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Evaluating the potential impact of global warming on the UAE residential buildings – A contribution to reduce the CO_2 emissions

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ABSTRACT

There is significant evidence that the world is warming. The International Panel of Climate Change stated that there would be a steady increase in the ambient temperature during the end of the 21st century. This increase will impact the built environment, particularly the requirements of energy used for air-conditioning buildings. This paper discusses issues related to the potential impact of global warming on air-conditioning energy use in the hot climate of the United Arab Emirates. Al-Ain city was chosen for this study. Simulation studies and energy analysis were employed to investigate the energy consumption of buildings and the most effective measures to cope with this impact under different climate scenarios. The paper focuses on residential buildings and concludes that global warming is likely to increase the energy used for cooling buildings by 23.5% if Al-Ain city warms by 5.9 °C. The net CO_2 emissions could increase at around 5.4% over the next few decades. The simulation results show that the energy design measures such as thermal insulation and thermal mass are important to cope with global warming, while window area and glazing system are beneficial and sensitive to climate change, whereas the shading devices are moderate as a building CO_2 emissions saver and insensitive to global warming.

1. Introduction

Climate change and global warming have been a growing concern in recent years. The reasons for climate change are complex and there are disagreements in the scientific community about the causes. Some scientists believe that changes are part of natural variability while others point to human activity as the cause of increasing atmospheric concentrations of green house gases (GHGs) and the key driver of climate change. It was stated that the expenditure of non-renewable energy has a direct impact on the environment, with potentially devastating results. This expenditure is said to be one of the prime factors affecting the environment. It causes three major problems, namely air pollution, acid rain and greenhouse effects. From this point of view, the use of non-renewable energy has increased the carbon concentration in the atmosphere and has also increased the earth's temperature, which is known as "Global Warming". In a recent publication by the Intergovernmental Panel of Climate Change [1], it was indicated that the largest growth in the carbon emissions has come from electricity generation, transport, industry and, above all, from building operation. Therefore, the global warming and increasing emission of GHG, most notably CO_2, have become a major concern in building industry and research community.

1.1. Research into the impact of global warming on building energy performance

Recently, a number of studies around the world have been conducted into the impacts of global warming on the possible changes to energy use patterns in buildings. In Europe and America, a great deal of research has been carried out to evaluate this impact on the different aspects of building performance. For example, the variation of energy consumption in dwelling due to climate, building and inhabitation was studied in Norway [2]. It was indicated that knowing the type of climate and approximate values for the external temperature and solar radiation is important to estimate the impact of global warming, while in Switzerland, a recent study [3] into the climate warming impact on degree-days and building energy demand was conducted and found that the heating degree-days were reduced by 11–18% during 1901–2003, but reached 13–87% between 1975 and 2085. Another study was carried out with respect to the sustainable development and climate change initiatives in France [4]. It was shown that the exploitation of thermal mass of concrete to create energy optimised solutions for heating and cooling residential and office buildings is positively contributing to the climate change initiative. In Denmark,

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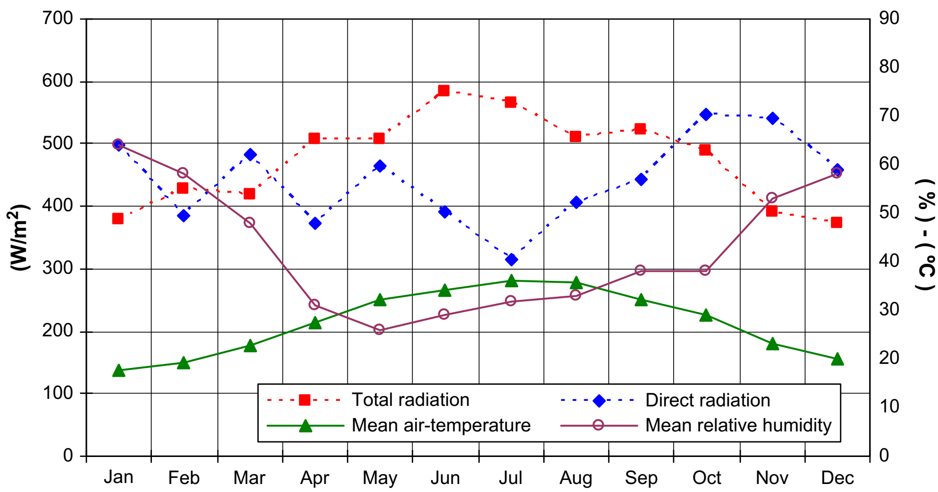

Fig. 1. Analysis of Al-Ain's climate.

a research [5] focused on the architectural and legislative changes in relation to the increased political interest in the consequences of climate change and concluded that technologies for renewable energy sources are only applied in exemplary housing projects. This is mainly because renewable energy sources are not affordable in average housing due to the payback time. However, the environmental benefits have increased the awareness of such technologies in the minds of building designers.

Much study in the UK has concentrated on the consequences of climate change. For instance, a scoping study [6] explored how likely the global warming can contribute to energy and associated CO_2 savings and concluded that global warming can help in reducing the CO_2 emissions due to the energy use for heating residential buildings. A recent study investigated the impact of climate change uncertainties of the performance of energy efficiency measures applied to dwellings. It was found that double glazing was the best option because it delivered the highest saving in heating energy demand for the lowest induced cooling load while loft thermal insulation was the worst option in thermal terms [7]. Another parametric study addressed the dual challenge of designing sustainable low-energy buildings while still providing thermal comfort under warmer summer conditions produced by anthropogenic climate change [8]. The use of efficiency measures such as shading devices to switch the sun and thermal mass to distribute the heat gain in order to reduce the peak was recommended. In addition, some ventilation and night cooling strategies were suggested. A comprehensive study of fuel choice and consumption in the energy sector was undertaken in the USA [9]. In this study, a notional energy model of the fuel choice by both house holder and firms was estimated and found that climate change will likely increase electricity consumption on cooling but reduces the use of other fuels for heating. A recent study [10] argued that both mitigation of greenhouse gases and adaptation to climate change should be added to building energy codes and thermal comfort standards. Another study [11] constructed a model to simulate emissions of CO_2 from electricity generation in the USA and found that applying energy standards such as those of California to the entire USA would result in a reduction of 34%. It was concluded that efforts now need to focus, not only on reducing GHG emissions, but also equally on preparing for the inevitable climate change.

