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Structure and Implementation of Multiuser Collaborative in Duty Cycling Control of Central Air Conditioning

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Abstract

Proposed optimization model of duty cycling control in central air conditioning based on human comfort index. The human comfort index is incorporated into the process of duty cycling control in central air conditioning, and we found that the range of reducing air conditioning load is affected by temperature and humidity parameters. When ensure the premise of human comfort, there exists a maximum volume of reducing air conditioning load. The changing of indoor and outdoor temperature determines the grouping number of air conditioning units and the space of duty cycling and other parameters. Meanwhile, this paper proposes a controlling model and platform which can exchange information between electricity supplying side and demanding side. Operation procedure of optimizing experimental scheme based on uses' feedback is also designed, then, simulating the experimental scheme and forecasting the effect.

Key words: Duty cycling control in central air conditioning; Human comfort index; Load control; Multiuser collaboration; Experiment design

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INTRODUCTION

Duty cycling control in central air conditioning, also known as central air conditioning system periodically pause technology, is the technology that periodic suspension control central air conditioning system host machine to save electricity for the whole air conditioning system. When the host machine of the central air conditioning system suspend operation, the air supply system and cooling water circulation system continue to work conveying cool air, which can maintain cooling the building for a short time, meeting the target that reducing air conditioning load and saving electricity. The research on duty cycling control in central air conditioning mainly concentrated in the control mode, case study, and feasibility analysis. Song expounded the principle, function, and structure of central air conditioning load management system based on GPRS technology, and put forward the implementation of centralized air conditioning system duty cycling opinion (Song, 2005, p.78). Du based on the background that duty cycling control in central air conditioning application in Nanjing summer electricity shortage, introduced the research ideas of this technology. Comparison and selection are made from several system control program and communication program (Du, 2006). Wu (2009) tested the central air conditioning periodic suspension technology. Based on the result, a recommendation is proposed for a corporation (p.36).

However, the study of the technology control model is not sufficient, and can't provide a theoretical basis for the selection of the important parameters, which leads to the judgment relying on artificial experience. Based on the lack of existing research, this paper attempts to discuss the parameters used in the duty cycling control in the central air conditioning. The research can be divided into two sides. The first is the duty cycling control in central air conditioning based on human comfort index, where the parameters are the crucial questions. The questions include, how to classify the host machines, how to choose the cycle period, and minimizing the air conditioning load without influencing the human comfort. The second is to design the scheme of multiuser collaboration in duty cycling control in central air conditioning and to simulate and analyze the result by using the system simulation.

1. THE ESTABLISHMENT AND ANALYSIS OF THE MODEL

The research of duty cycling control in central air conditioning based on human comfort index is divided into three steps: (a) research on the suitable temperature range of minimum human comfort requirements under different humidity based on the human comfort degree theory, (b) study on the maximum air conditioning load can be reduced in the given temperature range, (c) study on the parameters of duty cycling control in central air conditioning.

1.1 The Definitions of the Relative Indicators and Variables

To make the statement clear and easy to analyze, there are several variables that are going to be used in the proceeding parts:

- Human comfort index *F*. Human comfort index is from the meteorological point evaluation under different climatic conditions of comfort, and the development of bio meteorological indexes according to the heat exchange between the body and the environment of human.
- Indoor temperature *C*. Without considering the building insulation effect, can be considered, when the indoor air conditioner in the closed, the area of the indoor temperature is approximately equal to the outdoor temperature.
- Indoor humidity r_h. Mentioned in this paper, humidity concepts with no special instructions shall mean relative humidity, to measure drying and wetting degree of the air in a region.
- The total load of the central air conditioning unit *Q*.
- The reduction of the total load of air conditioning unit after the duty cycling control in central air conditioning is used *q*.
- There are three steps in duty cycling control in central air conditioning, which are reducing load, suspending, and loading. We choose to control the three steps to have the same time interval as *t*.
- The total time of the duty cycling control in central air conditioning is *T*, where *T*=3*t*.

The number of the classed units is *n*.

1.2 Temperature Analyses Based on Human Comfort

Research shows that, human comfort is influenced by many kinds of meteorological factors, such as temperature, relative humidity, wind speed, air pressure, illumination, and so forth. While the human comfort index in the world does not have a unified standard, the general is according to the natural environment and local weather conditions in the regions, using the empirical formula of the long-term statistics data. This research selects the air temperature and relative humidity as the main influence factors of human comfort, and human comfort index formula of a region is based on the statistical data:

$$F = 1.8C - 0.55 \times (1.8C - 26)(1 - r_h) + 28.08. \quad (1)$$

Heat balance, temperature of the human body, regulating endocrine system, and many other physiological functions will be affected by the environment comfortable degree. The study found that, in general the comfortable environment of *F* value was between 51 and 78, the best comfort value was at about 60 (Guo, 2009, p.387).

