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Optimization of CO_2 emission factors in urban cities of Kuwait

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Abstract: This paper presents a study examining strategies that assist in planning and constructing green buildings in urban cities. Hence, contributing in creating a sustainable environment. Two case studies including commercial and residential buildings in Mutla, Kuwait were analyzed for CO_2 emissions. Kuwait code requirements fall significantly short of what is required for low carbon housing. Therefore, energy consumption for the two types of buildings was modeled with an energy simulation software. Furthermore, optimization was carried out on the overall heat transfer coefficient value of the wall, roof and window. Moreover, the solar heat gain coefficient value of the glazing was optimized to improve the environmental performance of housing. Economical study was conducted to determine the effect of cost. The data was optimized with the payback calculations as a necessary optimality condition, which resulted in four optimized values for each case. The emissions decreased by 7% and 10% for the residential and commercial buildings..

Key words: Commercial, Residential, Energy Consumption, Optimization, CO_2 emissions

1. Introduction

The amount of energy consumed in Kuwait per capita is among the highest in the world. Some of the main factors include: rapid economic growth, highly subsidized energy costs and harsh summer climatic conditions, which require cooling. Kuwait has a hot and arid climate with long summers and short winters. The temperature may well exceed 50^{o}C in the shade, as the relative humidity increases.

The primary contributor to the problems of energy consumption in Kuwait is the increase in population, with an average growth rate of 3.3% [Kuwait Central Statistical Bureau, 2018]. What also adds to the insufficiency of energy supply is the significant amount of waste and over-consumption of energy. During 2013, the consumption of electrical energy per capita was 13,530 KWh [MEW Statistical Yearbook, 2014].

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The biggest silent energy users in residential and commercial buildings are air conditioning systems. Approximately 70% of the peak load demand is consumed on air conditioning systems in the summer, which accounts for 45% of the annual energy consumption [Kuwait Code MEW R-6-2014]. Energy consumption and carbon dioxide emissions are increasing at drastic rates worldwide.

Energy consumption of both low-rise and high-rise buildings makes up for 40 to 50% of primary energy. Nearly 40% of CO_2 emissions is a result of building usage.

The building envelope forms the main thermal barrier between the interior and exterior. These parts significantly effect the energy consumption of a building.

In this study, the annual energy consumption of residential and commercial buildings in Kuwait is analyzed using the four parameters: U-Wall, U-Roof, U-Window, and SHGC.

In this research, optimization is described as quantifying and implementing energy performance solutions in residential and commercial buildings in Kuwait. This in turn will help to determine where and to what degree of the total annual energy (KWh) is wasted.

Kuwait is committed in the development of projects, including the establishment of several mega residential cities, with the implementation of modern specifications for sustainability in all housing projects.

South Mutla is the largest residential project in the history of Kuwait comprising integrated housing projects. It includes around 28,363 residential plots and 600 service buildings. It is one of the most recent residential projects that has been introduced in Kuwait, with an expected occupancy of 400,000 people.

2. Methodology

Text Modeling energy consumption was carried out using Hourly Analysis Program 4.7 (HAP) energy simulation software, and optimizing the results was done using MATLAB. The optimization parameters include those of building envelopes, windows, and fenestration. Two base cases were studied, Case 1 involved commercial buildings and Case 2 involved residential buildings. A multi-objective function with inequality constraints was formed. Constrains are: parameters values < +20% of Kuwait code value and parameters values > –20% of Kuwait code value with an increment of 2.5%. The data was optimized with the payback calculations as a necessary.

The commercial building used in the test study is an office building located in Kuwait, which has an approximate area of 245,069.76ft^2 on nine floors, ground floor and two basements. In addition, the glazing area is 36,566.4ft^2, the glazing area represents 40% of the gross area. The commercial building contains spaces mainly designed for office use, consists of 12 floors, two of which are basements and are unconditioned spaces. The remaining nine floors along with the ground floor are conditioned spaces. Each floor has an area equal to

20,429.9 ft^2 with average ceiling height of 13.1 ft, all details of the input data of the thermostat (office HVAC), office lights/elec., office occupants, office elevators and office svc hot water of the office building were imported from HAP version 4.7 for Kuwait Code requirements. The cost rate (flat price) is assumed to be 0.14 $/KWh for the owner and the CO2 emission factor was set to equal 1.41 Ib/KWh. The residential building used in the case study is a house located in Kuwait that has a floor surface of 4,305.6ft^2. The building has an approximate total area of 14,262.2ft^2 on three floors and a basement. It is a semi-detached single-family dwelling consisting of a basement, ground floor, first floor, and second floor. The ground floor and the basement each are 4,305.6 ft^2. Moreover, the first and second floors each are 2,825.5ft^2. The equipment load is 0.62 w/ft^2 for the basement and the three floors. In addition, the overhead lighting for all the floors is 0.93 w/ft^2. The building was completed in compliance to Kuwait Code requirements. The air conditioning system consists of split DX fan coil units and CAV air system.