In the Far East, a considerable amount of researches has been carried out to evaluate the impact of global warming and CO_2 emissions. In Malaysia, for example, a study [12] was conducted to predict the potential CO_2 reduction due to changing the fuel type and found that the substitution will reduce CO_2 emission from power plants when the fuel is changed from 70% gas, 15% coal, 10% hydro and 5% petroleum in the year 2000 to 40% gas, 30% hydro, 29% coal and only 1% petroleum in the year of 2020. In China, the potentials of energy saving and greenhouse gases emission mitigation offered by the implementation of building energy efficiency policies were investigated and found that more ambitious efficiency improvement policies in both supply- and demand-side as well as

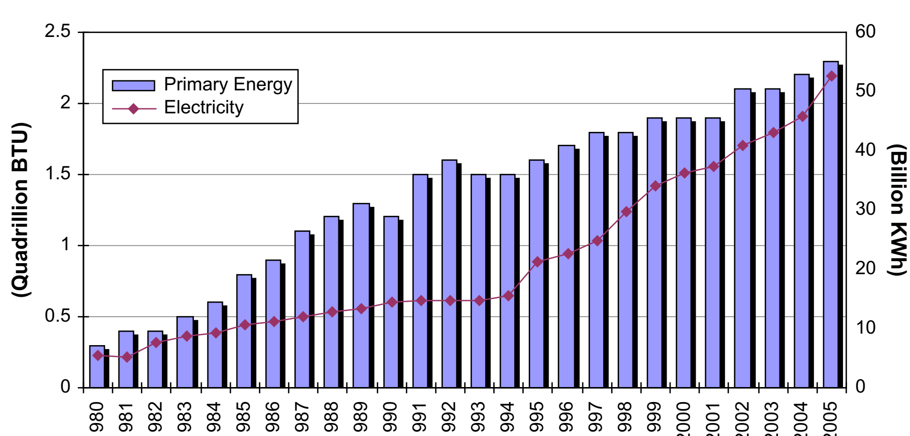

Fig. 2. UAE electricity consumption from 1980 to 2005.

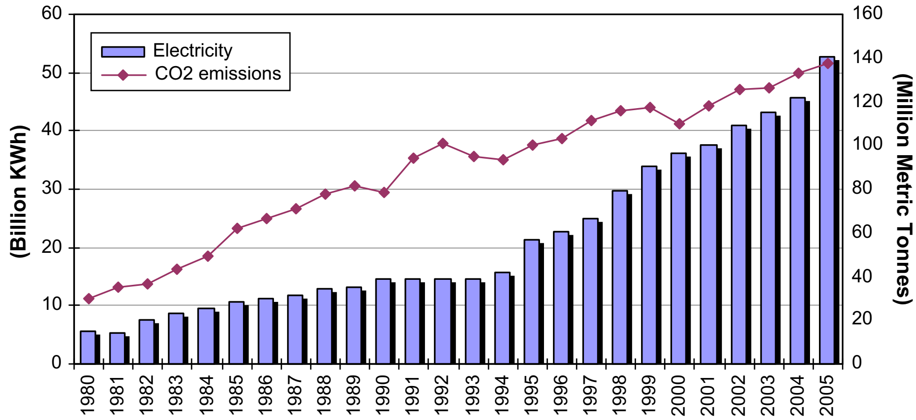

Fig. 3. Increase in CO_2 emissions relative to the use of energy.

the carbon price should be taken into account in the policy scenarios to address drastic reduction of CO_2 emission in the building sector to ensure climate security over the next few decades [13].

In the Middle-East, few studies have been conducted into the impact of climate change on the energy performance of buildings. One of them is a parametric study [14] to explore the energy requirements for the heating and cooling of residential buildings in Jordan. It was shown that additional insulation and better ventilation strategies may save up to almost 50% energy in costal locations and more than 90% in the highlands. In the Gulf area, although there are some researches and writing which are relevant to climate change, to date, there is no research on the evaluation of the potential impact of global warming on the building energy performance appears to have done. Much study in Gulf area has focused on building energy performance under certain climatic conditions. For example, a comparison of the accuracy of building energy analysis using data from different weather periods was conducted in Bahrain [15], while a recent study [16] introduced a systematic methodology to optimise the energy performance of buildings under the current climate. Another study introduced a new approach to develop standards in order to optimise the energy performance of office buildings in the Gulf States [17]. A comprehensive review of literature concerns building energy performance and efficiency measures was carried out with the aim of assessing the ability of envelope codes to reduce electricity and CO_2 emissions in different types of buildings [18]. It was shown that the envelope measures can significantly improve the energy performance of residential buildings, but their impact on the performance of commercial buildings is various, depending largely on the amount of heat gain from internal sources.

This current study carries out a systematic investigation into the impact of global warming on the energy consumption of air-conditioned buildings and its associated CO_2 emissions in the hot arid climate of the UAE, where the cooling load is dominant. The residential sector in Al-Ain city was chosen as a case study. This paper also addresses the important principles associated with building energy design to cope with the global warming in this region. It presents the CO_2 emission index as a key principal criterion by which the performance of a building can be judged.

2. UAE situation

2.1. Current and future climate

The United Arab Emirates (UAE) is a federation of seven Emirates that spans approximately 83,600 km^2. The general characteristics of the UAE's climate resemble those of arid and semi-arid zones: summers are very dry with temperatures raising to about 48 °C in coastal cities – with accompanying humidity levels reaching as high as 90%. In the southern regions, temperatures can reach 50 °C. Such a situation can be found in Al-Ain city. Fig. 1 shows an analysis of climatic elements of Al-Ain provided by the Directorate of Meteorology of Abu Dhabi. In general, Al-Ain city is located in the southern part of the UAE. The cold season spans from

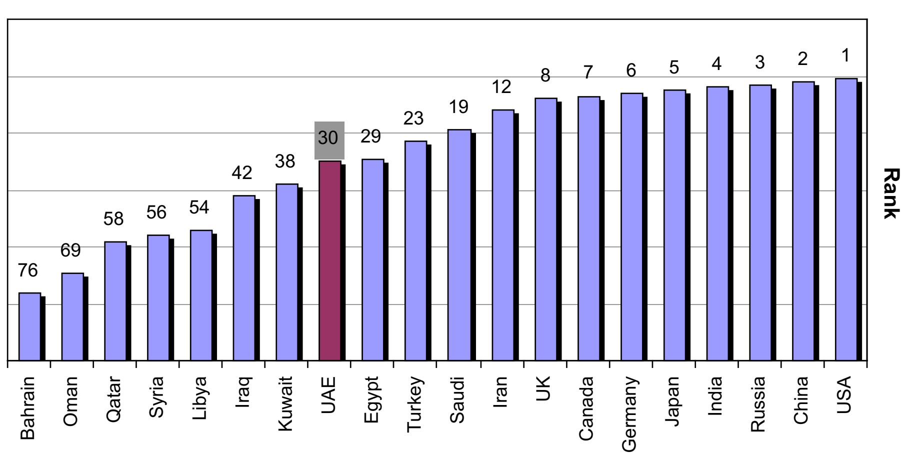

Fig. 4. Rank of UAE in terms of CO_2 emissions.

late December through January and February. From March until early April is considered the transitional period between the mild winter and hot summer. The summer season spans from late April to September, during which the monthly mean temperature is around 32.2–35.5 °C. In October and November sunny skies are dominant, with dry conditions and monthly mean temperatures between 29 °C and 23 °C respectively.

The analysis shows that Al-Ain city has an annual average temperature of 27.2 °C with a monthly average maximum temperature of 46.1 °C (June) and a monthly average minimum temperature of 8.2 °C (February). Relative humidity is least during the month of May, and increases during winter months. The monthly average relative humidity is 42%, with a maximum monthly average of 64% (January) and a minimum monthly average of 26% (May). Winds from a north-west direction throughout the year are the characteristic of Al-Ain city. The wind speed average shows slight variation, being generally low from November to January with a monthly average of 3.5 m/s, while from February to October it is well above 4.2 m/s, reaching a monthly average of 4.6 m/s in May. The analysis indicates high solar radiation levels. The highest monthly averages of total and direct radiation are 613 W/m^2 and 546 W/m^2 in May and October respectively, while the highest monthly average of diffuse radiation is 273 W/m^2 in July. The lowest monthly averages of the same three parameters are in December (total and diffuse radiation) and July (direct radiation) with 408 W/m^2, 163 W/m^2 and 314 W/m^2 respectively.

