A PARAMETRIC STUDY OF THE ENERGY EFFICIENCY OF EXISTING AIR-CONDITIONED BUILDINGS IN KUWAIT

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ABSTRACT

In Kuwait air-conditioning systems consume approximately 70% of the grid energy during the long summer months. In this paper, various practical approaches are investigated to enhance the energy efficiency and decrease the energy consumption of five existing air-conditioned (AC) buildings in Kuwait City. The process of energy management in air-conditioned buildings in Kuwait is overwhelming due to high energy consumption in the building sector. This study proposed an optimization technique for the proper energy management of installed AC systems to target energy-efficient buildings. In this study the aim is to explore the effect of different operating parameters, both theoretically and experimentally, and to contribute to the reduction of AC energy consumption. Consequently, the relationship between the thermal load in the air-conditioned buildings and the actual electrical energy consumption is determined, and remedial measures, along with different recommendations for energy saving, are presented. The actual thermal loads of each selected building were calculated and compared with the installed cooling capacity of the AC systems. From the results obtained it was concluded that, by implementing the suggested remedial measures, the predicted load in the selected buildings could be decreased significantly from the existing installed capacity of the cooling systems. Most of the remedial measures suggested for energy management lead to a reduction in power consumption and increased energy efficiency at different levels based on the specifications of the buildings considered and the AC systems installed, resulting in improved in economy, a reduced carbon footprint, and a cleaner environment.

KEYWORDS

reducing energy consumption, energy efficiency in buildings, AC systems, energy management in buildings.

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NOMENCLATURE

A	Surface area, ft^2
AC	Air-conditioning
CFM	Air flow rate, ft^3/min
CLF	Cooling load factor
DBT	Dry bulb temperature, °F
WBT	Wet bulb temperature, °F
RH	Relative humidity, %
h_j	Heat transfer coefficient, Btu/hr ft^2 °F
m	Mass flow rate of air, Ib/hr
Btu	Power consumption for lighting, Btu
MEW	Ministry of electricity and water
Q_L	Latent heat, Btu/hr
Q_S	Sensible heat, Btu/hr
T	Temperature, °F
$\dot{V}$	Air volume flow rate, ft^3/min
U	Overall heat transfer coefficient, Btu/hr ft^2 °F
W_i	Humidity of inlet air, Ibw/ Ib d.a.
W_o	Humidity of outlet air, Ibw/ Ib d.a.
ρ	Air density, Ib/ft^3

1. INTRODUCTION

The climate in Kuwait is hot and dry in the desert areas and hot and humid along the coastal regions during March to November, the long nine months of summer. The maximum ambient temperature may reach 120.2°F, and the average temperature is 96.8°F for most of that time. In Kuwait, the building sector consumes almost 70% of public electricity generation, hence there is a critical demand for air-conditioning in buildings to operate in an energy efficient manner. Energy consumption in buildings directly depends on outdoor and indoor environmental conditions and corresponding CO_2 emissions, resulting in more global warming. Thus, the main focus of this study in the building sector is to minimize energy consumption levels as low as possible, but how can this be achieved? This question is not easy to answer directly; there is a need to analyze all the parameters contributing to the energy consumption in buildings and a great deal of research and effort are needed in this field to achieve the target of making buildings energy efficient and green. To this end, literature in this area was reviewed and analyzed.

Previous studies have mainly focused on the methods that can be applied to minimize the energy consumption in air-conditioned buildings; for example, selecting special types of window glass with high thermal resistance, specialized glazing, materials, and layers. The researchers in (Kontoleon K.J. and Bikas, D.K. (2002), Cordoba et al. (1998)) used window glass with special coatings or film layers to increase the reflectivity of glass, thereby reducing the rate of heat gain through the building by conduction or due to solar radiation. It was found that using the thermal insulation, colored coatings for glazing of window glass, and increased shading are beneficial to the reduction of energy consumption. It was reported that an increase in the ambient temperature from 95°F to 122°F can increase the energy consumption of an air-conditioning unit by approximately 20% due to the increase in the cooling load of a building. Askar et al. (2000) used double or triple glazed window glass with interface air spaces to increase the thermal resistance of windows which led to a decrease in the overall thermal coefficient and subsequent conduction through the window glass. Smart window technology can be used to save energy in air-conditioned buildings (Sekhar S.C., and Toon, K. (1998)). Moreover, decreasing their surface area and size leads to a reduction in the conduction heat gained through glass walls and in the effect of solar radiation, which directly reduces energy consumption, as reported in (Al-Sallai, K.A. (1998).