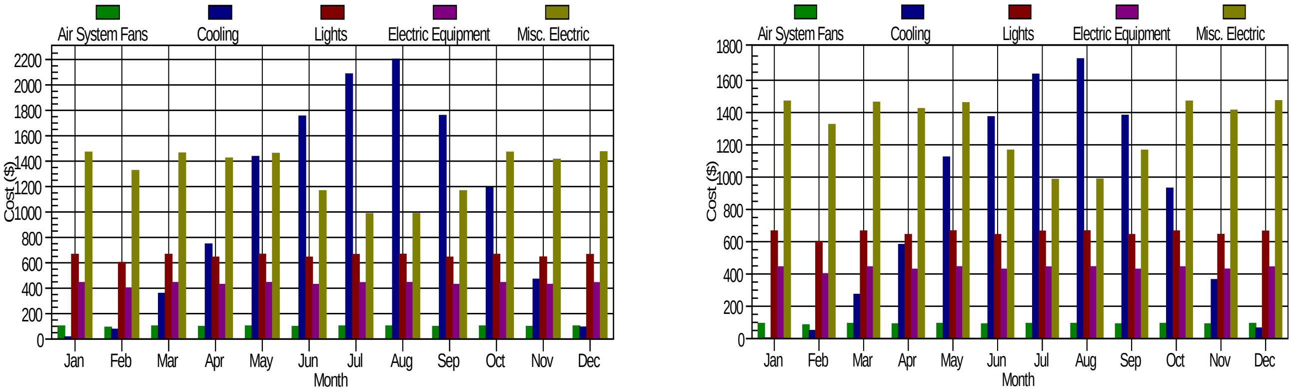
Table 1: Shows the optimized parameter values of base Case 1 and their effect on the annual energy consumption plus its payback periods.

Parameter	Optimized Value	Parameter Percentage to Kuwait Code	Reduction Percentages on AEC	Payback Periods (Year)
U-Wall	0.08	–20%	0.534%	1.8
U-Roof	0.056	–20%	0.420%	1.1
U-Window	0.557	–5%	0.124%	4.8
SHGC	0.237	–17.5%	0.984%	4.8

Table 2: Shows the optimized parameter values of base Case 2 and their effect on the annual energy consumption plus its payback periods.

Parameter	Optimized Value	Parameter Percentage to Kuwait Code	Reduction Percentages on AEC	Payback Periods (Year)
U-Wall	0.08	–20%	0.605%	1.9
U-Roof	0.056	–20%	0.476%	1.1
U-Window	0.572	–2.5%	0.0514%	2.7
SHGC	0.244	–15%	0.965%	4.5

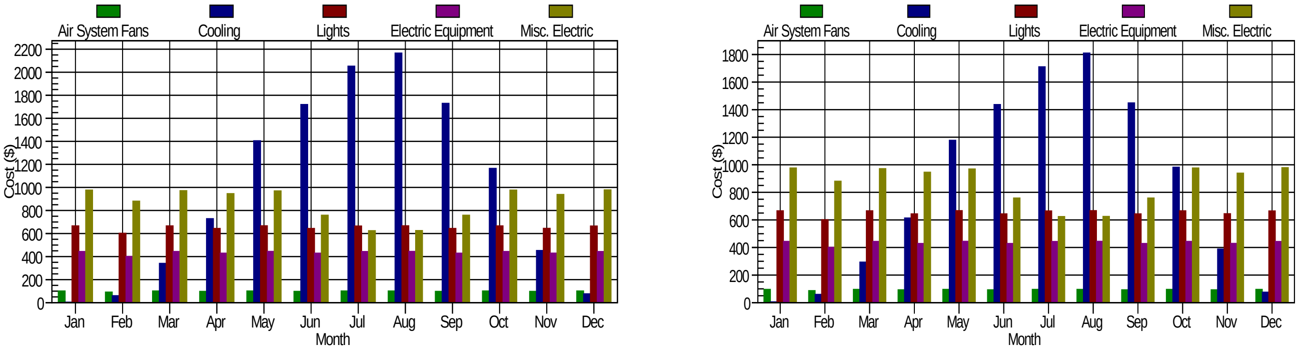
*AEC: Annual Energy Consumption (KWh).