Arid regions such as Al-Ain and other cities in the UAE are sensitive to global climatic changes and the effects they produce. The Environment Agency of Abu Dhabi and the Ministry of Energy and other concerned parties in the UAE [19] have stated that temperatures in the UAE regions could increase while precipitation levels could significantly decline by the end of the 21st century. This scenario was simulated and the output was generated at the regional level and then scaled to eight cities within the UAE including Abu Dhabi, Dubai, Sharjah, Al-Ain, Ras al-Khaymah, Khawr Fakkan, Umm al-Qaywayn, and Ajman. The annual average temperatures in 2050 are projected to be between about 1.6 °C and 2.9 °C warmer than they were over the period 1961–1990, and between 2.3 °C and 5.9 °C warmer by 2100. The reasons why the climate of the UAE is tending to get warmer are numerous and include the urban heat island effect, changes in atmospheric pollution and increases in GHG emissions. This tendency will impact the built environment and the energy use in buildings and consequently CO_2 emissions.

2.2. Energy consumption and CO_2 emissions

With rapid economic expenditure and high population growth rates and a fairly low-energy cost, the UAE's energy consumption has increased tremendously, making it one of the highest energy consumers per capita in the world [20]. Over the last few decades, the installed capacity, energy demand and annual electricity use have grown substantially. Fig. 2 illustrates the primary energy and electricity scenario from 1980 to 2005. It is expected that as the fraction of the total energy increases, the production of CO_2 emitted becomes greater. The net energy consumption of the UAE in 2006 was 52.6 Billion kW h. Consequently, the total annual CO_2 emission from the consumption of fossil fuels was 137.8 million metric tonnes [21]. Fig. 3 shows the increase in CO_2 emissions relative to the use of energy. It is important to note that the production and consumption of energy are the dominant source of GHG emissions in the UAE. Energy-related CO_2 emissions from fossil fuel production and combustion are about 95% of the CO_2 emission total [20]. As shown in Fig. 4, in 2003, the UAE was ranked as the world's 30th largest CO_2 emitter [22]. According to the 1999 statistics, about 4%

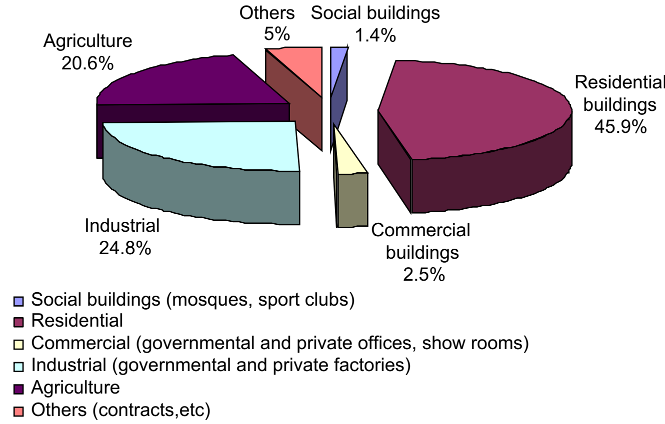

Fig. 5. Energy consumption per sector in 2005.

of the CO_2 production in the UAE is caused by the direct emissions of buildings, 43% by electricity generation and 45% by manufacturing and construction [23], which at least partly influenced by building construction and operation.

In Al-Ain, as in most cities in the UAE, electricity is the major form of energy. If one excludes electricity generation, the final energy consumption is split into four major sectors including buildings, industry, agriculture and contracts. As shown in Fig. 5 the buildings, particularly those in the residential sector, have the largest impact on this growth, as 45.9% of the total electricity is used in this sector. Several factors have contributed to the growth of electricity use in residential buildings, namely the increase in population, the improvement of comfort levels and the increasing number of electricity-using devices in buildings. Most of the electricity is used for air-conditioning during the summer months [24]. The growth in electricity consumption for cooling buildings in the UAE in general and in Al-Ain in particular has increased ten times (from 5 to 50 Billion kW h) over the past two decades [25].

To tackle with the above economic and environmental issues, two fundamental changes in patterns of energy consumption are required: first, effective measures to protect the depleted resources and second, valid policies to replace fossil fuels with non-fossil fuels through the use of free and clean energies such as wind and solar energy. As the first step in this task, several Emirates began planning regulation energy efficiency codes for buildings. New building energy codes were regulated in Dubai. The prescriptive thermal insulation was the first energy code. It was regulated with the aim of achieving a 40% reduction in energy use [26]. In the current building regulations of Al-Ain city, however, there is an absence of a formal energy code. Following the steps of Dubai, building energy regulations for Abu Dhabi, Al-Ain city and the western region are currently under development. It should be emphasised that using the envelope prescriptive codes as the only mean to assess the energy performance of building may be easy to implement and comply with; however, it is not adequately comprehensive.

Table 1
Statistics of the Taweelah A1 power and desalination plant.

Subject	Statistic
Net electricity sales (MW h)	4,249,835
Annual CO_2 emissions (tonnes CO_2)	3,229,518
Gas consumption (GJ)	57,742,615
Gas oil consumption (GJ)	1,296,062
Total fuel consumption (MBTU)	59,038,677
Gross electricity production (MW h)	4,682,480
Auxiliary EL cons. (MW h)	433,645

Fig. 6. Buildings under study.

A principle disadvantage of these codes is that their effects on overall energy consumption of buildings with different types and functions are various. An evaluation of such codes in the hot climate of the Gulf States shows that envelope codes, at best, are likely to reduce the energy use of skin load dominated buildings such as residential buildings by 25% if the building envelope is well-insulated and efficient glazing is used, while this percentage is reduced to 5% with respect to load dominated buildings such as commercial buildings [18]. Although envelope codes such as thermal insulation and window parameters represent a good energy design measures to reduce the heat gain through building envelope, their use as the only criterion to improve the energy performance in different types of buildings is insufficient because they cannot guarantee the optimum energy design for complex building systems nor they are able to ensure the efficient use of energy by building occupants. The performance based-codes such as the energy performance index (EPI) or the CO_2 emissions index (CEI) may offer better criteria. They can be implemented jointly with codes on specific envelope elements or system components (e.g., insulation, window area, thermal mass, shading devices, Ac system) in order to ensure the dissemination of the most efficient building.

With respect to the second pattern, Abu Dhabi Emirate including Abu Dhabi, Al-Ain and the western region, has planed an economic development programme dedicated to establishing an entirely new economic sector focused on alternative energy and sustainable technologies. Two promising projects are planed to be completed in the next few years, first, a $350 millions solar power plant and second, a $2 Billions hydrogen-fuelled power plant [27]. Such projects, in general, can contribute to the sustainable development including economic, environmental and technological well being. They will not only contribute towards employment generation, but also reduce significant amount of GHG emissions which

Table 2
Buildings description for the simulation program.