The historical data of relative humidity, r_h, of the area of each month in 2013 is shown in Table 1.

Table 1
Average Relative Humidity of a Region in 2013 Monthly (unit:%)

Month	Average relative humidity
January	75
Feburary	79
March	83
April	82
May	84
June	85
July	82
August	82
September	78
October	71
November	70
December	70

Note. Adapted from Chinese meteorological data sharing service system.

r_h is a known quantity, and take the range of *F* for [51, 78], according to the formula 1 for the indoor temperature interval of human comfort in the region in 2013 the monthly is shown in Table 2.

Table 2
A Comfortable Temperature Interval of Each Month in 2013

Month	The comfort temperature range (℃)	
	The lowest temperature	The highest temperature
January	12.46	29.85
Feburary	12.51	29.47
March	12.56	29.1
April	12.57	29.02
May	12.55	29.19
June	12.58	28.93
July	12.55	29.19
August	12.55	29.19
September	12.50	29.56
October	12.41	30.26
November	12.4	30.36
December	12.4	30.36

1.3 Analysis of the Relationship Between Reducible Load of *q* and the Indoor Temperature *C*

In the control of summer air conditioning load, when the air conditioning load decreases, the indoor temperature will rise, but according to the theory of heat exchange the indoor temperature change is not linear. In the initial stage of load control, the difference between indoor and outdoor temperature is great, heat exchange speeds, and indoor temperature rises higher. With the air conditioner gradually shutting down, the difference of indoor and outdoor temperature is more and more small, the heat exchange slows down, and the indoor temperature rises gradually lower. In general, with reducible load increasing, temperature changing rate is higher, and then the rate of change is lower and lower. On the common sense of the assumption, the minimum value of q is 0; the maximum value is the air conditioning unit load Q. When the air conditioner is in normal operation state, the load reduction is 0, and room temperature is C_1. When the air conditioner is all closed, load reduction for the total air conditioning load Q, room temperature and outdoor temperature is the same C_2. As shown below.

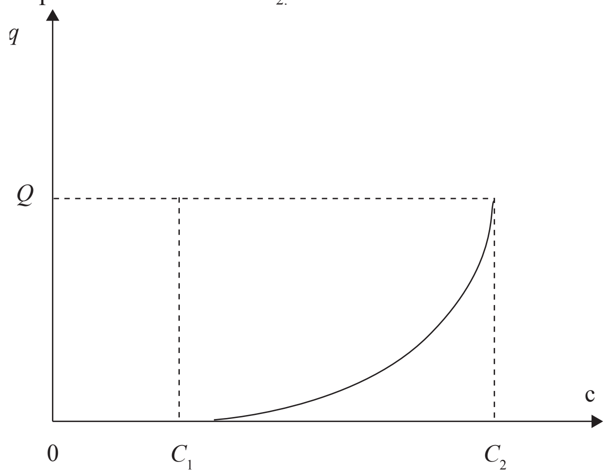

Figure 1
The Diagram of the Temperature and the Reducible Load

It can be seen from Figure 1 that along with the rise of reducible load, the curve is downward convex. According to the boundary conditions, the following formula can be set.

$$q = p_1C^2 + p_2C + p_3 , \tag{2}$$

where p_1、p_2、p_3 are parameters. According to the function of the boundary conditions and the symmetry axis location, the formula can be got.

$$\begin{cases} p_1C_1^2 + p_2C_1 + p_3 = 0 \\ p_1C_2^2 + p_2C_2 + p_3 = Q \\ -\dfrac{p_2}{2p_1} = C_1 \end{cases} . \tag{3}$$

From Equation (3), we can get, $p_2 = -\dfrac{2*c_1Q}{c_2 - c_1}$, $p_3 = \dfrac{c_1^2Q}{(c_2 - c_1)^2}$. Then the formula between q and C:

$$q = Q\left(\frac{c - c_1}{c_2 - c_1}\right)^2 . \tag{4}$$

Parameter Analysis of the Duty Cycling Control

On the basis of the analysis of human comfort and the relationship between variables Q and C, the parameter analysis of the duty cycling control in central air conditioning is proposed. To make an intuitive graphic display of the duty cycling control in central air conditioning, suppose $n = 4$. In $[0,T_1]$period the first group air conditioner gradually reducing load, in $[T_1,T_2]$ period the first group of air conditioner to suspend operation, in $[T_2,T_3]$ period the first group air conditioner was gradually loading, while the second group air conditioner gradually reducing load, and so on, by group of duty cycling control, until all the air conditioning host to complete this process. According to the above duty cycling control strategy, the curve of the total load in the process and the per unit load curve are shown in Figure 2.

