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Optimization of the Energy Performance in the Hospitality Sector in UAE by Using the Integrated Control Methodology in the Guestrooms

تحسين أداء الطاقة في قطاع الضيافة في دولة الإمارات العربية المتحدة باستخدام المنهجية المتكاملة للتحكم في غرف النزلاء

By

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Abstract

This dissertation aims to study the energy efficiency in the hospitality sector in UAE. It will discuss the energy benchmarking analysis for the lodging buildings to differentiate between the usual practice and best practice in terms of energy performance for the hotels. This research focuses on developing several criteria such as; the hotel's gross floor area, star classification, building age, occupancy rate, guestrooms number, construction code and regulation and cooling energy source, to appraise the hotel building energy consumption with, by gathering a real energy data and basic building information, normalization of energy use index and analyze these data statistically to ascertain the expected energy performance and consumption in UAE. About 19 hotel buildings energy data was analyzed to provide the energy benchmarking findings in UAE hotels. Besides, the normalized energy use index kWh/m²/year has been concluded for the best, usual and poor practice hotels. It was found after the analysis of the collected data that the normalized EUI ranges between lower than 241.5 kWh/m²/year as a best practice and greater than 361.3kWh/m²/year of the poor energy practice for the hotels constructed after the year of 2003, when more stringent code adopted by Dubai Municipality. Whereas the hotels' energy data showed higher values for those constructed before 2003, as the normalized EUI varies between lower than 348.4 kWh/m²/year as best practice and greater than 511.1kWh/m²/year.

As the hospitality sector in UAE is growing to meet the current and upcoming demand. It would be an important requirement to reduce the gap between the poor, usual and the best energy management practices. In this dissertation, the integrated control strategy for the guestroom has been studied and modeled to present the potential of energy savings that might be achieved by using such integrated techniques. The building energy model in hourly basis has been conducted to assess the energy performance improvement after adopting the proposed system. It shows that at least 31.5% might be improved out of entire energy consumption of the hotel including electricity and gas; 43.2% energy savings for the cooling system and 13.2% for lighting system of the guestroom by installing the integrated control system.

خلاصة البحث

تهدف هذه الأطروحة إلى دراسة كفاءة استخدام الطاقة في قطاع الضيافة في دولة الإمارات العربية المتحدة. كما ستطرح هذه الدراسة مناقشة وتحليل قياس استهلاك الطاقة للمباني السكنية ذات الاقامة القصيرة، وذلك للتفريق بين الممارسات المعتادة وأفضل الممارسات من حيث أداء و كيفية استخدام الطاقة للفنادق في الدولة. يتناول هذا البحث تطوير عدة معايير لتقييم كفاءة الطاقة مثل؛ المساحة الكلية لمباني الفندق، وتصنيف الأداء، وعمر البناء، ومعدل الإشغال للغرف، و عدد غرف النزلاء، ومواصفات البناء، و مصدرطاقة التبريد. سيقوم البحث بجمع بيانات الطاقة الفعلية التي يتم استهلاكها سنويا عن طريق المبنى بالاضافة الى معلومات البناء الأساسية، ثم استخدام مؤشر استهلاك الطاقة وتحليل هذه البيانات إحصائيا للتأكد من أداء الطاقة المتوقعة والاستهلاك في دولة الإمارات العربية المتحدة.

لقد تم في هذا البحث تحليل 19 من بيانات الطاقة للمباني الفندقية عالية الرفاهية لتقديم نتائج قياس الطاقة في الفنادق بالدولة بشكل عام. الى جانب ذلك، تم تعريف و تحديد مؤشر استخدام الطاقة (كيلو واط ساعة / متر مربع / السنة) للمباني الفندقية حسب كفاءتها الى مبان ذات كفاءة عالية الأداء، مبان متوسطة الأداء، ومبان فقيرة الأداء. هذا وقد تبين بعد تحليل هذه البيانات التي تم جمعها أن مؤشر استخدام الطاقة يتراوح بين أقل من 241.5 كيلو واط ساعة / متر مربع / السنة باعتبارها أفضل الممارسات وأكبر من 361.3 كيلو واط ساعة / متر مربع / السنة وللمبان فقيرة الأداء و ذلك ضمن فئة الفنادق التي شيدت بعد عام 2003، التي انتهجت مواصفات بناء أكثر صرامة اعتمدت من قبل بلدية دبي. في حين أظهرت بيانات مؤشر استخدام الطاقة في الفنادق التي شيدت قبل عام 2003، أنه يتراوح بين أقل من 348.4 كيلو واط ساعة / متر مربع / السنة في أفضل الممارسات وأكبر من 511.1 كيلو واط ساعة / متر مربع / السنة للمبان فقيرة الأداء.

حيث أن قطاع الضيافة في دولة الإمارات العربية المتحدة ينمو بشكل مضطرد لتلبية الطلب الحالي والقادم، فانه سيكون مطلبا مهما جدا أن يتم تقليل الفجوة بين المباني الفندفية عالية الأداء و المتوسطة منها و الفقيرة. وفي هذه الأطروحة، تمت دراسة استراتيجية التحكم المتكامل للغرف الفندقية، وذلك لتحديد مدى تأثيره لتحسين كفاءة استخدام الطاقة بتبني هذه التقنيات المتكاملة للمباني الفندقية القائمة و الحديثة. وقد تم أجراء نموذج محاكي للمبنى ليتم تحديد الطاقة المستهلكة في كل ساعة، وذلك لتقييم التحسن في أداء الطاقة بعد اعتماد النظام التقني المتكامل المقترح. و بناءا عليه، فإن نظام المحاكاة أظهر تحسنا في اداء الطاقة بمعدل 31.5٪ على الأقل من استهلاك الطاقة للمبنى بأكمله، بما في ذلك الكهرباء والغاز والتبريد منها 43.2٪ لنظام التبريد و 13.2٪ لنظام الإضاءة عن طريق تركيب نظام التحكم المتكامل.

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Thanks to Prof. Bassam Abu-Hijleh and Dr. Alaa A-Ameer, who supervised this dissertation and guided me to the right direction. Thanks so much for their continuous support to produce this work.

Thanks to all the hotels and organizations that provided the information of the energy consumption and operating data of the hotel’s buildings.

Dedication

This humble work is lovely dedicated to my respective parents who support and pray for me forever, to my wife who inspires and helps me in this journey of life and to my amazing daughters; Marwa, Leen and Dana.

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Nomenclature- List of Abbreviations

Nomenclature		
Abbreviation	**Description**	**Unit**
ASHRAE	American Society of heating, Refrigeration and Air conditioning Engineers	____
CDD	Cooling Degree-Day	degree day
CDD1	Cooling degree-days for the typical year	degree day
CDD2	Cooling degree-days for the observed year	degree day
CFM	Cubic feet per Minute	CFM
DCP	District Cooling Plant	____
DM	Dubai Municipality	____
E1cal	Energy use index calculated by the method of TECMI	kWh/m^2/year
E2	Observation year	____
E3cal	EUI calculated by the method of quadratic average	kWh/m^2/year
Ei	annual energy consumption that adjusted by the climate coefficient	kWh
EUI	Energy Use Index or Energy Use intensity	kWh/m^2/year
EUIi	Normalized energy use index of the sample buildings	kWh/m^2/year
EUIj	Normalized energy use index of less that the arithmetic average	kWh/m^2/year
EUInorm	Normalized Energy Use Index	kWh/m^2/year
FCU	Fan Coil Unit	____
GFA	Gross Floor Area	m^2
kWh	Kilo Watt hour, Energy unit	kWh
r	Correlation coefficients	____

Tav	Daily average outdoor temperature	^{0}C
Tb	The base temperature of 18^{0}C	^{0}C
TECMI	total energy consumption mean index	kWh/m^2/year
WWR	Windows to Wall Ratio	____
μc	Climate adjustment coefficient	____

Chapter 1

Introduction

1.1 Research Background

In the last decades the carbon emissions showed a monumental increase and the reports of the natural resources depletion indicated a continuous environmental degradation and significant reduction of the fossil fuel resources. Besides, the demand on the electricity increased drastically and the sustainability of the energy sources becomes a big concern. As a result, it is not ambiguous that the increasing earth temperature, sea-level rise, substantial ice cap melting and glaciers withdrawal are a clear evidence of the climate change. Accordingly, tremendous efforts should be coordinated to contribute in optimize the energy performance and increase the efficiency in different industries and sectors. The hospitality sector is one of these areas that should strive to significantly reduce energy consumption. Stefan (2002) estimated that 97 TWh were consumed in hotel buildings over the world in 2002.

In the UAE, the hospitality industry is one of the fastest growing businesses in the country with very high occupancy rates comparing to the rest of the world of such facilities. In Dubai alone, it received in 2012 more than 12million visitors from abroad, and the majority of these visitors stayed in hotels. The plan in 2020 in Dubai is to host more than 20million in its hotels and short stay accommodation. According to this significant growth in the tourism economy, volume projects have been announced to build new hotels. It would be important to mention what Hu and Wang (2006) stated in their research that “as long as a good balance between economic growth and efficiency of energy consumption is reached, sustainable development with sufficient energy supply can be achieved". And this is a substantial strategy that should be implemented for the continuous development.

This research will analyze a sample of the hotels' energy data in UAE and try to establish a benchmark of the hotel industry in this region. In this dissertation, the study is also focused on increasing the energy efficiency of existing and potentially new hotels without compromising the comfort levels of the guests and occupants. This study will evaluate the importance of using the integrated control strategy on all the hotels systems and services and will show the savings that could be achieved in practice if it will be applied.

1.2 The Aims and Objectives

This dissertation aims to highlight the energy consumption of the hotels in UAE and provide a benchmarking analysis to assist finding a practical indicator of energy consumption in the luxurious hotels. It will discuss the improvement of the conventional practice of the hospitality sector and optimize the energy performance in the guest rooms by using the integrated control strategy.

Therefore the objectives of this research to mean the aim are as follows:

A. Evaluate the usual practice of the energy consumption and performance of the hotel buildings in UAE.
B. Ascertain the energy use index of the hotel buildings sample by different method considering the building basic characteristics and weather conditions.
C. Group the energy performance of the hotels into poor, usual, good and best practices by providing a range of normalized energy use index.
D. Provide energy conservation measure to improve the energy performance from lower level to higher for instance from usual practice to good practice and from good to best and so on.

E. Analyze the impact of adopting the integrated control strategy in the guestroom and the expected improvement in energy consumption.
F. Run hourly based building energy modeling and simulation to highlight the impact of using integrated control system and the individual energy conservation measures.
G. Discuss the recommendations that might be applicable on the hospitality sector.

1.3 Research Question

In the business as usual, the buildings systems work in isolated islands and they don't talk to each other. Additionally, separate systems don't perform optimally for the overall building energy consumption and comfort level perspective. For example, the room temperature might be achieved in core spaces, but it might be unmet in the perimeter spaces because of glazing and the solar gain. The integrated control strategies in these cases will enable the space to be cooled to meet the human thermal satisfaction and with the optimum efficiency. Another practical example has been found in the hotels that several hotels facility managers prefer to keep the set points of the room temperature constant if it is occupied or not because they would be concerned that the system will not quickly reach the set point if it has been changed during unoccupied times. Hence the comfort level of the guest might be low and this may affect the overall satisfaction of the guests. In order to solve these problems, which happen because of lack of coordination or integration between the different systems, the integrated control strategy is one of the advanced solutions that addressed recently to overcome the lack of performance of the systems by centralize the logic and methodology of thinking in these systems to do the appropriate function and human comfort with the lowest energy consumption. Many actions and strategies would act at the same time of the room being unoccupied to reduce the heat loss and accordingly save the energy in the guest rooms.

1.4 Potential for Energy Savings in the Hospitality Sector and Its Necessity

According to statistical information mentioned by WAM news 07 March 2012 and Dubai Department of Tourism and Commerce Marketing (DTCM, 2012), in 2011 the hotels' numbers were 575 hotels and hotel apartment buildings (a 5% increase from 2010) with 53,828 hotel rooms and 21,015 hotel apartment flats. And the hotels' rooms in Dubai were 67,396 rooms in 2010 with average occupancy rate of 71.7%. By 2016 the DTCM says there will be about 94,000 hotel rooms.

The hotels in UAE consume a massive amount of energy and especially in Dubai that has the highest rate of water and electricity consumption. According to a recent survey conducted by facilities management company (Farnekavireal, 2009), it revealed that hotels in Dubai on average used between 650 -1,250 liters of water per guest per day and consumed 275 - 325 kWh/m²/year per year of power. In stark contrast, similar hotels in Germany for example used only 350 liters of water and 100 kWh per square meter per year, a difference of 225 per cent. In the other countries in Europe, the energy use index is 215 kWh/m²/year in Italy, 287 kWh/m²/year in Spain and 280 kWh/m²/year in Greece, whereas in France it is higher 420 kWh/m²/year.

As mentioned, 94,000 hotels' guestrooms will be in operation in 2 years, and according to this research's findings, the hotel's guestroom consumes in average 57,177kWh per annum, which represent in average 157kWh/ guest-night. Therefore the estimated annual energy consumption in 2016 by the hotel sector in Dubai alone electricity consumption will reach approximately 3.1 TWh. Hence the necessity of improvement of the energy performance in this sector to minimize the negative impact on the environment and reduce the carbon emission that will reach to 1,925,000 tons of CO_2 per year Based on the carbon emission factor (0.631kgCO2e/kWh) would be very high. (Elkhoury, G. 2012). The major strategy to improve the energy performance and increase the energy savings in the hotel's buildings is to increase the energy efficiency that may optimize the energy consumption by 54% as indicated in some studies (Khemiri and Hassairi, 2005)

As a contribution and to optimize the energy performance in the hospitality field in UAE, this research will provide an analysis of adopting the integrated control strategy and to operate the systems on demand in dynamic way as a response on the cooling load changes during the day and night times and the seasons periods.

1.5 Structure of the Dissertation

This dissertation consists of six chapters. In the following chapter, the existing and available literatures will be reviewed on the previous benchmarking studies that compared the energy consumption of the hotels facilities in the global and the strategies that have been pursued to find the relevant factors and the relationship between conventional use and the high performance hotels. In the same chapter the integrated control strategies studies that have been published previously will be discussed and reviewed to find its impact on the guestrooms’ energy consumption and how it has improved the thermal and visual comfort. In chapter 3, the research strategy will be outlined and justified, and the data collection methods that adopted and employed by this dissertation will be highlighted and discussed. Moreover, the benchmarking methodology will be presented and illustrated. In chapter 4, it will discuss the benchmarking analysis, data collection, the findings and the energy performance practices in UAE. Besides, it will explain the philosophy of the integrated control strategy, the findings and outcomes from the data analysis for the different cases and the run energy models will be presented highlighting the major differences and how the integrated control strategy will be modeled by adopting the energy local and international standards and design parameters assumptions as per the business as usual.. In chapter 5, it will discuss the energy model finings along with the energy improvement by using the integrated control strategy the main outcomes answering comparatively of this research question. It will show the comparison of energy consumption results between the baseline model and the integrated control system energy conservation measures In Chapter 6, it will summarize the main outcomes answering comparatively of this research question and it is going to conclude the best and most affection ways to follow and implement at the design stage for the new construction and the existing hotels, commenting and on its restrictions, limitations and constraints, and presenting some hints and indications for further research especially in United Arab Emirates.

Chapter 2

Literature Review

2.1 Energy Benchmarking of the Hospitality Sector

The comparison of energy performance and its usage in the buildings in the past two decades, has evolved and emerged under the term “building energy benchmarking” (Chan, 2012). The energy benchmarking is a vital method to track, evaluate, monitor and find out the energy performance and behavior of the buildings and to detect the energy consumption wastes (Li et al., 2014). Nowadays, the methodologies of the benchmarking studies use the normalized energy intensity in percentile calculation (Chung et al., 2006). A Number of these researches utilize the hotels benchmarking analysis in form of the Energy Use Index EUI based on unit standard guest room and based on unit area (Chan, 2012). However, the collected energy data would be normalized and adjusted with the changes of the outdoor temperature, floor areas, occupancy rate and any major renovation or any justifiable factor.

Currently, regression is another method used for the benchmarking analysis to calculate the regression coefficient of the above substantial factors that may effect on the energy consumption in the hotel buildings (Lee and Lee, 2009; Deng, 2003). Besides, Lee (2008) used multiple linear regression method and data envelopment analysis to evaluate the impact of best management practices. The regression method was used in his research to find out the predicted energy intensity, whereas the other method; data envelopment analysis is used to find out the total energy efficiency of the building by assessing of different factors; environment and management (Lee, 2009).

Another method of benchmarking adopted by various researches and energy audit is called the subsystem averages that estimate the building energy subsystems that supported by field measurements to breakdown the annual electricity usage into air conditioning systems, lighting, elevators and other receptacle loads (Canbay et al., 2004; Lee, 2010).

Presently, a very strong and useful tool and method, is used to identify the baseline and to provide the inputs for the benchmarking analysis of the hotel buildings energy consumption, is the energy modeling and simulation in hourly basis that enables all the variable and different factors to be simulated and run with different scenarios. However, this way is time consuming and it would need a high engineering proficiency and skills to deal and model the different energy systems. Besides, the statistical method is one of the best methods that might be used with plenty of data base availability (Chan, 2012).

Fumo et al. (2010) explored a simple approach to assume the energy consumption of the building by using only the energy information gathered in monthly basis. This benchmarking approach focuses on the fuel and electricity consumption data and analyzes this information by using the predetermined coefficients to obtain the hourly distribution to of the energy consumed. These coefficients may provide the subsystems energy consumptions that aren’t provided by the utility bills. Moreover, these coefficients can be extracted by running an hourly based energy model; EnergyPlus Benchmark Model Simulation for example. Lee and Lee (2009) highlighted the methods of evaluating the buildings and benchmarking them. They indicated that there are two methods to assess the energy performance in any building; mathematical model and statistical analysis. The mathematical model, which is extracted from the energy simulation, is used to calculate the theoretical building energy consumption and to compare it with the actual building energy consumption. Various energy simulation tools could be used to implement this method by calculating the Energy use Index- EUI and the overall benchmarking factors. The statistical method uses the data that are gathered by the surveys and to compare the parameters and units with each other.

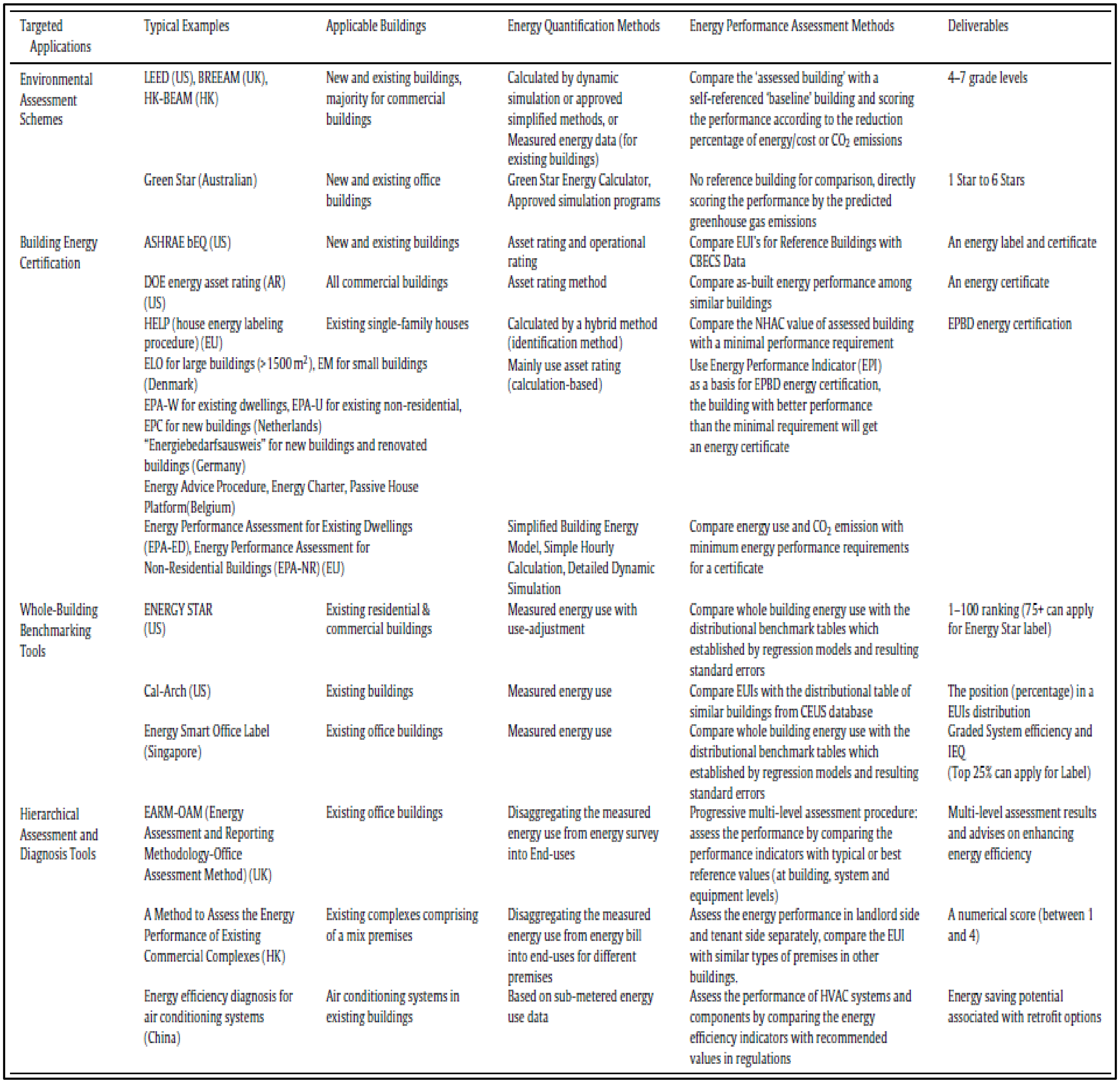
Steadman et al. highlighted in 1994 (cited in Chan, 2012) the UK methodology to evaluate the non-residential building including the hotels that developed by the global Atmosphere Division of the Department of Environment. The buildings were differentiated based on 5 climate zones, building enclosure statistics and built forms.

