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ORIGINAL ARTICLE

Analysis of energy management for heating, ventilating and air-conditioning systems

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VRV

Abstract In the office buildings, large energy is consumed due to poor thermal performance and low efficiencies of HVAC systems. A cooling load calculation is a basis for the design of building cooling systems. The current design methods are usually based on deterministic cooling loads, which are obtained by using design parameters. However, these parameters contain uncertainties, and they will be different from that used in the design calculation when the cooling system is put in use. The actual cooling load profile will deviate from that predicted in design. A modified bin method was used in this paper to optimize the energy efficiency ratio (EER). A design optimization method is proposed by considering uncertainties related to the cooling load calculation. Impacts caused by the uncertainties of seven factors are considered, including the outdoor weather conditions and internal heat sources. The cooling load distribution is analyzed. Comparison between the modified bin method and CLTD/SCL/CLF method is also conducted. With the distributions of their energy consumption, decision makers can select the optimal configuration based on quantified confidence. According to the economic benefits and energy efficiency ratio, using modified bin method will increase the overall energy efficiency ratio by 45.57%.

1. Introduction

Energy is a vital factor for the success of all economies in the immediate and long-term future. Since the energy crisis of 1970 s, people needed to determine how much energy buildings were using and to identify how that energy use could be reduced. This would have direct effects on building designers, managers, and owners. As a result, Building Energy Analysis (BEA) is becoming an important tool in the HVAC design field. BEA is the technique of estimating energy use and operating costs for building and its energy consuming systems. A wide variety of building energy analysis methods are currently available to HVAC engineers and range from simple to sophisticated one. The simplest methods involve the largest number of simplifying assumptions and, therefore, tend to be the least accurate. The most sophisticated methods involve the fewest assumptions and thus can provide the most accurate results. In selecting the procedure to be used for a specific project, it is important that the limitations of the procedure be recognized. Modified Bin Method is one of the most energy analysis methods used. It estimates both heating and cooling loads, using instantaneous energy calculation at many different outdoor dry bulb temperature conditions, and multiplying the results by the number of hours of the occurrence of each

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Nomenclature

A	area (m^2)
c_p	specific heat at constant pressure (J/kg K)
ESTD	temperature difference (°C)
FPS	fraction of possible sunshine
h_{fg}	evaporation heat energy (J/kg)
q^o	heat energy per unit of floor area (W/m^2)
SC_i	shading coefficient of fenestration component of exposure (i)
T	temperature (°C)
TSCL	total solar cooling load (W/m^2)
U	heat transfer coefficient ($W/(m^2 K)$)
V^o	volume flow rate (m^3/s)

Greek symbols

ρ	density
ω	humidity ratio of the air (kg_w/kg_a)

Subscripts

a	air
c	conduction
eq	equipment
i	orientation number
inf	infiltration
L	lighting
lat	latent
o	outside
occ	occupancy
r	room
s	sensible
sg	solar glass
sw	solar wall

Abbreviations

AHU	air handling unit
AU	average usage during the occupied or unoccupied time periods
COP	coefficient of performance
dbt	dry bulb temperature
DX	direct expansion
EER	energy efficiency ratio
Eff	efficiency
HVAC	heating ventilation and air conditioning
PLF	partial load fraction
VRV	variable-refrigerant-volume

condition. This procedure accounts for the part load performance of HVAC equipment and coefficient of performance of the HVAC system. The calculations are performed monthly or annually, and for occupied and unoccupied building hours. Thus, several hundred calculations are used to characterize building energy consumption, rather than 8760 h.

Many contributions have been made in the research to improve the modified bin method to obtain more accurate results and decrease the errors and the defects of this method in order to get more precise results and increase the performance of the calculations. One of the first developments in energy calculation is done by Fazli et al. [1]. They performed 780 annual building energy simulations using BEopt and Energy Plus to predict the energy and cost impacts of realistic excess static pressures for typical new and existing single-family homes with both permanent split capacitor (PSC) blowers and electronically commutated motors (ECM) in 15 U.S. climate zones. Garnier et al. [2] modeled a real non-residential building located in Perpignan using the Energy Plus software. They used the predicted mean vote (PMV) index as a thermal comfort indicator and developed low-order ANN-based models to be used as controller's internal models. A genetic algorithm allowed the optimization problem to be solved. Also they compared the proposed management strategy with basic scheduling techniques. The factors that affect the adoption behavior for residential Heating, Ventilating, and Air Conditioning (HVAC) systems were identified by Noonan et al. [3]. Their study included a spatial and temporal contagion effect, house characteristics, and other economic and contextual factors. Reductions in HVAC (heating, ventilation and air conditioning) energy consumption can be achieved by limiting heating in the winter or cooling in the summer. However, the resulting low thermal comfort of building occupants may lead to an override of the HVAC control, which revokes its original purpose. This has led to an increased interest in modeling and real-time tracking of location, activity, and thermal comfort of building occupants for HVAC energy management. To measure physical activity, Rana et al. [4] developed an activity classifier, which achieves 10% higher accuracy compared to Support Vector Machine and k-Nearest Neighbor. A multilayer perceptron ensemble was selected by Wei et al. [5] to build the total energy model integrating three indoor air quality models, the facility temperature model, the facility relative humidity model, and the facility CO_2 concentration model. To balance the energy consumption and the indoor air quality, a quad-objective optimization problem was constructed. The problem was solved with a modified particle swarm optimization algorithm producing control settings of supply air temperature and static pressure of the air handling unit. Kusuda [6] work included a comparison between the modified bin method and different simulation programs (ECUBE, EASA, BLDSIM, BLAST, DOE-2, AXCESS, and TRACE). This comparison showed a similarity in the results if the simulation is done by the same user. Also Kusuda et al. [7] established the load as a function of outside dry bulb temperature by using the diversified loads rather than peak loads. The modified bin method was extended by Knebel [8] to calculate weekday/weekend and partial-day occupancy effects. To enhance the primary and secondary equipment performance, the building load was calculated at two temperatures (peak cooling T_{pc} and peak heating T_{ph}). Moreover, the advantages and disadvantages of using modified bin method were provided by Knebel and Silver [9]. In another hand, a methodology for retrofit Canadian office buildings and screening energy efficiency was developed by Chidiac et al. [10]. Vadon [11] developed a linear equation between the outside air temperature and solar insolation. In addition, Claridge et al. [12] compared the performance of