The difference between dry and wet bulb temperatures is large in Kuwait, especially on very hot and dry days, so it is better to use evaporative cooling which can achieve significant energy savings, as discussed in (Al-Rogom et al. (1999). The use of an indirect evaporative cooler coupled with an air cooled condenser in an AC system will reduce the energy consumption of a building. Elfahed B. and Koluib, A. M. (2004) used evaporative cooling in a 10 TR package air conditioning unit, and it was shown that the condenser air inlet temperature could be decreased by 23–30% by evaporating cooling, and hence the coefficient of performance (COP) of the cooling system increased by 35–42%. An approximate saving in energy consumption of 26% was obtained for the AC system. Many investigators have designed and tested evaporative coolers under different climatic conditions, as discussed in (Mc. Clellan, C. H., (1988), Huang, et al. (1991). From the results it was shown that evaporative cooling systems are very effective to provide comfortable conditions during very hot and dry conditions.

Sodha et al. (1986) applied simple methods for calculating the cooling load of buildings based on the use of very low thermal resistance wall layers and a very high shading coefficient. Also, they used an indirect evaporative cooler system for cooling the air condenser of the package central cooling system, which was also reported in (Tulsidasani et al. (1998). A mathematical model for calculating the thermal load and overall performance of the AC system in a building was studied by Hatamipour et al. (2007). They analyzed the power consumption and its relationship with environmental and operational issues. Bejan, A., (1978) designed an efficient pair of condenser and evaporator of the chilled water cooling system. The performance of the heat exchanger applied to the design criteria was measured and performance was compared with conventional units. The results showed a reduction in energy consumption by 20–25% when using a fin enhanced heat exchanger with a condenser manufactured for the AC system. The entropy based mathematical model was developed and applied to the condenser of the AC unit to assess the performance and size of the condenser. Typical of energy based studies are those presented by (Bergles et al. (1978) and Cowell (1990).

Alexis et al. (2012) investigated the methods used to increase the energy efficiency of 42 AC commercial buildings under humid, tropical climatic conditions. The thermal design of these buildings was considered to be very poor. The authors noted an increase in energy saving of 12.3% in the buildings considered by utilizing the efficient thermal design of the building envelope and selection of efficient AC systems. Srinivasan et al. (2015) investigated energy efficient AC system designs and selection of equipment to reduce the energy consumption of buildings. Proper selection of components of the chilled water system such as pumps and air handler were discussed. The energy consumption of a central AC package unit was measured by Luiz and Nogueira (2013). It was noted that the energy consumption increased with increase in ambient temperature, window glass area, low shading effect and high condenser temperature.

Elahee (2014) investigated the energy management system in AC buildings. He focused on the use of efficient tools for energy saving in buildings and studied the effect of different factors on energy consumption, including lighting, intensity, external wall insulation and load type. Guo et al. (2013) investigated methods of optimizing the energy saving in central AC package units in existing buildings. The authors focused on the use of recent technologies for improving the performance of AC systems, such as an electronic inverter. Gavin et al. (2015) measured the performance of AC buildings in the UK. This study evaluated an office buildings using chilled water AC systems. The total energy consumption of an AC system was reduced by approximately 12.8% by improving the operational factors of the system. Daisuke et al. (2006) investigated the energy performance of a heat pump chilled water AC system, using inverter controller technology, and achieved an energy saving of approximately 20%. Fulin et al. (2009) utilized different methods of saving energy in AC rooms. From the results it was found that AC systems controlled by energy saving controllers that govern the appropriate logic and parameter settings can save energy up to 3% when compared to ordinary controllers.

The present work considers the feasibility of improving the energy consumptions of AC systems under the climatic conditions of Kuwait using analytical and experimental approaches. Optimization techniques were used for the proper energy management of installed AC systems to target the energy-efficient buildings. So, the main aim of this study is to explore the effect of different operating parameters, both theoretically and experimentally, and to contribute to the reduction of AC energy consumption. A simple computer program was developed to analyze the results of thermal load and energy consumption during the summer season. Different suggestions and guidelines were adopted to reduce the thermal load and energy consumption in the buildings considered.

2. BUILDING THERMAL LOAD ESTIMATION PROCEDURES

Before the selection of the proper air-conditioning system for any building, the thermal load of the building has to be estimated. It is essential to know the instantaneous thermal load of a building in order to define its energy consumption. The thermal load of the building involves many factors, including heat transfer through the building envelope, solar radiation heat gain through glazing portion, number of lights, occupants and equipment. Estimations of the refrigeration capacity are used to select the air-conditioning system and the appropriate energy consumption rates are determined.

