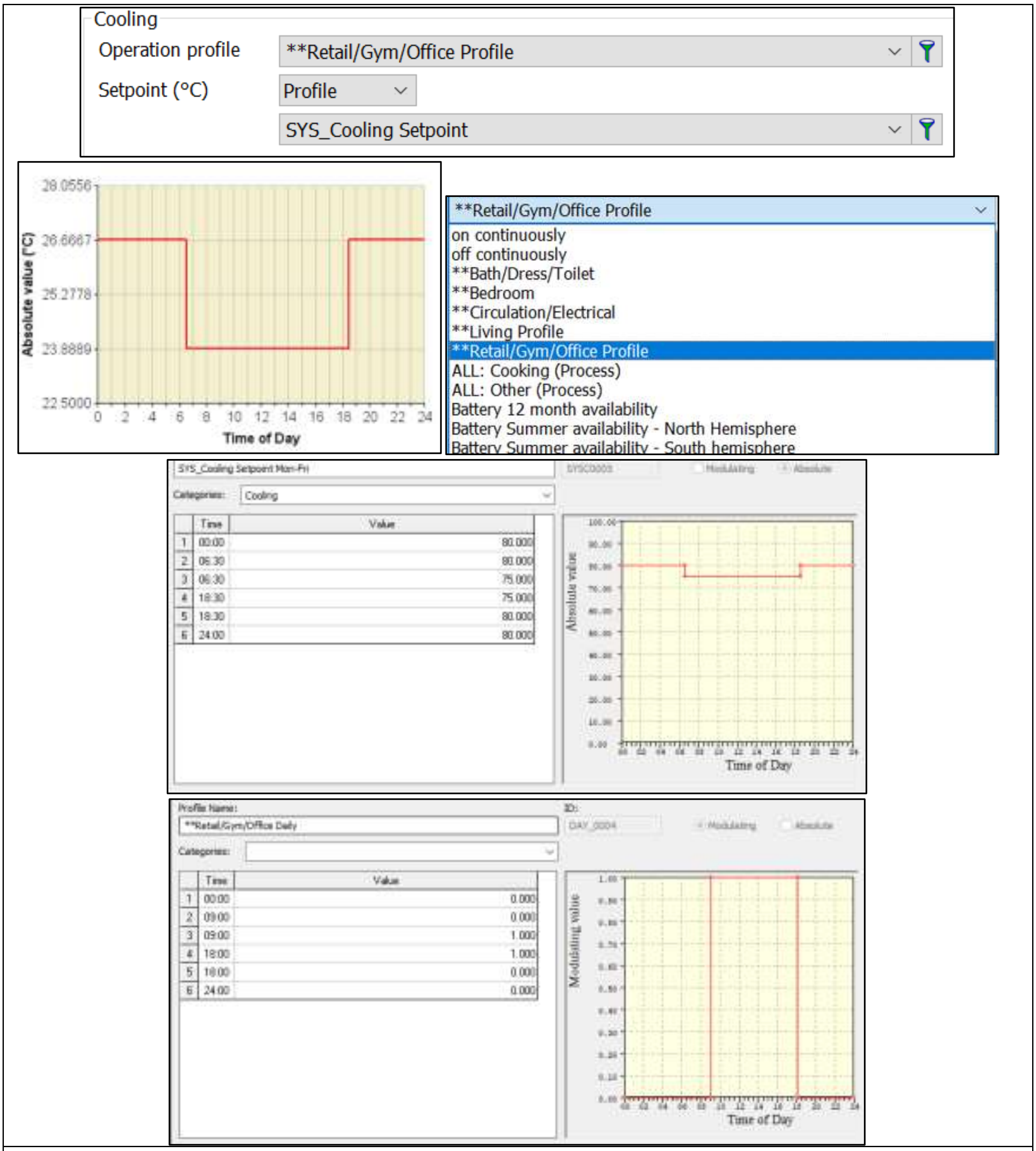


Figure 52 Adjusting the Set point based on Occupancy (IES VE)

The results showed that controlling the thermostat set point based on the occupancy and the duty hours in the building to be 23 C during duty hours and to be 26 C after duty hours has reduced the yearly electricity consumption of the HVAC system by 9%, from 973.4194 MWh in the base case model to 856.9238 MWh in the simulated scenario, as seen in figure 53, which is equivalent to 80.5 MWh and AED 35,418 per year. The reduction of the energy consumption is due to lesser working time of the AC compressors in the HVAC system when increasing the thermostat set point temperature to 26 C after duty hours which means consuming less power consumption.

	Base Case	HVAC based on Occupancy
Date	**MWh**	**MWh**
Jan	70.1914	64.1487
Feb	65.0076	59.4013
Mar	73.4208	67.1285
Apr	74.902	68.4672
May	83.0538	75.8879
Jun	83.6778	76.482
Jul	89.3171	81.6667
Aug	90.1366	82.4469
Sep	83.2554	76.113
Oct	79.9607	73.0786
Nov	72.6272	66.4066
Dec	71.869	65.6964
Total	**937.4194**	**856.9238**

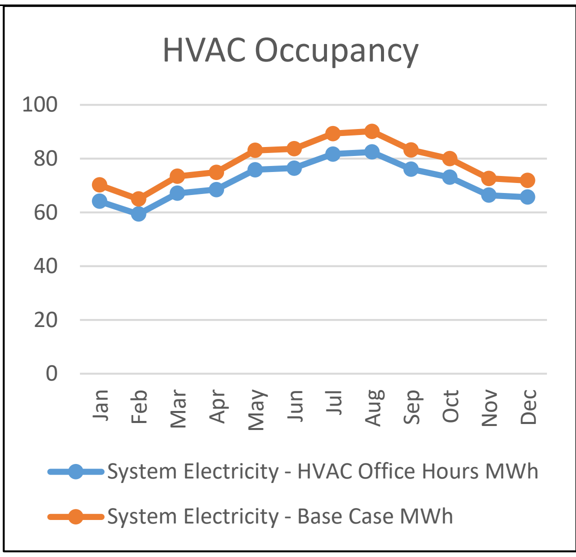


Figure 53 Set point based on occupancy Results compared to Base case (IES VE)

