THE INFLUENCE OF AIR-CONDITIONING EFFICIENCY IN THE PEAK LOAD DEMAND FOR KUWAIT

Ahmad Al-Mulla Ali*
Associate Research Scientist

G.P. Maheshwari
Senior Research Specialist

Building and Energy Technologies
Environmental and Urban Development Division
Kuwait Institute for Scientific Research
P.O. Box 24885
13109 Safat - Kuwait
*E-mail: ahmulla@kisr.edu.kw
*Fax: (+965) 498-9099

ABSTRACT

A model co-relating the peak load demand of a utility with the allowable power rating (PR) of air-conditioning (AC) systems has been developed in this paper through a well defined methodology. The model is capable to predict the extent of allowable increase in the capital cost of the AC system for an improvement in PR from its base case as well. Furthermore, effectiveness of better PR of AC system for peak load management has been analyzed for Kuwait as a case study. It is found that up to 5,752 MW in reduction in peak load demand and savings of KD 2,301 million in capital expenditures are possible for the years between 2001 and 2025 if the PR of AC systems are improved to 1.2 kW/RT from its present level of 2.0 kW/RT. Also, it is estimated that extent of increase in capital cost of AC system by 106 % is justified for reducing the expenditure for new power plants. The paper will be useful for the energy planner and policy makers in the countries of Arabian Peninsula with huge demand for air-conditioning.

Key words: Peak power, air-conditioning, power rating.

INTRODUCTION

During last few years, between 1999 and 2006, the peak load demand in Kuwait increased from 6,164 MW to 8,900 MW and the annual electricity generation increased from 31,574,694 MWh to 43,700,000 MWh as shown in Fig. 1. An average yearly increase of 5.0 and 5.1%, respectively is being observed. Furthermore, a recently developed model using artificial neural network and incorporating effects of air-conditioning (AC) units, gross national product, population growth, number of buildings, and index of industrial production forecasted growth of 21,000 MW in peak load demand by the year 2025 with 2001 as base case [1]. The forecasted values using this model for the years 2000 to 2003 were found to have a maximum deviation of 4.3%, thus, validating the accuracy of this model. Fig. 2 shows the peak load demand and the annual capital expenditure that will be incurred for the years 2001 to 2025. Annual increase in peak load demand is expected to grow gradually from 413 MW (KD165 millions) between 2001-2002 to 1,071 MW (KD 428 millions) in 2016-2017 and thereafter it is forecasted to drop gradually. The accumulative value of the capital expenditure likely to be incurred between 2001 and 2025 is KD 8.2 billions (≅ $28.3 billions).

Ministry of Electricity and Water (MEW), the sole agency for producing and supplying electricity in the country, is deeply concerned about continuing increase in demand for electricity inspite the enforcement of the energy conservation measures, through a well-defined code of practice for new and retrofitted buildings since 1983. The code stipulates minimum thermal insulation requirements for walls and roofs, maximum glazing areas for a given type of glazing, and minimum ventilation rates; controls the performance rating of different types of AC systems; and does not permit the cooling demand or power requirement per unit area to exceed a specified value for a given building and type of AC system [2]. It is estimated that buildings constructed after the implementation of the code need 40% less cooling, 40% less peak power and 40% less annual energy. Thus, implementation of the code until 2001 resulted in savings of over 1,760 MW of peak load, 0.83 million RT of cooling capacity and over 78 million barrels of fuel. The estimated cost of these benefits is well over KD 1.5 billion (≅ $5.2 billions) [3].