The main parameters affecting the rate of estimation of the thermal load in a building are the ambient temperature, ambient humidity ratio, thermal insulation of external walls, glazing wall area, type of glazing, building area and orientation, density of occupancy, appliances, lighting, and ventilation rate. The ambient temperature has a predominant effect on the thermal load in buildings, and higher ambient temperatures lead to increases in cooling load while lower ambient temperatures lead to increases in heating load and consequently the increase in energy consumption. Furthermore, the overall cooling/heating load depends on both outdoor and indoor design conditions.

In hot and arid areas, such as Kuwait, the ambient temperature during summer may reach 131°F and thereby cause a huge increase in the energy demand required for cooling. Presently, the existing installed cooling systems in Kuwait are vapor-compression air-conditioning units to meet the cooling demand of buildings. The recommended design conditions for Kuwait are given in Table 1.

TABLE 1. Design conditions for Kuwait (Kuwaiti MEW Code).

Condition	DBT	WBT	% RH
Outdoor	115°F	82°F	45–90%
Indoor	78°F		50%

The cooling load (both sensible and latent heat load) is calculated by taking into account the effect of heat gain through different sources:

$$Q_t = Q_C + Q_S + Q_I + Q_V \tag{1}$$

where Q_t is the total cooling load; Q_C is the heat gain by conduction from external walls and partitions; Q_S is the heat gain due to the effect of the sun's radiation through glass windows and glass walls; Q_I is the heat gain due to lighting, people and appliances; Q_V is the heat gain due to the ventilation rate into the building.

The heat gains due to conduction through the exterior roof, walls, and glasses are calculated from the following equation:

$$Q_C = U \times A \times TD_C \tag{2}$$

where U (BTU/hr-ft^2-°F) is the overall heat transfer coefficient for roof, wall, and glass and TD_C is the corrected temperature difference, °F. If the actual conditions differ from any of the above, the TD_C is corrected as follows:

$$TD_C = (TD + LM)K + (78 - t_R) + (t_a - 85) \tag{3}$$

where TD is the tabulated temperature difference; LM is a correction for latitude and month; K is a factor based on the color of the external surfaces which is 0.75 for walls, 1 for the roof or glass; t_R is the room temperature on a design day, °F; t_a is the average outside temperature on a design day, °F. The temperature t_a can be calculated as follows:

$$t_a = t_o - (DR/2) \tag{4}$$

where t_o is the outside design dry bulb temperature, °F; DR is the daily temperature range, °F which is taken as 20°F for the design conditions in Kuwait. The external wall surface temperature must be determined using different equations in the case of an unsteady state. It is based on various factors such as radiation intensity, dry bulb temperature variations and peak time calculation. The accumulation heat inside the wall also affects the outside ambient design temperature.

A large amount of the heat gain in a building takes place due to transmission of heat from solar radiation across glass walls and windows. The thermal load due to solar radiation can be determined using the following equation:

$$Q_S = SHGF \times A \times SC \times CLF \tag{5}$$

where *SHGF* is the maximum solar heat gain factor which is based on building orientation, BTU/hr-ft^2; *SC* is the shading coefficient; *CLF* is the cooling load factor for glass. The final cooling load in an air-conditioned building can be divided into two main loads: internal and external. The internal load consists of heat gain due to lighting, people and appliances. The total internal cooling load is therefore determined using the following equation:

$$Q_I = Q_{\text{Light}} + Q_{\text{Person}} + Q_{\text{Appliances}} \tag{6}$$

The heat load from lighting in the building can be calculated by using the following equation:

$$Q_{\text{Light}} = 3.41 \times W \times Fu \times Fs \times CLF \tag{7}$$

where *W* is lighting capacity, watts; *Fs* is the Ballast factor; *Fu* is the use factor; *CLF* is the cooling load factor for lighting. The factor *Fs* accounts for heat losses in the ballast in fluorescent lamps, or other special losses. A typical value of *Fs* is 1.2 for fluorescent lighting. For incandescent lighting, there is no extra loss and *Fu* is equal to 1.

The heat gain rates in the building due to occupancy (persons) and appliances are determined from the Tables listed in Ref. [27]. The heat gain from people consists of two parts, sensible and latent heat. The total heat gains due to occupancy can be calculated using the following equation:

$$Q_{\text{Person}} = n(q_s \times CLF + q_l) \tag{8}$$

where q_s and q_l are sensible and latent heat gains per person respectively and n is the number of occupied persons in a space. The rate of heat gain from people depends on their physical activities. The heat storage factor *CLF* applies to the sensible heat gain from people only. If the air-conditioning system is shut down at night, then no storage should be included and the value of *CLF* will be 1.0.

