A Statistical Model to assess Indirect CO_2 Emissions of the UAE Residential Sector

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ABSTRACT

This study presents a regional bottom-up model for assessing space cooling energy and related greenhouse gas emissions. The model was developed with the aim of improving the quality and quantity of cooling energy and emission data, especially for the benefit of local decision making. Based on a benchmarking study, a representative archetype was developed, simulation software used and linear statistical model constructed. This model explores the way in which CO_2 emission levels are affected by different energy efficiency measures to reduce cooling energy consumption in buildings. The analysis showed that improving building energy efficiency could generate considerable carbon emissions reduction credits with competitive benefit. The developed model was found to be capable in selecting cost-effective, environmentally-preferred building efficiency measures and evaluating the future trend of CO_2 emissions in the residential building of Al-ain city

Keywords: A Statistical model, CO_2 emissions, UAE residential buildings.

INTRODUCTION

The increasing emission of green house gases (GHG), most notably CO_2, has become a major concern for building industry and research community due to two main reasons: 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 the CO_2 level and global warming. With its rapid and increasing economic expenditure with huge architectural projects and 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 [1]. In the UAE, the final energy consumption is split into four major sectors including buildings, industry, agriculture and others. As shown in Figure 1, buildings, particularly those in the residential sector, have the largest impact on this growth, as 49.8% of the total electricity is used in this sector. Most of this electricity is used for air-conditioning during the summer months [2]. It was reported that the growth in electricity consumption for cooling buildings has increased ten times (from 5 to 50 Billion KWh) over the past two decades.

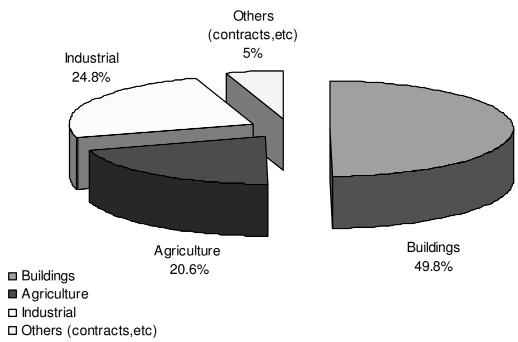

Figure 1 Energy consumption per sector

As a result, the production of CO_2 emitted due to electricity use has become greater. Figure 2 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 is the dominant source of CO_2 emissions in the UAE. According to the UAE statistics, some 4% of the CO_2 production is caused by the direct emissions of buildings, 43% by electricity generation and 45% by manufacturing and construction, which at least partly influenced by building construction and operation [3].

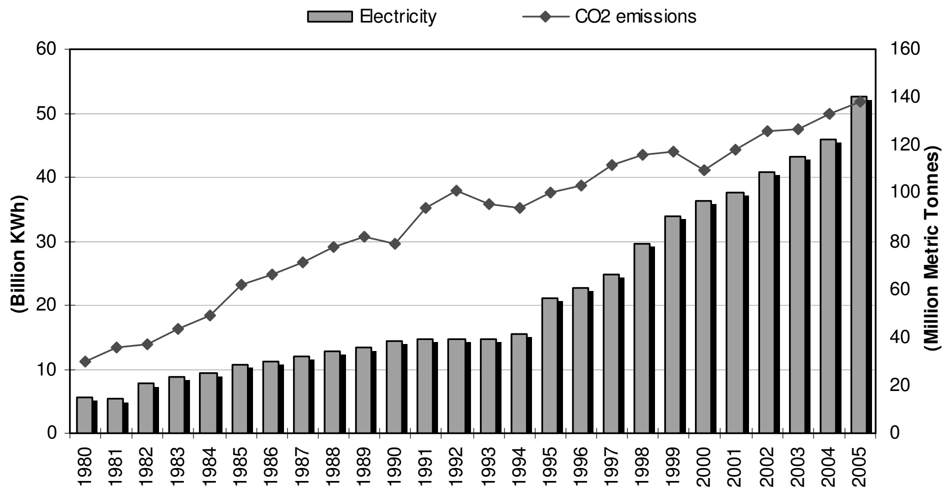

Figure 2 Increase in CO_2 emissions relative to the use of energy [3]

To tackle with CO_2 emissions and global warming issues, UAE began planning regulation energy efficiency and environmental codes for buildings. Therefore, new standards have proposed in Dubai and Abu Dhabi. However, there is an absence of methodology or model to evaluate the impact of such codes on the CO_2 emissions reduction with respect to the local and regional contexts.