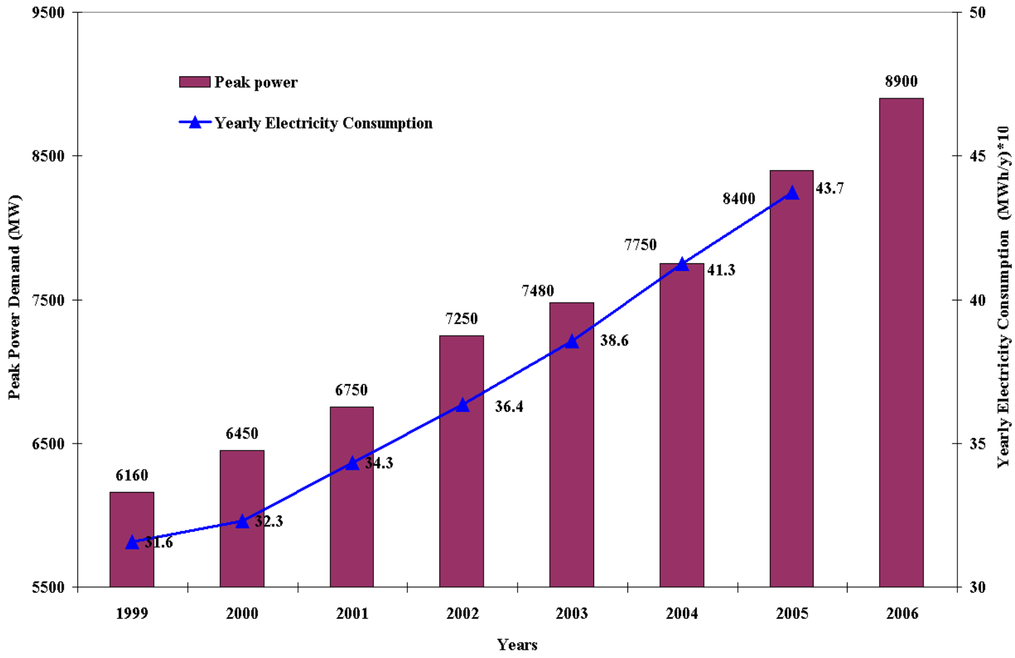

Fig. 1. Yearly Peak Load and Energy Generation in Kuwait.

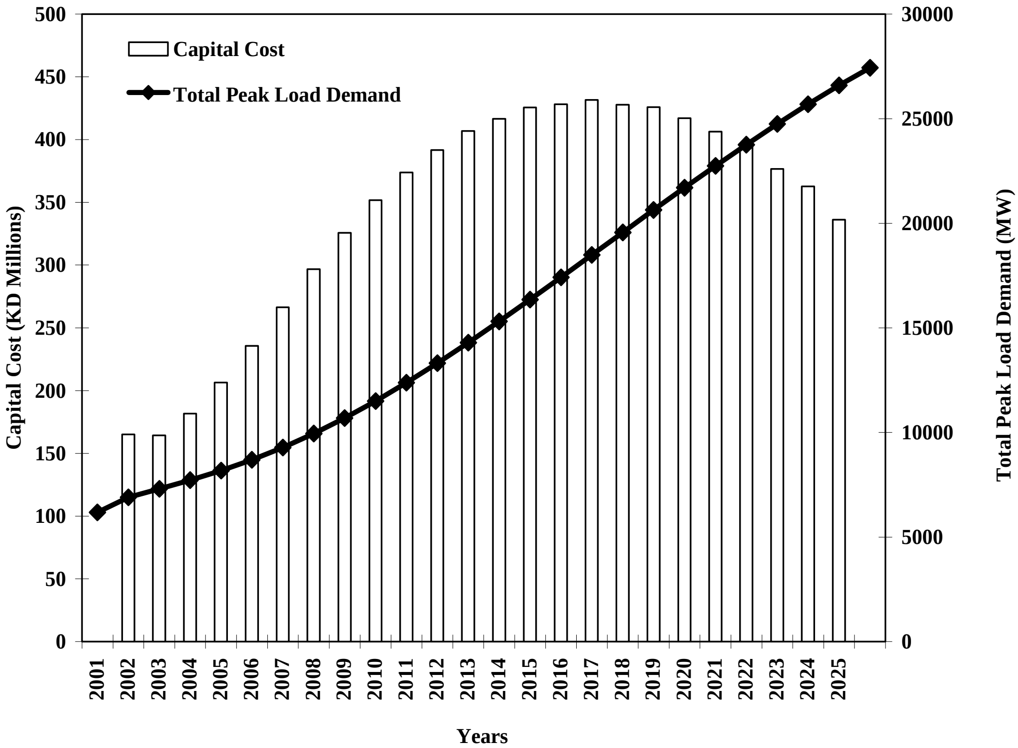

Fig. 2. Forecasted peak load demand and capital cost.