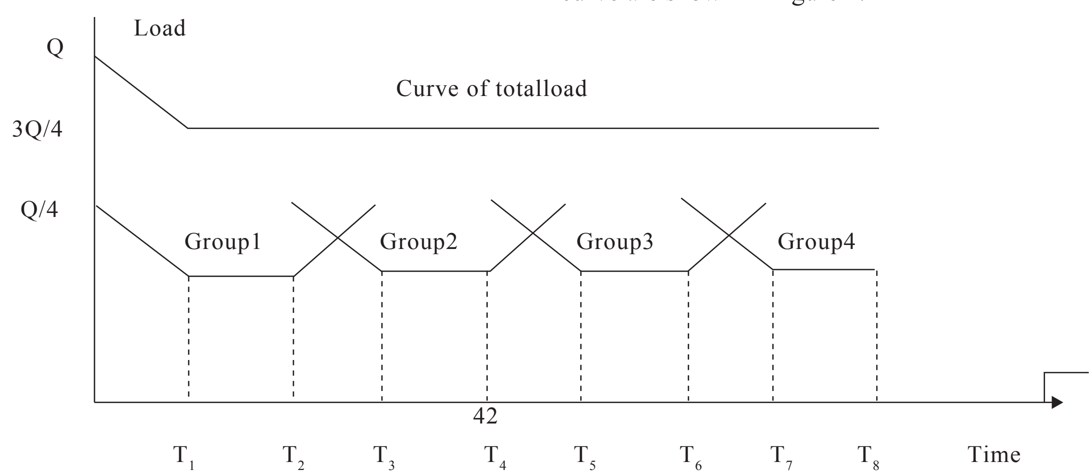

Figure 2
Diagram of the Duty Cycling Control in Central Air Conditioning

Due to reducing load, suspended load, and loading have the same amount of time, that is to say $[0,T_1]$, $[T_1,T_2]$, $[T_2,T_3]$, are equal. We can see from Figure 2, the load can be reduced to

$$q = \frac{q}{n}. \quad (5)$$

Time interval is

$$t = \frac{T}{2n+1}. \quad (6)$$

To sum up, load that can be reduced determines the number of units and the cycles, and the load has functional relationship with the indoor temperature. So through the temperature and humidity data we can determine the maximum reducible load, the number of units, and the cycle. The duty cycling control model analysis process with human comfort index can be summarized as follows:

a). According to the human body comfort degree theory and the Equation (1), suitable temperature interval is obtained as described in Table 2.

b) According to Table 2 and Equation 4, calculate the maximum reducible load q.

c) Based on Equation 4 and Equation 5, the number of units n can be got.

d) Based on Equation 5 and Equation 6, get the cycle T.

2. DESIGN OF MULTIUSER COLLABORATION

The duty cycling control in central air conditioning needs to ensure precise directions, timely feeding back, and real-time control when multiuser participate. So a test scheme on the multiuser duty cycling control in central air conditioning is proposed.

2.1 Control Mode and Platform

The research designs the supplying side and demanding side interactive duty cycling control in central air conditioning mode, as shown in Figure 3.

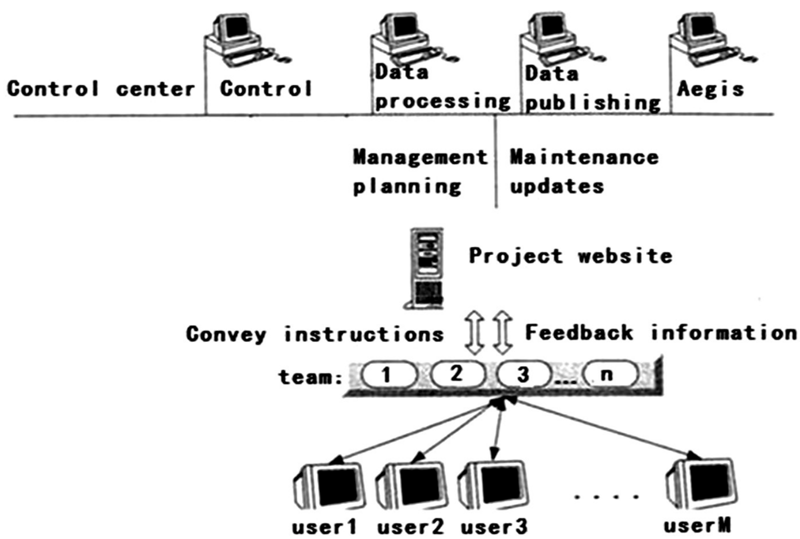

Figure 3
Schematic Diagram of Control Mode

We establish the interactive information transmission platform which includes several functions as follow:

a) User login, the user can login the platform, query information, including the air conditioning load data, historical data, the air conditioning load average indoor temperature and humidity data, historical wheel stop operation instruction.

