Applied Energy 135 (2014) 329–338

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Effect of load-sharing operation strategy on the aggregate performance of existed multiple-chiller systems

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HIGHLIGHTS

- The tested operation strategies obtain aggregate performance from 1.06 to 1.41.
- The load-sharing operation strategies have been affected by operation parameters.
- The best load-sharing operation strategy is better than conventional by 22–33%.
- COP of individual chiller ranged from lower than 1 to about 5.
- Testing different operation strategies involves monitoring the COP of chillers.

ARTICLE INFO

Article history:
Received 24 July 2013
Received in revised form 9 May 2014
Accepted 28 June 2014

Keywords:
Chiller operation strategies
Chiller performance
Load-sharing operation strategy
Part and full load operation

ABSTRACT

This paper examines the effect of load-sharing operation strategies on the aggregate performance for existing multiple-chiller system under different partial loads and environmental conditions. The various tested load-sharing operation strategies obtain aggregate performance from 1.64 to 2.18 during the day hours and from 1.06 to 1.41 for the full day indicating significant effect of the operation strategies on the aggregate performance. The conventional (same part load ratio) strategies attain aggregate performance that is lower than the best strategy by 22–33%. At very low system partial load, the performance of the multiple-chiller system falls to less than quarter its value at large load whereas the performance of individual chiller drops to about one sixth of its large load value.

The load sharing strategy is influenced by many parameters such as the condition of the chillers and compressors, the piping arrangement, and the heat loss from the chilled water piping where these parameters may overwhelm the individual chiller performance. Accordingly, the load-sharing operation strategy may vary from case to another and should be periodically examined to verify proper system operation, rectify the existing chiller performance and identify chiller faults. Therefore, the need for maintenance can be predicted and the standby chiller may be eliminated.

1. Introduction

In hot climate countries, the use of air-conditioning equipment during summer is essential in every building which is reflected on large power consumption. According to official report, heating, ventilating, and air-conditioning (HVAC) sector consumes about 70% of the national generated power [1]. Thus, efficient design and operation of HVAC systems may result in substantial energy saving both nationally and worldwide particularly in hot climate countries.

For large buildings, multiple chiller systems are practiced to operate in parallel to meet large cooling requirements. The aggregate performance of chiller systems depends on dynamic factors such as heat rejection medium, ambient conditions and compressor efficiency in addition to another important factor which is the load carried by each operating chiller (load sharing). Bekker and Carew [2] stated that there is little understanding of the factors that influence chillers performance, due to many interrelated variables.

Many studies were conducted to improve the chiller system performance. Sun et al. [3] proposed an optimal strategy for operating chillers in steps in response to the changing building cooling loads. The Gordon and Ng's thermodynamic model correlates the chiller COP with the temperature monitored at the evaporator and condenser sides [4]. Chan and Yu [5] analyzed how the chiller component interact with each other and discussed the use of

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http://dx.doi.org/10.1016/j.apenergy.2014.06.065
0306-2619/© 2014 Published by Elsevier Ltd.

Nomenclature

c_w	specific heat of chilled water (J/kg K)
COP	coefficient of performance (–)
m_{cw}	mass flow rate of the chiller chilled water (kg/s)
m_{sw}	mass flow rate of the system chilled water (kg/s)
RH	relative humidity (–)
T_{ci}	inlet chilled water temperatures to the chiller (°C)
T_{co}	outlet chilled water temperature from the chiller (°C)
T_{si}	inlet chilled water temperatures to the system (°C)
T_{so}	outlet chilled water temperatures from the system (°C)

Abbreviations

AHU	air handling unit
ARI	air conditioning and refrigeration institute
CAV	constant air volume
FCU	fan-coil-unit
HVAC	heating, ventilation and air conditioning
VAV	variable air volume

floating condensing temperature control to improve chiller performance.

Various approaches are reported in literature to handle the complexity of the many interrelated factors that affect the chillers performance. Some studies coupled empirical models and genetic algorithms with other advanced techniques to optimize physical and operating characteristics of chillers [6–9]. Other studies introduced approach based on statistical analysis to investigate the effectiveness of these parameters [10–15].

