Optimization of Chilled Water Flow and its Distribution in Central Cooling System

G. P. Maheshwari, A. E. Hajiah and A. I. ElSherbini

Department of Building and Energy Technologies
Environment and Urban Development Division
Kuwait Institute for Scientific Research
P.O. Box 24885, 13109, Safat, Kuwait
gmhshwri@safat.kisr.edu.kw

ABSTRACT

This paper analyzes the impact of chilled water flow and its distribution on energy efficiency and comfort quality, using the results of a field study conducted for a central cooling production system during 2006 in Kuwait. The paper identifies design and operational inefficiencies and measures their impact in deteriorating the energy efficiency and comfort quality through actual implementation. Over sizing of chilled water pumps was identified as the major design inefficiency. The operational inefficiency included improper distribution of chilled water in the main branches, and bypassing return water through non-operating chillers.

Key words: **Chilled water pump, over sizing, non uniform flow.**

INTRODUCTION

Cooling is essential for all types of buildings in Kuwait. Most of the air-conditioning (A/C) systems used in commercial and institutional buildings are of large capacity. These systems use chillers for cooling production and a network of chilled water piping for cooling distribution to the individual Air-Handling Units (AHUs) or Fan Coil Units (FCUs). The cooling production system is designed to meet the maximum cooling load during worst design conditions to ensure comfort for the building occupants. Thus, cooling systems operate under part load conditions for most of the time.

Chilled water flow and its distribution in central cooling plants are often considered of less significance for energy efficiency and comfort quality. Lately, limited attention is being paid to its design for energy efficiency consideration. The operational aspect also continues to be neglected. In Kuwait, the revised Energy Conservation Code of Practice fixes a power limit of 0.07 kW/RT for the chilled water pumps (Maheshwari et-al, 2000). This was not part of the earlier code of 1983 which is being applied for all types of air-conditioned buildings.

This paper analyses the impact of chilled water flow and its distribution on energy efficiency and comfort quality in the main building of Kuwait Institute for Scientific Research (KISR). The findings are part of a project conducted during 2006 with the objective to develop and implement an optimal operation strategy for the cooling production system.

APPROACH AND METHODOLOGY

The optimization was carried out by maintaining desirable indoor comfort during the occupancy period, with minimum peak load and annual energy consumption. KISR's building is occupied between 07:30 and 15:00 h, Saturday through Wednesday. An energy efficient operation strategy was developed and implemented during the summer of 2006. The scope of implementation was confined to the cooling production system that comprises of chillers and chilled water pumps. It excluded the air-distribution system. Performance results before and after the implementation were compared and savings were quantified.

Optimization of cooling production was based on improving the power rating of the chiller and reducing the power consumption of the auxiliaries (i.e., the chilled water pumps). It was achieved by implementing a combination of energy efficiency and energy conservation measures.

Important energy efficiency measures that were implemented included: optimization of water distribution in the three branches, closing flow through the chillers that were not in operation, and increasing the loading of chillers by reducing the number of chillers in operation. These measures were implemented while delivering water at the same temperature to different AHUs. Important energy conservation measures that were implemented included: keeping supply chilled water temperature higher during non-occupancy periods and low demand season, while maintaining the required comfort level during occupancy periods, and minimizing the number of chilled water pumps in operation, both during the occupancy and the non-occupancy periods.

Based on the field data, this paper analyses the importance of chilled water flow rate and its distribution in achieving the optimum operation of the cooling production system.

AIR-CONDITIONING SYSTEM DESCRIPTION

The A/C system, commissioned in 1984, is designed to provide year-round comfort conditions with constant air and chilled water circulation. The cooling production system consists of ten air-cooled chillers, each with a centrifugal compressor using refrigerant R12 and three condenser fans. The cooling distribution subsystem has four chilled water pumps (including a standby pump). Major components of the cooling system and their power requirements are presented in Table 1 and a schematic diagram of the cooling system is shown in Fig. 1.