This paper analyzes imporvement in efficiency of the AC system as an option to reduce peak load requirements for the coutry since AC alone accounts for 70% of the peak load in the country [4]. Also, the paper gives an overview picture of the latest technology in the AC systems and sets criteria of selection of an energy efficient cooling systems.

MATHEMATICAL FORMULATION

Power rating (PR), the electric power requirements (kW) per unit of refrigeration cooling (RT) indicates the performance standard or energy efficiency of an AC system. An improvement in the efficiency of an AC system decreases its PR which in turn reduces the peak load requirements. A mathematical model has been developed for conducting the present analysis considering the following:

1. AC systems accounts for 70% of peak load,
2. Base PR value for the AC system is 2.0 kW/RT,
3. Average cost of A/C system is KD 300/RT,
4. Cost of electrical power equipment and distribution network is KD 400/kW.

Accordingly, the power share of AC systems (PL_{AC}) in the peak load (PL) and the cooling capacity in operation during the peak load hours (Q) are:

$$PL_{AC} = 0.7 * PL \qquad (1)$$

$$Q = PL_{AC} \frac{1{,}000}{PR} \qquad (2)$$

For a new power rating (PR_N), the revised power demand for any year n for AC ($PR_{AC,PR,n}$):

$$PL_{AC,PR,n} = Q \frac{PR_N}{1{,}000} \qquad (3)$$

The annual savings realized in peak load demand $PL_{SAV,PR,n}$ and cost of electric power generation and distribution network ($SAV_{PR,n}$) due to this revision are:

$$\Delta PL_{AC,PR,n} = PL_{AC} - PL_{AC,PR,n} \qquad (4)$$

$$SAV_{PR,n} = \Delta PL_{AC,PR,n} * 1{,}000 * 400 \qquad (5)$$

The total savings in peak load demand and cost electric power generation and distribution network acquired for the period between 2001 and 2025 having 2001 as the base case are as follows:

$$PL_{SAV,PR} = \sum_{n=1}^{24} \Delta PL_{AC,PR,n} \qquad (6)$$

$$SAV_{PR} = \sum_{n=1}^{24} SAV_{PR,n} \qquad (7)$$

In this paper, the PR is ranged between 1.20 – 2.0 and applied in the model. Fig. 3 shows the savings in both peak load and capital cost as compared with the base case of PR = 2.0 kW/RT. Reduction up to 5,752 MW in peak load and savings of KD 2.3 billions (≅ $8 billions) in capital cost can be achieved if the PR is reduced from 2.0 kW/RT to 1.2 kW/RT.