5.3.7 Using Variable Air Volume (VAV) systems:

The HVAC system in the base case model uses DX system. To measure the impact on the power consumption when upgrading the HVAC system, the IES VE software is used to re-configure the HVAC system to a more precise temperature control multi-zone variable air volume reheat system (VAV cool and vent - DX cool only and no reheat), which supplies a variable airflow at a constant temperature, the supply and the return fans are equipped with variable speed drives, and the outside air damper equipped with minimum outdoor air and airside economizer operation with high limit. The VAV box controls the flow at zone level and calibrates the air dampers using automatic actuators to minimize the cooled air flow into the space. Similar to the base model, the set point is maintained at 23C and the system runs continuously for 24 hours. The details of the upgraded simulated HVAC system is shown in figure 54.

The results from the simulation shows that using VAV system instead of DX system in the building reduces the yearly electricity consumption of the HVAC system by 20%, from 973.4194 MWh in the base case model to 748.7963 MWh in the simulated scenario, as seen in figure 55, which is equivalent to 188.62 MWh and AED 82,994 per year. The reduction in power consumption is due to having the VAV system decreases the overcooling and lowers the fan speeds and lower the compressors power consumption because it operates the compressor at a warmer suction temperature.

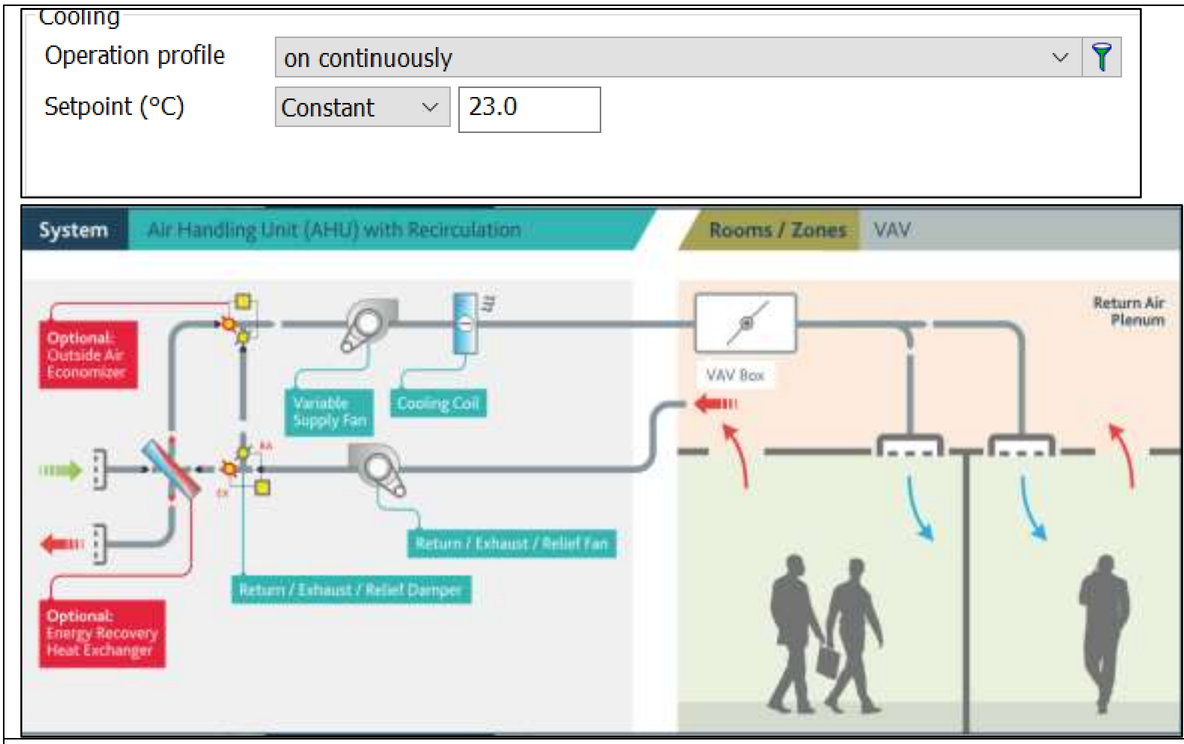


Figure 54 Using VAV (IES VE)

	Base Case	VAV
Date	**MWh**	**MWh**
Jan	70.1914	36.4148
Feb	65.0076	39.3615
Mar	73.4208	53.5462
Apr	74.902	63.4724
May	83.0538	72.8545
Jun	83.6778	74.5138
Jul	89.3171	80.3776
Aug	90.1366	81.0711
Sep	83.2554	73.7286
Oct	79.9607	68.3474
Nov	72.6272	60.1301
Dec	71.869	44.9783
Total	**937.4194**	**748.7963**

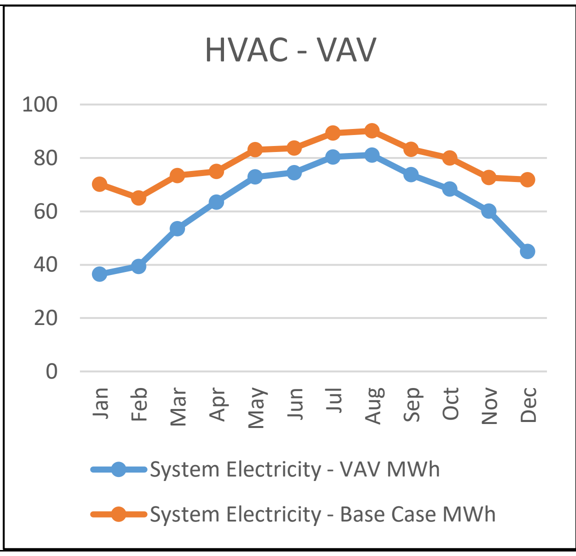


Figure 55 Using VAV Results compared to Base case (IES VE)