Chilled Water Flow Rate and Distribution

Chilled water is fed to the main header and most of it (over 96%) is distributed in three parallel branches running along the width of the building. Water from these branches is fed to a number of AHUs and FCUs and each one of them is provided with a 3-way motorized valve that controls the water flow through the cooling coil, depending upon the cooling demand. However, regardless of the cooling demand of individual users, the water flow in the three branches and the main header is fixed for a given number of pumps in operation. The return water from the individual users, collected through their branches and the main header, is brought to the pumps for recirculation.

Table 1. Important Features of the Cooling System of KISR's Main Building.

No.	**Component Name**	**Quantity**	**Connected Load (kW/Unit)**	**Total Load (kW)**
1	Chiller	10	418	4180
2	Chilled water pump	4	75	300
3	Supply air fans for AHUs	23	0.55-45	258
4	Return air fans for AHUs	15	0.25-22	114
5	Fan coil units	67	0.18	12
6	Exhaust fans		0.18	
	Total connected load		Over 4780 kW	

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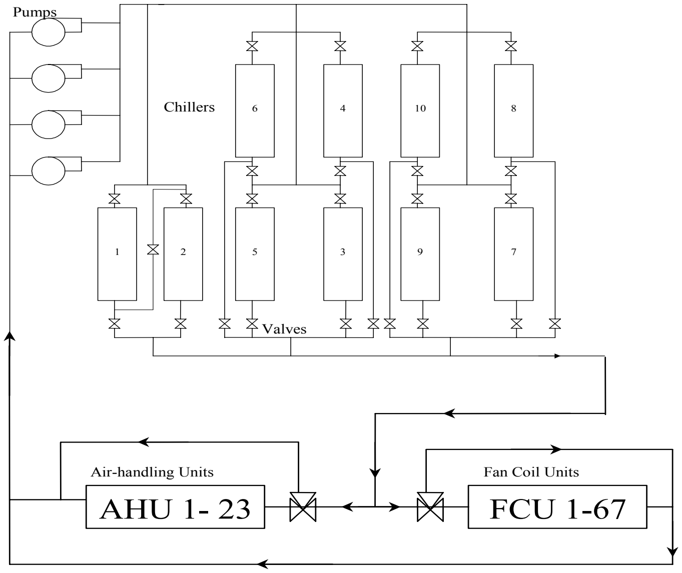

Fig. 1. A schematic of the cooling system in KISR's main building.

RESULTS AND DISCUSSION

Optimization of chilled water flow and its distribution made a significant contribution in improving the energy efficiency of the cooling production system. The results of implementing different modifications and their impact are discussed and analyzed herewith.

Optimization of Water Distribution Through Main Branches

As a first step, optimization of water distribution through the main branches was carried out with a simple approach to ascertain nearly same temperature rise in the three branches. For a peak summer day, the temperature rises in the three branches were monitored with water flowing through six chillers. With three pumps in operation between 7:00 and 19:00 h and two pumps in operation thereafter, the temperature rises ranged between 1.0 and 2.5°C (Fig. 2a) as against a common practice of 5.6°C (10°F). This clearly indicated that the water flow through all the three branches was considerably high. Furthermore, the water distribution through the three branches was not in proportion to the cooling demand of the areas fed by these branches as they had different temperature rises. Branch 2 had a temperature rise of little over 1°C while it was close to 2°C for the branch 3. This revealed that proportionately, the branch 3 had less than the required flow while the opposite was true for branch 2.

After the readjustment of the flow in proportion to the cooling demand, the temperature rises in the three branches were nearly the same. The temperature rise with 2 pumps in operation and six chillers in flow circuit is shown in Fig. 2b. This adjustment facilitated proportionate flow in the three branches. In addition, it ensured that two pumps delivered to branch 3; the branch with maximum cooling load and proportionately deficient water flow, the same amount of water (10,000 l/m) it was receiving with three pumps, as shown in Table 2. This measure saved the power of one pump and reduced its consequential heat gain to the system cooling load, besides ensuring uniform comfort in different parts of the building.