The heat gain in a building due to appliances can be calculated based on the rated power consumed by appliances in that building which can be taken directly from the nameplate data. Some heat output generated from typical appliances can also be taken from [27]. The appliance heat gain in the air conditioned building can therefore be calculated using the following equation:

$$Q_{\text{appliances}} = P \times CLF \tag{9}$$

The heat gain due to air infiltration through cracks around windows or doors can be divided into sensible and latent heat loads. Whereas most air conditioning (AC) units have special devices to make ventilation in very isolated spaces such as internal rooms. Ventilation is required to reduce indoor air pollution, refresh indoor air and improve air quality. As a rule, 50% of inside air volume must be replaced every 24hrs for proper ventilation of buildings. The required equations for determining the sensible and latent heat gains through the building due to ventilation are:

$$Q_s = 1.1 \times CFM \times (T_o - T_i) \tag{10}$$

$$Q_L = 0.68 \times CFM \times (w_o - w_i) \tag{11}$$

where *CFM* is the air ventilation rate, ft^3/min; T_i is inside temperature, °F; T_o is outside temperature, °F; W_o, W_i represent the outdoor and inside humidity ratio respectively, Lbw/Lb d.a. The total heat gain due to outside air flow used in ventilation (Q_A) is calculated using the following equation:

$$Q_V = Q_S + Q_L \tag{12}$$

After calculating the total cooling load in the building, the refrigeration capacity of the air conditioning system can be determined based on the peak conditions of thermal load in the building. The total refrigeration load should include the heat loss in the external ducting and heat generated by the motor blowers of air handling units.

3. SPECIFICATIONS OF THE BUILDINGS SELECTED

In the present study, five different air-conditioned buildings were selected for evaluation. These are a hospital in Farwaniya, a primary school for girls in Farwaniya, a health center in Farwaniya, and buildings 23 and 102 at the College of Technological Studies (CTS) in Kuwait. The specifications of the selected buildings were obtained and used for calculations of thermal load and power consumption. Only the specifications for the hospital in Farwaniya are shown in this paper as an example, see Table 2.

4. METHODOLOGY

4.1 Experimental Measurements

Various tools/instruments were used to measure the operating parameters during the peak cooling load period in the selected buildings. Peak energy consumption in Kuwait occurs

TABLE 2. Specifications of the Farwaniya hospital building.

Parameter	Description
Shell wall	Hollow concrete blocks 28 cm thick with cement plaster as exterior furnish, K, = 1.5 W (m. °C), solar heat absorption factor = 0.56
Roof	Concrete blocks, 15 cm thick, K = 1.4 W (m. °C), ρ = 1000 kg/m^3 solar heat absorption = 0.56.
Interior wall	2 cm thick made from gypsum plaster, light green color
Windows	Aluminum frames, 1.6 × 0.8 m
Glass type	Normal clear glass, 4 mm thick, with vertical screen, light brown color
Air flow rate	4500 m^3/h
People	630 persons in building
Lighting	Lighting heat load = 55 W/m^2
Equipment	Appliances heat load 942 kW.
Building overall area	105000 m^2

between the middle of June and middle of August. The power consumption of all AC equipment in the building, for example, compressors, fans, blowers and pumps were measured using a watt meter with an accuracy of 0.2 W. Also, different temperatures were measured inside and outside the buildings, including temperatures of rooms, ambient temperature, supply air flow rate and return air flow rate temperatures. Some temperatures at certain points that were at different locations were measured using T-type thermocouples, while the other temperatures were measured by portable digital thermometers, where their accuracy is ±0.1°C. Also the air flow rates from blowers were measured using a hot-wire anemometer, with an accuracy that is ±0.05 cfm. Each case was measured individually and the experimental results were compared with the normal situation and operating conditions. For proper comparison among different cases, experimental data was taken to maintain the outdoor temperature within the variable studied ranges. The measured data was analyzed using Excel software with special designed programs.

4.2 Theoretical Calculations

Eighteen different cases involving various parameters were considered for the calculation of cooling load and power consumption of the selected buildings described in Table 3. In these cases seventeen parameters or combinations of parameters were considered as having the potential to improve energy efficiency and reduce the cooling load and consequently the power consumption of the air-conditioned buildings. The power consumption in these cases was calculated with and without the involvement of these parameters to estimate the reduction in power consumption. These parameters could be taken into account during the design phase of building specifications and other related HVAC system specifications.