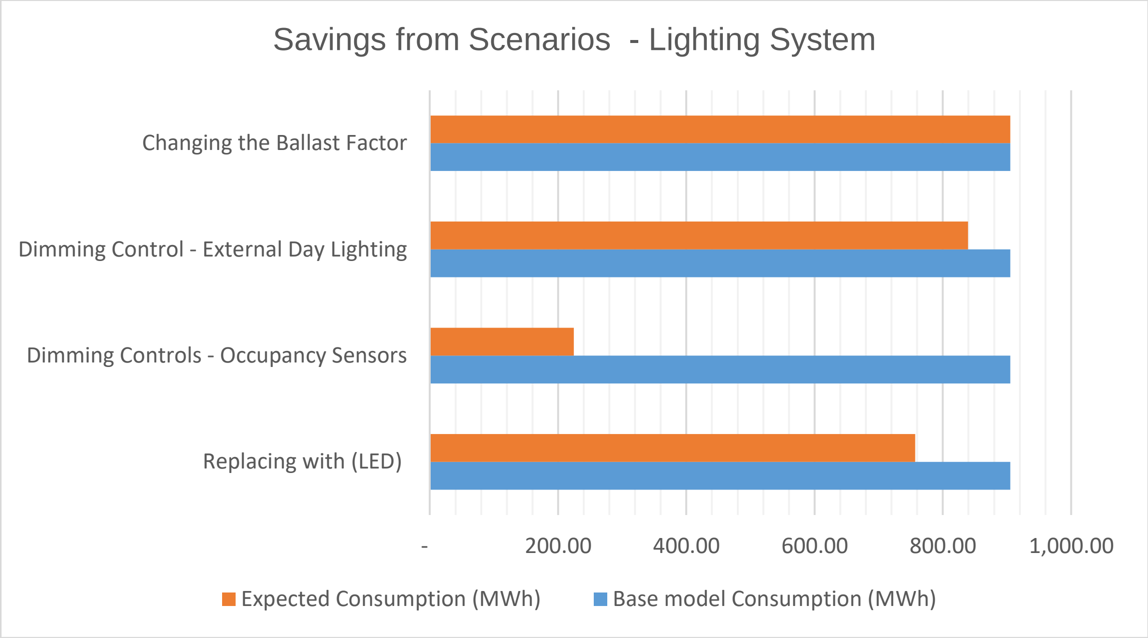
5.3.8 Summary of the Results from the different Simulation scenarios:

Table 23 summarizes the outcomes obtained from the IES VE software when the different scenarios of energy efficiency is applied. The existing base model consumption represents the power consumption from the base case model without any modifications, the consumption from the scenario represents the outcomes of the energy consumption after applying the energy efficiency scenario, the savings are the difference between the base case model power consumption and the power consumption after applying the scenarios, the cost savings are calculated based on electricity cost of 0.44 AED/KWh by multiplying the savings by the electricity cost, and the percentage of savings is calculated as the rate of consumption from the scenario over the base case model consumption.

Table 23 Summary of the Results from the different Simulation scenarios

#	Scenario	Existing Base model Consumption (MWh)	Consumption from the scenario (MWh)	Savings (MWh)	Cost Savings (AED)	% Savings
	Formula	**A**	**B**	**C = A-B**	**D = C x 0.44 x 1000**	**E=1-(B/A)**
1.	Replacing Fluorescent lights with Light Emitting Diode (LED) Lights	905.22	756.86	148.36	65,277	16%
2.	Controlling the lights through Dimming Controls based on Occupancy Sensors	905.22	224.64	680.58	299,453	75%
3.	Using lights Dimming Control based on External Day Lighting	905.22	839.12	66.10	29,084	7%
4.	Changing the Ballast Factor	905.22	905.22	-	-	0%
5.	Controlling the Cooling Set point for the HVAC system in Winter Season	937.42	873.83	63.59	27,981	7%
6.	Adjusting and controlling the operation of the HVAC system based on Occupancy	937.42	856.92	80.50	35,418	9%
7.	Using Variable Air Volume (VAV) systems	937.42	748.80	188.62	82,994	20%

The results are also illustrated in Figure 56, where it shows the base case consumption and the consumption after applying each of the different scenarios for the lighting system and the HVAC system.