Whereas, in the United States, the data base collected by the US Energy Information Administration, four regions, namely, Northeast, Midwest, South and West, are distinguished. There are four steps in the energy end-use consumption estimation process (Andrews and Krogmann, 2009):

- Regressions of monthly consumption on degree-days.
- Engineering modeling by end use.
- Cross-sectional regressions to calibrate the engineering estimates and account for additional energy uses.
- Reconciliation of the end-use estimates to the survey’s total building energy consumption.

Wang, Yan and Xiao (2012) have proposed in their research a frame work to categorize the energy benchmarking method for the existing buildings as illustrated in table (2.1). However, Li et al. (2014) stated that the selection of any benchmarking method should be as per the available input, outputs, projects’ needs and the energy modeling tools and expertise.

Table (2.1) A summary of energy performance assessment methods (Wang, Yan and Xiao, 2012)



Targeted Applications	Typical Examples	Applicable Buildings	Energy Quantification Methods	Energy Performance Assessment Methods	Deliverables
Environmental Assessment Schemes	LEED (US), BREEAM (UK), HK-BEAM (HK)	New and existing buildings, majority for commercial buildings	Calculated by dynamic simulation or approved simplified methods, or Measured energy data (for existing buildings)	Compare the 'assessed building' with a self-referenced 'baseline' building and scoring the performance according to the reduction percentage of energy/cost or CO_2 emissions	4–7 grade levels
	Green Star (Australian)	New and existing office buildings	Green Star Energy Calculator, Approved simulation programs	No reference building for comparison, directly scoring the performance by the predicted greenhouse gas emissions	1 Star to 6 Stars
Building Energy Certification	ASHRAE bEQ (US)	New and existing buildings	Asset rating and operational rating	Compare EUI's for Reference Buildings with CBECS Data	An energy label and certificate
	DOE energy asset rating (AR) (US)	All commercial buildings	Asset rating method	Compare as-built energy performance among similar buildings	An energy certificate
	HELP (house energy labeling procedure) (EU)	Existing single-family houses	Calculated by a hybrid method (identification method)	Compare the NHAC value of assessed building with a minimal performance requirement	EPBD energy certification
	ELO for large buildings (> 1500 m^2), EM for small buildings (Denmark)		Mainly use asset rating (calculation-based)	Use Energy Performance Indicator (EPI) as a basis for EPBD energy certification, the building with better performance than the minimal requirement will get an energy certificate	
	EPA-W for existing dwellings, EPA-U for existing non-residential, EPC for new buildings (Netherlands)				
	"Energiebedarfsausweis" for new buildings and renovated buildings (Germany)				
	Energy Advice Procedure, Energy Charter, Passive House Platform(Belgium)				
	Energy Performance Assessment for Existing Dwellings (EPA-ED), Energy Performance Assessment for Non-Residential Buildings (EPA-NR) (EU)		Simplified Building Energy Model, Simple Hourly Calculation, Detailed Dynamic Simulation	Compare energy use and CO_2 emission with minimum energy performance requirements for a certificate	
Whole-Building Benchmarking Tools	ENERGY STAR (US)	Existing residential & commercial buildings	Measured energy use with use-adjustment	Compare whole building energy use with the distributional benchmark tables which established by regression models and resulting standard errors	1–100 ranking (75+ can apply for Energy Star label)
	Cal-Arch (US)	Existing buildings	Measured energy use	Compare EUIs with the distributional table of similar buildings from CEUS database	The position (percentage) in a EUIs distribution
	Energy Smart Office Label (Singapore)	Existing office buildings	Measured energy use	Compare whole building energy use with the distributional benchmark tables which established by regression models and resulting standard errors	Graded System efficiency and IEQ (Top 25% can apply for Label)
Hierarchical Assessment and Diagnosis Tools	EARM-OAM (Energy Assessment and Reporting Methodology-Office Assessment Method) (UK)	Existing office buildings	Disaggregating the measured energy use from energy survey into End-uses	Progressive multi-level assessment procedure: assess the performance by comparing the performance indicators with typical or best reference values (at building, system and equipment levels)	Multi-level assessment results and advises on enhancing energy efficiency
	A Method to Assess the Energy Performance of Existing Commercial Complexes (HK)	Existing complexes comprising of a mix premises	Disaggregating the measured energy use from energy bill into end-uses for different premises	Assess the energy performance in landlord side and tenant side separately, compare the EUI with similar types of premises in other buildings.	A numerical score (between 1 and 4)
	Energy efficiency diagnosis for air conditioning systems (China)	Air conditioning systems in existing buildings	Based on sub-metered energy use data	Assess the performance of HVAC systems and components by comparing the energy efficiency indicators with recommended values in regulations	Energy saving potential associated with retrofit options

2.2 Energy Consumption of the Hotels Facilities

Various studies and researches in different geographical areas and climate zones in the world have reported the energy consumption of the hotel buildings by using the energy use index EUI or energy intensity per unit area. When benchmarking any building, one of the key metrics that used is energy use index, or EUI. Basically, the EUI expresses a building's energy use as a function of its size or other characteristics. In this dissertation, the EUI is expressed as energy per square meter per year. It's calculated by dividing the total energy consumed by the hotel building in one year (measured in kWh) by the total gross floor area of the building.

In recent research conducted by Priyadarsini, Xuchao and Eang (2009) about the energy performance of hotel buildings in Singapore, they found based on the survey on 29 hotels that the energy use index was 361kWh/m²/year in 2006. However, several variables and factors influence the energy intensity in the hotels' buildings such as design and construction standards of the new buildings and the best practices of the existing buildings. The evolving concept in energy efficiency and the more stringent standards and the best practices are important factors to improve the energy performance over time. This hypothesis has been supported by studying an earlier survey conducted in 1993 in Singapore and indicated that the energy use index was 468kWh/m²/year (Priyadarsini, Xuchao and Eang, 2008). In other parts of the world like; Europe, United States and Canada, the energy supplied by several sources of energy such as natural gas for hot water and heating the spaces and electricity for the other loads such as; cooling, fans, pumps, plug loads, elevators, appliances and lighting. An earlier study, during the mid-nineties research undertaken in USA showed that the annual energy use index in 1995 was 401kWh/m²/year and 688.7kWh/m²/year in Canada (Bohdanowicz and Martinac, 2007). In Europe, Bohdanowicz and Martinac (2007) in their recent paper mentioned that the energy use for the European hotels for the nineties was between 239 and 300 kWh/m²/year. Santamouris et al. (1996) reported on the energy intensity in Italy that reflects the hotel buildings energy consumption that was 215kWh/m²/year, 273kWh/m²/year in Greece and 278kWh/m²/year in Spain. Whereas, the energy use index of the hotels in France is higher than other mentioned Europe countries, but in United Kingdom the researches and surveys indicated that the current energy benchmarks quote 540kWh/m²/year for the conventional and typical holiday hotels and 340kWh/m²/year for the best practice holiday hotels (CIBSE, 2004). In New Zealand, the hospitality sector has the lion share of the energy consumption in the accommodation sector. Becken and et al. (2001) reveal in their study that the largest energy consumers in this sector are the hotel's buildings. They consumed in 1999 around 67% of the total accommodation energy consumption, which contribute 4.4% of the energy use of the commercial sector and 0.4% of the total energy consumption in the country of New Zealand. Besides, Batle et al. (2010) has presented the difference of energy consumption per unit area between the three star and four star hotels and how the luxury may effect on the energy consumption of the hotels' buildings. They have indicated that the energy use in a sample of 31 hotels in the Balearic Islands in Spain is 179.6 kWh/m²/year for three star hotels, whereas the energy use index for four star hotels is 199.8 kWh/m²/year. However, Erdogan and Baris (2007) found that more efforts spend by five star hotels to increase the energy efficiency and to reduce the carbon footprint in order to reduce their massive energy consumption.

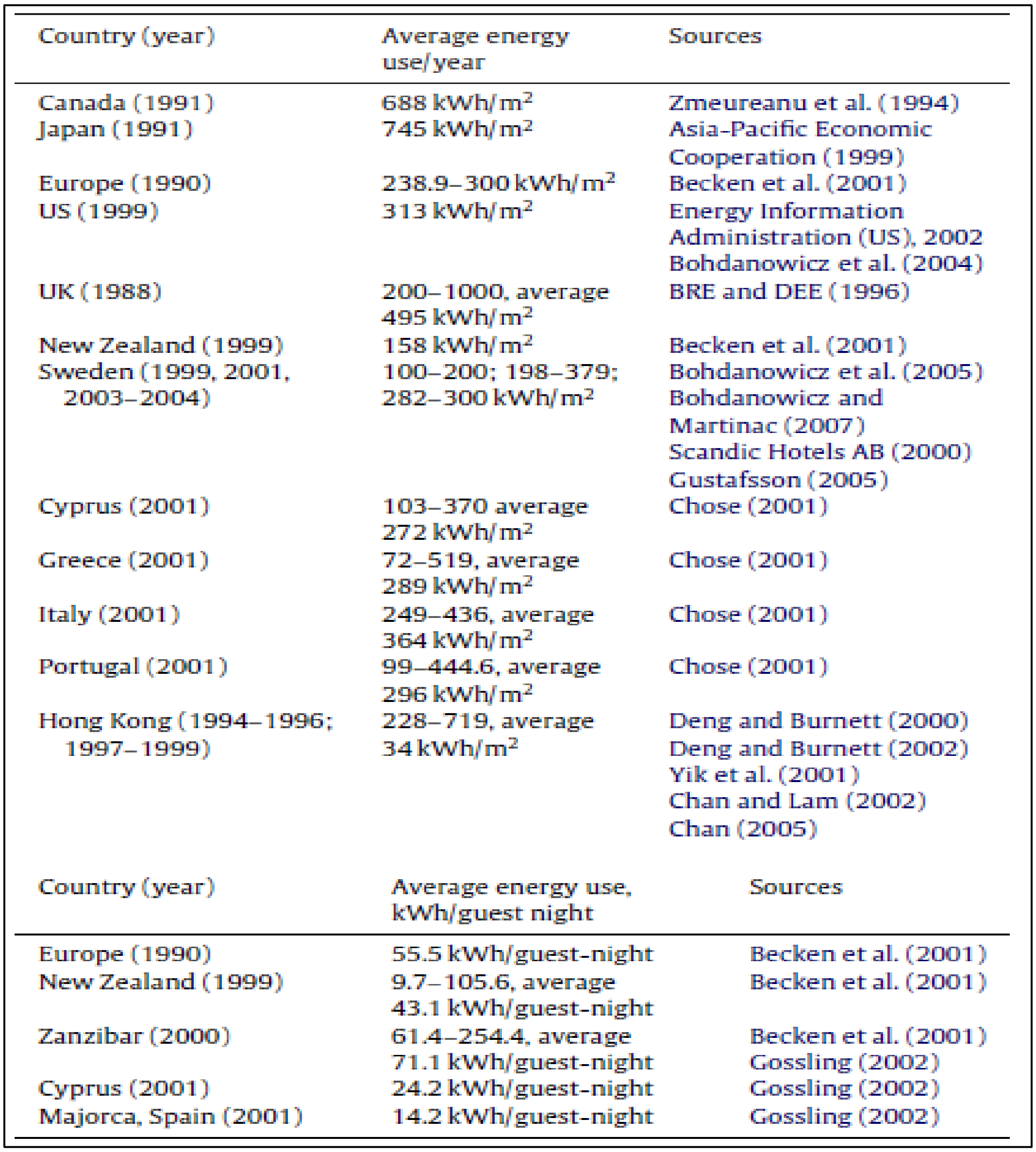
Many variables and criteria would be taken into consideration when evaluating the energy performance of the hotels and when discussing the baseline and benchmarking analysis. These variables are the gross floor area, construction date, cooling degree day and weather status at the observed year, occupancy rates, guest room numbers, night spent, energy sources and many other factors as have been referred by Xin et al., (2012). However, these factors, in terms of energy intensity, are significant based on Deng and Burnett (2007), they have reported an average energy use index of 564 kWh/m^2/year and concluded that hotel class, occupancy level, total floor area, hotel age, the number of guestrooms by t-tests using the energy information of 16 Hong Kong hotels.

Onut and Soner (2006) highlighted the importance of taking into consideration the occupancy rate of the hotels in Antalya, Turkey. From their results presented in that study, they noticed that the energy consumption correlated strongly with the occupancy level. Hence in this dissertation the occupancy rate will be one of the factors that would be examined to evaluate its effect on the hotels energy consumption in UAE.

Another important methodology to simplify the relationship between these factors and the energy use index, it is to formulate an equation by means of multiple regression analysis. This approach has been supported in the work of Chung et al. (2006).

Chan (2012) has summarized in his recent research the average energy use intensities for hotels' building globally as shown in Table (2.2)

Table (2.2) the average energy use intensities for hotels' building globally, (Chan 2012, p.1132)



Country (year)	Average energy use/year	Sources
Canada (1991)	688 kWh/m^2	Zmeureanu et al. (1994)
Japan (1991)	745 kWh/m^2	Asia-Pacific Economic Cooperation (1999)
Europe (1990)	238.9–300 kWh/m^2	Becken et al. (2001)
US (1999)	313 kWh/m^2	Energy Information Administration (US), 2002 Bohdanowicz et al. (2004)
UK (1988)	200–1000, average 495 kWh/m^2	BRE and DEE (1996)
New Zealand (1999)	158 kWh/m^2	Becken et al. (2001)
Sweden (1999, 2001, 2003–2004)	100–200; 198–379; 282–300 kWh/m^2	Bohdanowicz et al. (2005) Bohdanowicz and Martinac (2007) Scandic Hotels AB (2000) Gustafsson (2005)
Cyprus (2001)	103–370 average 272 kWh/m^2	Chose (2001)
Greece (2001)	72–519, average 289 kWh/m^2	Chose (2001)
Italy (2001)	249–436, average 364 kWh/m^2	Chose (2001)
Portugal (2001)	99–444.6, average 296 kWh/m^2	Chose (2001)
Hong Kong (1994–1996; 1997–1999)	228–719, average 34 kWh/m^2	Deng and Burnett (2000) Deng and Burnett (2002) Yik et al. (2001) Chan and Lam (2002) Chan (2005)

Country (year)	Average energy use, kWh/guest night	Sources
Europe (1990)	55.5 kWh/guest-night	Becken et al. (2001)
New Zealand (1999)	9.7–105.6, average 43.1 kWh/guest-night	Becken et al. (2001)
Zanzibar (2000)	61.4–254.4, average 71.1 kWh/guest-night	Becken et al. (2001) Gossling (2002)
Cyprus (2001)	24.2 kWh/guest-night	Gossling (2002)
Majorca, Spain (2001)	14.2 kWh/guest-night	Gossling (2002)

2.3 Integrated Control Strategy

The hotels as buildings are unique when compared to other buildings' types. This is because of the different operating schedule and nonlinearity of the operational of the functional facilities with different occupation types and rates, like restaurants, laundries, kitchen, public areas, lobbies, gymnasiums, guestrooms, meeting rooms, conferences rooms and event halls. All this uniqueness of the hotels' systems would push them not to work individually but rather to work in integrated approaches on demand based on these variables (Karjalainen, and Lappalainen, 2011). The energy systems of the hotel's buildings are broken-down into various services and systems. The energy flow starts from the primary energy that could be electricity, chilled water and gas and ends by the individual end users systems such as; space cooling chillers, air conditioning units, ventilation, lighting, electrical equipment, space heating, domestic hot water and other loads (Goncalves and et al., 2011).

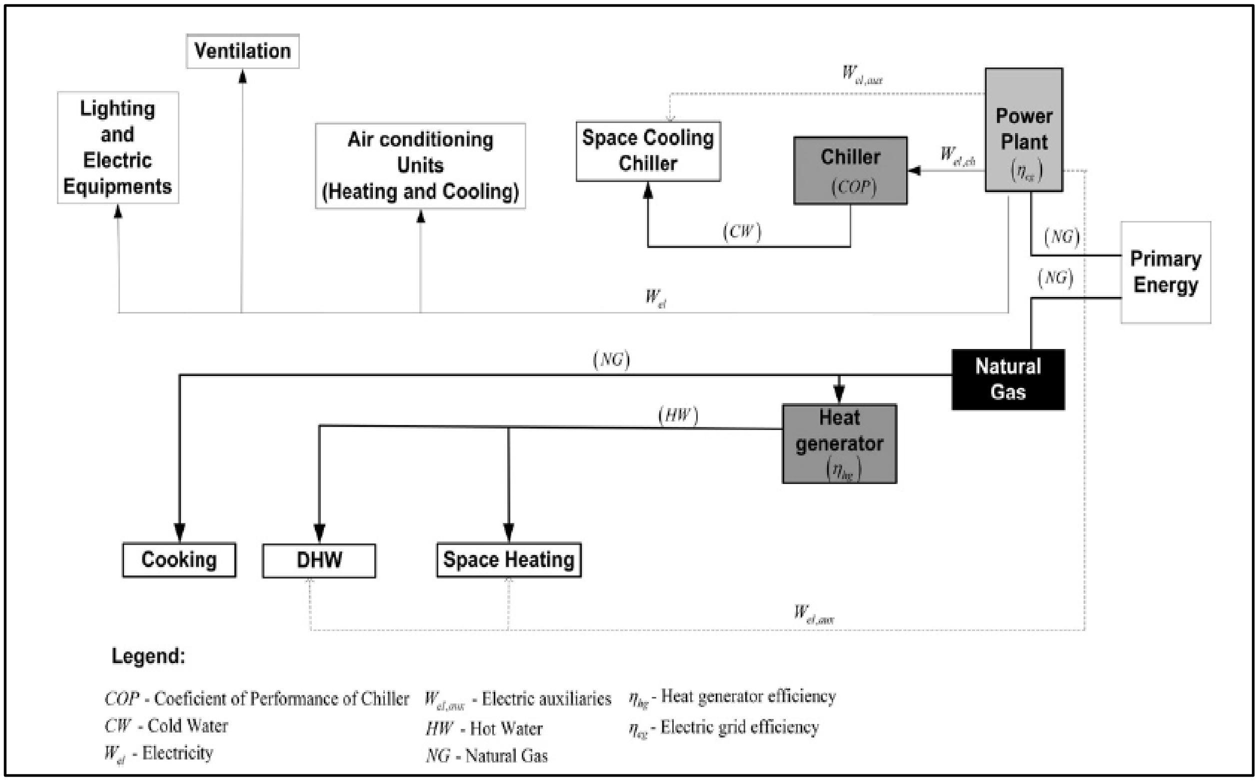


Figure (2.1) Hotels' energy end-user systems (Goncalves and et al., 2011, p. 184)

Various ways have been suggested to calculate the energy intensity and the hotels' energy efficiency as discussed above. However, the ways to reach the high building energy performance to optimize the energy cost could be achieved by using renewable energy, measuring the real energy consumption, adopting and implementing the energy conservation measure, operating and run the systems efficiently and finally controlling energy facilities, especially during un occupied times. As showed by Eynard et. al (2009), three control schemes, the standard Proportional Integral Derivate (PID), the Model Predictive Control (MPC) and the Fuzzy Logic Control (FLC), have been tested with the objective of completing the legal documentation and enhancing energy savings, using the global energy indicator.

The integrated strategy would be interfaced with the existing systems to provide the proper signals for to control in integrative way with the following purposes (Karjalainen and Lappalainen, 2011):

- Air Conditioning: in order to maintain the climate zone more comfortable by adjusting the room temperature to be very close to the set point. The room temperature set point relies on the occupants' selection to satisfy his thermal satisfaction or it could be adjusted automatically according to the season and the outside temperature. However a good potential to work on demand could be offered by increasing the room temperature set points to save energy during unoccupied times.
- Ventilation: one of the high efficient techniques is to supply the fresh air according to the occupants' needs. Hence, the demand controlled ventilation doesn't allow for the excessive fresh air and it conserves the cooling energy.
- Lighting: the luminance level is very a significant factor for the visual comfort of the occupants. However, the lighting consumes a considerable amount of energy if it is not designed efficiently. Therefore, lighting should be provided full attention to be controlled based on the demand of the space and the occupants' needs as per the international standards. Accordingly, the integration between the natural and the artificial light would be an interesting strategy to increase the energy efficiency.
- Automated blinds in public areas: The integrated system includes the automated blineds control system to avoid the solar gain during the unoccupied hours and to reduce the

cooling energy that is required to cool the spaces. However, the occupant would have the choice to override this measure.

Karjalainen and Lappalainen (2011) discussed the possibility of how this system would work and provided the structure of it through determining the inputs and outputs. They suggested that integrated control system should have inputs and outputs as illustrated in figure (2.2).

These inputs for an integrated control and optimization system are:

- Inside measurements of the room temperature, illumination level, carbon dioxide level, occupancy detection, energy consumption by smart metering system and user identification from the elevator systems.
- Outside measurements are required for weather data to adjust the settings of the control system like for example; the humidity, outdoor temperature and solar radiation.
- Energy cost as an input would be useful to share the guest his responsibility toward the environment and he might be incentivized if worked in the economic settings.