The existing building without any modifications was taken as a base case (0-case) to be a reference against which the effect of changes in the selected parameters and corresponding cooling load could be compared. The effects of each parameter either alone or in combination were determined and the corresponding cooling load was calculated for each case of the selected buildings. The percentage improvement in power consumption in all cases was considered using the simple Excel program and the theoretical equations (1–12). The percentage power consumption was calculated only for certain reference days in the month of July.

5. RESULTS AND DISCUSSIONS

The predicted cooling loads of the selected buildings were estimated using a simple computer program. The installed cooling system capacity was compared with the predicted cooling load. The results obtained for the five selected buildings are summarized in Table 4 where the comparison between the cooling capacity (kW) of the installed cooling systems, new predicted cooling capacity (kW) with the suggested modifications incorporated (Cases 1–17) in the basic case building and the corresponding percentage of energy saving is shown.

From Table 4 it can be seen that the average percentage saving in energy consumption was approximately 10.8% in all five buildings, however, in the government building 23, CTS, the saving was approximately 18.1%. This means that in most government buildings in Kuwait the cooling load needs to be adjusted to save energy. The results of all the suggested cases (0–17) shown in Table 3 of the governmental building CTS 23 are shown in Table 5. The other four selected buildings' results are summarized in Table 6.

During the cooling load calculations, it was assumed that the coefficient of performance of the cooling systems is fixed and taken as 3.5 for water cooled condensers and 2.5 for air

TABLE 3. List of cases considered.

Case No.	Effects of different parameters and combination of parameters	Description
0	Base case (reference)	Building with ordinary walls and roofs (mild color), ordinary glass, interior curtain (SC = 0.04)
1	Interior curtain color	Same as case 0, curtain light color (SC = 0.56)
2	Existence of interior curtain	Same as case 0, without curtain (SC = 1)
3	Outside shading screen	Same as case 0, with outside shading screen (45° angle, SC = 0.15), no interior curtain.
4	Glass type	Same as case 3, windows with reflex glass with color coefficient of 50% (SC = 0.11).
5	Outside roof color	Same as case 3, but light color roof (roof absorbance = 0.4, SC = 0.15).
6	Color of exterior wall finish	Same as case 0, but light color wall (wall absorbance = 0.5, SC = 0.15).
7	Double glazed window	Same as case 0, but with double glazed window, distance between them 1 cm.
8	Air circulation rate	Same as case 7, but double air circulation rate
9	Combined double glazed windows + color of exterior walls and roofs.	Same as case 8, but light color of exterior walls and roofs.
10	Combined double glazed windows + color of exterior walls and roofs + outside screen shading	Same as case 9, but with external shading screen.
11	Insulation of roof	Same as case 10 but with 6 cm sand wool insulate on roof, k = 0.04 W/m.°C, ρ = 100 kg/m^3.
12	Insulation shell wall	Same as case 11, but with 6 cm sand wool insulate in walls.
13	Illumination of the building	Same as case 0, but with saved energy fluorescent lamps
14	Room set point temperature	Same as case 0, but increase room temperature but 20%. 75°F
15	Set thermostat on AUTO	Same as case 0, but put room set temperature on AUTO position.
16	Condenser unit temperature	Same as case 0, but with reduced condensing temperature by using evaporative cooler water jet on condenser of cooling system.
17	Outside fresh air quantity (ventilation rate)	Same as case 0, but with decreasing amount of outside fresh air.

TABLE 4. Comparison between the installed cooling capacity and the new predicted cooling capacity (kW).

Buildings	Installed cooling capacity, kW	New predicted cooling capacity, kW	Energy saving percentage %
Farwaniya hospital	8750	7980	8.8
Farwaniya primary school	196.6	174	11.5
Farwaniya health center	210	195	7.1
Governmental building 102	156	143	8.3
Governmental CTS, building 23	2455	2010	18.1

cooled condenser cooling systems. From the results shown in Tables 5 and 6, it can be seen that in most cases the cooling load calculated (using a simple computer program) is less than the installed cooling capacity of the cooling systems. It was found that the refrigeration capacity of the installed air-conditioning system was higher than the calculated cooling capacity for the tested buildings. This difference may also be attributed to some other factors which were taken

TABLE 5. Detailed results for the governmental building 23, CTS.