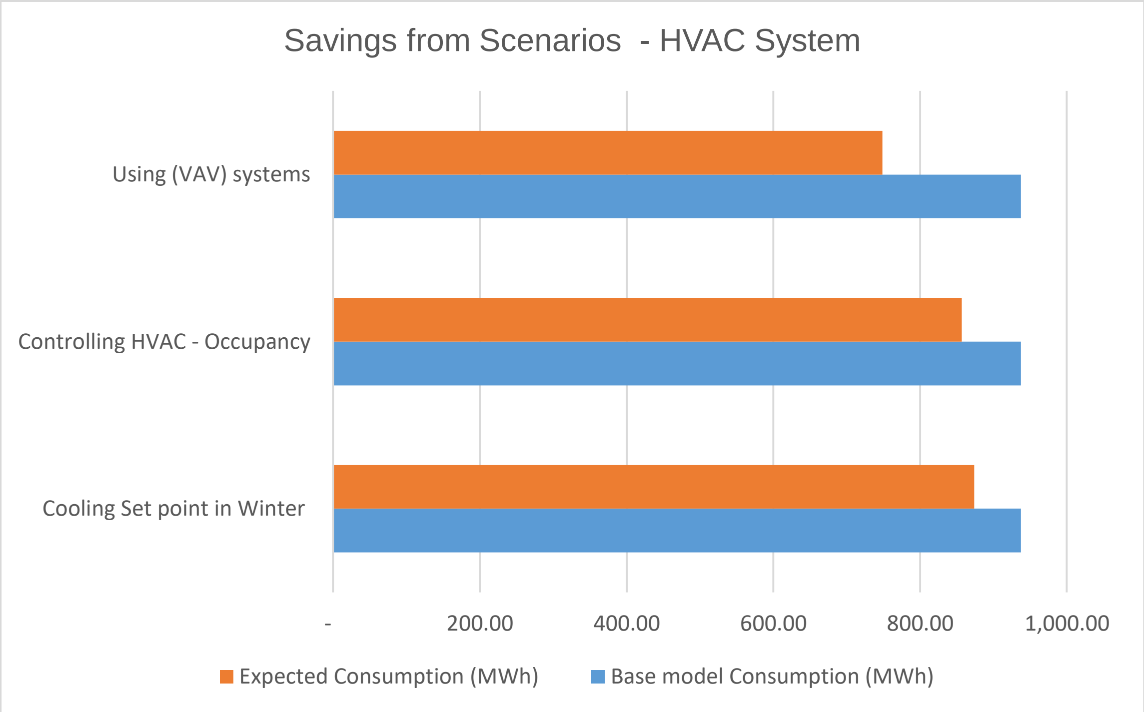


Figure 56 Savings from the different scenarios applied in the simulation software IES VE

Chapter 6 Conclusion and Recommendations

6 Conclusion and Recommendations

6.1 Conclusion

There is increased demand on energy from the building sector which is predicted to grow to above 50% by the year 2030 as a result of the fast development of the countries' population and economy. The electricity consumption per capita in the Arab gulf region is considered the highest worldwide caused by the significant use of the air conditioning loads in buildings particularly in the summertime. In 2015, the UAE consumed about 75 TWh in its overall building sector, also, electricity consumption in Abu Dhabi from 2014 to 2016 shows that the commercial building sector contributes to the growing demand of energy with accumulated percentage of 52.2%, meaning that there is a significant energy demand by the building sector which requires some serious actions to optimize the energy efficiency in this sector.

Due to the lack of academic research papers in the UAE and GCC counties that tackle the issues of high energy consumption in existing buildings and opportunities to reduce this consumption by using smart technologies. This research focused on retrofitting existing buildings in the UAE (hot and humid climate) to demonstrate how could retrofitting existing buildings in the country to be smarter and more energy efficient reduce their energy consumption and increase their energy performance.

This research used a mixed mode methodology, starting from conducting Literature Review on various case studies to convert old ordinary buildings like (educational institutes, governmental, residential, and commercial buildings, with attention to office buildings) to be smarter and more energy efficient. These case studies revealed a good potential in reducing the energy demand, however the percentage of reduction varied from one case to another depending on the state of the building, location, building envelop, electrical and mechanical systems, occupancy and application, and many other factors.

The literature review was then followed by conducting an actual case study on existing governmental office building in Dubai, various data was collected through actual field measurement and from historical records of the building energy performance, the data was analyzed to understand the overall building energy consumption. Using the outcomes of the data analysis, energy efficiency scenarios were proposed for the building HVAC system where most energy was found to be wasted.

The literature review and the field assessment was complemented by Modelling and Simulating an office building in Abu Dhabi, the IES VE software was used to simulate the proposed energy conservation scenarios for the model and to realize their impact on the energy demand from the modelled building, explicitly, for the lighting and the HVAC systems.

The obtained results from the energy conservation scenarios to the 82,194m2 governmental building in Dubai that has a baseline of annual electricity consumption of 17.151 MWh accounting to energy costs of 7.5 Million AED per year, show that, the expected savings from upgrading the HVAC system and using cloud software in the studied building, could achieve a reduction of 17% from the energy consumption of the FHAU, AHU, FCU, and Car parking system which is equivalent to 684 MWh and AED 905,449 per year, while installing a Chiller Plant Manager could a achieve a total savings of 14% from the energy consumption of the chillers which is equivalent to 928 MWh and AED 408,438 per year. Also, retrofitting existing conventional DX units with invertor DX units in the building could achieve a substantial reduction by 38% of the energy which is equivalent to 225 MWh and AED 99,330. In addition, the savings from installing Adiabatic Cooling System touches 11% of the chillers energy consumption which is equivalent to 740 MWh and AED 223,925 per year.

The 9,600 m2 modelled office building in Abu Dhabi was simulated using the IES VE software to apply different retrofitting energy conservation measures, the building energy baseline is 905 MWh for the lighting system and 937 MWh for the HVAC system. The results from implementing different scenarios were found as follows; replacement of the fluorescent light with LED lights has achieved an annual saving of 148 MWh which is equal to 16% of the total light electricity consumption and the monetary saving reaches up to AED 65,277 per year. Using dimming system that is linked to the occupancy sensors shows a significant reduction in the light electricity consumption by 75% which is equivalent to 680.58 MWh and AED 299,453 per year, also, using dimming controls for the indoor lights while considering the intensity of the external day light entering the building shows that the electricity consumption from the lights dropped by 7% which is equivalent to 66.1 MWH and AED 29,084 per year, furthermore, adjusting the thermostat cooling set point to 26 C instead of 23 C in the winter season (December to February) reduces the yearly electricity consumption of the HVAC system by 7% which is equivalent 63.59 MWh and AED 27,981 per year, and controlling the thermostat set point based on the occupancy and the duty hours in the building to be 23 C during duty hours and to be 26 C after duty hours reduces the yearly electricity consumption of the HVAC system by 9% which is equivalent to 80.5 MWh and AED 35,418 per year, whereas using VAV system instead of DX system in the building reduces the yearly electricity consumption of the HVAC system by 20% which is equivalent to 188.62 MWh and AED 82,994 per year.

Therefore, from the first case study of the actual office building in Dubai, it was found that the most efficient energy conservation measures from the proposed scenarios are as follows; installing Chiller Plant Manager with expected annual savings of 14% equivalent to 928 MWh, and installing Adiabatic Cooling System for Air Cooled Chiller which could save annually 11% of the energy corresponding to 740 MWh. Nevertheless, from the second case study of the modelled office building in Abu Dhabi and due to the building characteristics, it was found that controlling the lights through Dimming Controls based on Occupancy Sensors was the most energy efficient scenario with expected savings of 75% corresponding to 680.58 MWh, followed by using the VAV system with annual expected savings of 20% corresponding to 188.62 MWh.