The benefits of implementing the integrated control approach in the guest rooms are largely related to the buildings envelope, windows to wall ratios, existing air conditioning systems, the occupancy rate; occupied and un-occupied times and the climate conditions. Karjalainen and Lappalainen (2011) found that the theoretical energy savings after implementing the integrated control strategy might vary between 11% and 38% depending on the mentioned factors and the level of integrations adopted in the installed system.

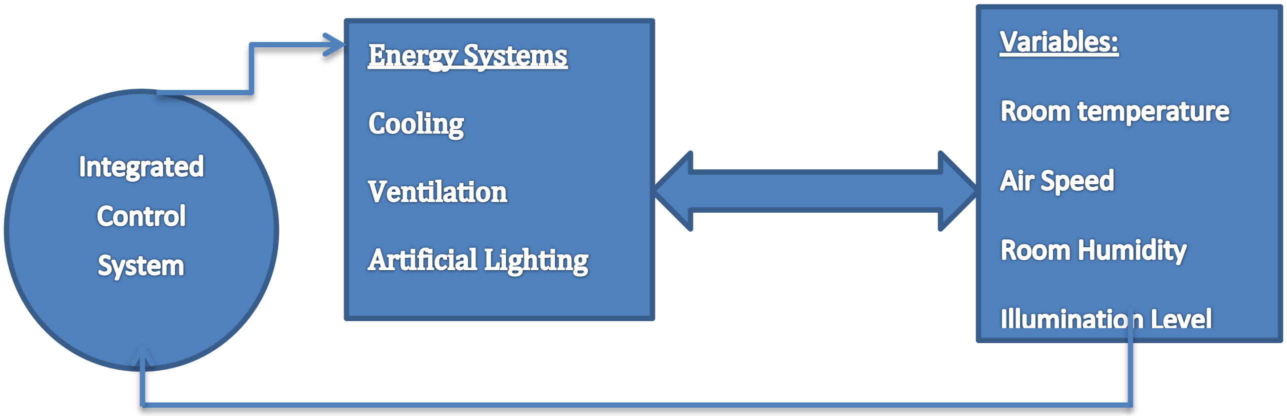


Figure (2.2) The integrated Control System Inputs and Outputs (Adapted from Karjalainen and Lappalainen ,2011, p.940)

For the thermal comfort, the integrated control strategy maintain the minimum level of the outdoor fresh air that calculated based on the combination method of occupants and floor area as per ASHRAE standard 62.1 (Karjalainen, Koistinen, 2007), however, it will reduce the unneeded outdoor fresh air during unoccupied times to the minimum level to assure that the energy is delivered as per the demand and hence it would save a massive amount of energy used for cooling during unwanted times. This technique can be implemented by using the demand control ventilation that controls the fresh air quantities as per the carbon dioxide concentration in the thermal zone, which is the guest room. Further research (Klein, et al., 2010) showed that implementing the integrated control strategy with the demand control ventilation and by using multi-agent comfort and energy simulation to model the thermal comfort factors and control parameters, 17% building savings while maintaining high level of occupants' comfort reached to 85%.

Karjalainen and Koistinen (2007) have addressed the thermal comfort and occupants' satisfaction in their research. They showed that the integrated control has a substantial potential to improve the quality of delivered indoor environment by avoiding the overcooling. This would be shown obviously in the integrated system when integrate all the separate systems and product to do the common control job. For example, the motion detector would be utilized to control the lighting and at the same time to shut the blind during unoccupied time and also provide the order to raise the temperature set point along with enabling the demand control ventilation settings. These all integrated techniques in one approach would maintain the indoor air quality with reducing the guest room energy consumption (Asadi et al., 2011).

Figure (2.3) shows with more details the structure of the proposed system and the inputs and outputs of the integrated control strategy in a thermal zone (Karjalainen and Koistinen, 2007).

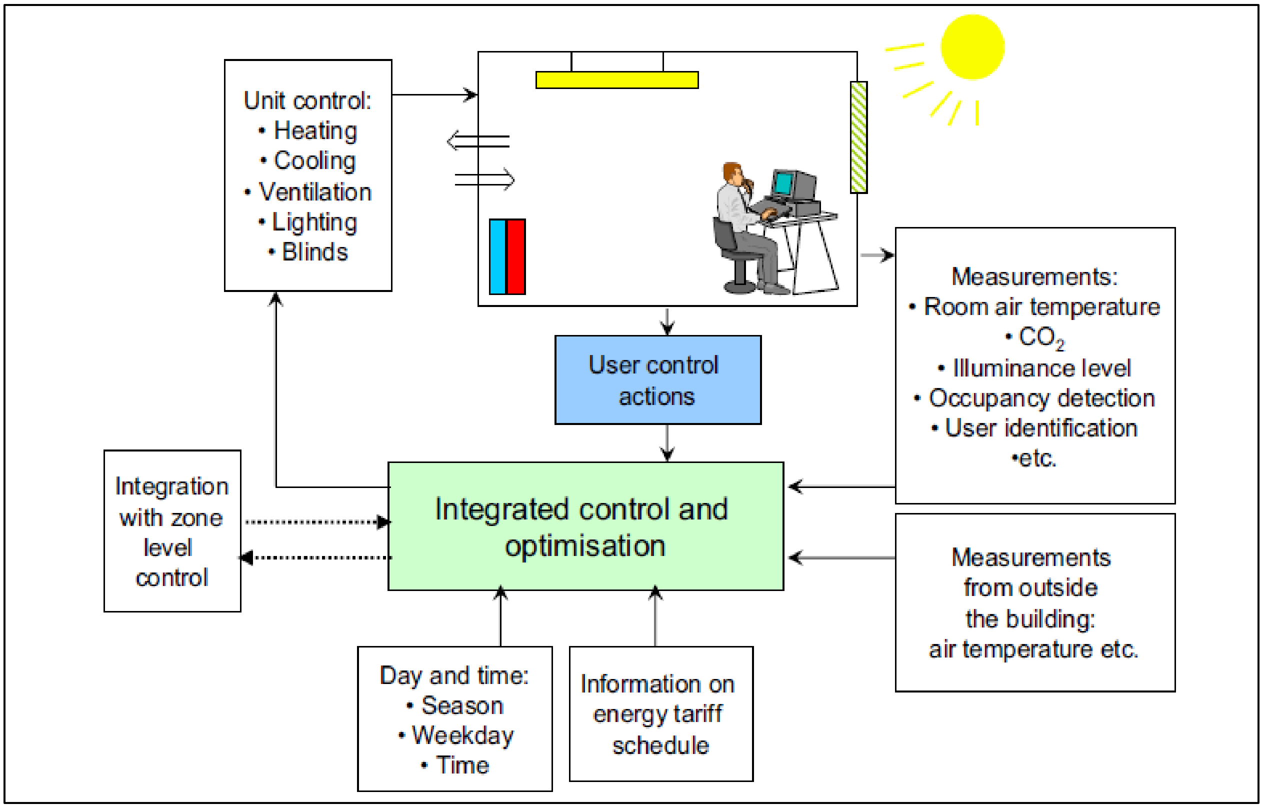


Figure (2.3) The Inputs and outputs of the integrated proposed control strategy (Karjalainen and Koistinen, 2007, p. 940)

2.4 Summary and Gaps in the literature

In Sum, the papers and researches were conducted have addressed the method of energy benchmarking of the hotel buildings by finding the energy use index kWh/m^2/year by taking into consideration the other factors that influence the variation of the energy intensity for each hotel buildings. Moreover, the benchmarking that obtained from the studies showed the effect of the weather conditions in the various locations and geographical areas. They showed that energy intensity in Europe is totally different from the energy intensity in United States and Canada and also the gulf region. Yet, gaps are founded to link between the conventional hotel buildings that consume energy as usual and the high performance and efficient hotels that implement the best practices. As pointed out by various scholars, the surveys conducted for a set of hotels in different areas in the world, discussed only the benchmarking methodologies and energy consumption figures for the samples. However, still there is a need to group these hotels and to differentiate between the best practices buildings and the conventional buildings in the hospitality sector. And also, there is a need to provide the hotels' operators and facility manager a proper key and methodology to appraise their facilities and to figure out how far these buildings away from the high performance hotels. In UAE, these studies were not found except few exercises that have been done through different energy management consultants that were not published globally and couldn't be accessed by the scholars and researchers.

For the benchmarking studies of the hotels in UAE, more research needs to be carried out to evaluate the hotels energy performance and to develop a baseline that could be compared with, especially that the hospitality industry in the country has recorded a high growth in the recent years and more new hotels will be constructed until 2020 for expo event.

Several energy conservation measures for the hotels have been recommended in different researches (Zhao, Ma and Gu, 2012), however, the integrated control strategy that covers various energy efficient practices have been discussed in few papers (Klein, et al., 2010; Karjalainen and Lappalainen, 2011) that have showed the percentage of improvement in the energy performance after implementing this technique. Scholars have studied the integrated control strategy in countries that have totally different weather conditions from UAE. Besides, they haven't showed the types of air conditioning systems that may lead to vary the energy savings drastically since the response of this equipment changes depending on its components and control algorithm. Therefore, these gaps of using and assessing the integrated control methodology in the hotel's guest rooms would be discussed in this dissertation alongside with the available air conditioning systems to highlight the outcomes that might responding against different A/C types and to recommend the most efficient solution for the new and the existing hotels.

Chapter 3

Methodology

3.1 Research Strategy

The energy benchmarking is vital strategy to track and evaluate the behavior of the building energy performance. However, there is no single method to establish the energy benchmarking. As each method has different strengths and weaknesses.

In order to assess the energy consumption in any building, three elements could be pursued. These elements are divided into; gathering the data from the field, processing these collected information by either statistical method or energy modeling, and finding out the energy performance. Gathering data that are used as inputs include 1) the energy consumption for at least 12 consecutive months to study the weather conditions of the winter and summer seasons, 2) building basic information such as; the construction year, occupancy rate, running energy systems and other operational information. This information that was collected by the hotel's building operator is processed through statistical method, hourly energy modeling or both. In this study, these both methods have been discussed to appraise the energy performance and to establish the benchmarking analysis. The input parameters were used to ascertain the energy systems major consumers and the expected energy waste between the supply and demand sides according to the energy flow by running the hourly energy model as a tool. Finally, the output that represents the energy performance indicator includes energy benchmarking of the building based on the hotels' energy practices. These findings consist of the consumption of the several energy systems of the building. They will provide a measurable baseline to compare against when implementing the energy conservation measures. The proposed integrated control methodology on the hotel's building guest room is the focused area that addressed in this study in order to outline its impact on the hotels' energy consumption in UAE.

For the benchmarking method, this dissertation will focus on finding out the energy intensity of the hotels in UAE. Besides, it will illustrate the median or average values of energy use index by using the statistical method. Additionally, this study will try to find the correlation between different energy consumption and hotel's operating parameters such as; the occupancy rate, floor area and cooling degree days for the local hotels.

To support the expected findings, it would be substantial to breakdown the energy consumption for each system. Therefore, in this research the building hourly energy model has been developed to identify the major loads and the different energy systems in the hospitality sector. The energy model has balanced the energy consumption by finding out the end users energy consumption. It has provided a flexible tool in an integrative approach to evaluate the new technologies that may establish the energy baseline and optimize the energy performance.

In this research, several statistical methods were used to identify the building energy benchmarking by the following three strategies;

1) Collection of the energy information of the hotel,
2) Identifying the energy intensity and the proper index that represent the hotel buildings energy consumption and;
3) Identifying the results of the hotels into best practice, usual practice and poor practice.

3.1.1 Energy Data Collection

The basic building information of 19 hotels along with the energy data were gathered from the different locations in UAE. These data, through a distributed questionnaire as attached in the appendix, were filled in by the hotels' facility managers and engineering directors of the audited buildings samples. The main requested data were the energy consumption per year for 12 consecutive months and some basic information of the building that represent factors effect on the building energy performance such as; building age, gross floor area of the conditioned spaces, occupancy rate, guest rooms number and the consumed energy from different sources; electricity, fuel and chilled water taking in the consideration the hotels that are supplied chilled water by the district cooling plants. Moreover, all unites of energy data from different sources have been unified and converted to kWh and quantified to monetary wise by AED.

3.1.2 Energy Use Index

Various factors influence the hotel building energy performance and the total annual consumption, therefore a normalized energy use index was calculated considering the impact of each factor.

3.1.2.1 Weather Dependent Factors- Climate Adjustment

UAE has a harsh and unique weather and it is one of the hottest and most humid regions in the world that must affect drastically in the hotels' energy consumption and performance. Since the reading years of energy data were different, so the climate factor should be neutralized and adjusted. Two methods may be used to normalize the weather factor of energy usage; cooling degree day method, and simple average method.

The cooling degree day method is a simple and efficient to figure out the cooling energy load and demand in the building (Christenson, et al, 2006). In UAE, the heating degree days is neglected in this dissertation since all the hotels don't install systems to heat spaces. According to ASHRAE, the Cooling Degree Days (CDD) is expressed in equation (3.1);

$$\text{CDD (Tb)} = N \sum_{k=1}^{n} (Tav - Tb) \qquad (3.1)$$

Where CDD is the number of degrees that a day's average temperature is above 18⁰C and the zones would need to be cooled by using the air conditioning systems; Tb is the base temperature of 18^0C; Tav is the daily average outdoor temperature that obtained based on the data of Dubai International Airport, AE (55.37E,25.25N); k is the sequence number of days in a year; N = 0 day if $Tav < Tb$, otherwise, N=1.

Based on the above and since the data collected covered the hotels' energy consumption for only 3 previous years, the climate adjustment coefficient could be calculated as per equation (3.2)

$$\mu\text{c} = \frac{CDD1}{\text{CDD2}} \qquad (3.2)$$

Where μc is the climate adjustment coefficient; CDD1 is the cooling degree-days for the typical year, which is in this study 2013 and CDD2 is the cooling degree-days for the observed year as per the questionnaire filled up data. The CDD has been illustrated in table 3.1 for the years 2011, 2012 and 2013 according to the Dubai International Airport Data.

Table (3.1) Cooling Degree-Days for the years 2011, 2012 and 2013 in Dubai (Dubai International airport data, 2014)

Years in UAE	**2011**	**2012**	**2013**
CDD	4085	4152	4011

On this basis, the energy consumption of the hotels that observed in 2011 and 2012 has been calculated based on the equation (3) to adjust the climate factor and normalize the energy consumption value.

$$Ec = \mu c . E_2 \tag{3.3}$$

Where Ec is the hotel building energy consumption climate adjustment value; E_2 is the observation year.

For the simple average method, it is the average of several sequence years of the building energy consumption that might reduce the climate factor effect but will not eliminate it. Moreover, these data were not provided by the participants as only one year energy consumption has been shared. Therefore, this dissertation followed the cooling degree day method to normalize the energy use index and adjust the climate conditions.

3.1.2.2 Correlation Analysis between Non-Weather Dependent Factors and the Hotel's Energy Consumption

Many other factors may influence the energy consumption of the buildings such as the age, occupancy rate, guest rooms' numbers, windows to wall ratio, hotel's classification, and building construction regulation and codes. Thus, in this dissertation, the correlation analysis would identify the most correlated factors and then would be used to normalize the energy consumption of the different hotels.

Correlation analysis is usually used to find out the direction and strength of the relationship between two variables. A strong correlation means that two or more variables have a strong relationship with each other while a weak, or low, correlation means that the variables are hardly related. Correlation coefficients (r) can range from -1.0 to +1.0. The value of -1.0 represents a perfect negative correlation while a value of +1.0 represents a perfect positive correlation. The most widely used type of correlation coefficient is the Pearson r, which is also referred to as linear or product-moment correlation. This analysis assumes that the two variables being analyzed are measured on at least interval scales. The coefficient is calculated by taking the covariance of the two variables and dividing it by the product of their standard deviations (Freeman and Young, 2009).

In this dissertation, the range of correlation coefficient is $r<=1$, the perfect correlation is when $r=1$, and generally, when $0<r<0.25$ there is weak correlation; $0.25<r<0.5$, low correlation; 0.5<r<0.75, significant correlation; 0.75<r<1, high correlation; and r=0, no correlation (Martina, et al, 2007).

3.1.3 Energy Benchmarking Statistical Method

To ensure that the hotels' data collection will be analyzed and processed in a way that produces realistic analysis, coding data, valid conclusion in a comprehensible method, various statistical methods have been adopted to figure out the energy consumption of the hotels in UAE according to the normalized energy consumption indexes analysis of the sample buildings. The statistical methods that used were mean index of total energy consumption (TECMI), mean of energy use index-EUI, quadratic average method, percentile method, median and mode.

3.1.3.1 Total Energy Consumption Mean Index (TECMI)

This method calculates the mean of the energy use index of the hotels energy consumption of all sample buildings per unit area or guest room. Equation (3.4) shows how to ascertain the total energy consumption mean index (Xin, et al, 2012).

$$E1cal = \sum_{i=1}^{n} Ei / \sum_{i=1}^{n} Ai \qquad (3.4)$$

Where $E1cal$ is the energy use index calculated by the method of TECMI; Ei is the annual energy consumption that adjusted by the climate coefficient; Ai is the guest room number, gross floor area or any other factor.

This method represents the overall energy consumption per unit area or guest room in the country level, but not in the same building. Hence, the accuracy of this method would increase if the sample buildings number is high.

3.1.3.2 Energy Use Index Mean- Average

It is the average of the normalized energy use index for all the hotel buildings studied that calculated by equation (3.5).

$$E2cal = 1/n \sum_{i=1}^{n} EUIi \tag{3.5}$$

Where $E2cal$ is another method to identify the energy consumption benchmarking; $EUIi$ is the energy use index per building. The average of normalized EUI gives a general level of the energy performance of the buildings.

3.1.3.3 Quadratic Average Method

This method calculates the advanced level of the normalized energy use index. It provides a good indication of the energy consumption for the best practice hotel (Zhou, 2009). In order to calculate this value, firstly, the average normalized energy use index should be investigated, and then the average of normalized energy use index of the studied hotel buildings that less than the arithmetic average calculated previously should be found. Finally, take the average of these two values as presented by equation (3.6).

$$E3cal = \frac{\left(\frac{\sum_{i=1}^{n} EUIi}{n} + \frac{\sum_{j=1}^{m} EUIj}{m}\right)}{2} \tag{3.6}$$

Where $E3cal$ is the EUI calculated by the method of quadratic average; EUIi is the normalized energy use index of the sample buildings; EUIj is the normalized energy use index of less that the arithmetic average.

This method provides more energy efficient level indicator of the hotel building classification in terms of the energy use index ranges. It calculates the average of the average of the total buildings sample EUI and the average of the values lower than the mean value. This would be used as an indicator in this research to classify the good practice hotels.

3.1.3.4 Median

Median is another statistical way to benchmark the energy consumption that used in this study. The median is the numerical value separating the higher half of a normalized energy use index data sample from the lower half. It can be found by arranging all the normalized EUIs from lowest value to highest value and picking the middle one. In this paper, there is an even number of observations, then there is no single middle value; the median is then defined to be the mean of the two middle values.

This method would not affect the extreme values on the top and bottom but rather it would show the central tendency of data.

3.1.3.5 Percentile Method

The percentile is a measure used in statistics indicating the value below which a given percentage of normalized EUI observations in a group of observations fall. In this paper and to meet the future challenges of the energy demand side in UAE in line with the country visions, the energy consumption benchmarking were set to be 50% and 60%.

3.1.3.6 Mode Method

The mode is the value that appears most often in a set of data. In other words, it is the value that is most likely to be sampled. In this dissertation, the mode obtained by grouping the normalized energy use index and then finding the group with maximum frequency.

3.2 Hourly Building Energy Modeling Approach

In this study, the energy benchmarking analysis methodology that illustrated above will provide the energy use index of the hotels and how to compare a specific hotel's energy consumption to poor, usual and best practice energy performance. Additionally, it will report on the energy consumption improvement after implementing the integrated control strategy in the hotels' guest rooms. The general target of this system is to optimize the energy performance of the hotels systems and to maximize the indoor comfort. Generally, this will happen by using the advanced control methods like for example fuzzy logic or neural networks. The approach that is pursued to evaluate using such energy efficiency measures is the hourly building energy simulation.

However in this dissertation, the overall hotel building will be simulated by using computerized hourly based energy modeling and simulation to run the hotel building according to the existing conditions and after simulating the integrated control system. Energy simulation is done by using eQUEST; the Quick Energy Simulation Tool which is a graphical user interface that drives the DOE-2 simulation engine. DOE-2 predicts the hourly energy use and energy cost of a building given hourly weather information and a description of the building and its HVAC equipment and utility rate structure. Using the program, it can be determined the choice of building parameters that improve energy efficiency while maintaining thermal comfort and cost-effectiveness. This program simulates the energy performance of a building using hourly time steps for all 8760 hours in a year by using METENORM, AbuDhabi.BIN weather file. By this software, the researcher will be able to evaluate the impact of the integrated control system and the thermal satisfaction by providing the unmet hours and all the systems performance room by room according to the simulated spaces. Besides, the energy simulation will run two times to highlight the percentage of energy savings by using the integrated control strategy compared to the base case that represent the installed air conditioning system of the existing hotels’ guest rooms; fan coil unit.

Karagiorgas, Tsoutsos and Moia´-Pol (2007), in their research, have conducted energy simulation by using RET- Renewable Energy Technology to find out the energy flow of the hotels energy systems to figure out the energy use index per night spent in hotel Montana that it consumes 94.14 kWh/night-spent as shown in figure (3.1). This model objective is to highlight the energy breakdown of major consumers in the hotel buildings and the weight of the different loads and services of the building. It includes also the losses during the operation of the hotel’s building energy systems.