Case	Sensible cooling load (kW)	Latent cooling load (kW)	Total cooling load (kW)	Peak load consumption (kW)	Energy reduction (kW, %)
0	1560	520	2080	1980	—
2	1549	520	2069	1950	1.5
3	1502	520	2022	1920	3.0
4	1423	520	1943	1840	7.0
5	1335	520	1855	1765	10.8
6	1290	520	1810	1705	13.8
7	1255	520	1775	1685	14.9
8	1210	520	1730	1790	9.5
9	1180	520	1700	1725	12.9
10	1150	520	1670	1644	17.0
11	1090	520	1610	1589	22.0
12	1020	520	1540	1566	20.9
13	970	520	1480	1490	24.7
14	1460	520	1980	1760	11.1
15	1380	520	1900	1835	7.3
16	1490	520	2010	1710	13.6
17	1100	520	1620	1420	28.3
	1420	423	1843	1565	20.9

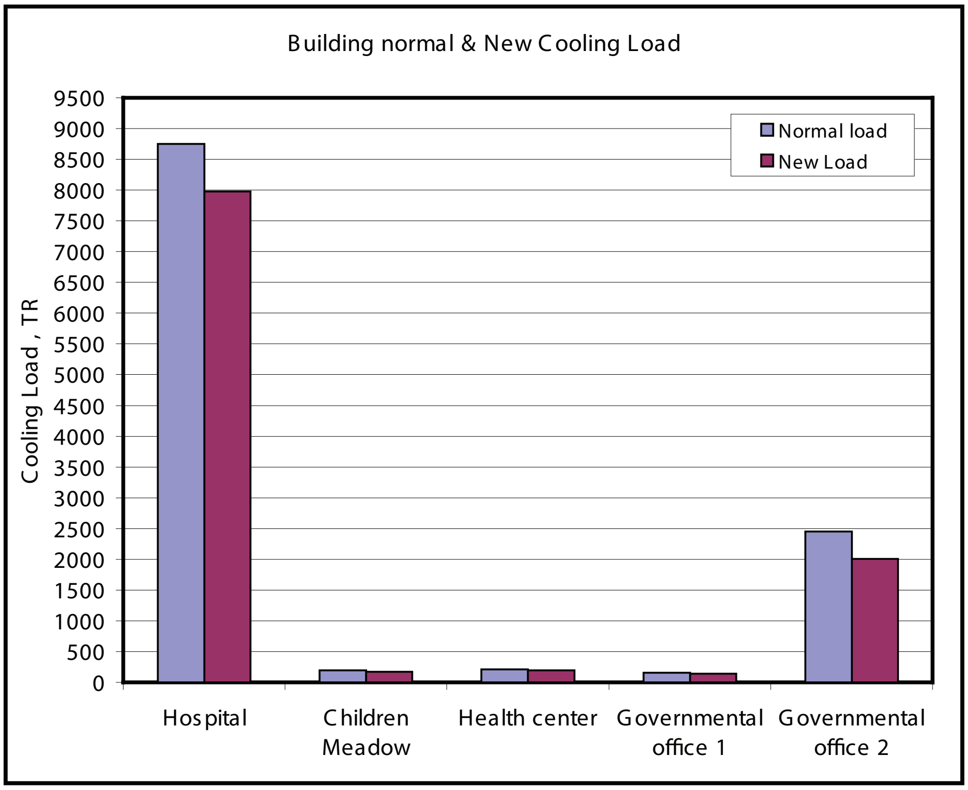
TABLE 6. Summary of the results of the four other selected buildings.

Cases	Hospital energy saving %	School energy saving %	Health center energy saving %	Building 102 energy saving %
0	—	—	—	—
1	2.8	1.8	1.2	0.89
2	2.8	2.4	2.4	1.9
3	8.8	6.2	6.8	5.0
4	7.3	-9.6	10.8	12.8
5	11.2	1.6	13.8	11.8
6	16.3	-2.6	16.9	14.1
7	12.7	8.4	9.5	10.5
8	14.9	10.5	12.9	14.9
9	16.8	13.5	19.1	13.6
10	19.9	13.2	22.0	20.9
11	21	18.2	22.5	21.6
12	23.2	17.5	19.9	25
13	8.9	15.6	12.3	10.2
14	5.2	7.3	9.6	7.9
15	2.9	13.6	14	12.9
16	—	—	—	19.9
17	32.5	23	29.3	4.3

into account during the design phase of the buildings, such as design temperature, difference in occupancy density, appliances, lighting rates, and glass surface area. It is difficult to obtain exact information about the planned cooling load for these buildings because they may have been built 20 or 30 years ago and parts of the AC units have been replaced more than once. Table 6 presents comparisons between four of the selected buildings. The percentage energy saving was calculated by determining the difference between the actual design load of the building and the calculated cooling load using the theoretical approach. The positive values in Table 6 presents energy savings while the negative values indicate that the actual values are lower than the calculated ones. The comparison between the buildings installed cooling load and the present calculated cooling load is shown in Figure 1.