Parameters	Bldg-1	Bldg-2
No. of floor	2	2
Total area	415 m^2	370 m^2
Floor height	3.7 m	3.7 m
Orientation	East to West	North to South
External walls	150 mm concrete block – 24 mm of plaster inside and outside	150 mm concrete block – 24 mm of plaster inside and outside
Internal wall	100 mm concrete block – 24 mm of plaster inside and outside	100 mm concrete block – 24 mm of plaster inside and outside
Roof	50 mm screed, 35 mm polyurethane and 150 mm concrete slab – 0.6 $W/m^2\,{}^\circ C$	50 mm screed, 35 mm polyurethane and 150 mm concrete slab – 0.60 $W/m^2\,{}^\circ C$
WWR	0.12	0.11
Glazing	6 mm single reflective glass	6 mm single reflective glass
Infiltration rate	5.0 $m^3/h/m^2$	5.0 $m^3/h/m^2$
Ventilation rate	7.5 L/s/person	7.5 L/s/person
Thermal zones	Multi-zones	Multi-zones
Equipment	5 W/m^2	5 W/m^2
Lighting	12 W/m^2	12 W/m^2
HVAC	Central	Central
Life span	12–15 years	12–15 years
Set point temperature	(22–24 °C) Summer (20–22 °C) Winter	(22–24 °C) Summer (20–22 °C) Winter
Occupancy	4.5 m^2/person	4.5 m^2/person

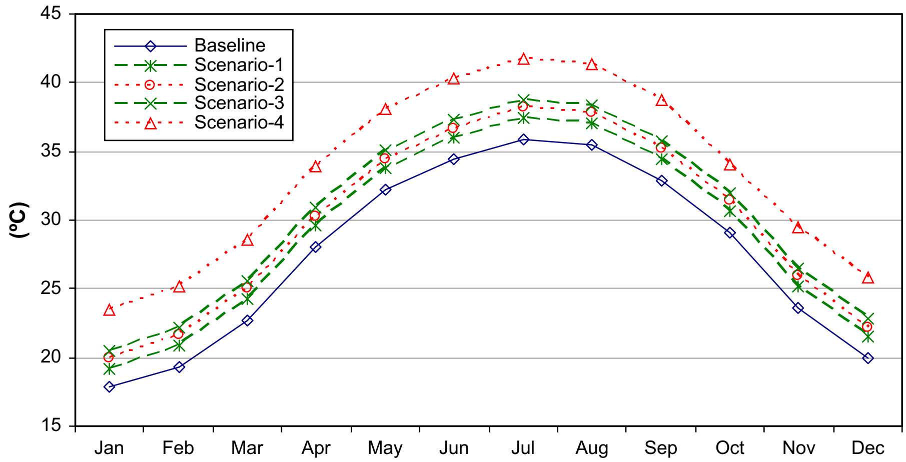

Fig. 7. Scenarios of global warming.

would have taken place in ordinary power plant scenario with natural gas and fuel oil based generation. In the latter project, the carbon dioxide will be kept under ground which represent one of the world first carbon capture and storage projects. Furthermore, solar energy based power generation system will be a robust and clean technology involving the latest state of art renewable energy options to be used for the purpose of electricity generation.

The above power plants are important to solve problems such as increasing CO_2 emissions and global warming. At the present, however, Abu Dhabi, Al-Ain and the western region get their electricity from power plants that are connected to grid and using natural gas and fuel oil for power generation such as Shuweihat, Sas Al Nakhl and the Taweelah A1 power and desalination plant. The Taweelah power and desalination plant has a combined cycle gas turbine. The gas turbines are dual fuel unites, with natural gas as the primary fuel and distillate fuel oil as back-up fuel. This facility produces 385 million litres per day of clean water and 1430 MW. It was said that the emissions of carbon dioxide per kilowatt-hours have been reduced by 50% from previous levels, and therefore, the CO_2 emissions will be reduced by almost the same percentage. Table 1 shows the electricity generation, fuel consumption and CO_2 emissions statistics of the Taweelah A1 power and desalination plant.

The United Nations Framework Convention on Climate Change (UNFCCC) [28] has recently estimated the carbon emissions factor of different power plants by multiplying the net electricity exported to grid and the combined margin grid emission factor. The estimation was based on three years data of the power plants around the UAE. 0.708, 0.938 and 0.881 are the calculated build margin CO_2 emission factor in a year, operating margin CO_2 emission factor in a year and combined margin CO_2 emission factor in a year, respectively.

Overall, although the first pattern is more sustainable, the second pattern can help in achieving a healthy environment. Both patterns are needed. This paper focuses on the former pattern as reducing the energy demand seems to be the first logical and practical step to achieve the energy efficiency target.

3. Methods

To examine the impact of global warming on the electricity consumption of air-conditioned buildings, this study first estimates the variation in heating and cooling degree-days, as they are the most straightforward indicators on building energy demands. This study then predicts the variation on heating and cooling energy demands of typical residential buildings to help illustrate the consequences at the national level. To estimate the CO_2 emissions, the electricity consumption was multiplied by the conversion of factor of the Taweelah A1 power and desalination plant provided by the Carbon Emissions Unit in Abu Dhabi Future Energy Company (MASDER).

Two typical buildings were used to represent the mainstream residential buildings in Al-Ain city as shown in Fig. 6. Detailed architectural, functional and operational data of the buildings were obtained from working drawings, utility bills and reports provided by Al-Ain Municipality and Al-Ain Distribution Company.

Table 3
Monthly and annual electricity bills.

Month	Days	Bldg-1 (kW h)	Base case (kW h)	Difference (%)	Bldg-2 (kW h)	Base case (kW h)	Difference (%)
January	31	8997	8646	3.9	7188	7188	5.2
February	28	8200	7716	5.9	6578	6578	3.4
March	31	7972	7725	3.1	6374	6374	4.9
April	30	9750	9175	5.9	7765	7765	3.7
May	31	11,664	11,244	3.6	9219	9219	3.9
Jun	30	12,305	11,788	4.2	9709	9709	2.6
July	31	13,950	13,615	2.4	11,096	11,096	4.1
August	31	13,380	12,791	4.4	10,737	10,737	5
September	30	11,073	10,486	5.3	8988	8988	1.5
October	31	10,552	10,415	1.3	8409	8409	4.2
November	30	7309	7017	4	5948	5948	3
December	31	9341	9089	2.7	7536	7536	3.7
Average				4.0			3.7
Annual (kW h/yr)	365	126,836	122,523.58		99,547	99,547	

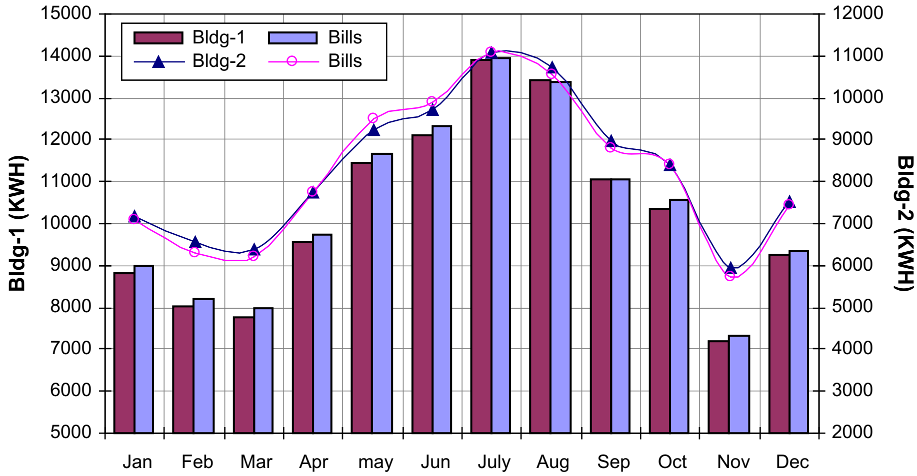

Fig. 8. Calibration of case buildings.