As outlined by Fumo, Mago and Luck (2010), Energy plus is used EnergyPlus simulations of Benchmark models to represent the energy performance by each building energy consumers and to find out through the energy model the expected energy consumption per each system per annum. Based on the DOE, EnergyPlus and eQuest software are widespread and accepted tool in the building energy analysis community around the world. This program combines the best capabilities and features including DOE-2. However, the main important point to select eQUEST in this dissertation is that it was designed to allow modeled project to perform detailed analysis of today’s state-of-the-art building design technologies using today’s most sophisticated building energy use simulation techniques but without requiring extensive experience in the "art" of building performance modeling. And since the integrated control methodology has a new technologies as this proposed advanced system includes four energy conservation measures that are integrated together in one system, which are; resetting the thermostat of the room temperature during un-occupied times, install the daylight control system that would benefit from the daylight and reduce the artificial light accordingly, use automatic blind system and control operating the fan of the guestroom in an intermittent way, to evaluate all these functions with the building envelope and other design parameters, eQuest software has been selected since all these energy conservation measures are available to be simulated and modeled hourly according to the weather data.

This dissertation will dive deeply in the integrated control strategy by simulating the appropriate structure, input and output signals, systems to be covered to optimize the energy performance and to secure the thermal comfort, percentage of savings and how it works with the different operating variables. Especially that the building automation and control, nowadays, is not a matter of luxury, but rather it is an essential part to save and reduce the energy consumption.

However, it is worth to mention that the hourly simulation tools are very promising technique to identify and develop a baseline of any existing or new buildings especially the hotels. They provide a reasonable prediction of energy performance to be compared against during the running and occupation time (Trcka and Hensen, 2010).

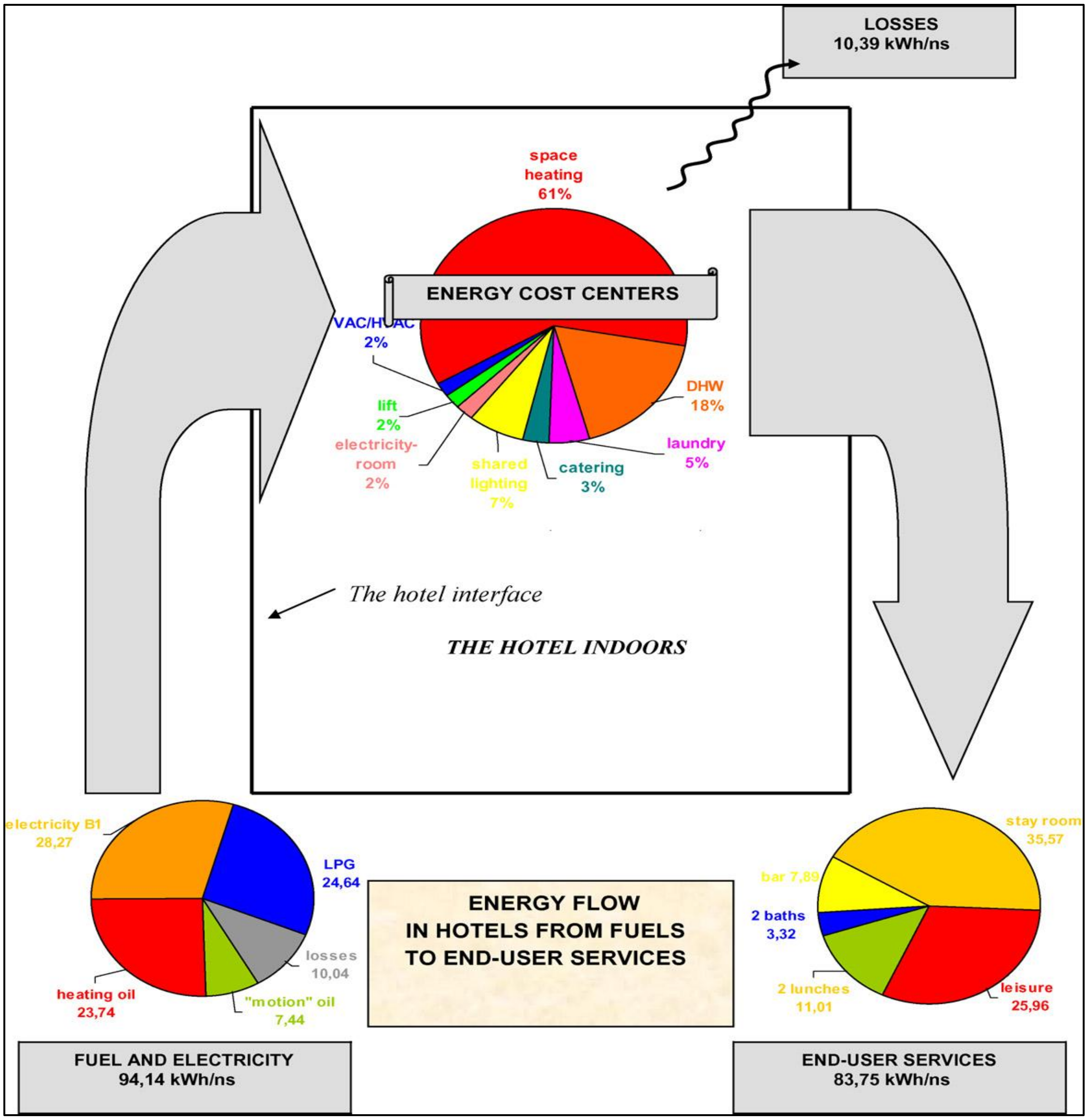


Figure (3.1) Energy flow in hotels from supply to demand side (Karagiorgas,Tsoutsos and Moia´-Pol, 2007)

Chapter 4

Data analysis, results and discussion

4.1 Data Analysis

4.1.1 Energy Data Collection

The data of energy consumption and the other basic hotel building information have been collected and analyzed for 19 hotel building with different characteristics to find out the common practice of the energy consumption. Also to classify the best and poor energy practices for the hotel buildings in UAE. The detailed information that gathered to evaluate their impact on the entire energy performance of the hotels are; the gross floor area, occupancy rate, guestrooms number, and equivalent guestrooms number that represents the average occupancy rate per year multiplied the total guestrooms number, building age, hotel’s class, windows to wall ratio (WWR), the annual energy consumption and the cooling source; whether using stand-alone chillers or district cooling plant (DCP). All of this information is summarized in Table (4.1)

Table (4.1) Detailed energy information of the sample hotel buildings

Hotel #	Floor Areas, m2	Cooling Source	Hotel Class	Guest Rooms	Occupancy Rate	Construction year	# of equivalent guest room	Annual kWh	Observation year	WWR%
1	8,500	Chillers	4	150	70%	2009	105	4,344,748	2013	65%
2	68,542	DCP	5	499	80%	2010	399.2	21,335,036	2012	80%
3	**37,587**	Chillers	4	161	85%	2009	136.85	9,034,031	2012	65%
4	12,000	Chillers	5	21	80%	2001	16.8	6,763,626	2012	40%
5	62,013	Chillers	5	200	85%	2006	170	17,617,433	2012	35%
6	39,000	Chillers	5	225	80%	2004	180	12,812,875	2012	30%
7	25,500	Chillers	5	211	85%	2002	179.35	13,323,943	2011	30%
8	68,634	Chillers	5	294	82%	2002	241.08	13,813,716	2011	30%
9	39,245	Chillers	5	218	78%	2006	170.04	22,657,815	2012	50%
10	32,288	DCP	5	316	80%	2008	252.8	11,237,978	2011	80%
11	70,070	DCP	5	498	80%	2008	398.4	17,235,980	2011	20%
12	50,000	Chillers	4	187	85%	1998	158.95	26,712,736	2012	20%
13	21,000	Chillers	5	318	71%	1998	225.78	9,202,142	2010	30%
14	11,600	Chillers	4	112	72%	1998	80.64	4,065,237	2010	30%
15	19,105	Chillers	4	384	72%	2009	276.48	6,425,297	2010	40%
16	33,677	Chillers	5	553	71%	2008	392.63	8,138,845	2010	30%
17	50,000	Chillers	5	393	63%	2002	247.59	22,223,798	2010	40%
18	54,085	DCP	5	244	85%	2004	207.4	12,707,931	2013	40%
19	19,218	Chillers	4	384	90%	2007	345.6	5,832,790	2013	40%

4.1.2 Normalized Energy Use Index

4.1.2.1 Weather Dependent Factors- Climate Adjustment

The weather is a variable factor that could not be controlled, but its impact on the energy consumption could be calculated and then adjusted. Since the energy data that has been received, were covered different years of hotel buildings energy consumption for 2011, 2012 and 2013, it was important to eliminate the climate factor by calculating the climate adjustment coefficient. The weather conditions for the years 2011, 2012 and 2013 would be represented by the cooling degree-day method to adjust the climate factor based on the equation (3.2). The CDD1 is the cooling degree-days for the typical year, which is in this study 2013 and CDD2 is the cooling degree-days for the observed year as per the questionnaire filled up data (2011, 2012 and 2013). Using the Dubai International Airport Data Table (3.1) showed the weather data, the calculation results are shown as equation (4.1) and (4.2)

$$\mu \text{ nd } \frac{CDD1}{\text{CDD2 (2011)}} = \frac{4011}{4085} = 0.98$$

(4.1)

$$\mu \quad \frac{CDD1}{\text{CDD2 (2012)}} = \frac{4011}{4152} = 0.96$$

(4.2)

According to the above coefficient climate adjustment, the energy consumption per each hotel building would be calculated by the equation (4.3) and (4.4).

$$Ec = \mu \text{c1. E2} = 0.98 \text{ .E2} \tag{4.3}$$

$$Ec = \mu \text{c2. E2} = 0.96 \text{ .E2} \tag{4.4}$$

Where E2 is the observed year and Ec is the normalized energy consumption at the standard year as illustrated in Table (4.2).

Hence, the adjusted climate energy consumption for 2013 is used as a reference year for all the sample buildings, and based on which, the related figures for the normalized energy use index per unit area for each hotel has been calculated as shown in equation (4.5)

$$\mathrm{EUInorm} = \frac{\mathrm{Ec}}{\mathrm{GFA}} \tag{4.5}$$

Where; GFA is the gross floor area per square meter. Hence the normalized energy use index unit is kWh/m²/year as outlined in Table (4.2).

Table (4.2) Climate factor adjustment

Normalized EUI climate adjustment				
Hotel #	**Standard Year**	**Observation year**	**EUI Climate Adjusted to 2013, KWh/m²/year**	**Annual kWh- Adjusted to 2013**
1	2013	2013	511.1	4,344,748
2	2013	2012	300.6	20,610,508
3	2013	2012	232.1	8,727,240
4	2013	2012	544.4	6,533,937
5	2013	2012	274.4	17,019,153
6	2013	2012	317.3	12,377,755
7	2013	2011	513.0	13,082,579
8	2013	2011	197.6	13,563,480.
9	2013	2012	557.7	21,888,366
10	2013	2011	341.7	11,034,401
11	2013	2011	241.5	16,923,749
12	2013	2012	516.1	25,805,583
13	2013	2010	430.2	9,035,445
14	2013	2010	344.1	3,991,595
15	2013	2010	330.2	6,308,902
16	2013	2010	237.2	7,991,409
17	2013	2010	436.4	21,821,213
18	2013	2013	234.9	12,477,726
19	2013	2013	303.5	5,727,128

4.1.2.2 Correlation Analysis between Non-weather Dependent Factors and the Normalized Hotel’s Energy Consumption

The building characteristics such as the age, occupancy rate, guest rooms’ numbers, equivalent guest rooms, windows to wall ratio and hotel’s classification have been analyzed through a correlation method with the climate adjusted energy consumption of the sample buildings. Table (4.3) shows how the above factors may influence the energy consumption of the hotel buildings. It is noticed that the windows to wall ratio, occupancy rate, guest rooms and equivalent guest rooms have a weak correlation with the building energy consumption. Also the hotel’s classification has a low correlation with the normalized energy consumption. On the other hand, there is a significant correlation between the energy consumed by the hotel and its gross floor area. From the results summarized in Table (4.3) it is noticed that the hotels occupancy rate has a weak correlation with the normalized energy consumption in UAE. The main reason is that there is no effective control system on the air-conditioning system during unoccupied times in the guestrooms. Besides, if the guestroom management system is installed the difference of the room temperature setpoint between the occupant and non-occupant times is very low (1-2 ^{0}C) as per the feedback was received by the engineering team of the sample hotel buildings that the energy savings would be negligible as will be explained in the section 5, and the uncertainty of tracking the reduction would be high.

Table (4.3) Correlation between the buildings’ normalized energy consumption and the building characteristics

Equivalent Guest Rooms Number	Age	Guest Rooms Number	Area	Occupancy Rate %	WWR%	Hotel's Classification
0.21	0.11	0.20	0.73	0.13	-0.08	0.35

Additionally, the sample building energy consumption has been normalized per unit area to find out the energy used index as indicated in equation (4.5), per guest room number and per equivalent guest room number. Therefore, these three indexes that represent the climate adjusted energy consumption per unit area, per number of guest room and per number of equivalent guest room were calculated and shown in Table (4.4).

Table (4.4) Normalized energy use index per unit area, number of guestrooms and number of equivalent guestrooms

Hotel #	EUI/ unit area (kWh/m²/year)	EUI/guest room (kWh/room/year)	EUI/equiv. guest room (kWh/room/year)
1	511.1	28,965	41,379
2	300.7	41,304	51,630
3	232.2	54,206	63,772
4	544.5	311,140	388,925
5	274.4	85,096	100,113
6	317.4	55,012	68,765
7	513.0	62,003	72,944
8	197.6	46,134	56,261
9	557.7	100,405	128,725
10	341.7	34,919	43,649
11	241.5	33,983	42,479
12	516.1	137,998	162,350
13	430.3	28,413	40,019
14	344.1	35,639	49,499
15	330.2	16,429	22,819
16	237.3	14,451	20,354
17	436.4	55,525	88,134
18	235.0	51,138	60,163
19	303.5	14,914	16,572

As illustrated in Table (4.4), three indexes; the energy use index per unit area, per number of guestrooms and per number of equivalent guestrooms, highlight the various energy consumption indexes that could be used to refer to the energy performance of the hotels. In this study, the energy use index per unit area used for the energy performance analysis.

Table (4.5) shows the correlation analysis between the normalized energy use index per unit area and the building age, number of guestrooms, number of equivalent guestrooms, windows to wall ratio, gross floor area, occupancy rate and hotel classification. It is demonstrated that there is a negative correlation between number of guestrooms and equivalent guestrooms, and hotel's area with the normalized EUI per unit area, whereas the correlation is low with the building age. However, there is a no correlation between the EUI per unit area and the hotel's classification or windows to wall ratio.

Table (4.5) Correlation between the normalized EUI per unit area- kWh/m^2/year and the building characteristics

Equivalent Guestrooms	Age	Guestrooms	Area	Occupancy Rate %	WWR%	Hotel's Classification
-0.53	0.39	-0.48	-0.48	-0.22	-0.01	0.04

Table (4.6) presents the correlation analysis between the second index of normalized energy use index per number of guestrooms and the building characteristics. It is outlined that there is a weak correlation between occupancy rate and hotel classification, whereas the correlation in negative significant with the equivalent guestrooms' number and guestrooms' number. However, there is a low correlation between the hotel' building age and EUI per number of guestrooms.

Table (4.6) Correlation between the normalized EUI per number of guestrooms-kWh/guestroom and the building characteristics

Equivalent Guestrooms	Age	Guestrooms	Area	Occupancy Rate %	WWR%	Hotel's Classification
-0.59	0.37	-0.59	-0.11	0.19	-0.11	0.15

Table (4.7) presents the correlation analysis between the third index of normalized energy use index per equivalent number of guestrooms and the building characteristics. It is seen that there is no difference between the number of guestrooms and equivalent number of guest rooms in terms of the correlation analysis with the building characteristics.

Table (4.7) Correlation between the normalized EUI per number of equivalent guestrooms-kWh/eq. guestroom and the building characteristics

Equivalent Guestrooms	Age	Guestrooms	Area	Occupancy Rate %	WWR%	Hotel's Classification
-0.59	0.37	-0.58	-0.13	0.13	-0.10	0.16

It is noticed that the number of guestrooms and number of equivalent guestrooms are correlated low and significant negatively with the energy use index per unit area. This means that when the hotel building has a high number of guestrooms and consequently higher guestrooms gross floor area compared to the public spaces floor area in the hotel building, the normalized energy use index EUI will be correlated strongly, and then it could be said that EUI per square meter is more convenient to represent the energy use. On the contrary, when these hotels public areas that include the leisure rooms such as; restaurants, gymnasiums and spa, lobbies, ballrooms, event and conference rooms and corridors, have a high weight of hotel's energy consumption, they will consume a massive amount of energy and hence the EUI would not be strong index to differentiate between the hotels' buildings energy performance. As a result, the hotels have a higher number of guestrooms with no significant leisure activities and less common areas, the energy use index per unit area would be more conservative and vice versa. In this dissertation, the percentages of the hotel's building common area and the guestrooms were not addressed that it would be recommended for future works, therefore the energy and building basic data of the hotel as a whole has been analyzed and studied. Accordingly, the building characteristics, apart from the number of equivalent guestrooms and the number of guestrooms, have shown neither significant nor high correlation with the normalized energy use index per unit area. Hence, it would be a good reason to use the normalized energy use index adjusted with climate as an indicator to the hotel energy performance and benchmarking to analyze statistically as outlined in the following section.

4.1.3 Energy Benchmarking Statistical Analysis

As outlined in section 3.1.3 statistical methods have been used to analyze the energy benchmarking for the hotel buildings in UAE. The methods used are mean index of total energy consumption (TECMI), mean of energy use index-EUI, quadratic average method, percentile method, median and mode. The results are summarized in Table (4.8) to show the different calculated options of the normalized energy use index per unit area.

Table (4.8) Normalized energy use index options by using the statistical methods

Statistical Method		
1) Mean Index of total Energy Consumption-TECMI	Total Energy Consumption, kWh	245,485,965
	total area m²	722,066
	EUI- kWh/m²/year	339.9
	Normalized EUI kWh/m²/year	331.3
2) Mean of EUIs	EUI Mean kWh/m²/year	369.4
	Normalized EUI Mean kWh/m²/year	361.3
3) Quadratic Average Method	Normalized EUI- kWh/m²/year, Arithmetic mean	361.3
	Normalized EUI- kWh/m²/year, less than Arithmetic mean	279.6
	Normalized EUI- kWh/m²/year (Average and advanced level)	320.5
4) Median	Normalized EUI- kWh/m²/year, 10th	341.8
5) Percentile	EUI-norm 75%	511.1
	EUI-norm 50%	330.2
	EUI-norm 25%	241.5
6) Mode	EUI-norm Mode	350

4.2 Results and Discussion

Table (4.8) shows the statistical analysis of the different options and the comparisons of the findings of the energy use index to figure out the **usual practice** of the hotel buildings energy performance in UAE. It is found that the minimum average normalized EUI is the quadratic average, which is 320.5kWh/m²/year, whereas the maximum one is the EUI calculated by 75th percentile method. Therefore, the range between these two values; the maximum and the minimum average EUI of the calculated statistical options is 320.5-511.1 kWh/m²/year that range the **usual practice**. However the 25th- 75th percentile are the range of the common practice in the hotel buildings sample. For the **best practice**, the lower than 25th percentile which means that the hotels that have normalized EUI lesser than 241.5 kWh/m²/year, whereas the poor practice hotel buildings in UAE have normalized EUI equal to or higher than 511.1 kWh/m²/year. Figure (4.1) shows the bell curve that group the energy consumption of the hotel building in UAE from the poor to usual then best energy practices.

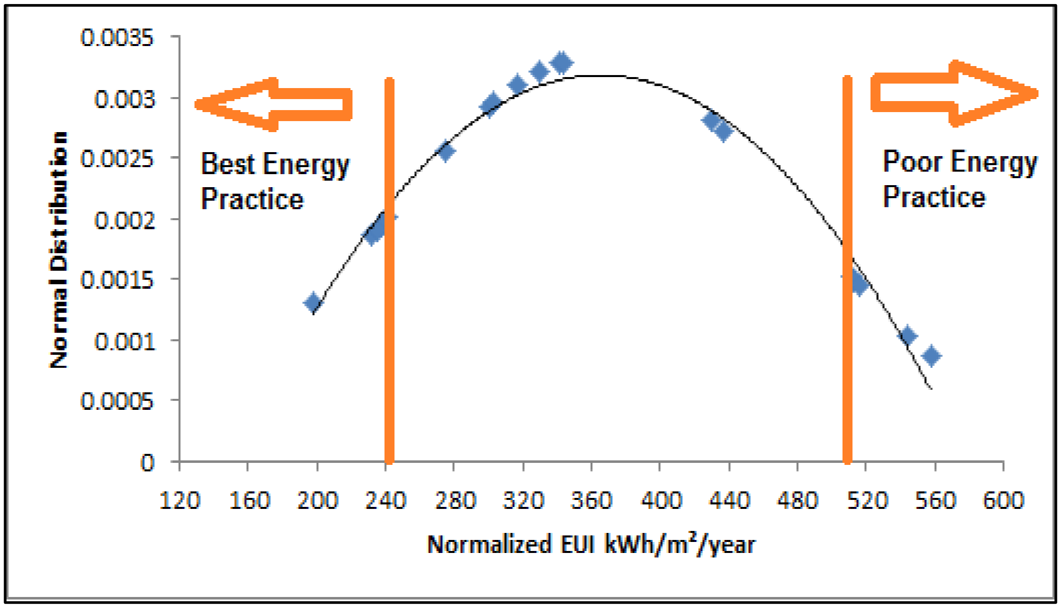


Figure (4.1) Normalized energy use index per unit area in UAE

The total energy consumption mean index for the sample hotel buildings is 331.3kWh/m²/year, which is more suitable to find out the average energy consumption per unit area over the country level in UAE. The average normalized energy use index 361.3 kWh/m²/year provides a clear picture about the average energy consumption for the hotels, but this value affected by the extreme values and hence the majority of EUI is not represented very well. Another average has been demonstrated through the statistical method, which is the quadratic average of normalized energy use index that it is an advanced average energy performance. It reflects the minimum average normalized energy use index per unit area (320.5 kWh/m²/year), but at the same time, this advanced index that produced through this method is very tough, too low and not easy to implement as an average on the hotel buildings in UAE. Nevertheless, it could be used and adopted by some hotels as an indicative and applicable target for the good energy practices. However, in order to eliminate the impact of extreme values, the median would be used to differentiate between the upper and lower halves and to select the value at the middle, which is in this study, is 341.8 kWh/m²/year. Although the median doesn't reflect the advanced value in this analysis, it is not far away from the quadratic average. Another flexible method used, which is the percentile method. It is applicable to identify the 25th, 50th or 75th percentile to assign the best, poor, good and usual practices energy practices. Moreover, to outline the majority, the mode method has been calculated as an advanced average, which is 350 kWh/m²/year.