Background

Over the last few decades many studies have been conducted to model the energy consumption and CO_2 emissions using different techniques including 'top-down' and 'bottom-up'. It was proven that quantifying and modelling the total amount of CO_2 emissions is possible using statistical and archetype models that are considered as bottom-up techniques. Hirst and Goeltz [4] for example, constructed a regression model to examine the weather and non-weather sensitive elements of the energy consumption by regressing the energy consumption data onto a non weather dependent constant and a weather dependent coefficient based on heating degree-days, while Snakin [5] presented an energy model for assessing space heating energies and related greenhouse gas emissions. The objective of Snakin's model is to improve the quality and quantity of heating energy and emission data.

In terms of archetype techniques, Parekh [6] outlined the process of developing archetypes for energy simulation as: geometric characteristics, thermal characteristics and operating parameters. Various studies of currently energy consumption and CO_2 emissions explored the relationship between the energy end-uses and factor influence the energy use. For instance, Weber, Koyama and Kraines [7] constructed a model to calculate the CO_2 emissions and costs by using different configurations of a decentralised system combining a solid oxide fuel cell to provide an office building in hot humid climate with electricity, cooling and heating. It was shown that the sizes of buildings do not have much influence on the CO_2 emissions reduction potentials. This is simply because all the equations used in that study are linear. Yao and Steemers [8] presented a simple method of formulating load profile for UK buildings where domestic space heating load profile for different types of houses was produced using thermal dynamic model which was developed using thermal resistant network method.

A principle advantage of bottom-up methods is that they mainly rely on computer programs, and thus have ability to analyse in detail the energy consumption characteristics of each building or sector. With respect to the Scottish buildings, for example, Clarke, Ghauri and Johnstone [9] studied the main determinants of energy demand using the following determinants and their value or level: insulation level, capacity level, capacity position, air permeability, window size, exposure and wall to floor area ratio. Each was modelled using the building performance simulation software ESP-r and a representative case model to determine the thermal energy requirements. System information such as heating / cooling, ventilation, DHW and lighting was then applied to calculate the total energy consumption. Hirano, Katoa, Murakami, Ikaga, Shiraishi and Uehara [10] developed an archetype model with respect to the Japanese buildings in order to show the effectiveness of porous residential buildings in hot and humid regions in the light of cooling load and CO_2 emission reductions. Thermal and airflow network analysis and LCA analysis were used for those simulations. Alternate approach to archetypes was taken in China by Wan and Yik [11] where the focus was on solar gains. After developing a single archetype, typical characteristics were applied including wall thickness, window to wall ratio, glass thickness and wall absorptivity. The HTB2 simulation engine was utilised with the developed archetype.

The current study presents a regional statistical model for assessing space cooling energies and related greenhouse gas emissions through the development of a representative archetype model and construction of statistical one. The objective of this model is to improve the quality and quantity of cooling energy and emission data, especially for the benefit of local decision making. It studies the way in which CO_2 emission levels are affected by different measures to reduce energy consumption in the residential sector. For simplicity, this study focuses on Al-ain city.

METHODOLOGY

Figure 3 show the methodology adopted in this study. As shown, it describes the representative case study, presents simulation processes and explains development of the statistical model.

Description of the Representative Case Model

For appropriate assessment, real buildings were used. They were chosen throughout a field survey and benchmarking study. To ensure a good representation, certain criteria and data filters were applied including building categories, system types and operation schedules. The building category filter was applied to select a building with the same basic operations (residential buildings). The building systems and operation schedules 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 buildings to be analysed. Figure 4 illustrates the architectural characteristics of the studied building.