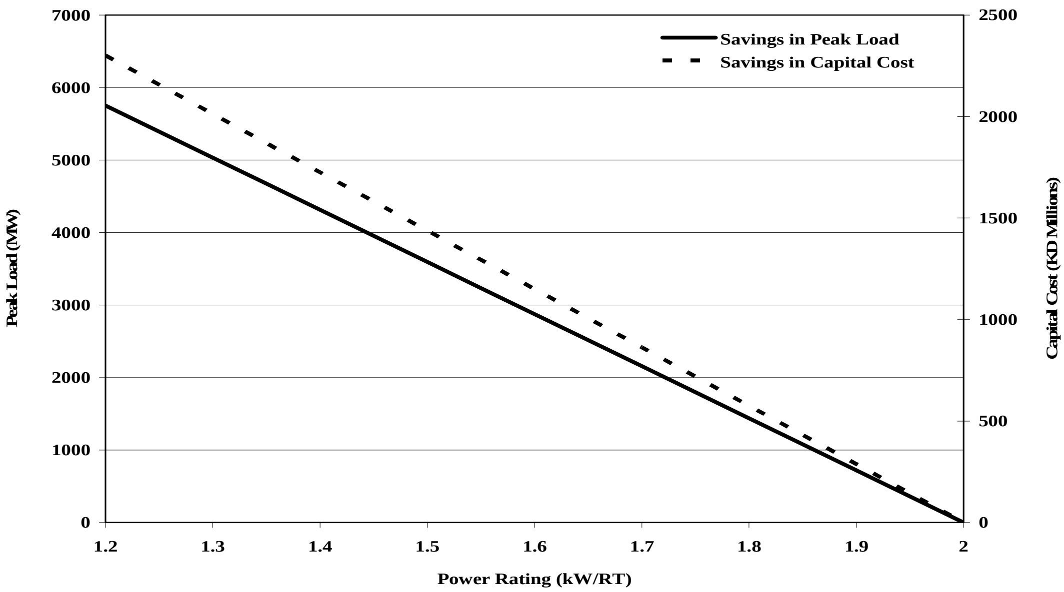

Fig. 3. Savings in Peak Load Demand and Capital Investment for Different Power Rating.

OPTIONS TO REDUCE THE GROWTH IN PEAK LOAD DEMAND FOR AC SYSTEMS

An AC system comprises components such as cooling production and cooling distribution (Fig. 4). Cooling production system includes a compressor and a condenser. The later can be either air-cooled or water-cooled based on the medium through which the heat is rejected. Accordingly the power requirements of the cooling production system are (P_c +P_{FD}) for system with air-cooled condenser and (P_c +P_{CW}+P_{CTF}) for a system with water-cooled condenser. Also, in places such as Kuwait of the other countries of the Arabian Peninsula, where fresh water is generated through desalination process, a water-cooled condenser system has to account for the energy cost of water (P_W) that is used in the cooling tower. Power requirement of cooling distribution system includes just power for air distribution (P_F) for a direct expansion system while for a chilled water system it needs an additional power for chilled water pump (P_{chw}). Improvement in design and proper selection of every component can be very important in improving the energy efficiency of the cooling system. Some of the options that can lead to a reduction in peak load demand of an AC system are as follows:

Updating Of National Standards

Present code, which was established in 1983 specifies a PR of 1.4 and 2.0 kW for the AC systems with water-cooled and air-cooled condensers, respectively. The latter includes direct expansion systems such as package units and mini-splits and the chilled water system. In view of significant improvement in energy efficiency of AC hardware and motors and accounting for the revision of outdoor design conditions more realistic PR values for different types of AC systems have been arrived by using the market information from the leading manufacturers [5]. The recommended PR values for different types of AC systems are given in Table 1. For window, split, and package units, the recommended PR of 1.7 kW/RT is 15% lower as compared to the value fixed by the 1983 MEW energy conservation code [2]. Accordingly, a revision of the 1983 energy conservation code will reduce the peak load demand by 2,157 MW and capital cost by KD 0.862 billions (≅ $3 billions) for the period between 2001 and 2025. This shows the need for a periodic revision of performance standards for AC system.