Two other important factors have been analyzed: the first one is the cooling source; whether the hotel building uses stand-alone chillers or district cooling plant. In this dissertation, the cooling consumption, which was collected in the buildings sample was the chilled water energy that was measured at the downstream; building main chilled water heat exchanger in ton.hour, and based on the kW/ton, which equals between 0.9 and 1, according to the engineering departments of the buildings hotel sample, the energy consumption has been calculated for the entire building. If the hotel uses the district cooling plant as a source of the chilled water and the cooling energy, slightly the cooling system would be more efficient compared to the installed chillers. As the average normalized energy use index per unit area for the sample hotel buildings that install chillers on-site is 383.1kWh/m²/year, whereas the normalized EUI for the sample hotels served by the district cooling plant is 372.4 kWh/m²/year.

The second factor that was addressed and analyzed is the local code of the building code, regulation and construction specification of the hotels. In Dubai, the green regulation has been developed and published after 2003 through Decree 66 building code regulation and construction specification was issued that contributed to improve the energy performance for the buildings in general. However, before 2003 the building practices were very less stringent and the energy efficiency was not prioritized. In 2001, the resulting constructive solutions focus on the use of a mid-plane insulated prefabricated block to attain the prescribed maximum wall U value (0.57 W/m2K), however the reinforced concrete frame typically remained non-insulated, and thus introduces significant thermal bridges in the building envelope (Friess, et al., 2012). However, other recent research has been conducted by AlAwadhi and et. al (2013) found that the thermal conductivity and insulation requirements of the building envelop in Abu Dhabi and the federal buildings in UAE are far away from those issued by ESTIDAMA rating system. And also, it is noticed that Dubai Municipality (Decree 66) in 2003 recommended more conservative figures compared to the values found by AlAwadhi and et.al (2013). Although the research done by AlAwadhi and et. Al (2013) was discussing the housing sector and this dissertation addresses the hotel building, but these findings at least show an indicative feedback about the construction thermal insulation before 2003 as illustrated in Table (4.9).

Table (4.9) The comparison between the building thermal insulation before and after 2003, adapted from AlAwadhi and et. al,2013 and Dubai Municipality, 2013)

	DM Green Building Code-2014	Decree 66 - Building Code 2003	Insulation specifications before 2003 (Alawadhi and et. al.,2013)
Wall U-value (W/m² ºC)	0.57	0.57	3.00
Roof U-value (W/m² ºC)	0.3	0.44	2.28
Glazing U-value (W/m² ºC)	2.1	3.28	5.39
Shading Coefficient	0.4	0.4	0.41

Accordingly, in this dissertation, the comparison has been conducted between the findings of hotels that constructed before 2003 and after. It was noticed a big difference and substantial improvement for the hotels that constructed after 2003. For example the average normalized energy use index per unit area for the hotels built after 2003 is 323.6 kWh/m²/year, whereas the normalized EUI for the hotels built before 2003 is 426.0kWh/m²/year. This outcome is very significant, moreover, it would provide an important feedback about the construction practices and its specification; including the thermal insulation of the building envelop. Not only, two different averages of the energy intensity should be provided and calculated to the construction before and after 2003. As shown in figure (4.2) the trend line of the energy use index is going down in the recent construction years, which means more energy efficient hotel buildings were constructed after the year of 2003.

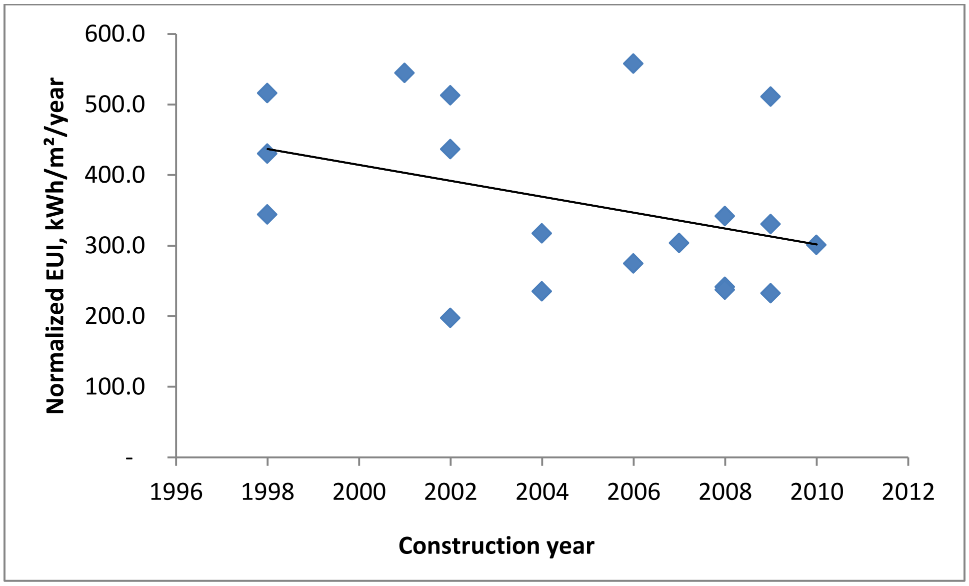


Figure (4.2) Normalized energy use index versus the year of construction

According to the results demonstrated above, the existing hotels energy consumption constructed after 2003 could be considered as a usual energy practice if the energy use index per unit area falls between 323.6-361.3 kWh/m²/year, which is between the two averages of the hotels built after 2003 and the mean value of all building sample regardless the year of construction. Whereas the hotels built before 2003, the usual practices are identified when the normalized energy use index per unit area fall between 426.0-511.1 kWh/m²/year, which represents the average of the hotels built before 2003 and the 75th percentile of the overall sample hotel buildings. The good practice of normalized energy use index falls between the advanced averages that produce by implementing quadratic average method and the lower limit of usual practice for the hotels built before 2003. Other more stringent way followed to select the good practice range of the hotels build after 2003 is that adopting the average of energy consumption per unit area of these hotels as an upper limit and the percentile 25th method as a lower limit since the retrofitting would be much easier for these hotels than those built before 2003, and also the thermal insulation is much better. For the best practices, as the bell curve shown in figure (3.1) and the 25th percentile method, the lower 25% of the normalized energy use index per unit area is the most energy efficient buildings which are almost equal to the figures selected in Table (4.9) that followed the lesser values than the lower limit of the good practice classification. Table (4.9) summarized the above description with the normalized energy use index per unit area values for the hotels constructed before and after 2003.

Table (4.9) Normalized energy use index- Hotels' Energy consumption practices

Normalized EUI, kWh/m2	Best Practice	Good Practice	Usual Practice	Poor Practice
Hotels constructed after 2003	Lower than 241.5	241.5-323.6	323.6-361.3	More than 361.3
Hotels constructed before 2003	Lower than 348.4	348.4-426.0	426.0-511.1	More than 511.1

It is also worth to mention that the energy use index isn't correlated significantly with the occupancy rate that means the energy systems are not affected considerable by the building users and their presence. Additionally, the operating set points and the internal cooling loads run almost continuously and in constant reference that doesn't vary on demand nor based on the occupancy level. This notice is almost applicable on several hotels in UAE and on the buildings sample analyzed in this study. Accordingly, to improve the energy efficiency and to optimize the energy performance, it is highly recommended to start retrofitting the existing hotels to run sharply on demand to overcome the energy challenges. Therefore, the practice of these hotels would be stepped up from poor to usual, usual to good or from good to best energy practices. The next section (5) would cover one of the important energy conservation measures and how it would affect positively on the energy performance of the hotels based on demand according to the integrated control methodology.

For the hotels' guestrooms numbers that included in this survey, it was reported that the total guestroom numbers for the 19 hotel buildings sample are 5,368 rooms, whereas the normalized used guestrooms that occupied by guest per night are 4,185 equivalent rooms. Accordingly the normalized energy use index per equivalent guestroom per year is 57,177kWh per year, which equal to 157kWh/night spent.

Chapter 5

Energy Modeling and Simulation, Results and Discussion

Generally, there are two methods to evaluate the buildings energy performance; prescriptive method and performance path. The performance path that uses the hourly energy modeling and simulation is more convenient method to evaluate the energy performance of the buildings from the design perspective and the enforcement of the building operator to meet the energy efficiency and the optimum consumption (Pérez-Lombard and et al. (2011).

Building Energy modeling and simulation involves gathering the building data of the new development and the as built drawings for the existing including to the data of construction documents, product specs, annual energy consumption, implemented energy conservation measures and the operating hours. A virtual model of the hotel would be simulated by an hourly energy modeling software. After entering all these inputs the model will be run to generate the report of simulation of the systems, hotel’s energy consumption with different scenarios. For the energy model run in this dissertation, the main objective is to find out the impact of the integrated control strategy on the energy consumption of the hotel and what is the improvement expected. Several models have been run to show the energy consumption improvement compared to the base case model that will reflect the new green building code issued by Dubai Municipality by March 2014.

The models run showed the improvement of installing a new integrated control strategy as a retrofitting measure by simulating the daylight technique with dimming system, reset the room temperature set points during unoccupied times, using the blind systems to reduce the solar gain and unnecessary load during unoccupied times. The original model included all the building geometry, envelop, air conditioning systems, lighting, systems, hot water, pumps, fans and other miscellaneous loads. The base cases referred to Dubai new code 2014- green building code that addressed the green building regulation.

5.1 Integrated Control Strategy Energy Simulation in the Model

In order to simulate the integrated control system, the following items should be modeled in the software to make sure all these inputs are available in the calculation and model.

Inputs for an integrated control and optimization system:

- Inside measurements of the room temperature, illumination level, occupancy detection and energy consumption by smart metering system.

- Outside measurements are required for weather data to adjust the settings of the control system like for example; the humidity, outdoor temperature and solar radiation, and thus Dubai weather file would be used in the model.

- The model will follow the green building code issued by Dubai Municipality and ASHRAE 90.1- 2007 standard to enter all the other variable of the building, such as; thermal conductivity of the roof and external walls, glazing performance, lighting power density, international operating schedules for the occupancy taking in the consideration the average occupancy rate in Dubai hotels.

5.1.1 Simulated Energy Conservation Model

Usually in UAE the hotel buildings use fan coil unit with 2-pipe system. The 2-pipe units usually have one cooling coil. The units modulate the flow of water to the coil; this is a variable air temperature system. Outside air for fan coil systems is usually introduced by a separate ventilation system; however, outside air may be introduced directly into the fan coil unit. In this study, the program does not simulate a separate ventilation system; all outside air is drawn through the fan coil.

In order to optimize the energy performance of the hotel guestrooms and to maximize the thermal comfort, the proposed integrated control system acts to meet this aim by providing control signals to achieve the following energy conservation measures;

- Air Conditioning: Reset the room temperature according to the demand based on the occupancy. In order to maintain the climate zone more comfortable by adjusting the room temperature to be very close to the set point. The room temperature set point relies on the occupants' selection to satisfy his thermal satisfaction or it could be adjusted automatically according to the season and the outside temperature. This system will rise up the room temperature set point from 23^{0}C as per ASHRAE 55 to 25^{0}C, 27^{0}C and 29^{0}C to find the most efficient and applicable findings. The access card and or occupancy sensors will be used as an indicator to the presence of the guest.

- Fan Control: The fresh air is required to be supplied to improve the indoor air quality for the occupants. Using the demand controlled ventilation will reduce the excessive outside air that is not required, however, in this model since the fan coil unit installed in UAE doesn't have automatic variable speed but only multiple speeds; low, med and high, this study will use the intermittent technique that provide the sufficient fresh air when the room occupied and switched off when room unoccupied through an intermittence control strategy. Intermittent fan control models fans which cycle with internal load to modulate cooling to the space with the supply temperature being that which is delivered at full coil capacity during the fan on period of operation, while the continuous will model the fans to operate with continuous flow whenever the fan are scheduled to be on with the supply temperature to the space modulated to meeting the cooling requirements. Since the integrated control strategy depends basically on the demand and the internal load, the system will be modeled by selecting the intermittent control methodology to meet the cooling requirement based on the demand.

- Lighting: the luminance level is very a significant factor for the visual comfort of the occupants. However, the lighting consumes a considerable amount of energy if it is not designed efficiently. Therefore, lighting should be provided full attention to be controlled based on the demand of the space and the occupants' needs as per the international standards. Accordingly, the integration between the natural and the artificial light would be an interesting strategy to increase the energy efficiency. The model as part of the integrated control strategy function will use the daylight integrated system that that occurs when a sensor measures daylight levels and signals a control to adjust electric lighting system output to maintain a desired task light level.

The algorithm of operation of the proposed daylight dimming system is securing (200-300) 250 lux in the guestroom as recommended by CIBSE (Chartered Institute of Building Services Engineers). The priority to be given by the natural light but if not sufficient and the system will control the illumination level of the artificial lighting to meet the required lux level. Because strong daylight availability is essential to daylight harvesting, these hotels are well suited to this control strategy since the glass area is relatively high. Recently, codes and standards are now beginning to address daylight harvesting—specifically, International Energy Conservation Code (IECC) 2009, ASHRAE/IES 90.1-2010, ASHRAE 189.1 and Title 24-2008. In review, IECC 2009 and ASHRAE/IES 90.1-2010 are energy standards offered as model energy codes for states and other jurisdictions. ASHRAE 189.1 is a green building standard. And Title 24-2008 is California's unique energy code.

- Automated blinds in the guestrooms: automated controls of blinds or curtains could be included in the system in order to block excessive light and reduce the need to use energy for cooling especially during unoccupied times. In the model, the blind will be shut down 100% during unoccupied times in order to minimize the solar heat gain along with switching off the fan coil and rising up the room temperature set point in integrative approach. Generally, automated controls of blinds or curtains should give occupants the opportunity to override the automation.

The integrated control methodology has been run in an integrative approach to meet the main objective, which is the optimization of energy performance and improve the thermal comfort and satisfaction. These separate four energy conservation measures could be implemented and show energy savings, but the thermal comfort might be affected and the energy savings would not reach to the maximum level because these systems usually perform individually and might contradict with the function of each other, for example the blind system may shutdown, the room temperature set point might increase but sequence of operation should be done as a one system and in a harmony enhances the energy savings. In this study, the recommended sequence of operation to maximize the system's benefit is as follows; when the system detects that the guest room is vacant and the outside temperature is higher than the room temperature, the blind will shut down and the artificial lighting will switch off. When the blind is totally closed and the light is off, the room temperature set point will be changed to 25^oC, 27^oC or 29^oC as different options, whichever is more suitable and efficient according to the PID controller or fuzzy logic, then fan to switch off when the cooling is unneeded.

5.1.2 Energy Model Assumption- Base Case Model

In order to measure the energy performance of the hotel buildings and the improvement of implementation of the integrated control methodologies as specified above, energy analysis is simulated using eQUEST. This program simulates the energy performance of a building using hourly time steps for all 8760 hours in a year by using METENORM, ARE_AbuDhabi_IWEC.BIN weather files to compare the energy consumptions and needs of the entire year in UAE. The energy analysis and modeling methodology have been conducted in line with the ASHRAE 90.1 2007 requirements. The main assumptions used in the base model are presented in the table (5.1). The external wall u-values simulated in the model is 0. 57W/m²K, which is equal to the recommended thermal conductivity values in Dubai based on the new green building regulation and the roof u-value is 0.3W/m²K. Additionally the windows to wall ration is equal to the average percentage that outlined by the hotel buildings sample. For the glazing performance, 2.1W/m2K has been simulated as u-value in the model which reflects the double glass windows that used commonly here in Dubai.

The lighting system assumed in the model complies with the ASHRAE standard 90.1- 2007 and Dubai green building regulation, which is about 10W/m². However, for the usual practice the lighting power densities for the guestrooms might reach higher than this amount.

According to the above inputs baseline model was run to provide an average consumption that match to the average of usual or poor practice to such existing hotel buildings constructed after 2003 and the new buildings follows the new green building regulation in Dubai. Accordingly, the energy use index per unit area is 374.6kWh/m²/year.

Table (5.1) Energy modeling assumption for the base case model of the hotel building as per Dubai Municipality green building code

Model Input Parameter	Units	Baseline assumptions
Weather file	None	ARE_Abu[1].Dhabi_IWEC.BIN
Weather file source	None	METENORM
Building Envelope		
Exterior Wall Construction	U-value, W/m2K	0.57
Roof Construction	U-value, W/m2K	0.3
Window-to-gross wall ratio (WWR)	%	40% (Average of sample buildings)
Fenestration and Glazing Type (%Fixed and %Operable)	None	FIXED
Fenestration		
Glazing U-factor	U-value, W/m2K	2.1
Glazing visual light transmittance	VT	0.5
Glazing SC	None	0.4
Shading Devices	None	NA
Lighting system		
Interior Lighting Power Density	None	10W/m2
Other Lighting Control Credits	None	NA
Domestic Hot Water System		
Domestic Hot Water Usage	Liter/Person/Day	150
Heating Source	None	Gas
HVAC		

Description	None	Fan Coil Unit (FCU), water cooled chiller, and variable speed control on the secondary chilled water pumps
Heating	None	NA
Cooling Type	None	FCU- Chilled water
Fan Control	None	2-speeds
Total Cooling Capacity	Ton	$25m^2$/Ton
Total supply fan	CFM	Cooling System: $33l/s/m^2$
Ventilation & Fans		
Outside fresh air	CFM/Ton	27
Fans & Pumps		
Total Fan Supply Power	Inch WG	2 inch WG
Heat Recovery Process	None	Not Modeled
Renewable Energy Sources		
Renewable Energy Type	None	NA

5.1.3 Base Case Model Validation

Hourly building energy model programs simulate all aspects of energy use and thermal and visual comfort in buildings. ASHRAE Standard 140 Method of Test for the Evaluation of Building Energy Analysis Computer Programs, was the first codified method of test for building energy software in the world, and has been referenced by ASHRAE Standard 90.1 for approval of software used to show performance path compliance (Judkoff *and* Neymark, 2006). According to Judkoff et al. in 1983(cited in Judkoff *and* Neymark, 2006) , three methods are available to assess the accuracy of the hourly building energy simulation software as follows;

- *Empirical Validation*: it compares the calculated results by the energy model software to the monitored data from a real building or laboratory experiment.
- *Analytical Verification*: it compares the calculated results by the energy model software to results from analytical solution.
- *Comparative Testing*: it compares the software to other programs.

In this study, the data available from the modeled building are limited to the building gross floor area, occupancy rate and monthly energy consumption. The other energy inputs have been estimated according to the usual practice in UAE that illustrated in table (5.1) taking into consideration the new green building code by Dubai Municipality. The energy model validation method that has be pursued is the empirical method, that adopts the real energy consumption data in monthly basis for the modeled building and compares it to the base case model and software results. Besides, in this validation method, the special circumstances and modeled assumptions that represent the uncertainty in some areas are highlighted and explained in order to isolate any factor in the operation may influence the energy performance that aren’t simulated properly.

Empirical Validation

Empirical data is a very powerful validation technique since a real comparison would be conducted between the model and the true energy meters that the building pays against (Jensen, 1995). In this building, the parameters used for the model divided into two groups; those belong to the actual building envelope and those related to the occupants of the building. The first category that represents the building envelope, the model used Dubai Municipality green building code and these values considered as used values since no data are available by the building in reality, however the HVAC system and control have been modeled as per the actual situation. For the parameters related to the occupants, it is not easily to estimate or figure out the occupants behavior that influence on the cooling load, lighting, hot water and other appliances in the hotel building. It is so hard to estimate this part and then to simulate it, hence the model has combined between the usual practice of the occupants that were collected from few interviews with the hotel building's facility manager, and the green building code requirements. According to these assumptions, the run model has been compared to the actual metering. After the calibration of the energy model with the occupancy schedule, the usual practice and adjusted behaviors of the building users, the energy model showed almost 2.7% higher than the actual energy consumption, which is less than 3% that represents the level of acceptance as per IPMVP option D (EVO, 2012). Figures (5.1) and (5.2) outline the pattern of energy consumption of the actual bills in monthly basis along with the calibrated energy model. The actual energy bills of the modeled building were calculated for 2010; it showed 4,065,240kWh as total annual energy consumption for 11,600 square meters, whereas the calibrated model has presented about 4,177,840 kWh.