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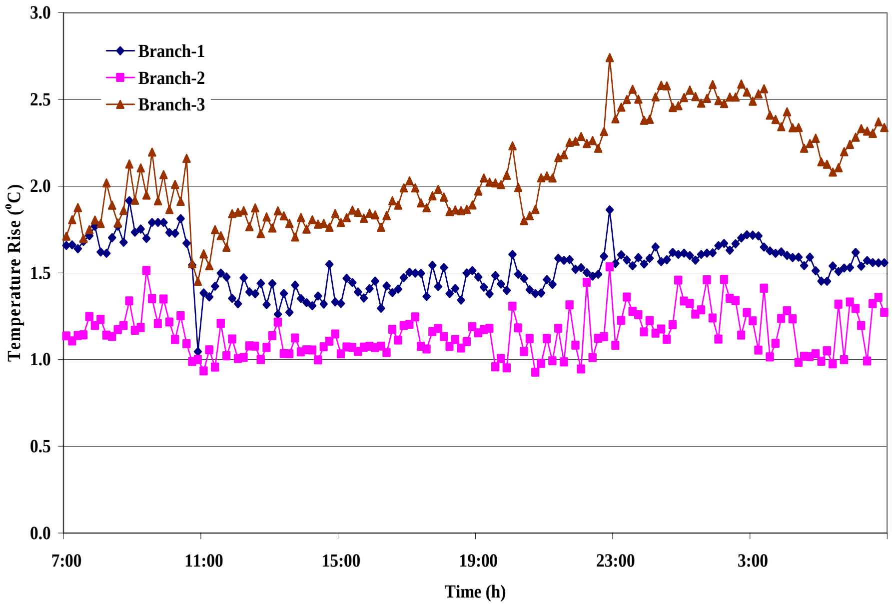

Fig. 2a. Temperature rise in three branches for the original flow with three pumps and six chillers in flow.

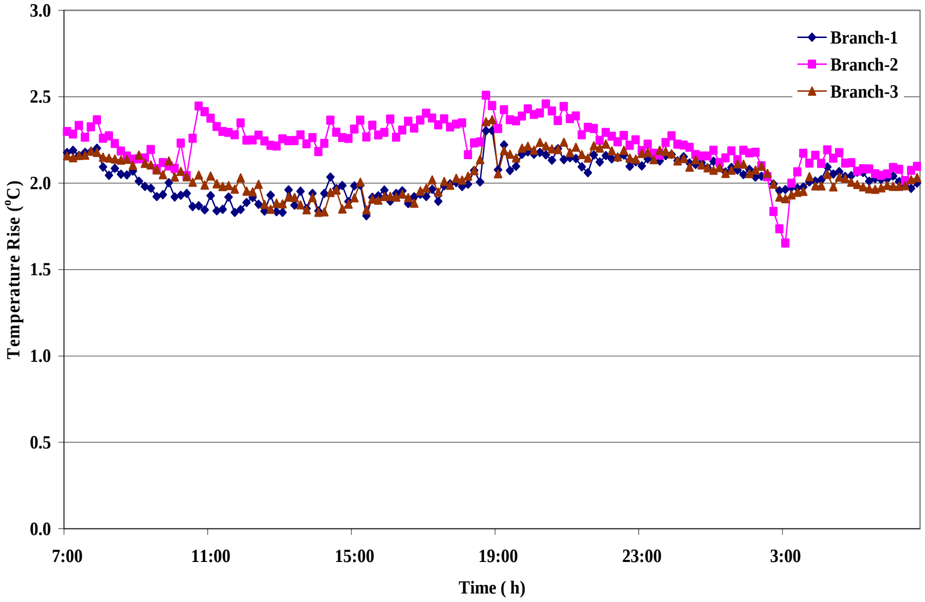

Fig. 2b. Temperature rise in three branches for the adjusted flow with two pumps and six chillers in flow.

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Table 2. Original and Adjusted Flow with Two and Three Pumps and Six Chillers.