Among the parameters that highly influence the multiple-chiller aggregate performance is the load-sharing operation strategy. It addresses how the building cooling load should be allocated to individual chillers operating in order to optimize their aggregate performance. Usually, the multiple-chiller systems are integrated with sequencing control to react to the building load demand [16]. It determines how many and which chillers are to be put into operation according to the instantaneous building cooling load. Under the arrangement of chiller sequencing, all operating chillers are running at the same part load ratio, and no additional chillers start to operate until each of the operating chillers is running at full load [17,18].

In a conventional pumping system, different numbers of chillers and constant-speed pumps operate in pairs. In such configuration the total flow of chilled water should satisfy various building cooling loads. Since the flow of chilled water passing through individual chillers is fixed, the load which each of the chillers carries is related directly to the temperature rise of the chilled water. In order to achieve the same chilled water temperature across all the chillers, they have to operate at the same part load ratio. Such an even load sharing strategy has long been used in multiple-chiller systems for equal size or different size chillers.

Instead of operating chillers at the same part load ratio, it is preferable to develop load sharing strategies that accounting for their part load performance characteristics to maximize the COP of the entire system. Yet there is limited research work relating to load sharing strategies for multiple-chiller system [19]. Chang et al. [17] employed a genetic algorithm to achieve the optimal chiller loading problem for two centrifugal chiller plants serving a semiconductor plant and a hotel. The genetic algorithm was utilized to search for their optimum loading points for any given system load. The authors pointed out that the optimum loading points mean that the individual chillers should operate at different part load ratios without explaining the rational for uneven load allocation to the chillers.

Austin [20] emphasized that optimum loading points for the part load operation of chillers should be based on their performance rating at any given constant condenser water temperature, rather than on the part load performance curve at ARI rating conditions [21]. Yet, the author did not justify the use of individual chillers at different part load ratios to meet the system load. Kaya [22] evaluated the optimum chiller load allocation considering cost-versus-load characteristics as an objective function. A maximum saving of 24% in the cost per ton of refrigeration is achieved using the optimum load allocation compared to the equal percentage load allocation.

Therefore, the aim of this paper is to experimentally investigate the effect of load sharing strategies for existing multiple-chiller system on their aggregate performance. Different load-sharing operation strategies are suggested, tested and compared based on their aggregate performance. The work is conducted on existing multiple-reciprocating chillers system under different partial loads and environmental conditions. In order to study the load effect on chiller and system performance under constant chiller capacity, a fixed number of compressors remain working during the experiments. The proposed approach is easy to implement as it requires only power consumption measurement and needs no additional cost. In addition, elimination of standby chiller may be possible by the use of performance monitoring to predict chiller malfunction prior to any failure or breakdown.

In order to achieve the above goals, the building and chillers were equipped with the necessary instrumentation to evaluate the performance of the chillers under the tested conditions.

2. Characteristics of the building and HVAC system

In order to understand the building systems, both architectural and mechanical drawings, equipment specifications and control sequences of chiller system in the building are scrutinized. The following description is based on a review of existing documents and site survey.

2.1. Building description

The building under consideration is the Mechanical Engineering Department, College of Technological Studies, Kuwait. The building is a two-story institutional facility with total floor area of 7020 m^2. The long side of the building is oriented toward east–west direction with four main entrance doors in the east side. The building is used by about 350 students, and 50 staff with irregular occupancy pattern between 8 am and 5 pm, five days per week during the academic semester. Less number of people uses the building during summer semester whereas no occupancy occurs during summer vacation.

The building wall construction can be considered as heavy mass and good insulation with overall heat transfer coefficient of 0.562 W/m^2 K. The roof of this building was made from light mass construction that is well insulated (0.187 W/m^2 K). The windows and entrance doors are aluminum framed constructed from 6-mm double-tinted glazing with overall heat transfer coefficient of 3.42 W/m^2 K. The lighting in the building space is predominantly 4-foot fluorescents T12 lamps with electronic ballasts and manual