To conclude, it was established from the 2 case studies mentioned earlier that there is a great opportunity to enhance the energy efficiency in both buildings by retrofitting the lighting and the HVAC systems using smarter devices, those smart devices schedule and control the operations to optimize the running time of the lights and the HVAC system, subsequently using less power to operate the lights while maintain the desired lux levels, and using less power to operate the HVAC system compressors and fans while maintaining the desired temperature and the indoor air quality in the building.

6.2 Recommendations

From the results of the two case studies it was found that energy demand from buildings in the Hot and Humid climate like the UAE could be significantly reduced using a variety of alternatives, especially for the HVAC system which constitutes as a major part of the energy consumption in those buildings during summertime.

Besides reducing the energy consumption, the optimization of the building energy performance has many other benefits, such as; reducing the energy bill cost, improving the performance of the systems in the building would reduce the breakdown time and the associated costs of repair activities and spare parts and would extend the efficient life cycle for those systems/ assets in the building, in addition to improving the occupants' comfort, and reducing the greenhouse gas emissions.

The most efficient energy saving scenarios from this research could be taken into consideration by buildings' owners when choosing the HVAC and Lighting systems for a new building or when upgrading them i.e. having a chiller plant manager along with cloud analytics to efficiently control and manage the operation of the chillers, and having light dimming control system connected with occupancy sensors and day light sensors.

Also, it is recommended for a building equipped with DX systems to convert the conventional AC system with invertor AC system as the results show significant energy saving of 38%. The same goes for controlling the speed and the operation of the fresh air handling units, and the car parking exhaust fans via indoor air quality sensors such as CO2 sensors, in which the results show reduction in the energy consumption from both systems by 59% and 38% respectively.

Considering the outcomes of this research, the UAE government may provide attractive incentive schemes for the existing building owners to encourage them taking serious steps towards retrofitting their buildings to be more energy efficient, and could facilitate the initial energy audits for the old buildings to provide an overview of the building energy performance to the owners and encourage/penalize them for improvement, this would support the UAE to achieve its green agenda for sustainable development 2030 and the demand side management strategy 2030.

In addition, due to the general relaxed lifestyle of the UAE citizens and residents, the government may provide public awareness campaigns regarding the impact of their energy consumption behavior on the energy demand from the different sectors, and may consider reducing the subsidy for the electricity and water consumption where consumers would be more cautious of their energy consumption behavior.

Furthermore, the energy services companies may use the outcomes of this research and other studies in this area to establish a proper database that could be categorized in a manner to enable them having easy access to the data that could be used for comparison and benchmarking purposes in future energy conservation projects.

6.3 Further Future Research

Researchers could benefit from the outcomes of this research for further investigation in the future in regards to:

- Studying the economic feasibility of retrofitting an existing building to be a smarter building and assess the return on investment or the payback period of similar retrofits.
- Utilizing the results obtained from the active retrofit measures in this research and propose passive retrofit measures, then to analyze the impact of both measures together on the overall building energy consumption.
- Studying the impact of retrofitting existing building to be more energy efficient on its indoor air quality and occupants comfort.
- Comparing the outcomes of this research with future retrofitting studies of buildings with similar characteristics.
- Studying occupants' energy consumption behavior in the public buildings (due to the high energy consumption and wasted energy in the studied governmental office building), and defining some policies to increase occupants' awareness and reduces any misuse or negligence made by them.

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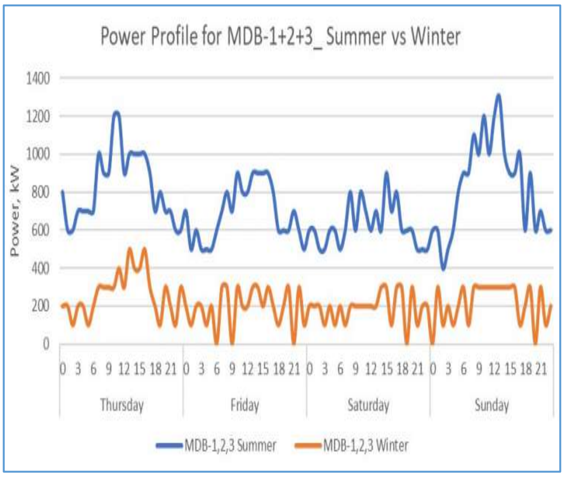
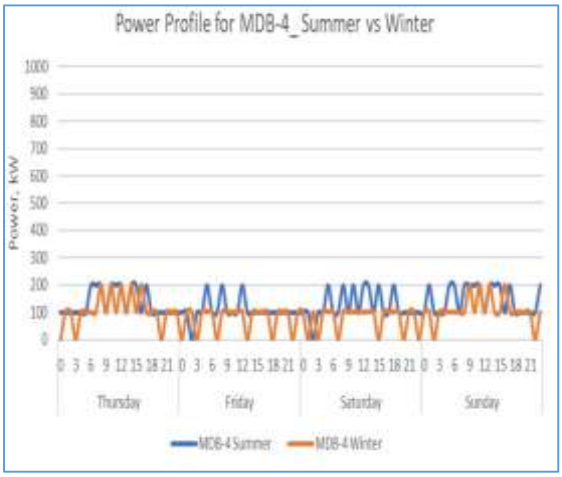
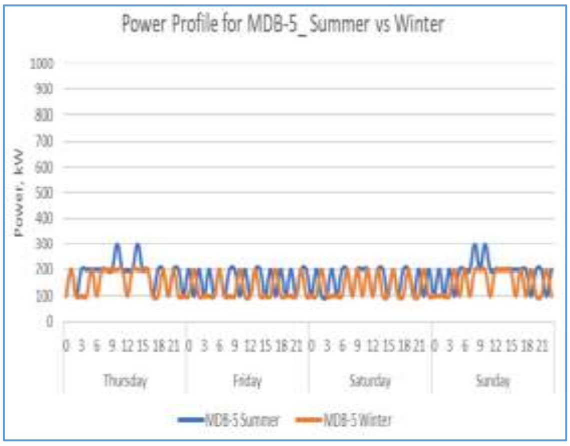
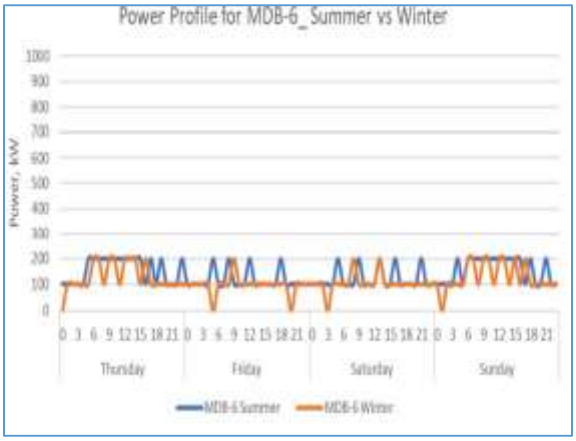
Appendices