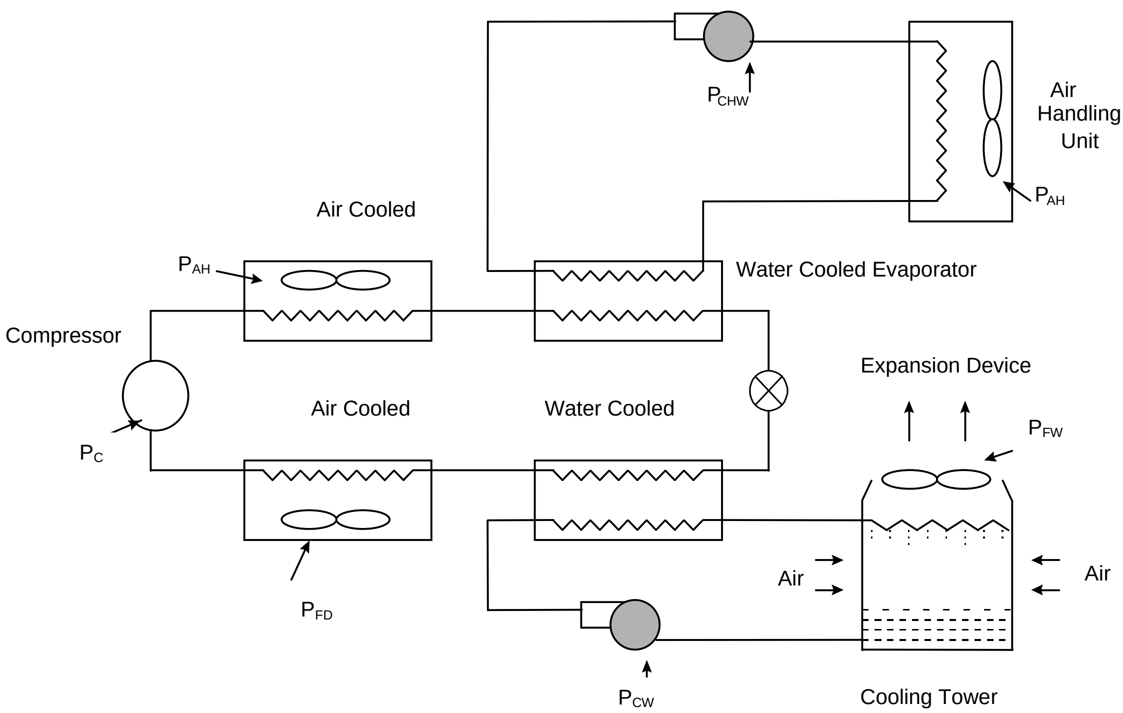

Fig. 4. Types of AC Systems.

Table 1. Recommended Power Ratings for Different Types of AC Systems [4].

System		Power rating kW/RT					
Type	**RT**	**PR_{CHIL}**	**PR_{CTF}**	**PR_{CW}**	**PR_{CHW}**	**PR_{AH}**	**PR**
Package and ducted splits	0-15						1.700
							1.700
Air-cooled	<100	1.600				0.38	2.050
	100-250						
	>250						
Water –cooled	<250	0.950	0.040	0.060	0.070	0.380	1.500
	250-500	0.750					1.300
	>500	0.700					1.250

Choice Of System

The weather in Kuwait is extremely hot and dry for most part of the country. Therefore, AC systems with water-cooled condensers are more efficient as compared with the systems with air-cooled condensers [6]. According to the present code, a water-cooled system requires 30% less power and this could be as high as 40% based on the recommended PR (Table 1). Thus, wider application of AC systems with water-cooled condensers from its present fixed capacity of 1000 RT and above can reduce the peak load demand considerably. Also, a direct expansion system such as package units, mini-splits is more efficient as compared to a chilled water system with air-cooled condenser as it does not require power to operate a chilled water pump (P_{Chw}), besides reducing the lift (pressure differential) for the compressor that leads to reduction in power demand for the compressor (P_c). Therefore, designers should opt for a chilled water system only when it is unavoidable.

Use Of Peak Power Shaving Devices

Use of peak power shaving devices such as cool storage can reduce the peak load demand significantly. A full cool storage can cut down 78% of the peak load demand for the air-cooled condenser systems and in the range of 64-70% for the water-cooled condenser systems. Although, the scope for reduction in peak load is limited in case of more cost-effective partial cool storage systems [7]. Partial storage system with chilled water is a better option, as it involves no penalties of energy and capacity during the charging mode.

DESIGN CRITERIA OF ENERGY EFFICIENT COOLING SYSTEMS

An energy efficient system has to incorporate energy efficient components besides optimum velocity in flow circuits to achieve less pressure drop. Although not limited to, it may include: use of energy efficient compressor such as scroll compressor for package units, use of more energy efficient motors and larger heat exchanger area to lower lift (pressure differential) for compressor, pumps and fans. Also, optimum sizing of piping and ducting network is important to minimize power for pumps and fans, respectively.

Impact of these factors will differ form one system to another. Nevertheless, these measures are bound to improve the energy efficiency of the cooling systems from its base case as (Table 1). Also, incorporation of these measures will incur additional expenditure. Thus, every measure has to be evaluated with proper cost- effective analysis accounting for capital cost and recurring cost for its operation during its lifetime. A simple analysis, accounting for the capital cost of the cooling systems and the power plant has been conducted for different PR ranging from 1.2 to 2.0 kW/RT. Results shown in Fig. 5 indicate that an increase in cost of cooling system with packaged units by 67% is well justified if PR can be improved from the base case of 2.0 KW/RT to 1.5 kW/RT and an increase of well over 106% is beneficiary if the PR can be lowered to 1.2 kW/RT.