Figure 1 shows that there is a significant difference between the cooling loads of all the buildings considered in this study. The calculated cooling loads in the considered buildings are lower than the actual refrigeration capacity of the cooling systems installed within them. Due to the discrepancies observed in the results, it is recommended that all of these buildings modify the operational conditions of their AC systems and replace the type of window glass used in order to reduce the total heat gain in the building. The shading effect in all buildings should be given due attention and modified where appropriate. Selecting, installing and maintaining windows, equipment and accessories can help reduce cooling, heating, and lighting costs. Furthermore, the roof of most of the buildings considered in this study need to be re-insulated with materials of a higher thermal resistance to reduce the heat gain through the roof towards

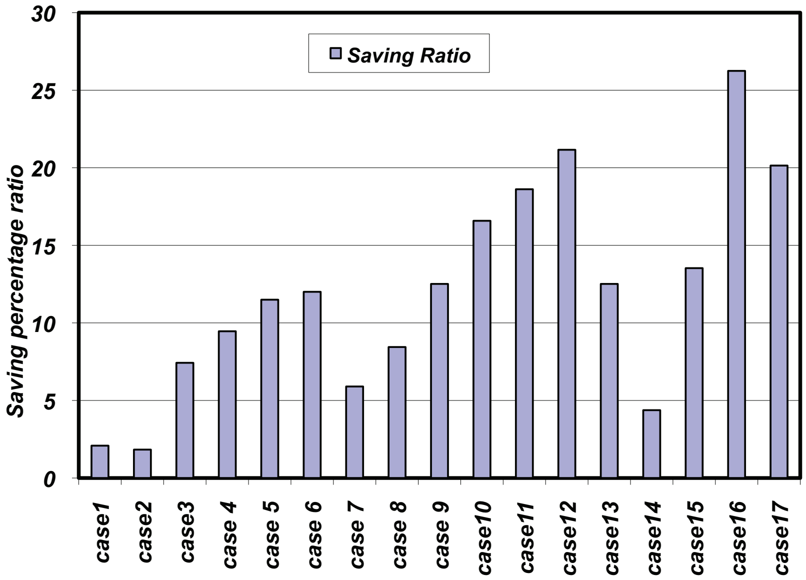
FIGURE 1. Comparisons between the buildings installed cooling load and the present calculated cooling load.



the inside of the building. The contribution made to energy savings by changes in the different parameters (displayed in Table 3 (cases 1–17), when applied to building CTS 23 is graphically illustrated in Figure 2.

Case 1 and 2 in Figure 2 indicate that the installation of colorful interior curtains at windows can achieve energy savings of about 2%. Cases 3–6 deal with the application of an outside shading screen, selection of glass type and color selection of the outside roof and walls of the building can save energy from 7 to 13% respectively. Cases 7–12 show that the application of double-glazed windows, air circulation rate, a combination of double-glazed windows and color selection of outside roof and walls, a combination of double-glazed windows and color selection of outside roof and walls and outside shading screens, insulating the roof and insulation of envelope walls, contribute between 6 and 22% respectively to the buildings' energy saving. Cases 13 to 17, which deal with illumination, the setting of room temperatures, setting the thermostat temperature to AUTO, operational temperature of the condenser units of cooling systems and the ventilation rate can be beneficial, producing energy savings ranging from 4 to 26%. From these results it can be seen that all the parameters selected, if implemented, have the potential to increase the energy efficiency of the buildings. As shown in Tables 5 and 6 and Figure 2, the major saving in the energy consumption of buildings 23 and 102 was achieved for case 16 which involved decreasing the condensing temperature of the AC system condenser unit. The temperature of the condenser unit could be decreased by the application of indirect evaporative cooling around the condensing units to increase their operational efficiency.