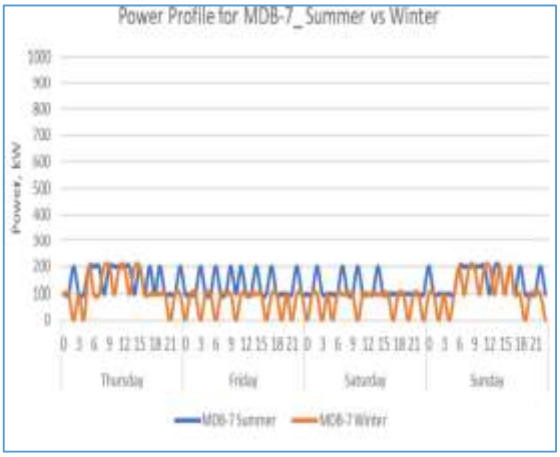
Appendix A - Comparison of Power Profile: Summer Vs Winter for the MDBs

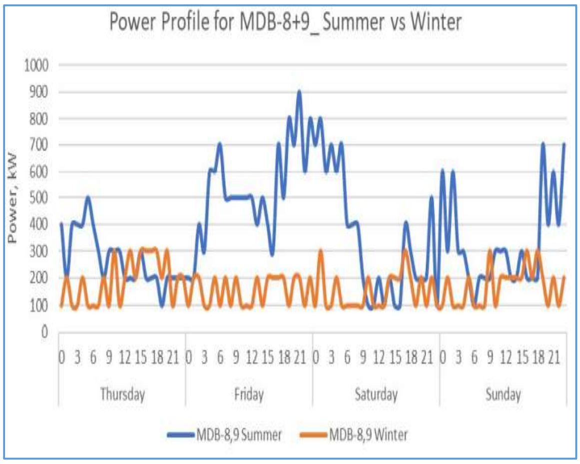

Power Profile for MDB-1+2+3_ Summer vs Winter
Power, kW
0
200
400
600
800
1000
1200
1400
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21
Thursday
Friday
Saturday
Sunday
MDB-1,2,3 Summer
MDB-1,2,3 Winter

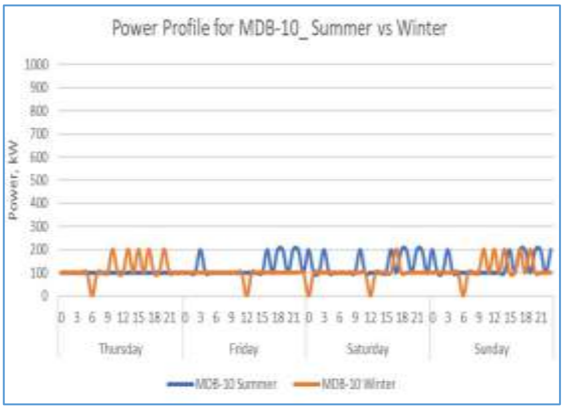
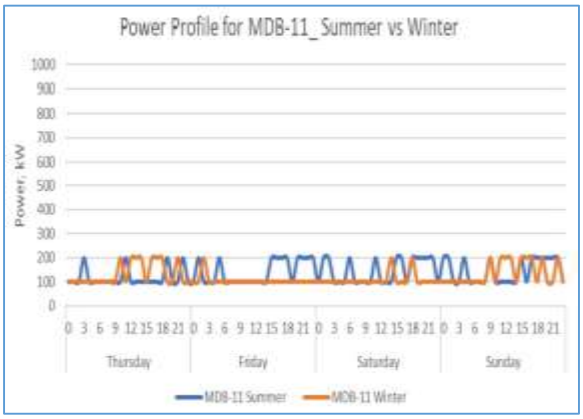
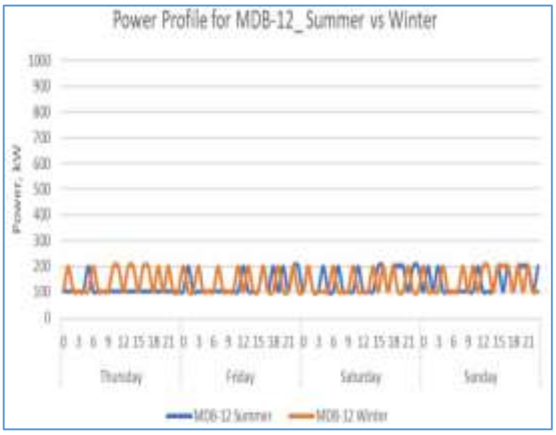
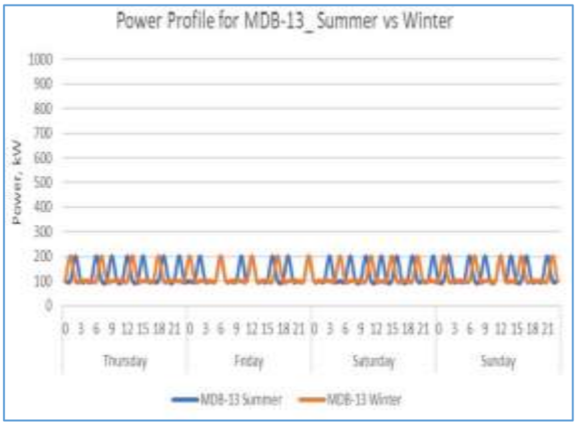
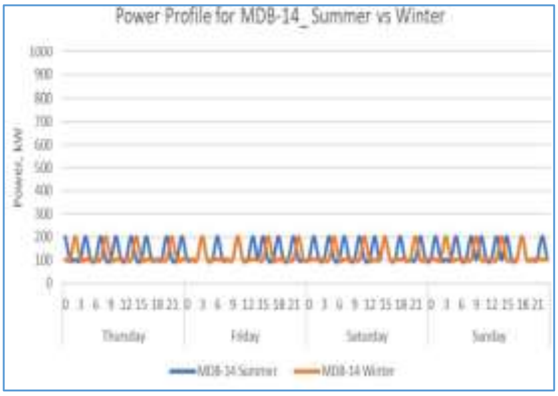