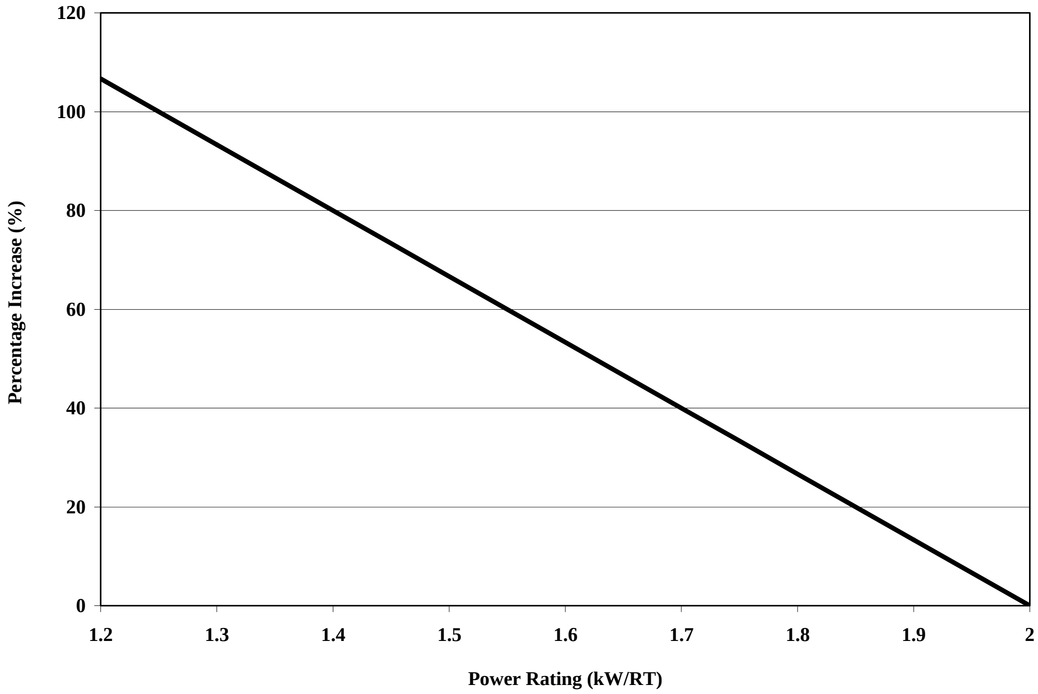

Fig. 5. Allowable Increase in the AC equipment cost.

CONCLUSIONS

A mathematical model was created to investigate the impact of different PR of the AC systems in the peak load demand. Important conclusions based on the analysis are:

- Revision of energy conservation of code as per recommended PR can achieve savings of 2,157 MW and KD 0.862 billions (≅ $3 billions) between 2001 and 2025.
- Savings up to 5,752 MW and KD 2,3 billions (≅ $8.0 billions) can be achieved in peak load demand between 2001 and 2025 if the PR is reduced from 2.0 kW/RT to 1.20 kW/RT.
- An increase in the cost of cooling systems with package unit by 106% is well justified if the PR is improved to 1.2 kW/RT from its base case.

This paper justifies selection of an efficient cooling system for better peak load management. Besides they offer added advantages of reducing the annual energy consumption leading to reduction in consumption of fuel and release of green house gasses.

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NOMENCLATURE

P	power, kW
PL	Peak load, MW
PR	Power rating, kW/RT
Q	Refrigeration cooling, RT
SAV	Savings of electrical power equipment and distribution network, KD millions

Subscripts

AC	Air-conditioning
C	Compressor
cf	Condenser fans
chwp =	Chilled water pumps
ctf	Cooling tower fans
cwp	condenser water pumps
N	New
n	Year
PL	Peak load
PR	power rating