(a) Case 1

(b)The optimized parameters of Case 1

Fig 3: Monthly Peak Load by end use in ($) for base Case 1 using Kuwait Code parameters and using the optimized parameters values of base Case 1.



(a) Case 2

(b) The optimized parameter of Case 2

Fig 4: Monthly Peak Load by end use in ($) for base Case 2 using Kuwait Code parameters and using the optimized parameters values of base Case 2.

The range of the four assessed parameters, in this study, has a great impact on the energy consumption. Two base cases were simulated and a parametric study was conducted to analyze the effect of energy performance, specifically on cooling loads. In these optimizations, one parameter was changed and the other three were kept constant. In this study, changing the U-Wall value based upon changing the insulation thickness. Optimizing the U-Wall parameter reduced the annual energy consumption in residential and commercial buildings of Kuwait. The optimized value of the U-Wall was 0.08 (Btu/ft^{2}h°F) for both cases. The roof offers most of the opportunities for passive cooling of buildings, but if it is not performing well, it can present a huge liability to the building.

On the one hand, the roof is the building element that is the most exposed to the sky, and nearly half of the heat load of a single story building comes from the roof. Different U-Roof values were simulated, to evaluate the most significant value on energy savings. For both study cases the optimum U-Roof value was 0.056 (Btu/ft^{2}h°F).

As performed previously, the optimized U-Window value was 0.557 (Btu/ft^{2}h°F) for base case 1 and 0.572 (Btu/ft^{2}h°F) for base case 2. The lower the U-Window value the better the material is at preventing heat loss. SHGC parameter has a major effect on the annual energy consumption in residential and commercial buildings. As a result, decreasing the SHGC values reduces the cooling loads. The optimized values were 0.237 and 0.244 for base case1 and base case 2, respectively.

Payback period (PBP) analysis was applied as an optimality condition. The consumer benefit is in less than five years. Optimization process for the large data was conducted. Using the data of Table 1, the CO_2 emissions were reduced by approximately 10% for base Case 1. In base Case 2, the CO_2 emissions was reduced by 7% and applied to the optimized values of the assessed parameters (see Table 2). The reduction of the optimal solution in the CO_2 emission of base Case 1 was higher than base Case 2. This is due to the lower values of the SHGC and U-Window.

3. Conclusions

Text This study aims to optimize and quantify achievable potential energy savings by applying various values of the overall heat transfer coefficient of the wall, roof, window and SHGC to residential and commercial buildings in Kuwait.

Higher energy savings can be achieved by variant configurations within each U-value, and SHGC.

A significant amount of insulation is necessary for the walls and roof in order to achieve the minimum U-Value to reduce electric energy consumption in residential and commercial buildings.

Decreasing the insulation thickness causes an increase in the indoor temperature of the building. Minimizing the U-wall and U-Roof values is a significant challenge in the design and operation of an energy-efficient building. It is concluded that, lower energy consumption and CO_2 emissions can be achieved by proper choice of glass, which delivers a positive impact for the environment in energy savings.

By analyzing the U-Window and SHGC parameters, it was found that reducing the SHGC of the fenestration system, in residential buildings, is more effective in saving energy.

Attention should be given to window thermal and solar radiation characteristics, when large window areas are used. The type of glazing system needs to be carefully considered in the early design phase of future buildings. A lower SHGC value is advantageous in cooling load consumption. The U-Window parameter was the most effective value on the incremental initial cost. A lower SHGC value accounts for higher construction material cost.

In base Case 1, the increase in occupancy and plug load variations increases the total energy consumption and CO_2 emissions by approximately 13% over base Case 2. This results in an increase in environmental pollution and harmful effects on human health.

Energy consumption is expected to increase as the occupancy and plug load increases. The U-Window parameter was the most effective in terms of reducing the initial cost.

Using the optimized values for each case resulted in the reduction of CO_2emissions up to 7% and 10% for residential and commercial buildings respectively.

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