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Energy optimization methodology of multi-chiller plant in commercial buildings

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ABSTRACT

This study investigates the potential energy savings in commercial buildings through optimized operation of a multi-chiller plant. The cooling load contributes 45–60% of total power consumption in commercial and office buildings, especially at tropics. The chiller plant operation is not optimal in most of the existing buildings because the chiller plant is either operated at design condition irrespective of the cooling load or optimized locally due to lack of overall chiller plant behavior. In this study, an overall energy model of chiller plant is developed to capture the thermal behavior of all systems and their interactions including the power consumption. An energy optimization methodology is proposed to derive optimized operation decisions for chiller plant at regular intervals based on building thermal load and weather condition. The benefits of proposed energy optimization methodology are examined using case study problems covering different chiller plant configurations. The case studies result confirmed the energy savings achieved through optimized operations is up to 40% for moderate size chiller plant and around 20% for small chiller plant which consequently reduces the energy cost and greenhouse gas emissions.

1. Introduction

Building requires power to satisfy the electrical and thermal loads for sustaining building activities, occupant comfort, and productivity [1]. In tropical regions, the chiller plant is the potential opportunity to reduce power consumption which consumes 45–60% of total power in commercial and office buildings. Most of the existing buildings consume power from the utility grid, and the options to reduce power consumption are efficient operation and demand response techniques [2,3]. The technology advancement and optimized control of equipment based on time-varying thermal loads and weather provide efficient operations and energy savings. The demand response such as load curtailment and shifting depends on the building ability to either reduce the non-critical loads or shift to the off-peak period. For example, the facility managers have the choice to turn off HVAC equipment or adjusting the indoor temperature and utilize energy storage for a short time. This study investigates the potential opportunities to reduce power consumption in chiller plant without compromising the building activities, occupant comfort, etc.

Fig. 1 shows the schematic of chiller plant in building with chillers, cooling towers, chilled water pumps, and cooling water pumps, etc. The primary and secondary pumps supply chilled water to chiller and building respectively. In conventional chiller plant, (i) the chiller and primary pumps operate at constant speed, (ii) the secondary pump operates with variable speed drive (VSD) to support building time-varying cooling loads [4], and (iii) the cooling water flow and temperature remain constant at design condition. The energy efficiency of chiller plant is optimal near design load, any variation in cooling loads (especially at part loads) reduces the efficiency. Usually, the chiller plant design considers building peak thermal load, harsh weather, and future expansion, etc. During operation, the building cooling load is time-varying and below design capacity [5]. The inefficiency arises due to inappropriate coordination between the chiller, cooling tower and pumps operations to meet the cooling load. This study aims to reduce the power consumption by operating the chiller plant efficiently through optimized decisions. The proposed energy optimization methodology derives the optimal operation decisions by accounting the energy efficiencies of all systems, time-varying cooling load, weather, etc.