Water Carrier	Three Pumps						Two Pumps					
	Original Flow			Revised Flow			Original Flow			Revised Flow		
	l/m	GPM	%	l/m	GPM	%	l/m	GPM	%	l/m	GPM	%
Branch-1	4880	1291	24.5	3100	820	18.2	4200	1111	25.5	2560	677	17.4
Branch-2	4310	1140	21.6	1770	468	10.4	3460	915	21.0	1510	399	10.2
Branch-3	10000	2646	50.1	11600	3069	68.2	8250	2183	50.2	10000	2646	67.8

Closure of Flow through Chillers not in Operation

Analysis of the June 10th data revealed that the chilled water was flowing through 8 chillers, although the number of chillers in operation varied between 4 and 6. Return water bypassed through non-operating chillers was thus mixed with supply water leaving the operating chillers. Due to this mixing, the temperature of chilled water supplied to the AHUs was higher than the temperature of water produced by the chillers. The rise in temperature ranged between 0.6 and 2.0°C and the daily average was 1.3°C (Fig. 3a). During the lean demand season when fewer chillers were in operation, the situation was worse. On February 6th, with a single chiller in operation and three chillers in flow (Fig. 3b), the temperature rise due to mixing was about 1.8°C and it was uniform throughout the day. All in all, throughout the year, water was cooled to a temperature 1-2°C lower than the supply water temperature to the AHUs. This wasteful mixing was avoided by closing the flow through chillers that were not in operation. The exact benefit of this action is hard to estimate as the performance characteristics of the chillers in KISR's building were not available. However, results of a study for another centrifugal chiller with water-cooled condenser has shown an efficiency decrease of 1.8% for every degree Celsius drop in chilled water supply temperature (Hajiah et. al, 2006).

Reducing the Number of Pumps in Operation

Prior to the optimization, a minimum of two pumps were in operation continuously while the third pump was added during the working days between 09:00 h and 22:00 h. An hourly profile of the number of pumps in operation on a working day is shown in Fig. 4, and the corresponding profile of temperature drop across the chillers (ΔT_{chil}) is shown in Fig. 5. On a summer day, the maximum ΔT_{chil} was a little over 2°C at around midnight with two chilled water pumps in operation. Since this ΔT_{chil} was significantly less as compared to the commonly used practice of 5.6°C (10°F), it was decided to reduce the water flow in the system in general and during non-occupancy periods and the low-demand season in particular. Accordingly, only one pump was operated on a continuous basis and the second pump was operated between 07:00 and 14:00 h. The second pump and a chiller were closed one hour prior to the closing hour as part of optimum closure. A profile of the number of pumps in operation on a working day after the optimization is shown in Fig. 4, and the corresponding profile of ΔT_{chil} is shown in Fig. 5. This strategy reduced the daily pump operation from 61 to 32 pump-hour without any adverse effect on the cooling supply to the building. The ΔT_{chil} reached a maximum of 3.6°C with single pump in operation during the non-occupancy period, although it was significantly less during the occupancy period when two pumps were in operation.

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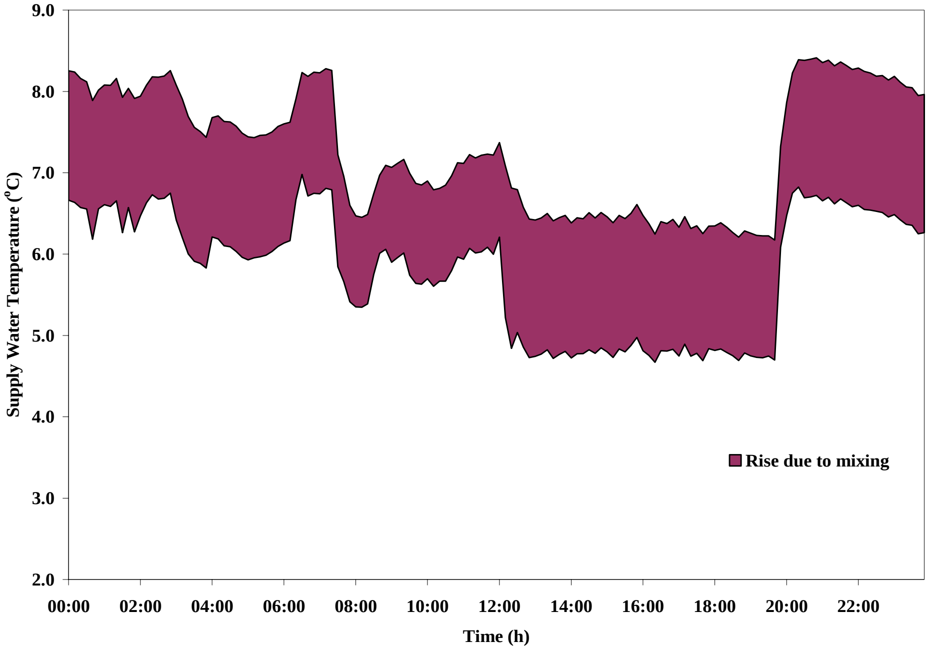