To ensure a good representation, the two buildings were chosen after applying certain criteria and data filters, including building category and system types. The building category filter was applied to select buildings with the same basic size and operations. The building systems filter was applied to define the group for evaluation. This allows representatives of the major typical class of residential buildings to be obtained and the physical and operational characteristics of such residences to be analysed. Complete details of the buildings' physical characteristics are presented in Table 2.

Based on real climatic elements, a statistically-based weather data file was generated using the MeteoNorm software [29] to reflect the current climate of Al-Ain city. In order to predict the impact of higher air-temperatures on the electricity performance, the air-temperatures were raised by 1.6 °C and 2.9 °C to reflect the climate in 2050, and by 2.3 °C and 5.9 °C to reflect the climate in 2100. The other climatic parameters were kept unchanged at this stage to confine the analysis to one variable. These increases were refereed to as scenario-1 (+1.6 °C), scenario-2 (+2.3 °C), scenario-3 (+2.9 °C) and scenario-4 (+5.9 °C), while the current climate was indicated as the baseline climate as shown in Fig. 7. Each scenario represented a weather input of a sophisticated simulation program. The Visual DOE program was used in this investigation [30]. This program has been developed to provide energy performance assessment that is as close as possible to the real performance of the building throughout its life cycle. The program is based on the transfer function, which calculates response factors for transient heat flow in walls and weighting factors for the thermal response of building spaces. Visual DOE performs hourly simulations of a building's energy consumption and energy cost, given a detailed description of the building's climate, architecture, materials, operating schedules and HVAC equipment. The accuracy of Visual DOE has been demonstrated using the BESTEST procedure, developed within the International Energy Agency Solar Heating and Cooling Programme [31], which has been adopted by the US Department of Energy and the international community as the accepted basis for verifying the credibility of computer simulation programs. Building design and materials and monthly utility bills of the case buildings were used to validate the Visual DOE program, as illustrated in Table 3.

As illustrated, there were as much as 3.7% and 4.0% differences between the actual annual consumption of the studied buildings and the base cases. Trials were made to manipulate the estimated input performance parameters, such as schedule of use rate, to closely match the electricity consumption of the base cases with electricity bills. For the final trials, as shown in Fig. 8, schedules were adjusted. Based on the above illustration, it is clear that Visual DOE predicted the monthly electricity consumption fairly well during different times of the year.

4. Climatic and interior factors affecting UAE building electricity consumption

Factors that affect the energy consumption of buildings can be divided into three categories: climatic effects, design effects and people effects. The climatic effects relate to the micro-climate and location of the building. The design effects focus on the building design and systems operation, while the people effects are concerned with the occupant's needs and behaviour. Because each building is unique the impact of these effects varies from context to another. This paper first studies the interior factors, namely building design and occupant behaviour and then focuses on the impact of the external factors, particularly the climate.

4.1. Impact of interior factors on building performance

The energy consumption in buildings is influenced by the interaction between three factors including envelope design, system design and occupant behaviour. The first two factors are related to the decisions made in the early stages of building design.

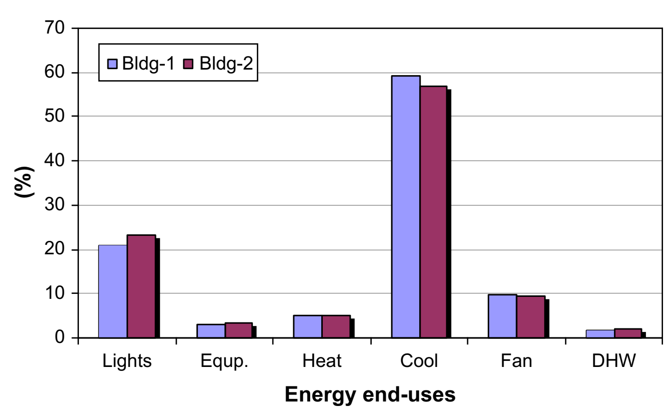

Fig. 9. Energy end-uses in the two typical buildings.

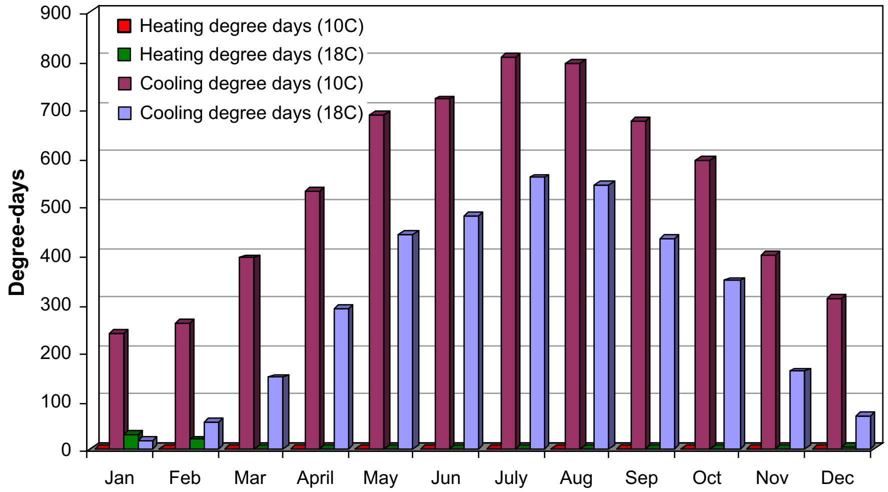

Fig. 10. Monthly heating and cooling degree-days of Al-Ain city.

It was indicated that the above three factors may be not entirely independent and there can be interaction between them [32]. Among these factors, the occupant's behaviour typically accounts for a two folds variation, in total variation of ten folds. Therefore, sequential processes should be followed to reach the energy efficiency target. These processes start with an optimum design of building envelope and end with an efficient operation of building system by the occupants. The optimum design of building envelope positively impacts the building systems, particularly the HVAC and lighting systems. The optimum design may reduce the building loads and equipment size and consequently the cost and energy use. However, to obtain the maximum benefits of this design the occupants should operate the building systems in an efficient way because they can directly alter the system performance through controllers. For example, the energy consumption for heating and cooling depends on internal temperature and ventilation and these parameters are controlled by the occupants.

In any region, the amount of electricity used in buildings depends largely on the above three factors in addition to the outside conditions. In Al-Ain city, the summer season is hot, long and extends over more than one half of the year. A key function of building design is to modify the indoor environment or at least to reduce the need to modify the indoor environment to be more suitable for habitation than the outdoor. If the envelope fails to meet this objective due to one or more reasons, such as insufficient design or extreme outdoor conditions that probably make it impossible for any certain level of comfortable indoor environment to be achieved through passive means. Then, it is necessary to rely upon mechanical means to achieve the comfort level. As a result, additional energy will be used by the HVAC system.