b) Power Grid Corp managers can update ralated news, notice and duty cycling instructions through the account login platform.

c) The user experience zone (message board) can be used to give comments, questiongs and feedbacks of cooling quality.

d) Data visualization comparison chart can be used to show air conditioning load and the real load prediction of air conditioning load. It also can show the load dropping percentage of the duty cycling control.

2.2 Experiment Procedures

In order to establish optimized duty cycling control procedure according to user feedback, the experimental process is divided into three stages.

First stage: Understand the experimental sample central air-conditioning system load under the condition of normal operation use. Analysis of the air conditioning load regularity and characteristics, to obtain the basic data for the implementation of duty cycling scheme analysis. Use the data to predict future load of air conditioning in a week. The specific steps are as follows:

a) Don't do any duty cycling control operation, ensure that the user use air conditioning according to daily needs;

b) Through the electric power data acquisition, transmission, analysis of the air conditioning load data, and publish on the information interaction platform.

c) The temperature and humidity data acquisition system acquisition, transmission, analysis of human comfort index, and publish on the information interaction platform;

d) Analysis of the air conditioning load regularity and characteristics, the comfort evaluation of human, and publish monitoring results on the information interaction platform;

e) By collecting data to predict future a week of air conditioning load usage, system simulation is carried out on the duty cycling plan, forecast meeting the peak reducible objection.

Second stage: Through the website instructions of duty cycling control in central air conditioning is sent, and the operation is conducted by the participants in the experimental. The effect tested of duty cycling control in central air conditioning, including peak load deduction effect and cooling quality influence. The specific steps are as follows:

a) The Power Grid Corp through the information interaction platform released instructions.

b) The user through the account login information interaction platform to view the instructions, and response to the instruction with the corresponding control on air conditioning system.

c) Through the electric power data acquisition and transmission, analyze the air conditioning load data and publish on the information interaction platform.

d) Through the temperature and humidity data acquisition system acquisition and transmission, analyze human comfort index, and publish on the information interaction platform.

e) The user response, filling the cooling quality questionnaire on the information interaction platform.

f) Drawing load curve, analyze the load and the human comfort index changing, and publish the results on the information interaction platform. Make the corresponding adjustment to the duty cycling control according to the experimental results, and prepare the third experiment.

Third stage: According to the feedback of the duty cycling control, conduct the experiment again, and evaluate the results of the experiment and the effect.

3. THE SIMULATION EXPERIMENT

To predict and analyze the experimental results of the duty cycling control scheme, use simulation software. Provide a set of simulation data for duty cycling control in central air conditioning. Because duty cycling control in central air conditioning technology is mainly to solve the summer peak power load problem, meteorological data of June, July, August and September are used, as shown in Table 3.

Table 3
The Simulation Data

	June	July	August	September
r_h(%)	85	82	82	78
C_1(℃)	25.7	25.9	25.9	26.2
C_2(℃)	31	33	34	34

Note. The simulation data based on the meteorological data of a city in 2013.

Through the use of simulation software, get in different months indoor temperature and reducible load peak ratio (ratio of reducible air conditioning load and the total load of sample air conditioning unit) diagram. As shown in Figure 4, with the indoor temperature increasing, reducible air conditioning load also increases, and the increasing rate also gradually becomes larger.