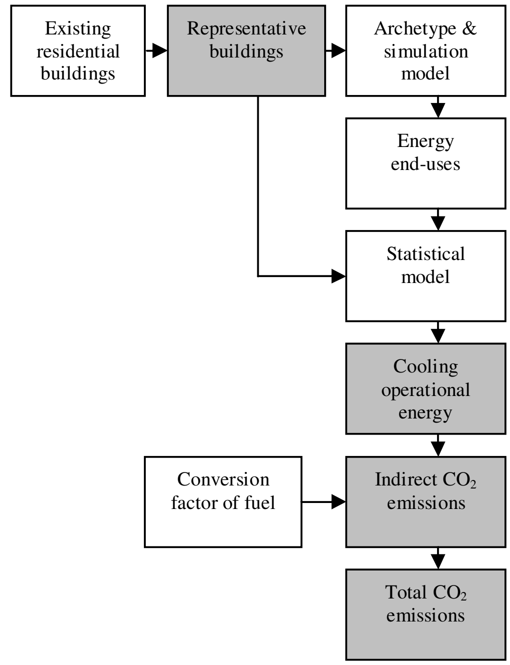

Figure 3 Structure and form of the constructed model

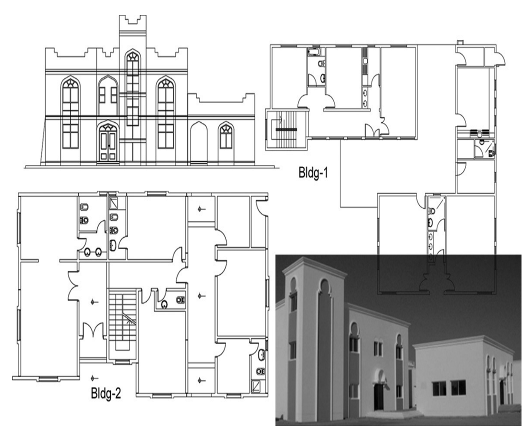

Figure 4 Representative case building

They are two storeys buildings with a floor to floor height of 3.5 m. The walls consist of mainly 150 mm concrete block, 24 mm of plaster inside and outside. The roof consists of a 50 mm screed, 35 mm polyurethane and 150 mm concrete slab. The windows are single glass with an approximate 0.30 window-wall ratio. The building has multi-thermal zones with a spilt unit system. Complete details of the buildings' physical and operational characteristics are given in Table 1.

Table 1 Characteristics of the case building

Parameters	Specification
No. of Floor	2
Total Area	370- 415m^2
Floor Height	3.5 m
Orientation	East to West
External walls	15 mm concrete masonry units block-24 mm of plaster inside and outside
Roof	200 mm concrete, slab 50mm screed, 50mm sand and 10 mm ceramic tiles
WWR	0.25 & 0.3
Glazing	6 mm single green glass
Infiltration	5.0 m^3/h/m^2
Ventilation	7.5 L/s/person
Thermal Zones	Multi-zones
Equipment	12 W/m^2
Lighting	20 W/m^2
HVAC	Split units
Set point temperature	(22-24^{o}C) Summer (20-22^{o}C) Winter
Occupancy	25 m^2/p

The Representative Model under Different Climatic Scenarios

The Environment Agency of Abu Dhabi and the Ministry of Energy and other concerned parties in the UAE [12] 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 were 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 1.6ºC and 2.9ºC warmer than they were over the period 1961-1990, and between 2.3ºC and 5.9ºC warmer by 2100.

Based on real climatic elements, a statistically-based weather data file was generated using the MeteoNorm software [13] to reflect the current climate of Al-ain city. In order to predict the impact of higher air-temperatures on the cooling load and electricity consumption, 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. Figure 5 shows the different scenarios of climate change in the UAE. Each scenario represented a weather input of a sophisticated simulation program. The Visual DOE program was used in this investigation [14]. It 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. Building design, materials, operation and monthly utility bills of the case buildings were used to validate the Visual DOE program, as illustrated in Figure 6.

