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The energy efficiency assessment and optimization of collaborative working air-conditions

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ABSTRACT

Although Computational Fluid Dynamics method has solved the impact on the building space environment of collaborative working air-condition in theory, the actual air distribution can't fully meet the boundary conditions due to the influence of these factors such as furniture, equipment and decoration. Therefore, the results of theoretical simulation cannot be directly applied to practical engineering. Not all the working condition can be covered by the theoretical calculation since the building load is changing. So a concise and effective model that can be used in practical engineering is needed to reduce energy consumption of collaborative working air-conditions. Based on the concept of single energy utilization efficiency, we come up with a method of calculating the efficiency of collaborative working air-conditions and propose an optimization strategy in energy usage. Experiments had proved that the method of energy efficiency optimization can improve the system energy efficiency of air-condition though reducing the entirety energy consumption.

1. Introduction

The environment parameters' adjustment is usually completed by multi-air-conditions cooperatively for large building space such as workshop and public areas in building. However, the temperature field in space is uneven whether caused by the palisade structure or other device in the space. It means that the contribution of each air-condition of changing environment is not completely equivalent. So, how to evaluate the contribution of a single air-condition is an important issue when they are working cooperatively. To solve the above issue, we usually use CFD (Computational Fluid Dynamics) method to make simulation according to the related theory of air distribution and temperature field [1–3]. Although this method can calculate the contribution to environmental change of single air-condition in theory, the influencing factors of airflow changes tend to be more unpredicted than setting parameters in calculation, nor can't satisfy the conditions of the simulation at the scene of the application. Therefore some errors often exist in the results of theoretical calculation [3,4]. For the problem of multi-air-conditioning equipment cooperative work, many literatures [1–10] has been researched, the research direction is mainly concentrated on the following points. First, they researched the influence of the multi air conditioning placement and the air outlet blade larger on indoor temperature field. Second, they researched how to save energy with multi – air – conditioner equipment cooperative working. Third, they researched how to assess the energy efficiency of the air conditioning systems. Multi air conditioning collaborative research is mainly based on numerical simulation or in a clean open room, without involving the real environment, but also did not take into account the differences between air conditioning. The evaluation of energy efficiency is mainly aimed at the air conditioning system or single equipment and did not consider the mutual influence factors of multi-air conditioning. The initial design of air-condition should meet the most unfavorable conditions, but air-condition load will change along with external conditions, which means that the power of collaborative working air-condition is not necessarily equivalent. Thus, how to use minimum energy consumption in the allowed range of environment to meet the demand of feeling comfortable is also an important issue. If the effects of air-conditions is not act on the space of changing crowd such as marketplace, this part of energy consumption is meaningless. So, in large place, these three parts – the influence region of air-conditions, the service object and the energy consumption – should be considered overall on the issue of energy efficiency. It is very important to research an evaluation and optimization method to improve the overall energy efficiency and reduce energy consumption in multi-air-conditioning system [5–8].

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CFD and other methods have solved the problem that how the indoor temperature changes under the influence of air-conditions. However, these methods are focusing on theoretical calculation and simulation analysis. For that differences exist between simulation and realities, this paper proposed a method to obtain a better energy efficiency through optimizing multiple air-conditions' working mode. For independently working air-condition based on three parts including influence region of air-conditions, service object and energy consumption, the author puts forward a method – assess the energy utilization efficiency. Then then analyzes the energy usage in public building areas by this method [9,10], excluding the circumstance of several air-conditions working together. Although the collaborative working air-condition can work independently, interior environment is the result of multiple collaborative working air-condition. Therefore, the energy efficiency evaluation and optimization of collaborative working air-condition can't simply copy the evaluation and optimization method of independent working air-condition. Considering the different contribution and energy usage of each air-condition, it is necessary to make an optimal way to assess the energy consumption, which is the main problem to be solved in this paper.

2. Energy efficiency of cooperative air-conditions

The influence on interior environment by the collaborative working air-condition can be divided into two cases, one is that each air-condition is working independently and has no effect on each other, the other is a collaborative work. It means there is a couple between air-conditions' working areas, which cause the result of collaborative working air-condition. The first working way can be regarded as a special case of the second, but it often appears in the process of changing building load. At the same time, building space formed by the collaborative work can also be treated as superposition of the independent working air-condition. So, this paper studies energy efficiency and optimization method of collaborative working air-conditions based on independent working air-condition utilization.