Power Profile for MDB-4_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday


Power Profile for MDB-5_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday


Power Profile for MDB-6_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday


Power Profile for MDB-7_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday


Power Profile for MDB-8+9_ Summer vs Winter
Power, kW
0
100
200
300
400
500
600
700
800
900
1000
0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21
Thursday
Friday
Saturday
Sunday
MDB-8,9 Summer
MDB-8,9 Winter

Power Profile for MDB-10_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday
MDB-10 Summer
MDB-10 Winter

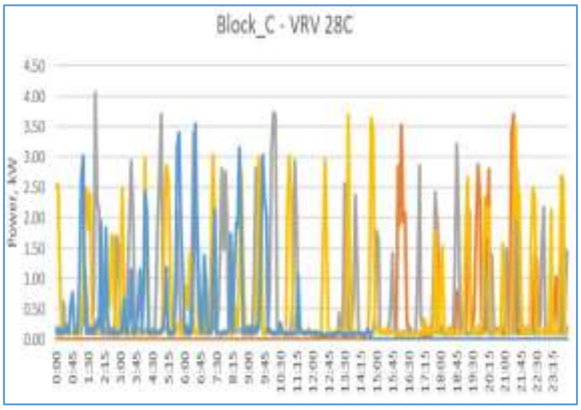
Power Profile for MDB-11_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday
MDB-11 Summer
MDB-11 Winter

Power Profile for MDB-12_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday
MDB-12 Summer
MDB-12 Winter

Power Profile for MDB-13_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday
MDB-13 Summer
MDB-13 Winter

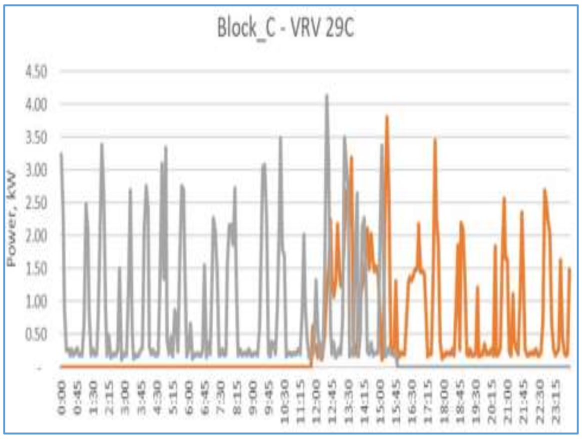
Power Profile for MDB-14_ Summer vs Winter
Power, kW
Thursday
Friday
Saturday
Sunday
MDB-14 Summer
MDB-14 Winter