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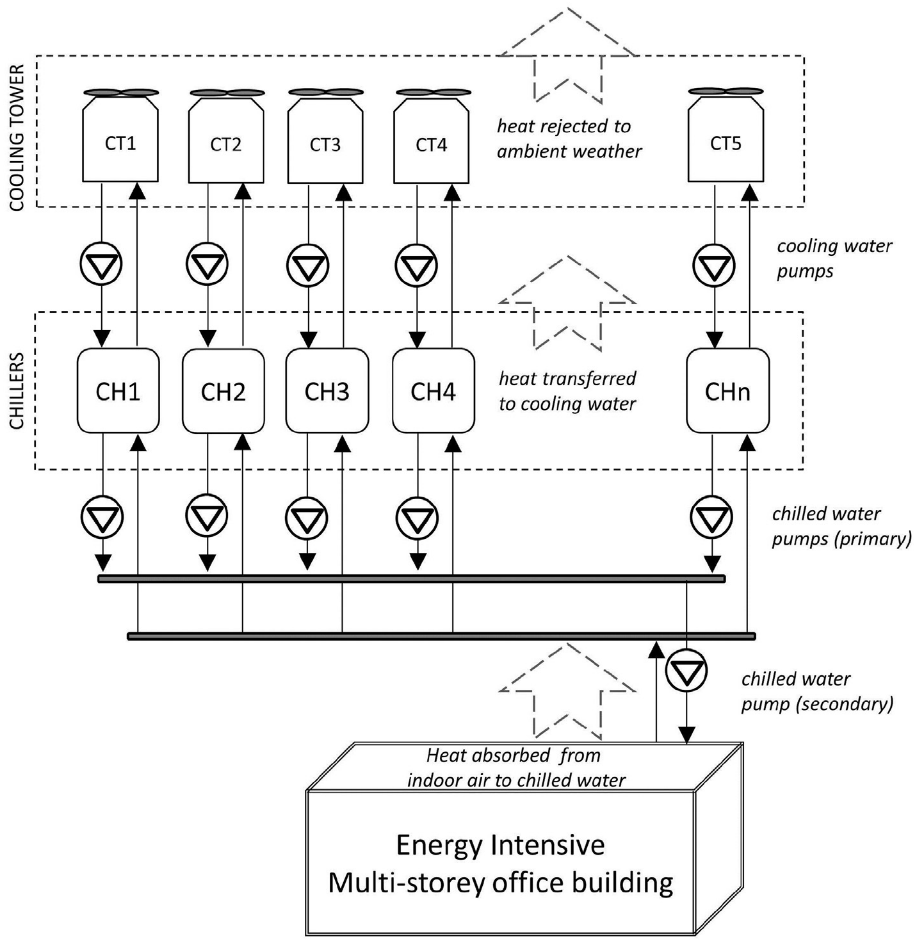

Fig. 1. Schematic of chiller plant in building with multiple chillers, cooling towers, chilled water pumps, and cooling water pumps.

2. Chiller plant operation practices and efficiency

Several operation strategies were practiced in chiller plants to improve the operational efficiency and reduce power consumption. An ideal chiller plant consumes less power and generates high cooling capacity. The operation of chillers, cooling towers and pumps influences the power consumption of chiller plant. The chiller is a dominant power consumer, so the prospective energy efficient options are multi-chiller sequencing and VSD chillers to operate based on time-varying cooling loads [1,6].

Designing a multi-chiller plant with different capacities and operating an optimal sequence of chillers improve the operational efficiency and reduce power consumption. Usually, the chiller sequencing is carried out based on total cooling load, return water temperature, direct current and bypass flow. Shan et al. [7] derived a robust chiller sequencing by measuring the electric current of operating chillers, vane opening and supply chilled water temperature. Liao et al. [8] studied the effect of uncertainties in the measurement, control, operational and threshold during chiller sequencing. In spite of various factors, the cooling load is predominantly considered for optimal chiller loading (OCL) to achieve best chiller efficiency [9]. Salari et al. [10] formulated a steady-state model of a multi-chiller system using polynomial functions to study the OCL problem. The part load ratio (PLR) and on/off status of each chiller is optimized to reduce the chiller power consumption. Abou et al. [11] experimentally studied the effect of load sharing on the aggregate coefficient of performance (COP) of the chiller plant. Three identical chillers (each contains four compressors) operated at different part loads using various combination of compressors and observed that equal load sharing provides poor performance. The compressor combination 3-1-2 and 2-4-0 provides better performance at day and night whereas the 3-3-0 combination provides the best performance during the day. Other than chiller sequencing and load sharing, the operation variables such as water flows, airflow and temperature set points are potential opportunities to reduce the power consumption of chillers, cooling towers and pumps.

The cooling tower fan is the second dominant power consumer which reduces by tweaking the airflow depending on the cooling water temperature and flow, and ambient condition [12]. For example, at tropics, low wet bulb temperature requires less airflow and fan power compared to humid conditions. Mu et al. [13] optimized the condenser water loop such as condenser water flow and cooling tower fan speed to reduce the power consumption of chiller plant. Huang et al. [14] optimized the cooling water temperature along with multi-chiller sequencing based on the cooling load. The chilled water temperature and flow are kept at design condition. In contrast, Zhang et al. [15] fixed the difference in cooling water temperature and varies the chiller on/off decisions, chilled water supply temperature, and water and airflow from the primary pump, condenser pump and cooling tower fan respectively. The empirical models of the chiller and cooling tower are exploited to optimize the decisions using surrogate Lagrangian relaxation (SLR) combined with sequential quadratic programming (SQP). Wei et al. [16]