Fig. 3a. Rise in supply water temperature due to flow through the non-operating chillers during summer..

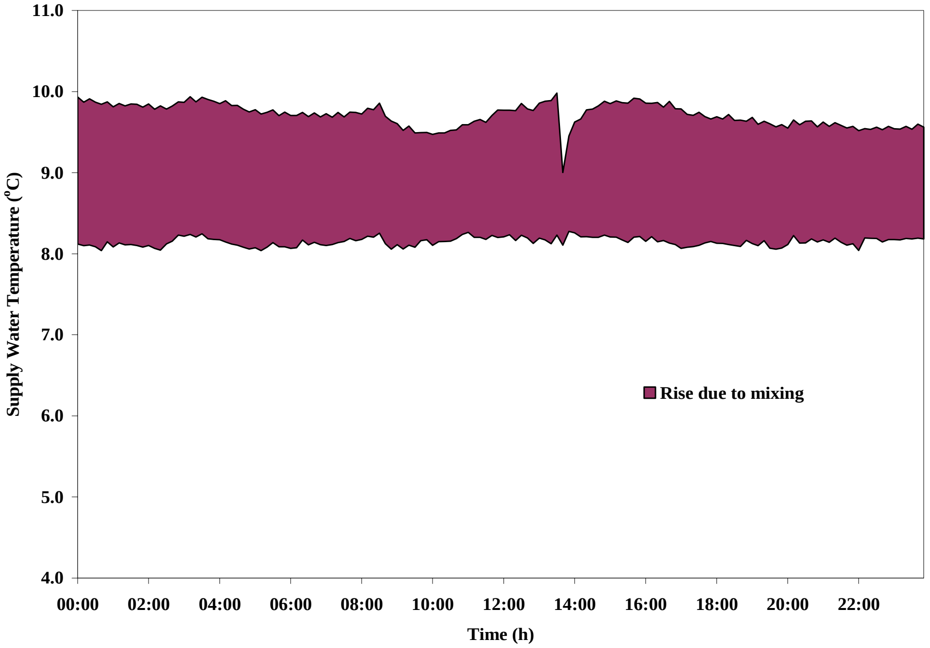

Fig. 3b. Rise in supply water temperature due to flow through the non-operating chillers during lean demand season.

