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Research Paper

Effects of scenario uncertainty on chiller sizing method

Yingzi Kang [a,*], Godfried Augenbroe [b], Qi Li [b], Qinpeng Wang [b]

[a] School of Mechanical and Automotive Engineering, South China University of Technology, Wushan, Tianhe District, Guangzhou 510641, China
[b] School of Architecture, Georgia Institute of Technology, Atlanta, GA 30332, USA

HIGHLIGHTS

- A new chiller sizing method considering scenario parameter uncertainty is proposed.
- The approach is based on the Monte Carlo method and dynamic simulation.
- The new method also balances the economy of chiller and indoor thermal comfort.

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ABSTRACT

Opportunities to save energy in the design and operation of Heating, ventilation and air conditioning (HVAC) systems have come into sharp focus. Lighting intensity, electric equipment load and occupant density have great impact on the peak cooling load of building, which is the basis of the chiller sizing. There is inevitable uncertainty in the determination of the values of these three scenario parameters at the detailed HVAC design stage and thus these uncertainties can considerably impact chiller sizing choice. However, the conventional chiller sizing method does not deal well with these uncertainties. A new chiller sizing method is proposed in this paper taking into account the scenario parameter uncertainty, the discrete spectrum of nominal cooling capacity of available chillers, the difference of chiller cooling capacity under nominal condition and peak cooling load condition. The new approach quantifies the impacts of scenario uncertainty on peak cooling load, chiller life cycle cost (LCC), and also on annual set point unmet hours based on the Monte Carlo method and dynamic simulation. For the case study, compared with conventional sizing method, the new sizing method can greatly reduce chiller nominal cooling capacity and the minimum reduction is 22.51%. The new method can help the HVAC designer to determine the optimal chiller size with the consideration of scenario uncertainty and the balance of chiller LCC and indoor thermal comfort of HVAC system.

1. Introduction

Heating, ventilation and air conditioning (HVAC) system consumes energy to provide the thermal comfort in the building and is typically the major energy consumer. The energy saving potential of HVAC systems deserves therefore constant attention.

With the emphasis on building energy efficiency and the strict implementation of building energy efficiency standards all over the world, in the total HVAC energy consumption, the ratio of cooling energy which is associated with the building envelop is getting smaller while the cooling driven by the internal gains from lighting, equipment and occupants is becoming the dominant. At the detailed design stage of HVAC system, the architect has finished the building design, which means that the building envelope's parameters, such as window-to-wall ratio and thermal conductivity of walls, window and roof types of the building have been fixed. If the building cooling load is predicted for a typical weather condition, the main parameters that need to determine are lighting intensity, electric equipment load and occupant density and the convective and radiative heat gains that result from them. But these three parameters can't be known through investigation with enough certainty at the detailed HVAC design stage hence some level of uncertainty in determining the value of these parameters is inevitable. The uncertainty of lighting peak use, plug load peak use, and occupant density are classified as building operation uncertainty [1,2] or scenario uncertainty [3]. In other research, the uncertainty of lighting intensity, equipment load and occupant density is regarded as HVAC system parameters uncertainty [4]. The uncertainty of lighting intensity, electric equipment load and occupant density is considered to be scenario parameter uncertainty in this paper. It can be reasoned that the uncertainties of

* Corresponding author.
E-mail address: 792765490@qq.com (Y. Kang).

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these three parameters are the most sensitive factors in the determination of cooling load uncertainty [1,5]. A main function of the HVAC system is to supply fresh air in order to remove the indoor air pollutants to maintain the desired indoor air quality. Because of the enthalpy difference between outdoor air and indoor air during summer, conditioning the fresh air consumes 20–40% of the total energy of the HVAC system [6]. In hot and humid regions this will be even higher. In China, the required flow rate of fresh air is determined according to the occupancy in the air conditioned zones [7]. So, the occupant density affects not only the internal cooling load but also the fresh air cooling demand. The chiller capacity not only greatly affects the operation energy of itself, but also is the base of its auxiliary equipment sizing and thus impacts the latter operation energy. Therefore, correctly sizing the chiller of the HVAC system is an effective way to realize higher energy efficiency of the total HVAC system.