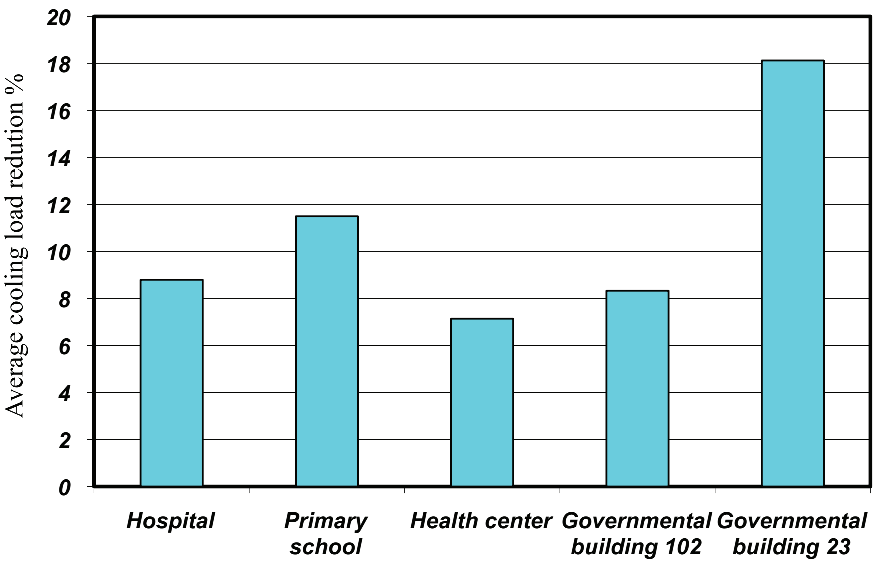
FIGURE 2. Energy saving ratio are 1–17 applied to the CTS building 23.



However, the most prominent parameters which should be given special attention are: the use of double-glazed window, glazing type of glass walls, air-circulation rate, insulation of roof and envelope exterior walls, decreasing the operational condenser temperature, and the ventilation rate of buildings. The average reduction in the cooling load (%) obtained by the implementation of the corrective measures mentioned in suggested cases 1–17 of Table 3 for the selected buildings is shown in Figure 3.

From the results shown in Figure 3, it can be seen that the average reduction in the cooling load of the five buildings due to application of the suggested parameters is 7–18%. The main

FIGURE 3. Average reduction in the cooling load of five buildings due to application of various cases (1–17).



requirement for the hospital and health center is a high rate of ventilation which results in a high energy saving when applied to such buildings. The illumination of the buildings also enhances energy savings. Reductions in heat gain or loss from the windows of the buildings leads to improved energy consumption and can be made possible through the utilization of double-glazed windows, films/coverings/curtains or use of energy-efficient nano-material coatings on window glass. Different combinations of frame style, frame material and glazing can yield very different results when weighting energy efficiency and cost. Most air conditioned buildings in Kuwait in the last few years have been designed as high energy consumers because there were no codes governing their design and specification. Now the MEW of Kuwait has adjusted and controlled the selection of AC equipment installed in buildings, and introduced a number of specifications, including for glass, walls, and roofs.

6. CONCLUSIONS

Use of the difference between dry and wet bulb temperatures to improve power consumption in Kuwait cooling systems has proved effective for most of the summer season. According to the results of the present study, the following suggestions can be taken into account to save energy in air-conditioned buildings in Kuwait:

1. From the present study it is concluded that all the parameters considered, if implemented in the design of new buildings or in existing buildings through a renovation process, have the potential to increase the energy efficiency of buildings and reduce power consumption, relieving the burden on the electricity grid during summer.
2. The most prominent parameters which should be given special attention are: the application of double-glazed window, the type of glazing used for glass walls, air-circulation rate, insulation of roofs and envelope exterior walls, decreasing operational condenser temperatures, and the ventilation rate of buildings.
3. The additional condenser evaporative cooling system is an alternative energy-conservation proposition to improve the performance of HVAC package units. Decreasing the condensing temperature of HVAC condensing units could play an important role in reducing the energy consumption of air-conditioned buildings.
4. The use of external shading screens, external curtains and planting shade giving trees or shrubs near windows would be a very effective way of reducing heat gain in buildings under hot and humid climatic conditions and result in energy saving. Further, less glass areas in external walls would generally decrease the energy consumption of buildings, as well as using small windows with proper shading.
5. The use of double glazed windows, light colored walls and roofs, and use of insulation in walls and roofs would lead to a reduction of up to 45% in the power consumption of buildings.
6. The inside temperature of a building's zone must be individually adjustable and should be set to the maximum possible value at night and when not occupied.
7. Decreasing the quantity of fresh air (ventilation rates) in buildings is a useful approach to saving electrical energy, especially during peak hours in summer.
8. During the extreme hot months in summer in Kuwait (June, July and August), it is very important to use thermostat selectors to set HVAC system fans to the AUTO position, because this will reduce electrical energy consumptions to about 14%.

9. It is recommended to recover heat from the return air to re-cool the air under ambient conditions surrounding the condenser unit. This approach is highly recommended in Kuwait buildings due to the large difference between the indoor design condition and the outdoor ambient conditions.

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