In general, most people feel comfortable at indoors temperature ranging from 22 °C to 27 °C along with a range of 40–60% relative humidity. The concern here is the set point temperature. For a residential building it would normally be designed with comfort temperature selected from range 20 °C to 24 °C. With a heating system one figure would be chosen, but with air-conditioning system two figures would be selected, the higher one for summer (cooling) conditions. These figures are taken to apply generally for cold climates such as North America and Europe, and for warm countries higher figures would often be used, and in the hot climates of Al-Ain city, where the average maximum air-temperature reaches above 46 °C, an internal temperature of 26 °C and 27 °C would be considered comfortable. It was shown that a significant amount of electricity and between 26.8% and 33.6% savings in energy cost can be achieved by raising the set point temperature from 24 °C to 26 °C in similar climate [33]. However, this is not the case in Al-Ain and most cities in the UAE, as the point temperatures are often set below 24 °C.

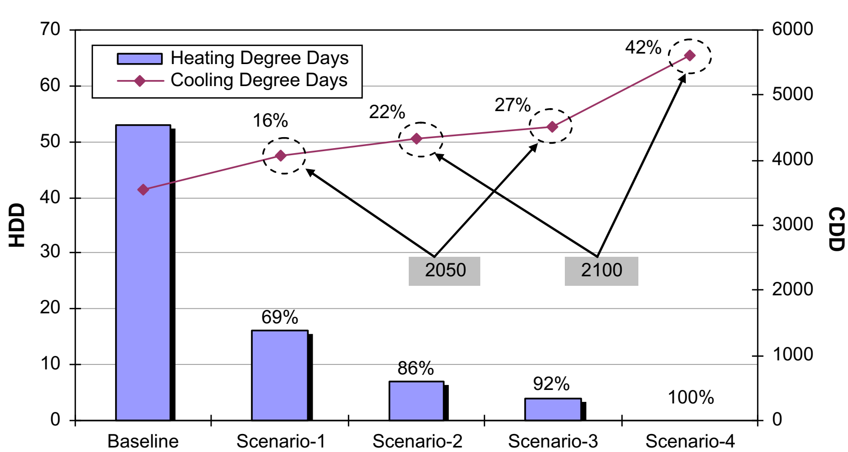

Fig. 11. Impact of global warming on heating and cooling degree-days.

Table 4
Increase in electricity and CO_2 emissions due to global warming.

	Heating (kW h)	Cooling (kW h)	Fans (kW h)	Electricity (kW h)	CO_2 emissions (Kg/m^2/yr)
Bldg-1					
Baseline (consumption)	6369	73,049	11,886	122,920	176
Scenario-1 (%)	−9.5	7.3	3.9	4.1	183
Scenario-2 (%)	−14.2	11.7	5.8	6.7	188
Scenario-3 (%)	−17.4	16.7	6.8	9.5	193
Scenario-4 (%)	−37.1	23.5	12.3	12.9	197
Bldg-2					
Baseline (consumption)	5074	56,719	9380	99,546	197
Scenario-1 (%)	−10	8.2	3.8	4.4	201
Scenario-2 (%)	−15.4	11.8	5.5	6.3	205
Scenario-3 (%)	−18.9	16.7	6.6	9	210
Scenario-4 (%)	−39.2	24.1	11.6	12.5	217

(−) Reduction.

This attitude can be related to two main reasons, first, low electricity prices and second, the support of the government where the citizen in Al-Ain city pays 0.05 Dhs (1 Dhs = 0.27 USD) for each kilowatt-hours and in some cases the government pays for the consumption [24]. These two reasons have reduced the people immediate interest in electricity conservation. They also encourage owners to install low efficient equipment and especially those of the HVAC system. Thereby, the most electricity is used for air-conditioning and at the hourly level the share of the AC demand can approach 80%. Fig. 9 shows the energy end-uses of the two typical residential buildings. It is clear, therefore, that electricity used by the HVAC system is the most significant, particularly for cooling energy, which requires more than 65% of the total electricity consumption to satisfy the cooling and ventilation loads. The remaining is divided between lighting, equipment and other building loads.

4.2. Impact of climate on building performance

Climate has a major impact on the energy performance of buildings. Such impact can be seen in the impact of temperature on heating and cooling loads, wind speed and direction on space heating and ventilation loads, the solar radiation on cooling and lighting loads, hours of day-light on lighting load and the cloud layer on space heating.

Changes in the external air-temperature will have significant consequences upon building performance, particularly internal air-temperature. Several parameters are of importance in terms of the thermal performance of the built environment, particularly cooling and heating degree-days. In general, the degree-day is a measure of the severity of the mean outside air-temperature related to cooling and heating energy consumption. This method is used to express the amount and length of time the outside air-temperature is below or above a specified base temperature. If the outside air-temperature is above a specified base temperature then space cooling is required in the building. Conversely, if the outside air-temperature falls bellow a base value then the space heating will be required. Fig. 10 illustrates the cooling and heating degree-days of Al-Ain city based on the baseline climate.

The statistical analysis of Al-Ain climate shows that the effects of global warming on degree-days are already being noted. Fig. 11 shows the impact of raising air-temperature on the number of cooling and heating degree-days. It is clear that there is a significant change, which positively influences the heating degree-days, but negatively influences the cooling degree-days. There is a sharp declination in the heating degree-days, especially under scenario-4, where the reduction reaches 100%. In contrast, there is a steady increase in the cooling degree-days. They can increase between 16% and 27% by 2050. This increase can reach between 22% and 42% by 2100. The growth in cooling degree-days implies that to reach a comfortable internal environment in the hot summer of Al-Ain city, a dramatic change will occur in the amount of electricity used by air-conditioning systems.

To establish the likely annual cooling demand for each aforementioned scenario the simulated changes in demand were related to the energy consumed for cooling and heating the case buildings. Table 4 illustrates the impact of global warming on the cooling and heating demands. As can be seen there is a brief drop in heating energy demand with different rates ranging from 9.5% in Bldg-1 to 39.2% in Bldg-2 under scenario-1 and scenario-4 respectively. When this applies to the cooling and ventilation energy, a different scenario occurs. There is a sharp increase in the cooling energy which reaches a peak of 24.1% in Bldg-2 under scenario-4. This

Table 5
Existing and assumed parameters.

Insulation				
Abbreviation	U-factor (W/m^2/K)	Roughness	Absorption	Specification from outside to inside
Existing wall-1	2.32	3	0.7	Plaster 12 mm, block, 150 mm, plaster 12 mm
Assumed wall-2[a]	0.3	3	0.7	Plaster 12 mm, polystyrene 35 mm, block, 150 mm, plaster 12 mm
Existing roof-1	0.6	0.9	0.5	Screed 50 mm, polyurethane 35 mm, concrete 150 mm
Assumed roof-2[a]	0.2	0.9	0.5	Screed 50 mm, polyurethane 35 mm, concrete 150 mm

Window					
Abbreviation	U-Value (W/m^2/K)	SC	SHGC	Visible transmittance	Summer inside glazing surface (°C)
Glazing type					
Single	6.3	1.00	0.86	0.9	23.9
Double[a]	2.78	0.89	0.77	0.81	31.8
Window area	20%[a]	6%			
Shading devices					
	500 mm overhang[a]				
	500 mm side fin				
Thermal mass					
Mass-150	Plaster 12 mm, polystyrene 35 mm, light weight concrete block 150 mm, plaster 12 mm				
Mass-250	Plaster 12 mm, polystyrene 35 mm, heavy weight concrete block 250 mm, plaster 12 mm[a]				

[a] Parameters used for optimisation.