Understanding the different building operating factors that show the real life effect building energy models is an essential part of the validation analysis which deserves further development and research (Menezes et al., 2014). This is especially important when there is no baseline for the building and the energy models are used to predict the energy use of new developments in which case there is no metering data to calibrate the model with (Ryan and Sanquist, 2012). However, the hourly building model software still provides an efficient and simple method to predict the energy consumption behavior for the existing and new buildings. Neverthless, Beccali and et.al, (2009) concluded that the empirical approach is a valid tool to evaluate the energy performance of the hospitality sector because of the indicators that used in which to analyze the energy load profile of the buildings.

It is noticed in the below figures that the peak load of the calibrated energy model is August, whereas for the actual energy bill, the month of June is the peak. This slight difference may reflect the variation of the occupancy rate per month between the model and the actual bills, but for the annual occupancy rate, it shows similar percentage. Also, the both energy patterns show some differences in monthly basis. The main reason of that is the methodology of the weather file that used by the energy model compared to the year of observation for the actual bills, which is 2010. The weather files are derived from up to 18 years of DATSAV3 hourly weather data originally archived at the source. The weather data is supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements, particularly cloud amount information. The IWEC is available from ASHRAE. The reference for the IWEC is: ASHRAE. 2001. International Weather for Energy Calculations.

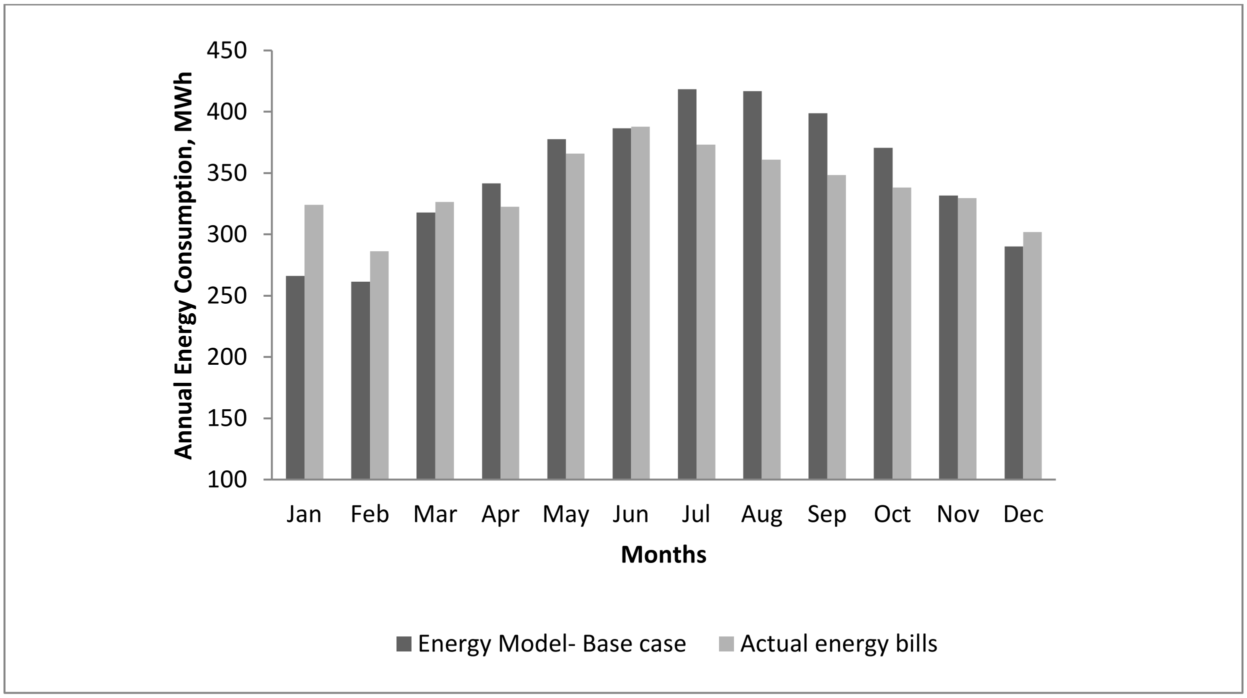


Figure (5.1) Monthly energy consumption of the calibrated energy model and the actual energy bills

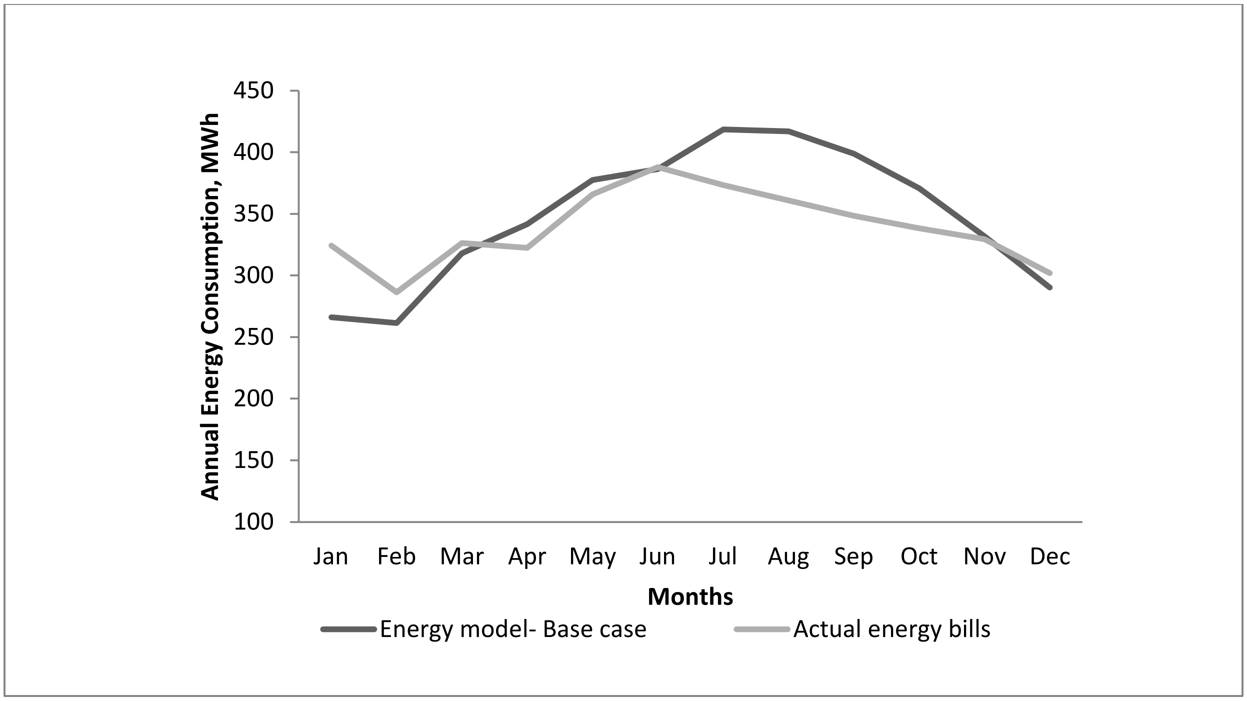


Figure (5.2) Monthly energy profile of the calibrated energy model and the actual energy bills

5.1.4 Energy Models Findings and the Achieved Energy Savings

According to the outlined energy assumption, standards and codes that used for the energy model and the energy conservation measures separately and integrated together under the integrated control methodology, the comparison between these models, which are the base case model that uses Dubai green building code and the energy models of stand-alone energy conservation measures and the integrated control model that combines four proposed energy conservation measures in the hotel guestroom, which are resetting the guestroom temperatures during unoccupied area 2 degrees Celsius above the base case until 29^{0}C, which use 23^{0}C as per ASHRAE 55 as a base, installing daylight dimming control system, installation of automatic blind system and control and using intermittent technique to control the fan operation as illustrated in table (5.2). The comparison has been conducted to show the total energy savings over the annual energy consumption of the entire building, therefore, the optimization of energy performance in the guestrooms has been measured against all the hotel's energy used.

Table (5.2) Energy models have been run

Energy Model	Description	Inputs
Model 1	Base case energy model	Green building code
Model 2	Reset unoccupied temperature setpoint of guestroom to 29^0C	Energy Conservation measure#1.1
Model 3	Reset unoccupied temperature setpoint of guestroom to 27^0C	Energy Conservation measure#1.2
Model 4	Reset unoccupied temperature setpoint of guestroom to 25^0C	Energy Conservation measure#1.3
Model 5	Daylight control system	Energy Conservation measure#2
Model 6	Automated blind control system	Energy Conservation measure#3
Model 7	Fan control system	Energy Conservation measure#4
Model 8	Integrated control model	4 Energy Conservation measures combined together in one model

5.1.4.1 Reset Unoccupied Temperature of Guestroom Model

The setpoint of the guestroom temperature as recommended by ASHRAE 55 to meet the thermal comfort for the occupants is 23^0C. In this energy conservation measure, the setpoint has been raised by 2^0C in each model to find out the most efficient energy savings measure and the rate of improvement of energy use. Hence, three energy models have three different temperature setpoints of the guestroom that are 25^0C, 27^0C and 29^0C during unoccupied times, were run and compared to the baseline model. The energy models show different energy savings as shown in table (5.3).

Table (5.3) The comparison between the base case model and resetting the guestroom temperature during unoccupied times

Unoccupied Temperature setpoint to	29⁰C	27⁰C	25⁰C
Energy savings percentage on the cooling system	13.9%	4.4%	1.7%
Entire building energy savings percentage	9.8%	3.1%	1.2%

It is noticed that 29^{0}C is the most energy efficient among the proposed energy models outlined in table (5.3). The energy savings on the cooling systems including chillers, fans, chilled water pumps and ventilation by raising the guestroom temperature during unoccupied times from 23^{0}C to 29^{0}C is 13.9%, which equals 9.8% out of the entire building energy consumption. On the other hand, the other 2 models, showed lower energy savings, 1.7% and 4.4% on the cooling system and 1.2% and 3.1% on the entire building energy consumption by raising the setpoint temperature from 23^{0}C to 25^{0}C and 27^{0}C respectively. As illustrated in figure (5.3) the lower curve shows in monthly basis the improvement of energy consumption of the proposed guestroom temperature setpoints without compromising the thermal comfort.

Additionally, the models show the energy consumption and savings achieved per energy system as illustrated in figure (5.4). It is very clear that the cooling system is the major consumer in the hotel buildings energy consumption here in UAE that consumes between 65% and 75% of the total energy consumption for the air conditioning related systems including; space cool, fans, fresh air packages and chilled water pumps. It is noticed that the supply air is lower by 9% for the setpoint temperature of 29^{0}C during unoccupied times than the other two proposed setpoints, which caused directly to reduce the cooling capacity (refrigeration tonnage) by 8.6% and consequently the input power of the cooling systems. However, a slight improvement has been seen when the room temperature setpoint during the unoccupied times has been increased from 23^{0}C to 25^{0}C and 27^{0}C. The main reason is that the cooling would be unrequired more often with a setpoint of 29^{0}C based on the weather conditions that modeled especially when taking into consideration using a thermostat type of Proportional thermostat the used to control the zone temperature in the energy models. The cooling setpoint is given with thermostat throttling range is given by 2^{0}R. The proportional thermostat type refers to the added cooling that is throttled in linear proportion to the difference between the zone set point temperature and the actual zone temperature.

Accordingly, since the difference in the setpoint temperature is significant between 29^{0}C and 23^{0}C, its impact were shown clearly in the monthly consumption. Therefore, it would be recommended when running the integrated control model.

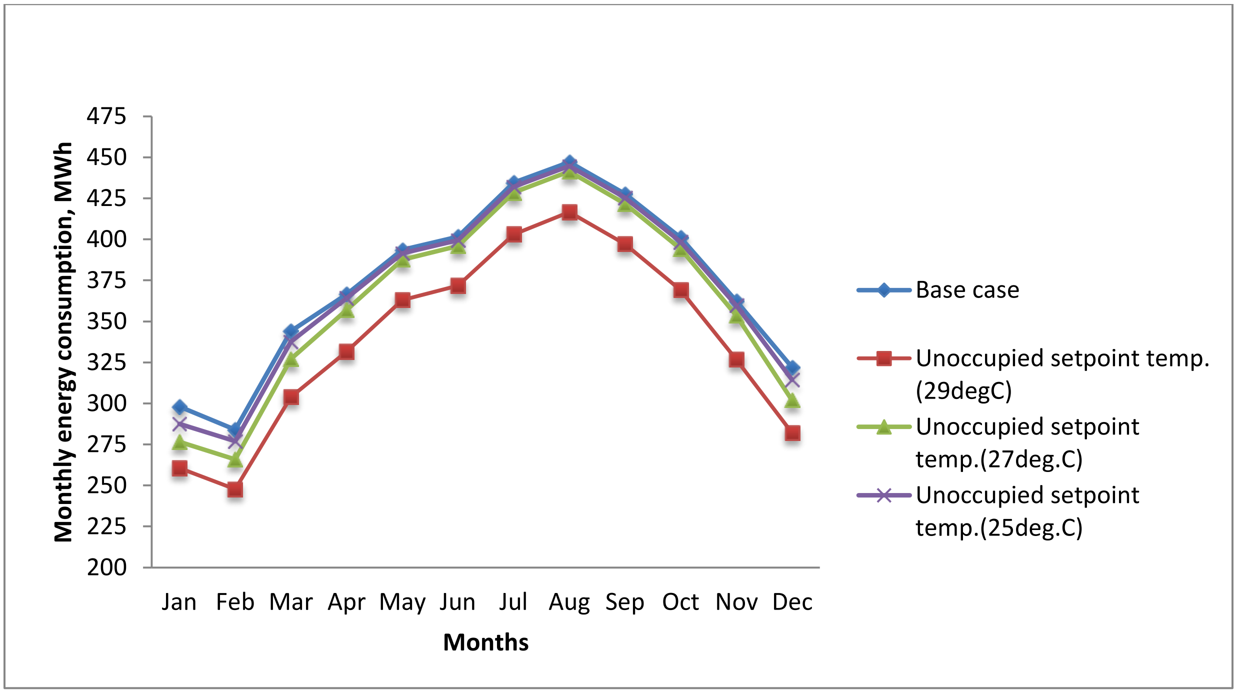


Figure (5.3) The comparison of the energy consumption between the base case model and the different scenarios of the resetting the guestroom temperature setpoint over the year

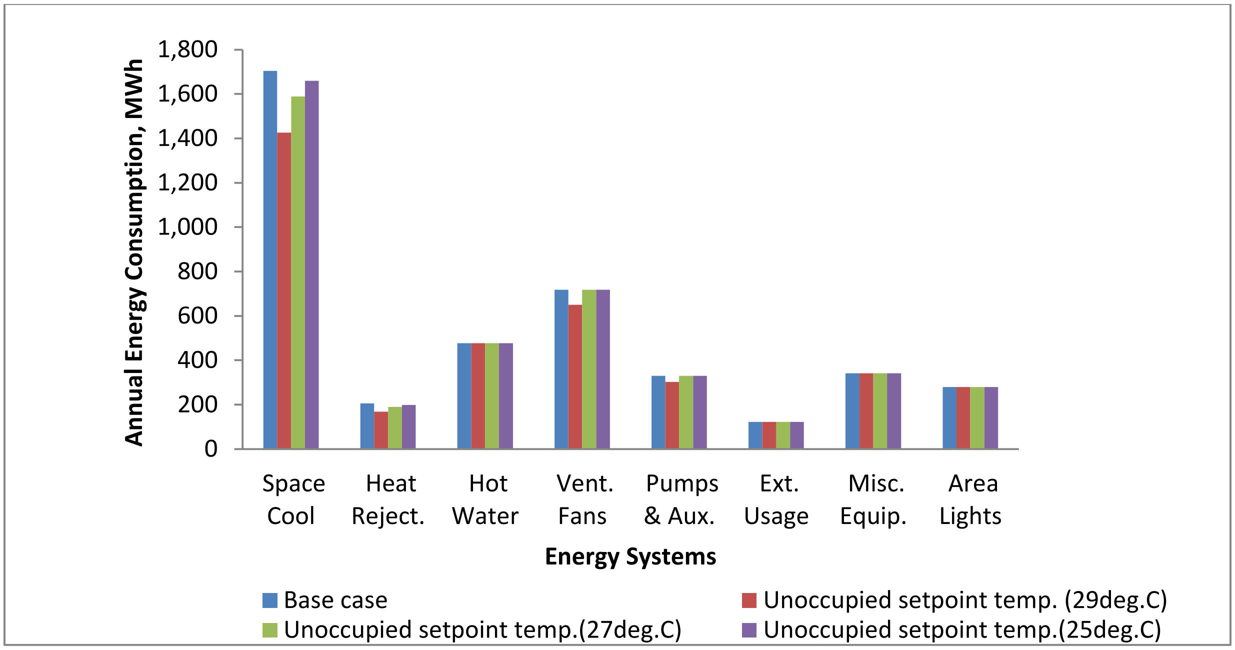


Figure (5.4) the energy systems annual consumption for each model

5.1.4.2 Daylighting Control Dimming System Model

The daylight control dimming control system as explained in section 5.1.1 has a reasonable energy savings on the lighting system as per the energy model run with the daylight control compared to the base case model. The results as illustrated in table (5.3), they show a very low energy saving over the entire building energy consumption about 0.87% and 13.2% savings for the lighting system alone.

Table (5.3) Daylight control dimming system energy saving compared to the base case model of the average hotel building

Percentage of energy savings on the cooling system	**0.87%**
Percentage of energy savings on the lighting system	13.2%
Entire building energy savings	1.50%

It is clear that the base case scenario that use the Dubai Municipality green building code is already conservative in terms of the lighting system requirements, as the lighting power density is 10W/m² that causes a low weight of lighting load as outlined in figure (5.5), and the shading coefficient is 0.4 that reduces the benefits of harvesting the daylight and hence to optimize the daylight control systems. The light load percentage is less than 10%, whereas the cooling load systems reach to 75% in UAE, therefore, the priority is given to what reduces the air conditioning system firstly.

However, for the existing hotel buildings that constructed before and after 2003, the daylight control system is anticipated to achieve more energy savings because the lighting power densities and the shading coefficient are much higher than the Dubai Municipality new green building code.

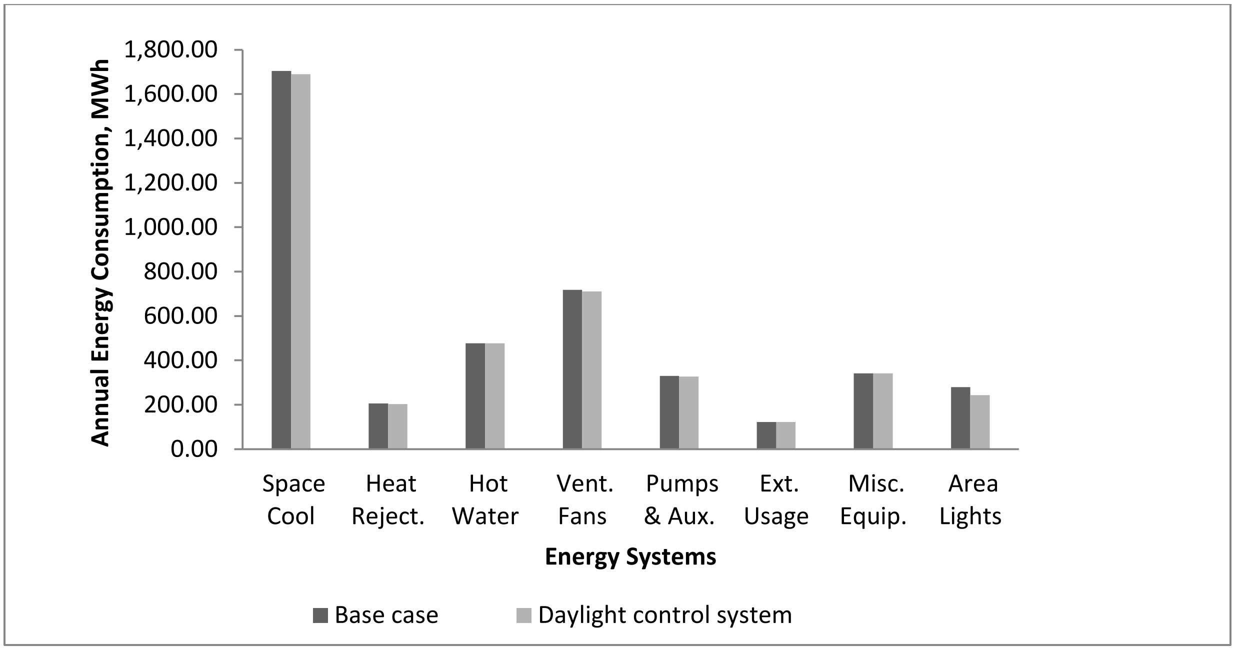


Figure (5.5) the energy systems annual consumption for daylight control and base models

5.1.4.3 Automated Blind Control System Model

The automated blind control system works to reduce the solar gain that is existed during unoccupied time and at the same time the blind is translucent to allow the solar radiation only to pass through and hence it would not work negatively. The automated blind control system has been modeled as explained in section 5.1.1, and the model was run to be compared to the base case. The results as outlined in table (5.4), they show a considerable energy saving for the air conditioning system; that includes chillers, fans, pumps and ventilation, which equals 8.8% over the baseline, whereas the energy savings for the entire hotel building energy consumption is about 6.2%.