Appendix B - VRV Power Profile in the Case Study Building



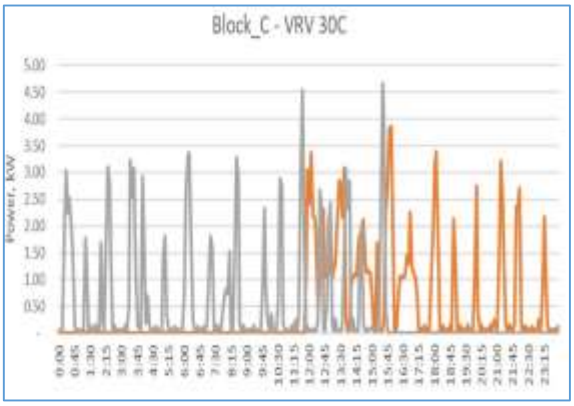
Thu	Fri	Sat	Sun

Block C - VRV 28C power profile



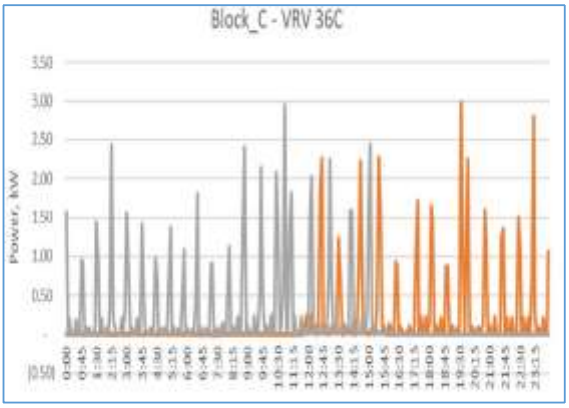
Wed	Thu

Block C - VRV 29C power profile



Wed	Thu

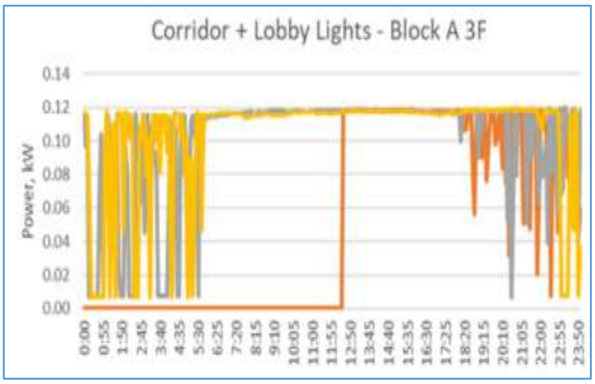
Block C - VRV 30C Power Profile



Wed	Thu

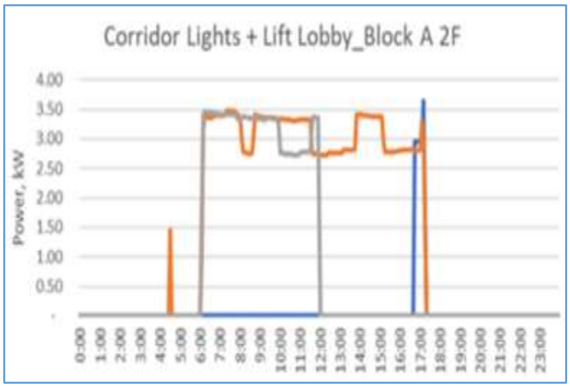
Block C - VRV 36C Power Profile

Appendix C – Lighting Power Profile of Samples Area in the Case Study Building



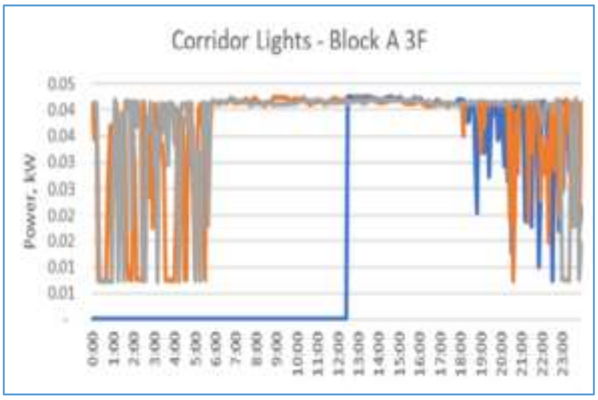
Sun Mon Tue

Lighting Power Profile for Corridor + Lobby Lights - Block A 3F



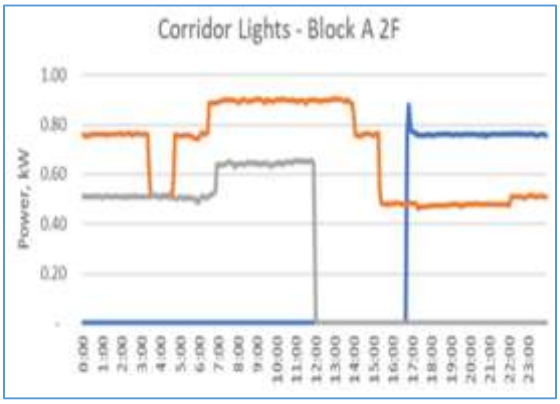
Tue Wed Thu

Lighting Power Profile for Corridor Lights + Lift Lobby – Block A 2F



Sun Mon Tue

Lighting Power Summary for Washroom Lights – Block A 3F



Tue Wed Thu

Lighting Power Summary for Corridor Lights – Block A 2 F

Appendix D – Lux Level Measurements in the Case Study Building

SL No	Block	Floor Ref.	Location	Type of Fixture	Lux Level (Lux)
1	A	2ND FLOOR	Corridor	LED TUBE (2/FIXTURE)	719
2	C	3rd FLOOR	Corridor	LED TUBE (2/FIXTURE)	558
3	A	9TH FLOOR	Corridor	FTL (3/FIXTURE)	272
4	A	10th FLOOR	Corridor	FTL (3/FIXTURE)	65
5	A	11th FLOOR	Corridor	FTL (3/FIXTURE)	48
6	A	2ND FLOOR	Lift Lobby	LED SPOTLIGHT	944
7	C	3RD FLOOR	Lift Lobby	LED SPOTLIGHT	363
8	C	9TH FLOOR	Open Office - Near	FTL (3/FIXTURE)	920
9	C	9TH FLOOR	Open Office - Near	FTL (3/FIXTURE)	900
10	C	9TH FLOOR	Open Office - Away	FTL (3/FIXTURE)	147
11	C	9TH FLOOR	Open Office - Away	FTL (3/FIXTURE)	260
12	C	9TH FLOOR	Open Office - Away	FTL (3/FIXTURE)	115
13	A	2ND FLOOR	Prayer Room	CFL	462
14	A	2ND FLOOR	Male Toilet	CFL	214
15	C	7TH FLOOR	Male Toilet	CFL	206
16	C	9TH FLOOR	Male Toilet	CFL	200

Appendix E - The Electricity Tariff by the Dubai Electricity and Water Authority DEWA

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Electricity Tariff

Residential/Commercial

Consumption (kWh)/ month		Slab tariff (fils/kWh)
G	0-2000	23
Y	2001-4000	28
O	4001-6000	32
R	6001 & Above	38

Water Tariff

Residential

Consumption/ month (IG*)		Slab tariff (fils / IG*)
G	0-6000	3.5
Y	6001-12000	4.0
R	12001 & above	4.6

Commercial/Industrial

Consumption/ month (IG*)		Slab tariff (fils / IG*)
G	0-10000	3.5
Y	10001-20000	4.0
R	20001 & above	4.6

Fuel Surcharge - June 2021

	Fuel surcharge
Electricity	5.0 fils / kWh
Water	0.4 fils / IG*

*IG – Imperial Gallon

Note: 5% VAT is applicable on these tariffs.

Reference: https://www.dewa.gov.ae/en/consumer/billing/slab-tariff