Table 6
Performance of design technologies under different scenarios.

Climate	Baseline	Scenario-1	Scenario-2	Scenario-3	Scenario-4
Consumption (kW h)					
Heating	6963	6318	6038	5818	4375
Cooling	75,462	80,434	83,390	86,811	96,203
Electricity	126,836	131,393	134,173	137,397	145,486
Reduction due to thermal insulation (%)					
Heating	25.6	25.2	24.8	23.8	17.4
Cooling	19.3	19.7	19.9	19.7	15.5
Electricity	15.5	15.9	16	15.9	13.1
Reduction due to thermal mass (%)					
Heating	26.2	27.2	19.5	26.4	21.5
Cooling	13.4	13.3	11.1	12.6	18.6
Electricity	11.9	11.8	9.5	11.2	14.8
Reduction due to shading devices (%)					
Heating	2.9	3.3	3.2	3.3	3.6
Cooling	3.7	3.6	3.5	3.4	2.9
Electricity	2.9	2.9	2.8	2.8	2.4
Reduction due to glazing system (%)					
Heating	8.2	8.7	9.1	9.4	10.9
Cooling	5.4	5.4	5.5	5.5	10.5
Electricity	4.5	4.6	4.7	4.7	8.1
Reduction due to glazing area WWR 0.06 (%)					
Heating	6	6.4	6.9	7	8.2
Cooling	3.7	3.8	3.9	3.9	9
Electricity	3.2	3.2	3.3	3.3	6.8
Reduction due to glazing area WWR 0.2 (%)					
Heating	−14.5	−15.7	−28.8	−16.4	−20.1
Cooling	−8.5	−9.1	−10.9	−8.4	−8.3
Electricity	−7.2	−7.7	−9.8	−7.4	−7.4

(−) Increase in energy demand.

figure represents a clear indication that global warming will lead to a negative impact on the total electricity demand, where changing from the baseline climate has reduced the heating energy demand at the expense of a rise in annual cooling energy demand, and therefore, additional total energy has been consumed. From the total energy increase; there has been in effect a further CO_2 increase, with electric cooling energy consumption.

The statistics of energy consumption per sector indicate that the residential sector in Al-Ain city accounts for 2646 GW h, or almost 45.9% of the total regional consumption. If global warming delivers a 5.9 °C air-temperature rise then the consumption can be increased to almost (current consumption × 12.5%) 2977 GW h, and consequently the total CO_2 emissions will grow to almost 7.6 million metric tonnes. The net Emirati CO_2 emissions could increase at around 138.4 million metric tonnes over the next few decades.

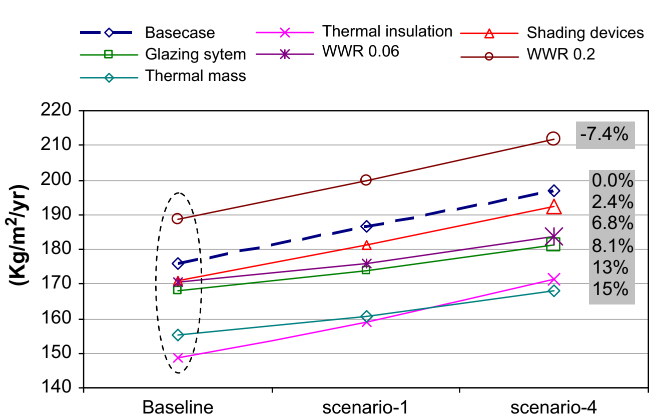

Fig. 12. Reduction in CO_2 emissions due to energy design measures.

5. Building energy design for different climate scenarios

Clearly, buildings in the UAE interact with the environment in two ways: firstly, CO_2 is the main by-product of the generation from fossil fuels of energy. As buildings are one of the largest consumers of energy then they are also the largest contributor to the increase in the atmospheric CO_2 and hence global warming and climate change. Secondly, building operation is likely to be especially affected by global warming. After having a clear understanding of this interaction and its impact on the energy use patterns, this study discusses the development of effective building design measures in order to overcome the negative consequences.

As reviewed, numerous design measures and techniques were examined to cope with the impact of global warming on the energy consumption in different countries, which are characterised as cold or moderate climates. This section focuses on the evaluation of certain climatic design measures to be used in the hot arid climate of Al-Ain city. The case studies were simulated to examine the most effective measures including thermal insulation, thermal mass, shading devices and window parameters. The first measure was tested by reducing the U-value of walls and the roof of the case buildings without changing the thermal mass, while the second measure was tested by using higher thermal mass and keeping the U-value fixed. The third measure was tested by adding different types of shading devices (overhang and side fin). The fourth measure was tested in two steps: firstly, altering the window area without changing the construction of the wall and properties of the glazing. Secondly, varying the glazing type and keeping the window area and the construction of the wall and properties fixed. The four measures were simulated under the baseline climate, scenario-1, scenario-2, scenario-3 and scenario-4 respectively. Table 5 presents the existing and the assumed parameters.

5.1. Evaluating the performance of energy design measures

Table 6 illustrates heating, cooling and electric energy demands and electricity savings due to each measure under different scenarios. The statistics of Bldg-1 show that space heating accounts for 5.2% or 122.9 MW h, while the electricity used for space cooling is approximately 65%. As tabled, reducing the U-value of the case building, under the baseline climate, reduces the heating demand by approximately 25.6%. Considering the small amount of heating energy demand this figure is not significant. When the same U-value is used under scenario-3 and scenario-4, the figure drops to 23.8% and 17.4% respectively. Clearly, reducing the thermal transmittance of building envelope negatively influences the heating energy demand in Al-Ain under the impact of global warming. The tabled data show that the amount of saving in cooling energy due to thermal insulation is significant comparing to the heating energy. The maximum reduction is 19.9% under scenario-2, which drops to 15.5% under scenario-4. As a great amount of energy can be saved by thermal insulation, an appropriate selection of thermal mass offer a considerable opportunity to control electricity consumption. As seen, using a higher thermal mass reduces the heating energy by 26.2% and 21.5% under the baseline climate and scenario-4 respectively. In terms of cooling energy, the reduction can reach around 13.4–18.6% under the same scenarios. Different from insulation and thermal mass the shading devices provide less savings for heating and cooling energy demands. As illustrated, the maximum heating energy reduction is about 3.6% under scenario-4, while the maximum reduction in cooling energy is about 3.7% under the baseline climate.