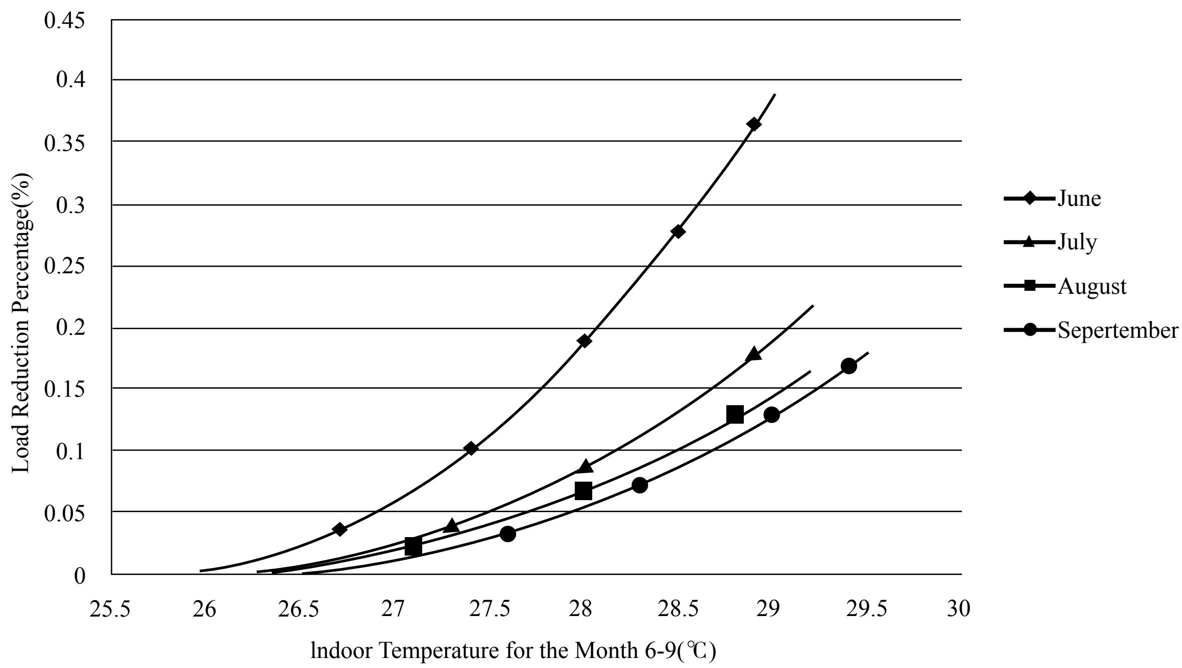

Figure 4 Relationship Between Room Temperature and Reducible Load Peak Ratio

In the simulation system, the length of *T* was 240 minutes. In general, the summer electricity peak load is from 11:00 to 15:00, we can get duty cycling control parameters as shown in Table 4. In September as an example, the corresponding meteorological parameters during the month, the sample air conditioning units are divided into five groups, and the load reduction, suspension, loading time is set to 21.82 minutes, the total duration is 240 minutes, which can reduce 18.56% of the sample air conditioning units total load capacity, and to ensure that the indoor the temperature in the appropriate temperature range.

The duty cycling control parameters can effectively guide the enterprise in different months, different temperature and humidity conditions to implement multiuser duty cycling control in central air conditioning.

Table 4
Duty Cycling Control Parameter

Month	June	July	August	September
Reducible peak load ratio (%)	0.3714	0.2147	0.1650	0.1856
Number of units(n)	3	5	6	5
One third of the total cycle (t/min)	34.28	21.82	18.46	21.82

CONCLUSION

In this paper, we establish duty cycling control in central air-conditioning, and research on the relationship between the room temperature and reducible load ratio. Then, we introduce the human comfort index into the duty cycling control model, and maximum reducible load. At the same time, we design the experiment scheme of the multiuser cooperative duty cycling control, using the feedback to optimize the duty cycling control based on user control air conditioning unit power supplying side and demanding side interactive operation procedure. Finally, through the system simulation duty cycling control experiments, we achieve results and do further analysis.

Through the research, the following conclusions can be made:

a) Reducible air conditioning load and the outdoor temperature is inversely proportional. When the outdoor temperature is too high, the user is in the open state of air conditioning, air conditioning load of the total load proportion is higher, in order to guarantee the comfort of the human body, which cannot close the air conditioning unit. On the contrary, when the outdoor temperature is low, the duty cycling control almost does not affect the human comfort of air-conditioning, the reducible amount of the total air conditioning load will increase, which is in agreement with the prediction and experimental simulation results.

b) Reducible air conditioning load and the indoor temperature is proportional. Indoor temperature's increasing can be viewed as the payment to reduce air conditioning load. When the room temperature rises to a higher level, reducible air conditioning load ratio is also higher.

c) The number of duty cycling control group and the outdoor temperature is proportional. From the perspective of human comfort , when the outdoor temperature is too high, in order not to affect the comfort of human body, duty cycling control group number are larger, so that each unit will complete the process load, suspended load and loading, in a shorter period of time, to reduce discomfort for users.

d) Cycle of the duty cycling control and the outdoor temperature is inversely proportional. From the perspective of human comfort, when the outdoor temperature is too high, in order not to significantly affect the human body comfort should shorten the cycle of load reducing, suspended load and loading time, to ensure the refrigeration time of air conditioning units.

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