Table (5.4) Automated blind control system energy saving compared to the base case model of the hotel building

Percentage of energy savings on the cooling system	**8.8%**
Percentage of energy savings on the lighting system	0.0%
Entire building energy savings	6.2%

The advantages of the automated blind control system are obviously seen at summer times, at which the sun effect is higher than in winter, this positive impact in reduction of the solar gain appears in figure (5.6). Besides, figure (5.7) illustrates the comparison between the base case model and the automated control blind energy consumption per each system in the hotel building.

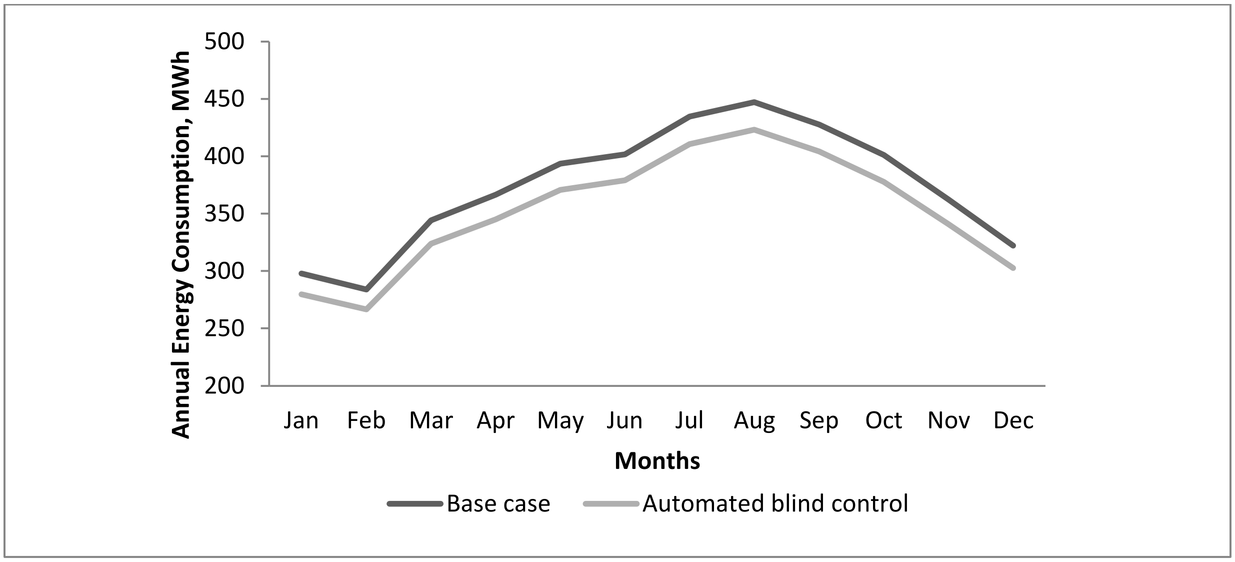


Figure (5.6) the comparison of the energy consumption between the base case model and the automated blind control system over the year

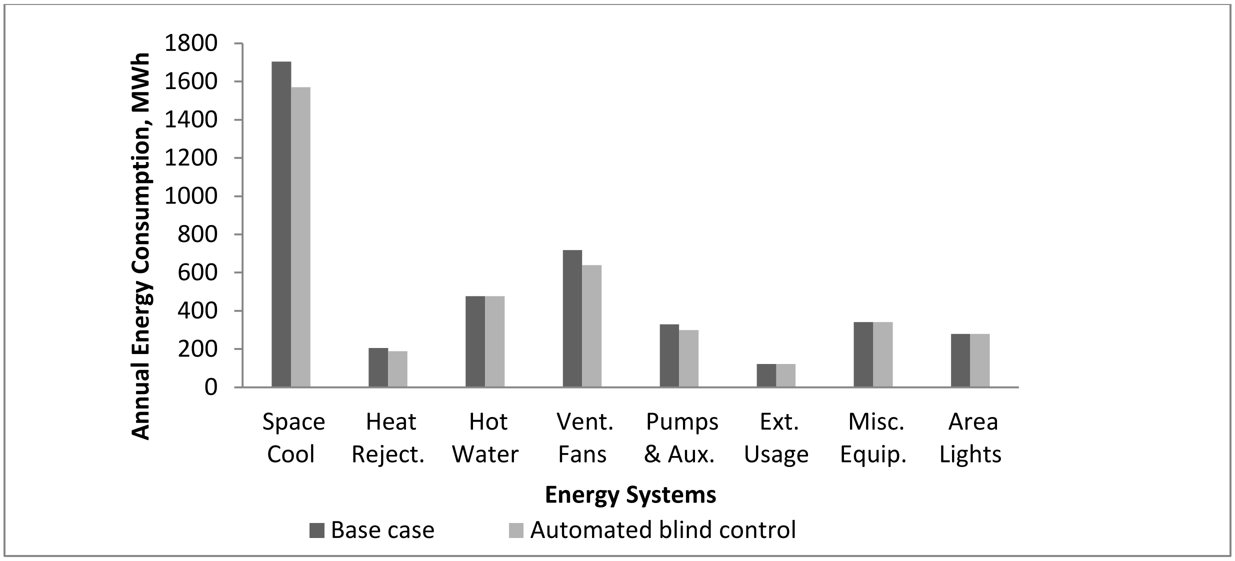


Figure (5.7) the energy systems annual consumption for automated blind control and base models

5.1.4.4 Fan Control System Model

The intermittent control strategy is one of the most efficient energy conservation measure that achieves a significant amount of energy savings for the cooling system comparing to the continuous operating mode of the fans that available usually in the logic of indoor fans operations especially the guestroom ones. This fan control system has been modeled as explained in section 5.1.1, and the model was run to be compared to the base case that operates the fan continuously. The results as outlined in table (5.5), they show a substantial energy saving for the air conditioning system; that includes chillers, fans, pumps and ventilation, which equals 26.4% over the baseline and a significant energy savings shown in the fan energy consumption by 75.4%, whereas the energy savings for the entire hotel building energy consumption is about 18.7%.

Table (5.5) Intermittent fan control system energy saving compared to the base case model of the hotel building

Percentage of energy savings on the cooling system	**26.4%**
Percentage of energy savings on the fans' system	75.4%
Entire building energy savings	18.7%

The most significant energy system that is affected by using the intermittent control system is the ventilation and fans energy consumption that reduced drastically because of this intelligent strategy, as shown in figure (5.8). Not only, the model shows the energy performance of the building that uses the intermittent fan control at summer and winter times to illustrate the improvement of the energy efficiency compared to the continuous fans running as outlined in figure (5.9).

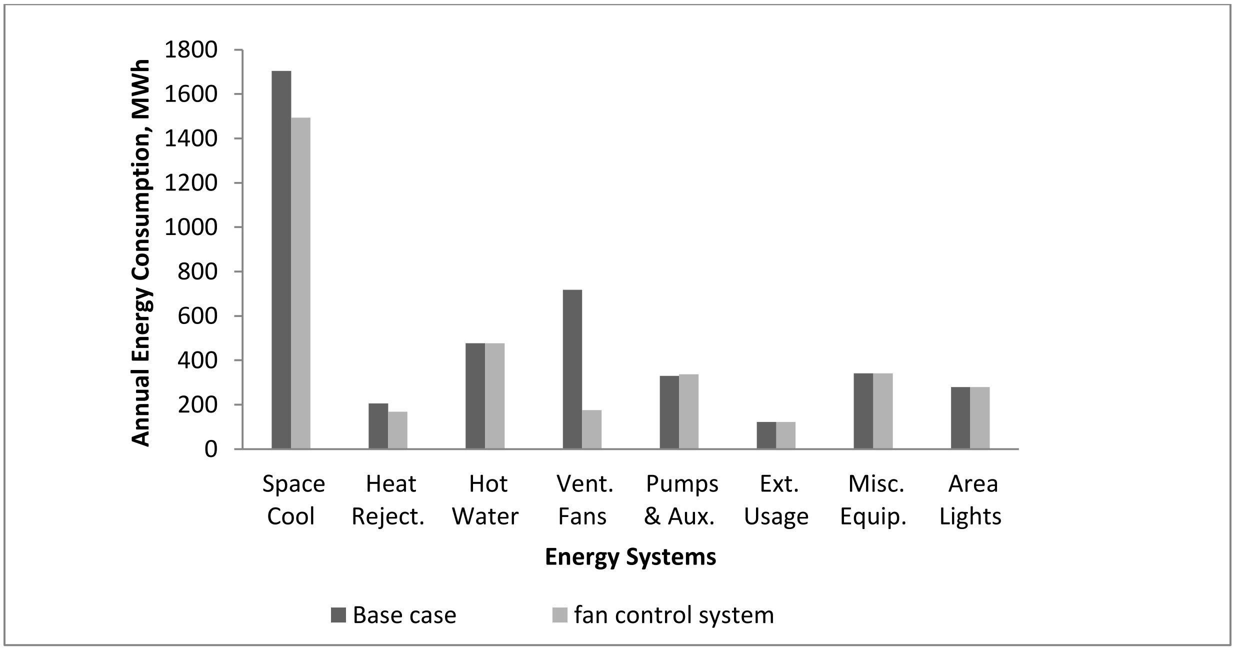


Figure (5.8) the energy systems annual consumption for intermittent fan control and base models

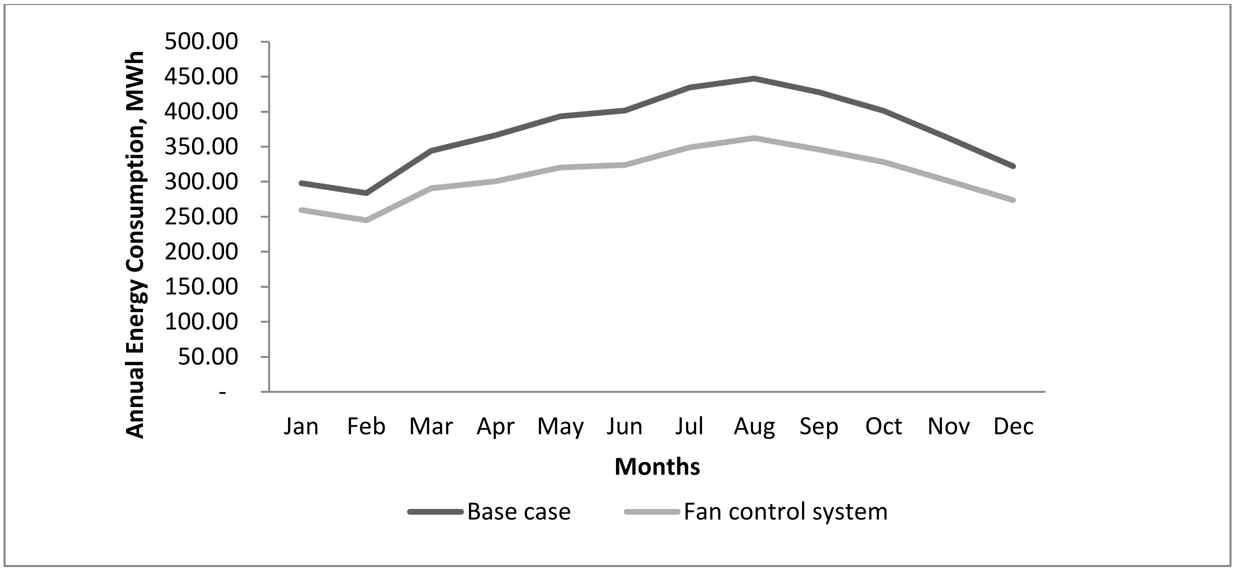


Figure (5.9) the comparison of the energy consumption between the base case model and the intermittent fan control system over the year.

5.1.4.5 Integrated Control System Model

The integrated control system model combines all the above energy conservation measures that explained previously; 1) resetting the room temperature thermostat during unoccupied times to 29^{0}C that showed the highest energy savings among other modeled setpoints, 2)installing daylight control system, 3) using automated blind control system, and; 4)adopting intermittent fan control method . In order to operate in integrative strategy and to avoid any clashes in the operation, and also to meet the maximum benefits, the integrated control methodology for the hotel buildings' guestrooms works effectively and achieve the highest energy savings percentage. As a result of running the integrated control system in one energy model mentioned in section 5.1.1, the major energy systems that have been affected were the air conditioning system, fans and ventilation system, chilled water pumps and lighting system all together. Not only, the energy model shows that in energy system wise, the cooling energy systems have been saved by using this integrated control strategy by 43.2% compared to the baseline, whereas the lighting system electrical consumption has been reduced by 13.2% and the total energy performance was improved significantly to reach 31.5% of the entire hotel building's energy consumption as shown in table (5.6). Additionally as illustrated in figure (5.10) the integrated control strategy showed a high impact at summer on the energy consumption compared to winter, means the energy savings are higher because the solar gain impact at summer months increases and by minimizing this effect by using the automatic blind the energy reduction will be obviously appeared by because of lowering the sun effect. Also, the difference between the outside temperature and the set point temperature would be higher at summer and consequently, resetting thermostat during unoccupied would play a substantial role during the hottest months and for the fan control, the energy improvement in summer is greater.

Table (5.6) Integrated control methodology energy saving compared to the base case model of the average hotel building

Percentage of energy savings on the cooling system	**43.2%**
Percentage of energy savings on the lighting system	13.2%
Entire building energy savings	31.5%

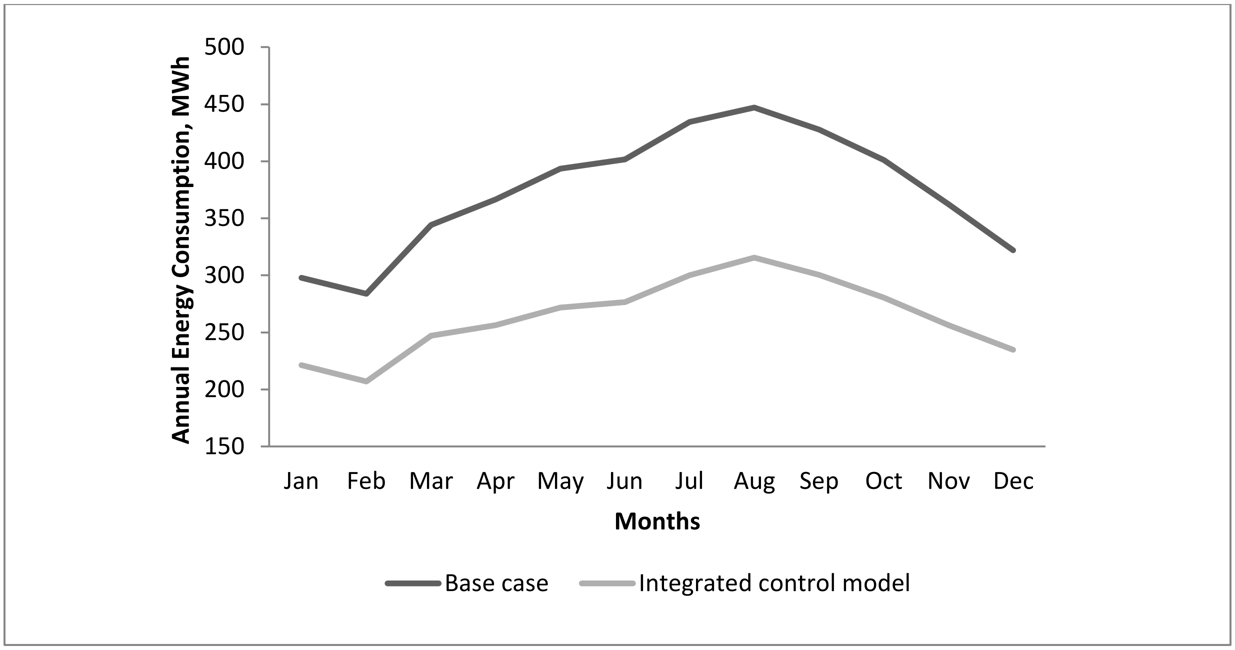


Figure (5.10) the comparison of the energy consumption between the base case model and the integrated control model over the year

Moreover, the model shows the energy consumption and savings achieved per energy system as illustrated in figure (5.11). It is very obvious that the cooling system is the major consumer in the hotel buildings energy consumption here in UAE that consumes between 65% and 75% of the total energy consumption as presented in figure (5.12) for the air conditioning related systems including; space cool, fans, fresh air packages and chilled water pumps.

However, there is a big difference of the energy performance between all the run models in this study. Figure (5.13) and (5.14) illustrate the improvement of optimization of the energy performance in the hotel buildings by simulating different energy conservation measures separately and to combine all these savings measures in one integrated model that serves the guestroom to operate efficiently compared to the base case scenario that uses Dubai municipality green building code.

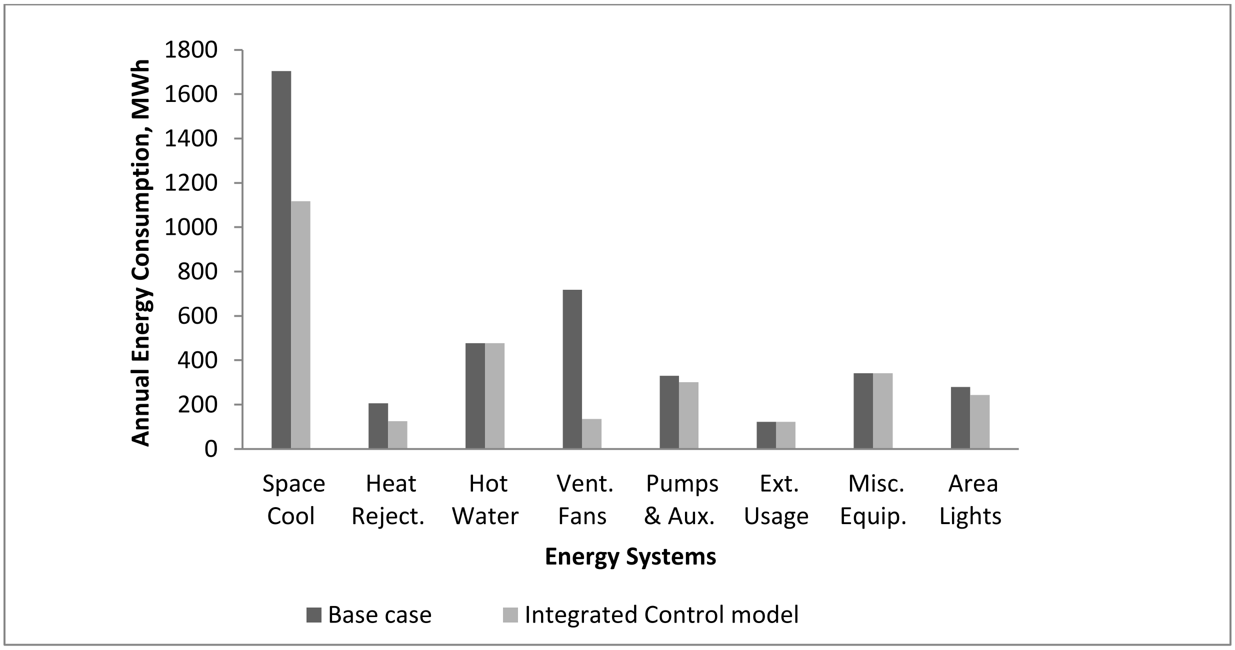


Figure (5.11) the energy systems annual consumption for both models

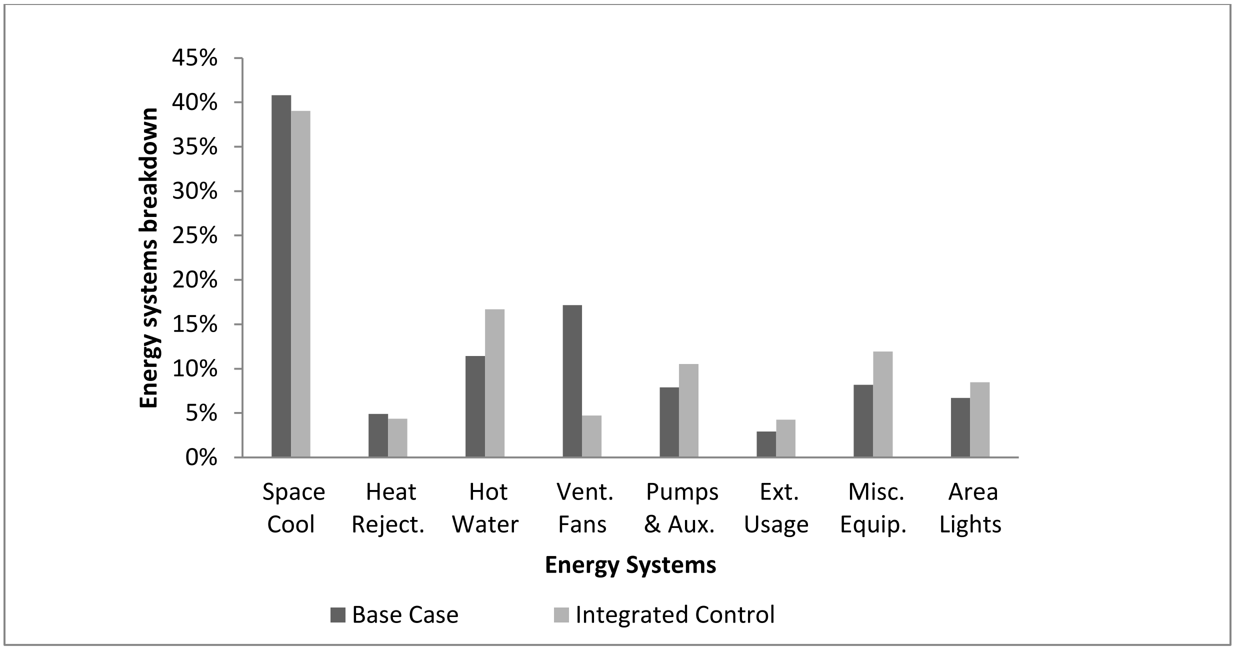


Figure (5.12) the energy systems breakdown for both models

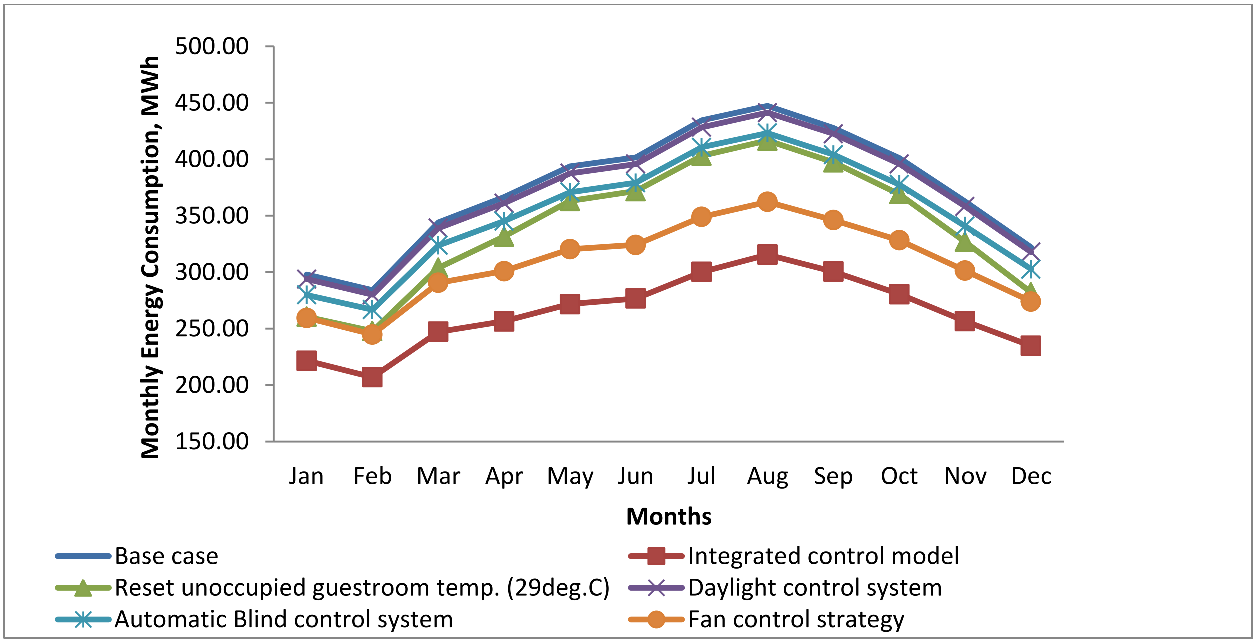


Figure (5.13) the comparison of the energy consumption between the base case model and the different energy conservation measure models over the year