Altering the window parameters offers more savings for cooling energy demands. For example, replacing the glazing type from single glazing to double glazing produces a significant savings in

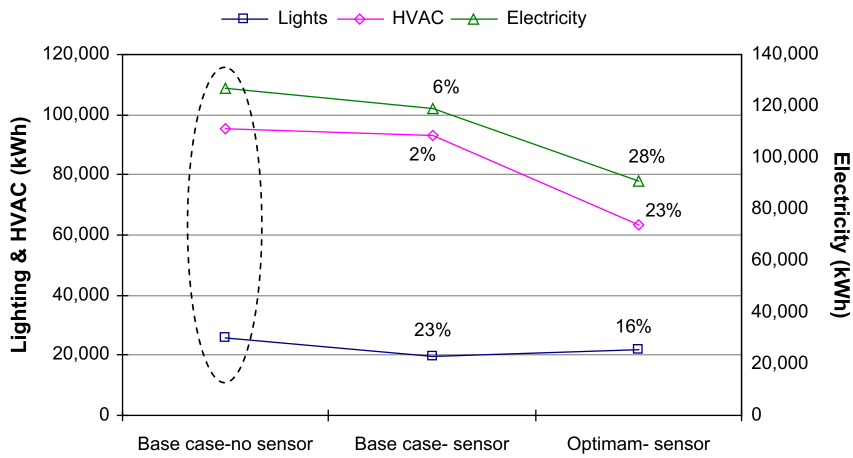

Fig. 13. Impact of optimisation on lighting & HVAC loads and electricity.

cooling energy demand as can be seen in the fall of energy consumption which reaches 10.5% under scenario-4. In addition, double glazing plays an important role in reducing the heating load as illustrated in the reduction in heating energy demand that reaches 8.2% and 10.9% under the baseline climate and scenario-4, respectively. The same situation can be observed with respect to the window area. In this study, the window area was first reduced from 12% to 6% and then enlarged to 20%. As shown, the differences in heating and cooling energy demands with respect to the former window area are 8.2% and 9%, respectively under scenario-4. When the window area is enlarged, the maximum increase in heating energy is 28.8% under scenario-2, while the increase in cooling energy is 10.9% under the same scenario. This amount, however, drops to 8.3% under scenario-4.

Overall, the thermal insulation measure, on the one hand, saves a large amount of heating and cooling energy demands coupled with a considerable reduction in total electricity use. It is also obvious that the amount of energy saved due to thermal insulation is changed under different climatic conditions. The energy savings drop from 15.5% under the baseline climate to 13.1% under scenario-4. The use of a high thermal mass significantly reduces the energy use for heating and cooling buildings in addition to saving a considerable amount of electricity that can reach 14.8% under scenario-4. It is clear that the amount of energy saved due to using a higher thermal mass is increased as the ambient air-temperature is getting warmer.

On the other hand, savings in electricity consumption due to shading devices are not significant. The maximum reduction is 2.9%, which reaches 2.4% under scenario-4. These figures show that the amount of energy saved under different scenarios remains almost the same. The amount of energy saved due to window design, particularly glazing system, is changed under different scenarios coupled with the ability to deliver a high level of savings in heating and cooling demands along with a considerable reduction in total electricity use. It can offer an 8.1% reduction in the total electricity demand under scenario-4. It is clear that the amount of energy savings due to glazing system is increased as the air-temperature raises. Although the glazing area is more constant comparing with the glazing system, it represents a good option because it is able to save a large amount of energy used for cooling buildings coupled with large reduction in the total electricity demand that can reach between 6.8% and 7.4% under scenario-4.

Clearly, the ability of energy design measures to reduce the energy consumption of the residential sector in Al-Ain city is variable. Since the objective here is to improve the energy performance of the building a whole, the carbon emissions index is taken as the criterion. Fig. 12 graphically illustrates the reduction in CO_2 emissions due to each measure. The figure indicates that thermal mass performs best, followed by thermal insulation, glazing system and window area in descending order. Although the thermal insulation measure gives better result under the baseline climate, the performance of thermal mass is higher under scenario-4. It is important to note that the impact of thermal mass and thermal insulation, in such residential buildings, is larger than that of the window parameters due to the fact that the window-to-wall ratio is small. Shading devices were found to be the least effective measure in reducing CO_2 emissions.

5.2. Impacts of energy design measures on buildings loads

An argument can be made that optimising building energy design by applying the above proposed measures may deteriorate other aspects such as day-lighting level and building visual performance. First of all, optimisation is the search for the best possible solution for a particular problem [34,35]. In the current case is the optimum building energy design. Before performing the assessment for any building design, however, criteria for building performance should be defined. Various criteria are used to evaluate building performance, including energy performance indicators, thermal comfort, day-lighting level, visual comfort and acoustic comfort. Each of these criteria measures one or more requirements of building performance. To take into account all factors that affect the performance of our building including design, systems, occupant behaviour and climate change, the amount of energy consumption and CO_2 emissions of the whole building represents sufficient indicators. Fig. 13 illustrates the result of optimising the design of Bldg-1 with respect to four measures including thermal insulation, thermal mass, window design and shading devices (these parameters are marked with "[a]" in Table 5). To assess the influence of these measures on the lighting load, the illustration shows Bldg-1 with respect to three cases. The first is the original case building without lighting sensor, while the second is the original case building with lighting sensor. The last is the optimised case building with lighting sensor.

Utilising the natural lighting by applying the lighting sensor measures to the case building reduces the lighting and cooling loads by 23% and 2% respectively. The reduction in the cooling energy is due to reducing the amount of heat gain from artificial lighting. Consequently, the total electricity consumption was reduced by almost 6%. Optimising the case building reduces the energy used by HVAC at the expense of a rise in annual lighting energy demand.

Although using shading devices, double glazing and keeping the window area within the area of 20% negatively impacts the lighting load, the total energy use has been reduced by 28%. From the total energy reduction; there has been in effect a further CO_2 declination.

From an economic and environmental point of view, simple steps taken into account during the design stages can yield buildings that produce 28% less CO_2 emissions. Such steps involve using climatic design measures including thermal insulation, thermal mass, window design and shading devices. These measures have a significant impact on the total energy consumption. However, to consider all factors that affect the energy consumption of buildings, the energy performance and CO_2 emission indicators represent effective criteria and play a critical role in energy and environmental terms.

6. Conclusions

This paper has examined the potential consequences of global warming on the energy performance of air-conditioned residential buildings in Al-Ain city – the United Arab Emirates. It was stated that global warming will have a significant impact on the built environment and on the energy used for air-conditioning buildings. The study has shown that a rise in the ambient air-temperature can lead to a significant increase in electricity consumption and its associated CO_2 emissions. Global warming is likely to increase the energy used for cooling residential buildings by 23.5% if Al-Ain warms by 5.9 °C. At the regional level, the energy consumption can be increased at around 5.4%. Consequently, the CO_2 emissions can increase to almost 7.6 million metric tonnes. The net Emirati CO_2 emissions could increase at around 138.4 million metric tonnes over the next few decades.

Clearly, controlling CO_2 levels and global warming is an international problem, which requires action on several fronts. Therefore, as one part of their contribution to the process, building authorities and energy code bodies in the UAE should make the relevant part of the building design and regulations more stringent, and emphasise that the goal of saving energy is to reduce CO_2 emissions into the atmosphere. This can be done by using CO_2 emissions as one of the principal criteria by which the design of a building is judged. It can be implemented jointly with measures on specific envelope elements, system components and energy use patterns in order to ensure the dissemination of the most efficient building. The analysis carried out in this study has demonstrated that the thermal insulation and thermal mass are effective and beneficial energy design measures for residential buildings. They offer a large reduction in energy demand and CO_2 emissions under different scenarios. The reduction can reach 13% and 15% of the total CO_2 emissions of such a sector. The window design including window area and glazing system are important design measures. They provide a considerable amount of energy savings that can be reached at around 6.8–8.1%. Although the sensitivity of shading devices to global warming is moderate and provides a limited reduction in terms of energy use, it can help in reducing the CO_2 emissions of residential buildings in Al-Ain city.

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