At the detailed design stage of the HVAC system, the conventional method of chiller sizing is based on peak cooling derived through dynamic energy simulation of the building with a fixed (deterministic) value for each input parameters. In conventional chiller sizing method, there are mainly two approaches to considering the influence of cooling load variability due to the scenario parameters uncertainty. The first approach is dealt with by selecting the value of scenario parameters from a feasible value range through the assumption of worst-case such that this will result in a best estimate of the largest peak cooling load that is deemed to result in a "safe" design [5] The problem is that this will typically lead to the over-sizing of the chiller, which will increase the initial cost, operation energy and operation and maintenance cost of the HVAC system and decrease the energy efficiency of chiller and the whole HVAC system. Not surprisingly, in practice over-sizing is a common phenomenon [8,9]. The second approach is applying safety factors directly to describe the parameters which have uncertainties to calculate the load, not applying the safety factor to the finished calculated load [10]. The latter tries to avoid overly conservative, extremely peak cooling load, but still belongs to deterministic approach. However, there is a great need to calculate and analyze the impacts of the uncertainty of scenario parameter on peak cooling load, and therefore their direct impact on initial cost and operation energy consumption of chiller and their indirect effect on indoor thermal comfort. Thus, at the detailed design stage of HVAC system, scenario parameter uncertainty should be taken into account in the sizing of the chiller. We suggest that this is of vital importance to propose a new chiller sizing method considering the scenario parameter uncertainty that can be injected in the actual HVAC design process.

This paper reports a new chiller sizing method that takes scenario parameter uncertainty into account. The sizing approach will consider not only the impact of scenario parameter uncertainty on peak cooling load but also on chiller life cycle cost (LCC) and indoor thermal comfort of the HVAC system during its life cycle. Furthermore, the new method takes account of two factors: (1) the discreteness of the nominal cooling capacity of chillers on the market, (2) the difference of chiller cooling capacity under nominal condition and peak cooling load condition.

In this paper, previous studies on cooling load prediction and HVAC sizing with consideration of uncertainties are reviewed in Section 2. In Section 3, the methodology of the proposed chiller sizing method and key technologies applied are introduced, followed by a chiller sizing case study that demonstrates the method. In Section 4, Chiller sizing result of proposed method is compared with that of conventional method. Conclusions are given in Section 5.

2. Literature review

Previous studies on cooling load prediction and HVAC sizing applying uncertainty analysis are presented in this section.

2.1. Uncertainty study on cooling load

Cooling load prediction is the basis of cooling system design and operation. The equipment of cooling system is sized according to the peak cooling load demand and therefore the energy and economic performance of the cooling system is greatly affected by the accuracy of the cooling load prediction.

Domínguez-Muñoz et al. [5] investigated the uncertainties in peak cooling load calculation at the early stage of a building project. The proposed method was based on the stochastic simulation method and mainly contained four steps: (1) choosing a mathematical representation for the uncertainty, (2) identifying the uncertain parameters and quantifying their uncertainties, (3) propagating the uncertainties of the input data through the model in order to determine their impact on the peak cooling load using Monte Carlo method, (4) performing a sensitivity analysis to identify the most important uncertainties. The result of peak cooling load calculation was a probability distribution showing the whole range of possible peak cooling loads together with the probability of each interval. The impacts of uncertainties in building and HVAC parameters on HVAC system peak cooling load, peak heating load, capital cost, annual cooling and heating energy and annual energy cost were studied by Rasouli et al. [4]. In Refs. [1,2,11,12] the uncertainty in peak cooling load calculation and quantification of the uncertainty of peak cooling load due to the uncertainty of input parameters was analyzed using a method similar to Ref. [5].

These researches mainly investigate the peak cooling load calculation considering the uncertainty of input parameters. This paper will follow the peak cooling load calculation approach of Ref. [5] to determine the peak cooling load as the basis for chiller sizing.

2.2. Uncertainty study on HVAC sizing or design

Uncertainties in building performance evaluations and their potential influence on the design decisions of whether or not a mechanical cooling system should be integrated were studied by De Wit and Augenbroe [13]. To research the HVAC sizing under uncertainty, Sun et al. [1] presented a new frame work using uncertainty analysis to replace the safety factor with quantified margins based on comprehensive quantification of different sources of uncertainty and sensitivity analysis to identify the important individual factors or groups of factors that contribute to uncertainty. This study offered a road towards risk management by utilizing better quality assurance approaches or negotiating performance contracts. However, the energy and cost performance of the chiller, i.e. initial cost and life time energy consumption and cost, LCC, as well as ramification of HVAC size for indoor thermal comfort were not analyzed in this paper. A design optimization method considering the uncertainties in nine operation factors related to the cooling load calculation is proposed in Ref. [2]. This method can determine the cooling system capacity with quantified confidence by analyzing the probability distribution of the cooling load and the potential capital cost. The cooling system configuration based on the risk and benefit analysis is also conducted in this study. Gang et al. [12] explored a novel design method to derive a robust optimal capacity of the building cooling system by quantifying the cooling load uncertainty with Monte Carlo method and chiller reliability using Markov method. The new method assessed annual total cost, including the capital cost, operational cost and availability risk cost, of cooling systems with different capacities, and the robust optimal cooling system was obtained by targeting minimum annual total cost.

Huang et al. [11] investigated a prototype HVAC system design approach that considers uncertainties in 12 input parameters. The approach is able to handle uncertainty directly in the design and is suited to predict the performance of a design at the design stage in