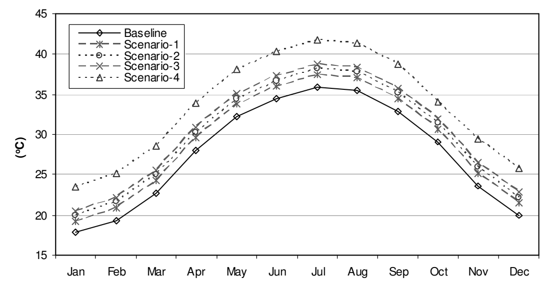

Figure 5 Scenarios of climate changes in the UAE

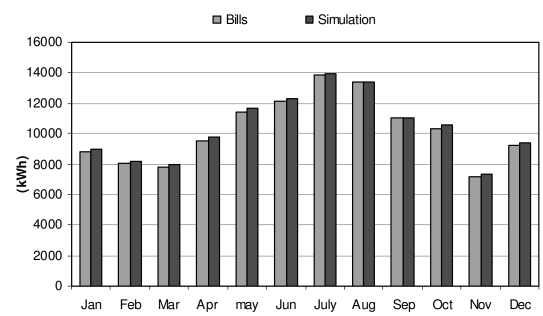

Figure 6 Calibration of the simulation model

Statistical Model to estimate the CO_2 Emission Reduction

In this study, a simple regression model to calculate the cooling requirements due to each scenario was constructed. The primary analysis of such a model is based on a weighted ordinary least squares regression. This basic form of regression allows for analysis of a dependent variable, in this case the CO_2 emissions due to the cooling requirement, subject to various independent climatic and building design parameters (*Dp*) such as outside temperature and envelope design. This linear regression can yield an equation of the form:

$$CR = C_0 + C_1Dp_1 + C_2Dp_2 + C_nDp_n \qquad (1)$$

Table 2 Variables of least square regression

weather dependent				
		Avg temp (°C)	Raised (°C)	
Base-line		26.5	0	
Scenario-1		28.1	1.6	
Scenario-2		28.8	2.3	
Scenario-3		29.4	2.9	
Scenario-4		32.4	5.9	
Non weather dependents				
Wall	U-Value $W/m^2/^oC$	window	U-value $W/m^2/^oC$	SC
Wall-1	2.00	Sng clear	6.17	0.95
Wall-2	1.8	Sng gray	6.1	0.69
Wall-3	1.6	Sng green	6.17	0.71
Wall-4	1.4	Sng blue	6.17	0.71
Wall-5	1.2	Sng low-e	4.26	0.84
Wall-6	1.0	Dbl clear	2.74	0.81
Wall-7	0.8	Dbl gray	2.74	0.54
Wall-7	0.6	Dbl green	2.74	0.57
Wall-9	0.4	Dbl blue	2.74	0.57
Wall-10	0.2	Dbl low-e	1.77	0.65

Statistically, this equation is used to know the relationship between several independent or predictor variables and a dependent or criterion variable. In the current case, the cooling requirement index (*CRI)* is the dependent and variables in the right side of the equation are the independents where C_1, C_2, and C_n represent the equation coefficients and *Co* is a constant. The developed regression models are structured to have the dependent variable to be the cooling requirement index. *CRI* is equal to the total cooling load divided by the gross floor area of the building, while independent variables appear on the right side of the regression equation. This study investigates four weather and non-weather sensitive elements of the cooling load by regressing the cooling load data onto non weather dependent coefficient and a weather dependent constant based on outside temperature. Table 2 shows these dependants. They were chosen based on the climate change scenarios and the architectural characteristics of residential buildings in the UAE and due to the fact that the UAE government began planning regulation energy efficiency codes for buildings. These codes include thermal insulation for the sold parts of buildings represented by the U-value and using more efficient glass for windows. U-Value is a measure of the flow of heat through an insulating or building material: the lower the U-value, the better the insulating ability. As there are some parameters that should be considered when the glazing type is concerned, this study focuses on the U-value and shading coefficient. The ambient temperature was chosen as a weather sensitive dependant in order to reflect the climate change in the UAE.

Back to equation (1), if Dp_1, Dp_2, Dp_3 and Dp_4 represent the outside temperature, U-value of the wall, U-value of the glazing and the SC of the glazing then the value of C_1, C_2, C_3 and C_4 represent the statistical correlation between the outside temperature, U-value of the wall, U-value of the glazing and the SC of the glazing and *CRI*. This correlation approximates the average relationship between these independents and each $kWh/m^2/yr$ of cooling load. This linear regression can be expressed as:

$$CRI = C_0 + C_1 Tao + C_2 U - v_{(w)} + C_3 U - v_{(g)} + C_4 SC \qquad (2)$$

The result of regressing the cooling requirement index (*CRI*) as obtained from the simulation model onto the outside temperature (*Tao*), U-value of the wall, $U\text{-}v^{(w)}$, U-value of the glazing, $U\text{-}v^{(g)}$, shading coefficient of the glazing, $SC^{(g)}$, as found in the 20 prototypes of representative residential buildings is shown in Table 3. It is clear that the coefficient of determination, or R^2 of the CRI, is 0.96 which would indicate a strong relationship between the CRI variables and the outside temperature, U-value of the wall, U-value of the glazing and the SC of the glazing.