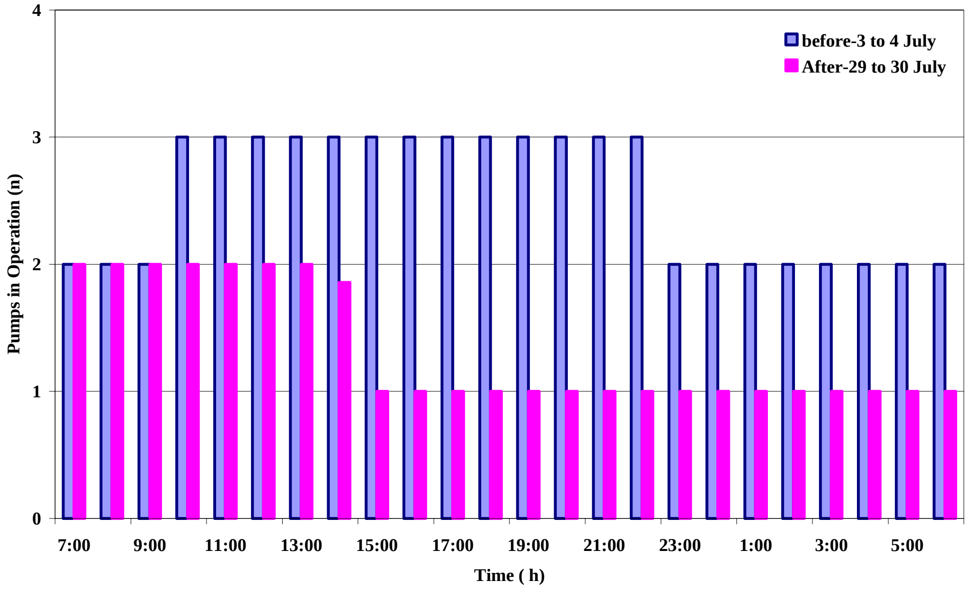

Fig. 4. Number of pumps in operation before and after optimization.

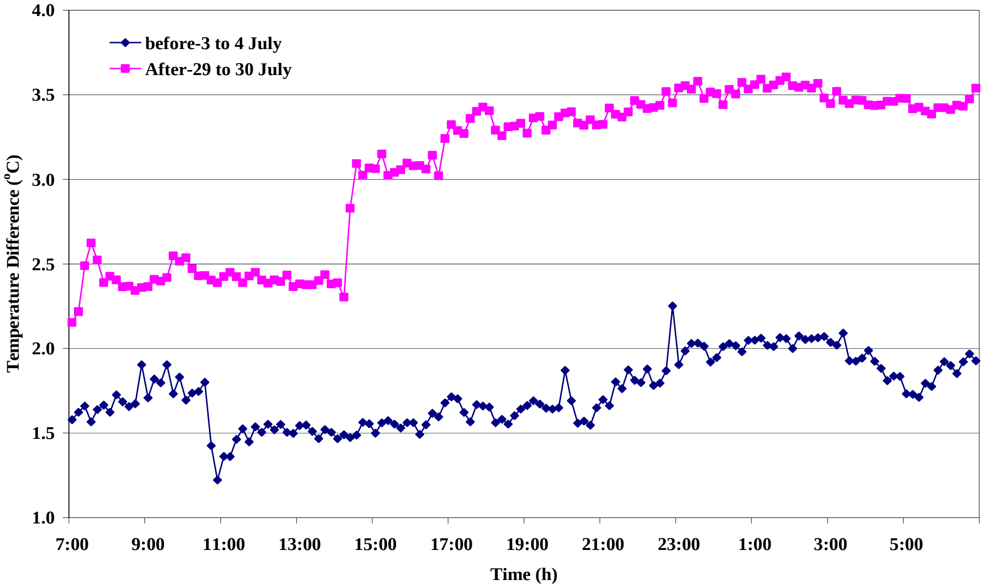

Fig. 5. Average drop in chilled water temperature across the chillers.

Each one of the chilled water pumps was operated by a 75 kW motor. The power demand of a single motor with six chillers in flow circuit was measured as 73 kW. This power increased to 132 kW for two pumps and 189 kW for three pumps in operation. Based on these numbers, the daily pumping energy was reduced by as much as 43%, from 3881 to 2214 kWh/d. Furthermore, a reduction in pumping energy is associated with a reduction in cooling demand as the power input to the pump (P_p)

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eventually adds heat to the chilled water (Q_w) and the plant room (Q_p). Since the pump motor is not in the water stream, the Q_w and Q_p are estimated as follows:

$$Q_w = P_p * \eta_m \qquad (1)$$

$$Q_p = P_p * (1 - \eta_m) \qquad (2)$$

where η_m is the efficiency of the pump motor and the plant room is air-conditioned. Further reduction in pumping energy can be expected during mild summer and early winter if the pump operation was to be controlled through a variable speed drive.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and analysis, the following recommendations are provided:

1. For quality of comfort and energy efficiency, it is important to have distribution of chilled water in major branches in proportion to their cooling demands.

2. Closing chilled water flow through non-operating chillers is recommended to avoid dilution of chilled water quality, thereby assuring better quality of comfort and higher energy efficiency.

3. Operation of the chilled water system with a minimum number of pumps is recommended. It helps to reduce the energy consumption of the auxiliaries and makes more cooling available for the users.

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