2.1. Energy efficiency of collaborative working air-conditions

Collaborative working air-conditions are normally laid out according to the building structure in certain rules. Although the shape of layout changes along with the building envelope space, the rectangular grid distribution is the basic rule of air-conditions design for large space. Therefore, this paper studies energy efficiency of collaborative working air-conditions focusing on the way of distributing in rectangular grid. Working state is different between each collaborative working air-condition, but interior environment is the result of the superposition by different air-conditions. So the energy efficiency of collaborative working air-conditions can be researched by the method of analyzing an independent air-condition through analyzing the relationship between them.

According to the research achievements on air distribution in large space of buildings, airflow field can be formed in buildings with an air-condition outlet as center and a changing temperature field uniformly within a certain range. If the range of temperature adjust by air-conditions is T, T ∈ $[T_{MIN}, T_{MAX}]$, then the temperature of any point I in the surrounding space whose center is air-condition outlet meets $T_{MAX} \geq T_i \geq T_{MIN}$.Though temperature field whit outlet as center changes unevenly, it can be regarded as the result of a single air-condition as long as Ti is in the allowable range. Therefore the influence on the building space in the case of collaborative working air-conditions can be divided into two parts, one is the result of a single air-condition and the other is the result of multiple collaborative working air-conditions. Fig. 1 shows an ideal distribution of temperature field in building. The area that is covered by the solid line with an outline as center is affected by the local outlet only. On the outside of the solid line means synergistic effect area of air-conditions. The area covered by the dotted lines means the biggest area one air-condition can affect. The ideal circular temperature gradient field in Fig. 1 can't be formed by the actual collaborative working air-conditions, but the whole building space can be regarded as a set of N ideal region showing in Fig. 1. Summer cooling condition are discussed as an example of air-condition 5 below. The influences scope between air-condition 2 and air-condition 5 are only drew in figure for graphic clarity.

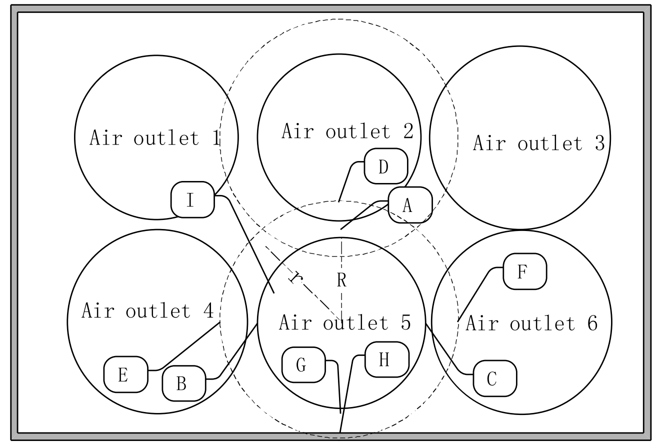

Fig. 1. An ideal distribution of temperature field in building.

The state of collaborative working air-conditions can be divided into two kinds, one is having no interaction and the other existing mutual influence between each other. There is no interaction between each other if the influence of each collaborative working air-condition is limited to the round solid line range in Fig. 1. In other words, the temperature of any point I within the solid line, meets $T_{MAX} \geq T_i \geq T_{MIN}$, which indicates that the temperature of the area covered by air-conditions is controlled in the scope of the design. The energy consumed by air-condition completely act on its work area effectively and the value of energy utilization efficiency can be thought of 1 according to the literature.

For the state of mutual influence between collaborative working air-conditions, we can obtain the system energy efficiency using mathematical average method though divided into independent area and mutual influence area. If the temperature of any point I inside the solid circular line meets $T_{MAX} \geq T_i \geq T_{MIN}$, the temperature of G on the solid line meets $T_G < T_{MIN}$, and the temperature of a point on the dotted circular line meets $T_E \leq T_{MIN}$, we can infer that there is an interaction between air-conditions. Suppose the radius of each independent working air-condition's planar projection area is R, and η_c means the energy utilization efficiency in this area, r means the distance between the overlapping area's edge and air outlet, η_s means the totally energy utilization efficiency, then the energy utilization efficiency of air-condition 5 can be represented by formula (2.1) [9].

$$\eta_5 = \frac{\int_0^R 2\pi x \cdot \eta_C dx + \int_R^r 2\pi x \cdot \eta_S dx}{\pi r^2} \tag{2.1}$$

Reduce it to:

$$\eta_5 = \frac{R^2 \cdot \eta_C + \left(r^2 - R^2\right) \cdot \eta_S}{r^2} \tag{2.2}$$

Among:

R: The radius of independent working air-condition's planar projection area.