The amount of CO_2 emissions (*E*) is subjected to the cooling requirement (*CRI*), operational schedule (*Op_sch*) and the conversion factor of fuel (*Cf*). Therefore, a simple linear equation was developed and used to calculate the CO_2 emission reduction due to different outside temperature, U-value of the wall, U-value of the glazing and the SC of the glazing. The following equation was used.

$$E = (CRI \times Op\_sch) \times Cf \qquad (3)$$

Table 3 Regressing the energy requirements

Cooling requirement (CR)					
	C_o	C_1	C_2	C_3	C_4
	-205	11.2	21.1	2.9	31.7
	9.1	0.26	0.99	0.4	5.7
R^2	0.96				
F	578				

DISCUSSION

To deal with the CO_2 emissions, two fundamental changes in patterns of energy use 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. The former can be done through various strategies to enhance and strengthen energy savings in buildings including good practice (design) and codes of practice (regulations). The latter can be achieved through the use of renewable resources, the installation of efficient power plants and the use of low carbon emissions fuels to generate electricity. Although the first pattern is more sustainable, the second pattern can help in achieving a healthy environment. Both patterns are needed. This study focuses on the former pattern as reducing the energy demand seems to be the first logical and practical step to reduce CO_2 emissions.

The summer season in Al-ain city is long and extends over two third of the year with air-conditioning required on a 24 hours per day basis, therefore, the most electricity is used for air-conditioning during those months, and at the hourly level the share of the AC demand can approach 80%. Figure 7 shows the energy end-uses of the representative residential building. It is clear 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. To establish the likely annual cooling demand for each aforementioned scenario the changes in demand were related to the energy consumed for cooling the representative building. Figure 8 illustrates the impact of global warming on the cooling demand using the developed model and compares it with the result presented in ref [15]. As seen, there is a brief increase in cooling energy demand with different rates under scenario-1 and scenario-4 respectively. This figure clearly illustrates the consequences of global warming on the electricity performance of residential buildings. It will lead to a negative impact on the total electricity demand, where changing from the baseline climate has increase the cooling energy and ventilation 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. A quick comparison between the results in ref [15] and those obtained using the developed model shows a small differences ranging from 3.2%, 6.4% and 0.8% under the baseline climate, scenario-1 and scenario-4 respectively.

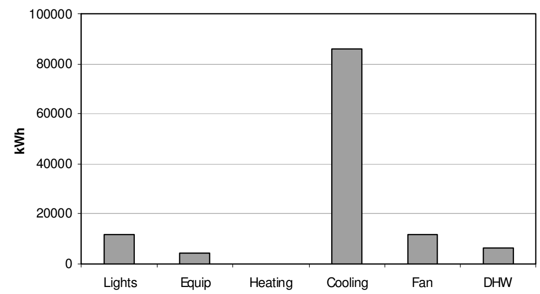

Figure 7 End-uses of the representative building

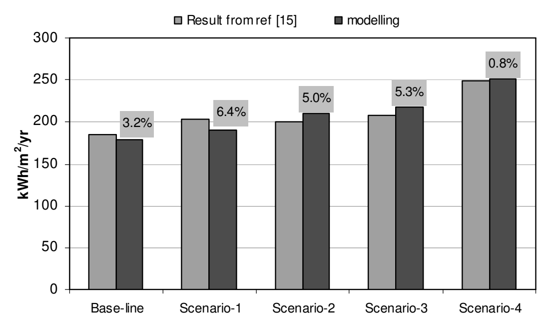

Figure 8 Impact of global warming on cooling demand

Al-ain figures show that 45.9% or 2646 GWh is consumed by the residential sector. If building energy codes are not applied and global warming delivers a 5.9°C air-temperature increase then the consumption can be raised to almost (current consumption x 13.3%) 3167 GWh, and consequently the total CO_2 emissions will grow to almost 8.0 million metric tonnes. The net Emirati CO_2 emissions could increase at around 145.6 million metric tonnes over the next few decades. Table 4 shows a comparison between figures obtained from ref [15] and figures obtained due to the use of the developed model. There seems to be an agreement between the two results.