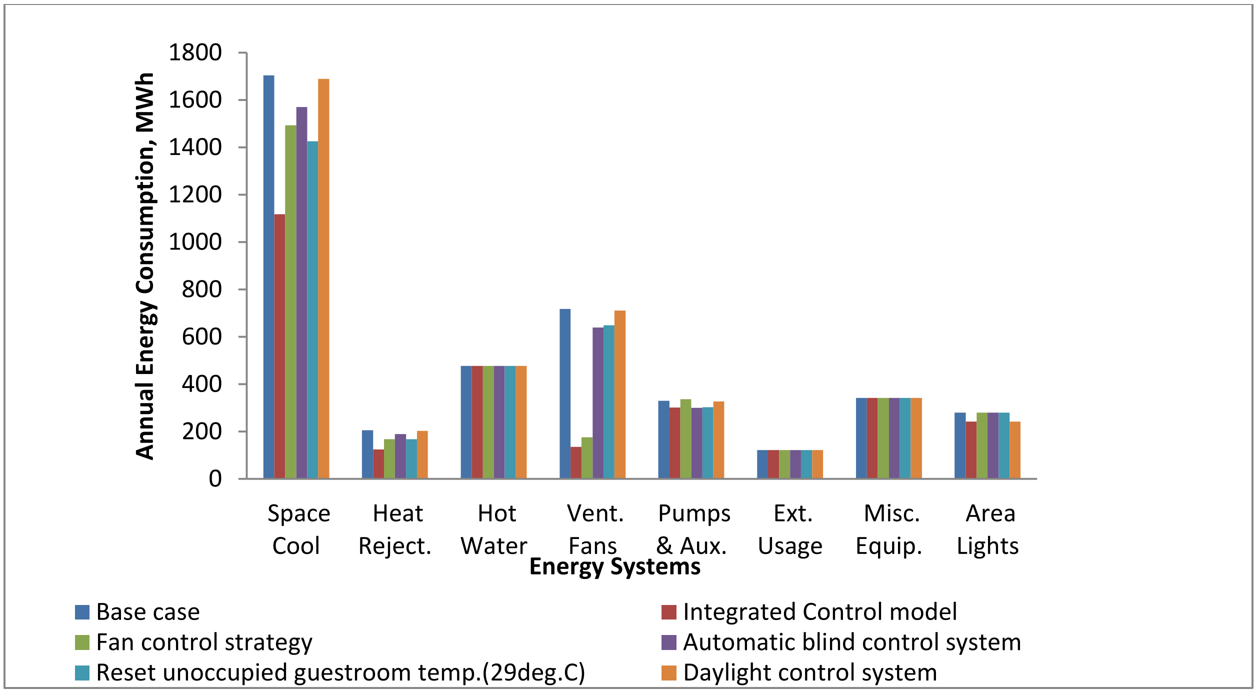


Figure (5.14) the energy systems annual consumption for all energy conservation measures and base models

5.1.5 Impact of Integrated Control System on ESTIDAMA Standard versus Dubai Municipality Green Building Code

In this dissertation, the integrated control system has been modeled with Dubai municipality green building code requirements such us the thermal conductivities of the building envelope and lighting power density, etc., however since the hotels in Abu Dhabi are subject to follow optionally ESTIDAMA rating system, two energy models have been run to reflect ESTIDAMA 1 pearl & 2pearls as per pearl villa rating system that the u-values were used in the models were just for comparison purposes to use an indicative low u-values as shown in table (5.7). Knowing that in ESTIDAMA rating system for new buildings (not villas), there are no specific thermal (u-values) requirements for the hotel buildings since the energy performance method is used to show the percentage of improvement over the baseline, which is ASHRAE 90.1-2007 by running hourly energy models.

Table (5.7) Thermal requirements of Dubai Municipality green building code and Estidama 1pearl and 2 pearls

	1-Pearl	2-Pearls	DM Green Building Code
Wall U-value (W/m² ⁰C)	0.32	0.29	0.57
Roof U-value (W/m² ⁰C)	0.14	0.12	0.3
Glazing U-value (W/m² ⁰C)	2.2	1.9	2.1
Shading Coefficient	0.4	0.3	0.4

The integrated control system model has been run with the DM green building code and with 1-pearl and 2-pearls thermal values to show that no much improvement has been achieved for 1-pearl model compared to the DM green building code although the u-values were lesser, but the shading coefficient of glazing are the same. However, a good energy saving has been shown with 2-pearls thermal values; this was because the lower shading coefficient value that made the difference. Table (5.8) illustrates the comparison between the energy models.

Table (5.8) the energy performance improvement by using the integrated control system with the thermal conductance values of pearls rating system compared to the DM green building code

	1-Pearl	2-Pearls
Energy savings percentage on the cooling system	3.2%	14.9%
Entire building energy savings percentage	1.8%	8.7%

The monthly energy performance has been presented in figure (5.15) to show the energy profile for each model.

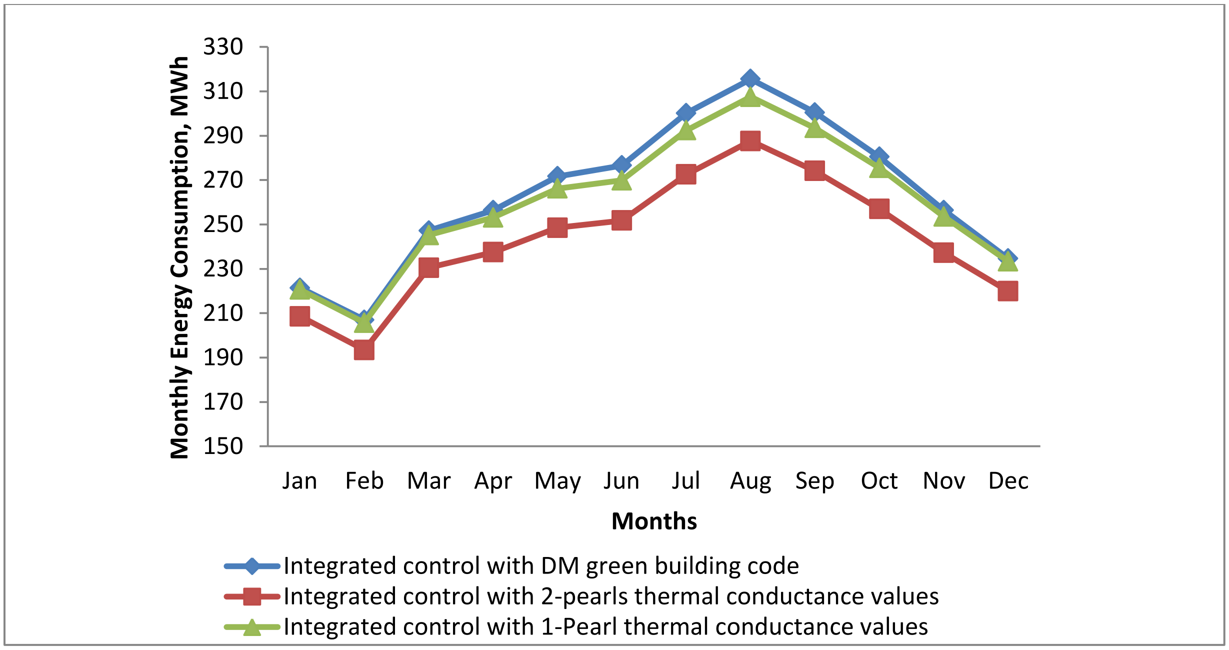


Figure (5.15) the comparison of the energy consumption between the DM green building code model and ESTIDAMA (1-pear and 2-pearls) models over the year

5.2 Discussion

In UAE, the hotel buildings energy consumption is higher than the international figures per unit area. Therefore, significant energy savings should be adopted and targeted by the hotels management. The integrated control methodology as an effective control system is one of the important opportunities that have a substantial energy saving in the guestrooms. As shown in the energy modeling results compared to the usual hotel energy practice, the energy use index improved from 374.6 kWh/m²/year to 256.7 kWh/m²/year that means the category of the hotel improved from poor or usual practice to good or even best practice by 31.5% as a reduction in the energy consumption. Also results show the importance of considering the effectiveness of control level on the cooling system and thermal zones parameters during unoccupied times by utilizing different energy conservation measures under one integrated control strategy. In other cases, the limited budget leads to prioritize the implementation of these energy conservation measures instead of take it as one integrated system. However, the energy savings, as outlined in the run different energy models outcomes, illustrate that substantial savings have been noticed by adopting the intermittent fan control system and the least savings achieved by implementing the daylight control system on the entire hotel building energy consumption.

Generally, the economic feasibility study should accompany the analysis in each building to assist taking the decision of the implementation of each measure or the overall integrated control system. The percentage of savings depends on many factors; such as the windows sizes (windows to wall ratio) of the building envelop, the control system used for the interior fans, thermostat, how the building automation system is optimized and the level of the building intelligence.

The integrated control methodology is an effective and vital strategy for the hotels building retrofitting that is always should be recommended to be part of the energy efficiency services, energy audits or the energy savings performance contracting. However, the appropriate measurement and verification option should be selected, designed and implemented. In this case, according to the International Performance Measurement and Verification Protocol, option C might be the most suitable option to pursue that needs to measure the actual energy consumption of the entire building and compare to the baseline taking into consideration the adjustment of the static and independent factors that influence on the baseline data and the meters readings (EVO, 2012).

By using the studied integration methodology, it is not only the energy conservation measures is implemented but also the potential of synergy of these measures together without affecting the sequence of operation and to sustain the measures with maximum expected benefits including ensuring the thermal comfort and occupants satisfaction. However, this system could be controlled and monitored by using the building management and automation system to perform centrally and to be maintained as part of the planed preventive maintenance. As addressed by Wang (2008) as an intelligent system, the proposed integrated control strategy system is assessed against four main criterions to evaluate the effectiveness of its performance and the integration of the operation. These four dimensions are; autonomy, controllability for complicated dynamics, man-machine interaction and bio-inspired behavior. The integrated control methodology that modeled as explained is connected directly with the hotel building management system or command and control center, if available, in order to perform efficiently. It is recommended also to use a common platform to process all the existing conditions for instance the occupancy, outdoor temperature and indoor temperature and humidity and provide the control signals accordingly. This could be done by three layers of operation:

1. An integration layer that overlays subsystems such as daylight control, blind control and thermostats.
2. A Business Process Layer for orchestrating subsystems and creating processes for service delivery and;
3. An interface portal layer for user access to information via a variety of means.

This system should be autonomous enough to control the values, set points and other variables threshold and it should have an outstanding ability to diagnose and correct the operation deviations. Another area that should be available strongly for the integrated system to evaluate the level of its intelligence in the function is the controllability for complicated dynamics. The system expected to have an advanced communication ways that can formulate a profound and sustainable platform to link multiple standalone building control systems from variety of manufacturers with different communication protocol and different locations as the installed

BMS is connected to the internet to control the integrated system components remotely. Also, to maintain the occupants' satisfaction and expectation of thermal performance, this system would have the provision to be integrated with the central check in system and the elevator access ID of the hotels to reduce the room temperature set points and change the mode of operation from un-occupied to occupied settings. The installed modeled system should also have an outstanding ability of man-machine interaction that could work through wire or wireless terminals. Besides, the bio-inspired behavior of the installed system should have a high level of adopting the adaptive control algorithm based on seasonal changes and occupancy changes. According to all these evaluation method that proposed by Wang (2008) the integrated control strategy system that proposed and modeled in this dissertation should be designed to comply with these important dimensions to make sure that the system will be intelligent enough for the hospitality usage to optimize the energy performance and increase the comfort level; thermal and visual.

Generally, this studied integrated system has showed a significant energy savings that depends on the buildings characteristics such as windows area, building envelop and thermal conductivities, air conditioning system types and efficiency, the control system installed and its complicity, the applied code and regulations and the building age. Also, this system could be adopted at the design stage to provide an intelligent and a high performance hotel to be implemented as an energy saving solution.

Chapter 6

Conclusion

6.1 Hospitality Energy Benchmarking

The statistical methods has been used in this dissertation to find out the energy benchmarking outcomes for the hospitality sector in UAE and to group the existing hotel buildings energy performance by using the normalized energy used index per unit area kWh/m²/year. It is also found that the correlation analysis is correlated with the energy use index per unit area correlated with the cooling degree-day method to represent the building energy consumption as an indicator. Eventually, according to the survey results and the information received with the analysis, the normalized energy use index of the hotel buildings sample in UAE has classified into four groups that reflect the energy consumption practice for the hotels as shown in table (4.9) that outlines the difference of energy performance between the hotels constructed before 2003 and after 2003. The normalized EUI ranges between lower than 241.5 kWh/m²/year as a best practice and greater than 361.3kWh/m²/year for the hotels constructed after the year of 2003, when more stringent code adopted by Dubai Municipality.

On the other hand, the normalized EUI varies from lower than 348.4 kWh/m²/year as a best practice to greater than 511.1kWh/m²/year for the hotels constructed before the year of 2003. It is worth to mention that this study covered the luxury hotels; city and resorts types in UAE.

According to the energy benchmarking of the hospitality sector in UAE as illustrated in table(4.9) it is strongly recommended to incentivize the hotels' administration who achieve lower than the best practice energy use index, which is 241.5kWh/m²/year for the buildings constructed after 2003 and lower than 348.4kWh/m²/year for the buildings constructed before 2003. This incentive scheme would be very important to encourage the sustainability and energy efficiency movement for the hospitality sectors, which would contribute achieving the UAE future green visions. On the contrary, the hotels' building exceeding the upper limits, their energy performance should be warned and kept under watching and monitoring in a certain period to start implementing energy conservation measures and reduce the energy consumption.

It was found that the average normalized energy use index per equivalent guestroom per year is 57,177kWh per year which equal to 157kWh/night spent.

6.2 Integrated Control Methodology

Integrated control methodology is an effective energy conservation measure that doesn't reduce the energy consumption alone, but provides the hotel building a level of intelligence in operation to work on demand according to the occupant availability and achieving the thermal and visual comfort level. This study provides a practical solution for the hotels' guestrooms and to optimize the energy performance of the hotels to improve the energy practice to better level with high indoor air quality.

A comparison has been discussed between various energy models, which are the base case model that uses the new Dubai municipality green building code issued in early 2014 and the energy models of stand-alone energy conservation measures and the integrated control model that combines four proposed energy conservation measures in the hotel guestroom, which are resetting the guestroom temperatures during unoccupied area 2 degrees Celsius above the base case until 29^0C, which use 23^0C as per ASHRAE 55 as a base, installing daylight dimming control system, installation of automatic blind control system and using intermittent technique to control the fan operation. The comparison has been conducted to present the total energy savings over the annual energy consumption of the entire building, therefore, the optimization of energy performance in the guestrooms has been measured against the entire hotel's energy use. By running each energy model to examine the energy conservation measure individually noticed that ;1) the energy savings on the cooling systems including chillers, fans, chilled water pumps and ventilation by raising the guestroom temperature during unoccupied times from 23^0C to 29^0C is 13.9%, which equals 9.8% out of the entire building energy consumption. On the other hand, the other 2 models, showed lower energy savings, 1.7% and 4.4% on the cooling system and 1.2% and 3.1% on the entire building energy consumption by raising the setpoint temperature from

23^{0}C to 25^{0}C and 27^{0}C respectively, 2) for the daylighting dimming control system, the results showed a very low energy saving over the entire building energy consumption, which is about 0.87% and 13.2% savings for the lighting system alone because of the low energy consumption weight of the lighting system out of the total energy use, 3) For the automatic blind control system, the energy model highlighted a considerable energy saving for the air conditioning system; that includes chillers, fans, pumps and ventilation, which equals 8.8% over the baseline, whereas the energy savings for the entire hotel building energy consumption is about 6.2%, and finally 4) the intermittent fan control energy model results outlined a substantial energy saving for the air conditioning system; that includes chillers, fans, pumps and ventilation, which equals 26.4% over the baseline including a significant energy savings shown in the fan energy consumption by 75.4%, whereas the energy savings for the entire hotel building energy consumption is about 18.7%.However, the energy model of the integrated control strategy that combines all the four energy conservation measures together shows that at least 31.5% might be improved out of entire energy consumption of the hotel including electricity and gas. 43.2% of energy savings for the cooling system and 13.2% for lighting system of the guestroom by installing the integrated control system as outlined in the energy models, section 5.

Finally, the integrated control system of the hotels guestroom proved through the energy modeling and simulation for the entire building in hourly basis that this system is suitable for such applications that operate 24/7 regardless the occupants presence, especially when the correlation analysis shows that there is low or no relation between the energy consumption and the occupancy rate in the hotels.

6.3 Works To Do in the Future

This dissertation discussed the energy benchmarking for the hospitality sector in UAE and how to improve the energy performance by using the integrated control system, however, still there are some areas should be analyzed in the future, such as;

1) The guestrooms energy consumption weight,
2) Include non-luxurious hotels (2 and 3 star hotel classification) and furnished hotels apartment in the survey,
3) Empirical analysis is required to measure the actual energy savings on the real example in a guestroom after the implementation of the integrated control strategy. and,
4) Economic feasibility of the energy conservation measures that applicable to the hotels including the integrated control system.

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Appendix A

Hotel Buildings Sample Questionnaire

Building Static Information and Energy Data

_______ Gross floor area (sm)

_______ # of rooms

_______ # of workers on main shift

_______ # of shifts

_______ # of commercial refrigeration/freezer units

_______ On-site cooking – yes or no

_______ Percent of floor area that is cooled

_______ Percent of floor area that is heated

_______ Total annual electricity consumption, kWh (**Attach the monthly electricity consumption- energy bills for entire year)**

_______Total annual electricity cost, AED

_______ Total annual Chilled Water consumption, Ton.hr (Please attach the monthly CHW consumption, if any)

_______Total annual CHW cost, AED

_______ Total annual Gas consumption for heating, kbtu (Please attach the monthly Gas consumption, if any)

_______Total annual Gas for heating cost, AED

_______ # of swimming pools

__________ Swimming pool size

_______ # Chillers, Types and capacities

_______ # Boilers, Types and capacities

Parking:

_______ Gross floor area that is enclosed (SF)

_______ Gross floor area that is not enclosed with a roof (SF)

_______ Gross floor area that is open (SF)

_______ Daily hours **of access**

Operational Information

_______ Hours per day the guests are on-site

_______ Square footage of gym/fitness center

_______ Laundry processed at site (drop down of options)

_______ Annual quantity of laundry processed on-site

_______ Average Occupancy (%)

AIR-CONDITIONING SYSTEMS

Type of chilled water source used:

Chilled Water- stand-alone ● District Cooling Plant ○