Table 4 comparison of CO_2 figures

	Model	Ref [15]
Electricity consumption (MWh)	3167	2977
Raise in CO_2 emissions (million metric tonnes	8.0	7.6
Level of CO_2 due to 5.9 °C (million metric tonnes)	145.6	138.4

Figures 9-10 illustrate cooling energy savings due to each energy efficiency measure under different scenarios. The statistics of the representative building show that electricity used for space cooling is approximately 65% or 97.5 MWh. As illustrated, reducing the U-value of the case building, under the baseline climate, reduces the cooling demand by 16.5%. Considering the large amount of cooling energy demand this figure is significant. The maximum reduction is 18.8% under scenario-4, which drops to 14.4% with respect to scenario-1. Furthermore, replacing the glazing type from single glazing to double glazing produces a significant savings in cooling energy demand as can be seen in the fall of energy consumption which reaches 7.0%. 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 reduce the cooling energy consumption and consequently the CO_2 emissions, the total CO_2 emissions is taken as the criteria. The above illustrations show the reduction in CO_2 emissions due to each measure. The figures indicate that thermal insulation performs best, followed by glazing system in descending order. It is important to note that the impact of 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.

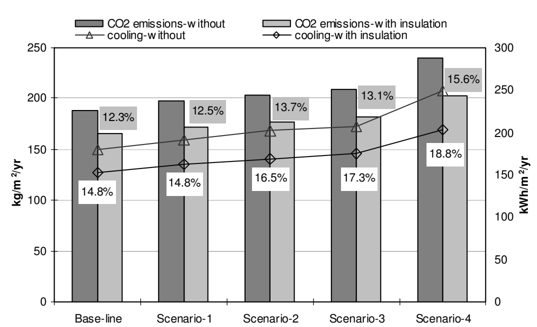

Figure 9 Cooling load due to thermal insulation

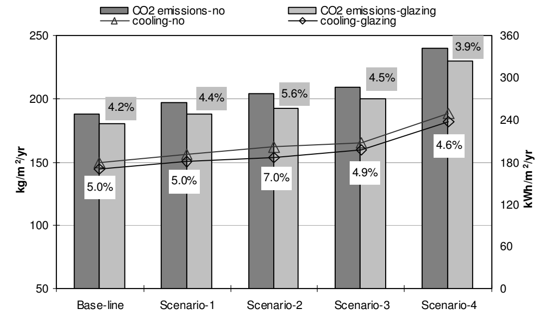

Figure 10 Cooling load due to glazing type

CONCLUSION

This study presented a statistical model in order to estimate the indirect CO_2 emissions in the UAE residential sector with the aim of improving the quality and quantity of cooling energy and emission data, especially for the benefit of local decision making. The developed model showed similar results when compared with other researches concern with the global warming in the UAE. It was found that a rise in the outside temperature can lead to a significant increase in electricity consumption and its associated CO_2 emissions. In the long run, global warming is likely to increase the energy used for cooling residential buildings by 27.7% if the UAE warms by 5.9°C. At the regional level, the energy consumption can be increased at around 5.6%. Consequently, the CO_2 emissions can increase to almost 8.0 million metric tonnes. The net Emirati CO_2 emissions could increase at around 145.6 million metric tonnes over the next few decades.

The developed model was found to be capable in selecting cost-effective, environmentally-preferred building efficiency measures and evaluating the future trend of CO_2 emissions in the residential building of Al-ain city. It was demonstrated that the thermal insulation is an effective and beneficial energy design measure for residential buildings. It offers a large reduction in energy demand and CO_2 emissions under different scenarios. The reduction can reach 15.6% of the total CO_2 emissions of the residential sector. Glazing selection is an important design measure. It can provide a considerable amount of energy savings that can reaches at around 5.6%. Therefore, as one part of it contribution to the process, building authority 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.

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