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Application of Building Energy Simulation to Air-conditioning Design

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Abstract

This paper briefly introduces the basic principles of building energy simulation, explains its relationship with air-conditioning load and energy calculations, and describe the application in air-conditioning design.

Keywords: Air-conditioning load calculation, energy calculation, building energy simulation.

1. Introduction

The rapid development of computers and their use in building design have changed the design procedure and method of the air-conditioning engineers and architects. In the past, air-conditioning design calculation focused on the estimation of peak loads which are determined by either manual calculation or simple computing methods. Nowadays, not only the load calculation has become complicated, but also there are requirements at the design stage to conduct energy analysis on the building design. In order to enhance the energy efficiency, it is necessary to conduct quantitative estimation on the building design schemes and assess the energy performance of completed buildings. Using computers to carry out load calculation and energy simulation is an important part of building design and energy efficiency research [1].

This paper briefly introduces the basic principles of building energy simulation, explains its relationship with air-conditioning load and energy calculations, and describe the application in air-conditioning design. It is hoped that the understanding on this subject can be increased and the technique of building energy simulation can be utilised to analyse air-conditioning design so as to achieve a better and more energy efficient building design.

2. Air-conditioning Load Calculation and Energy Calculation

Air-conditioning load calculation is the fundamental of building energy simulation and it is also the first step to be considered in building energy consumption.

2.1 Basic Principles and Methods

Air-conditioning load calculation is the design load estimation for an air-conditioning system. Based on design criteria and thermal properties of the building, the cooling, heating, latent and fresh air loads of the building will be estimated to determine the design flow rate and capacity of the air-conditioning system and its equipment [2]. In its simplest term air-conditioning load can be divided into "heating load" and "cooling load". The calculation of heating load is usually more straightforward because the heat transfer in a room in winter is relatively stable. In the coldest weather period the room may not receive sunshine, therefore, the heat gains from the sun, occupancies, lighting and equipment are usually not considered in the estimation of peak heating load. Thus, a steady-state calculation method is usually enough for computing heating load. However, for cooling load calculation, the complex effect of heat transfer, solar radiation and heat storage has to be considered and this make the calculation complicated. To understand the basic principle of cooling load calculation, one must distinguish the difference between "heat gain" and "cooling load" [3]. Figure 1 shows the relationship between instantaneous heat gain and cooling load.

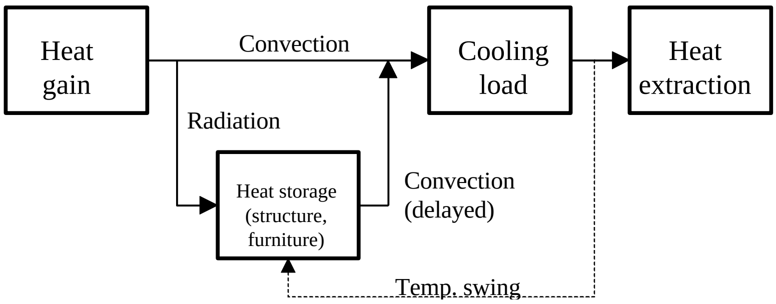

Figure 1 Relationship between instantaneous heat gain and cooling load

The cooling load of an air-conditioning system should be determined based on simultaneously usage of the rooms it serves, the type of air-conditioning system and the type of control method. The cooling load should be calculated using the block load which combines the hourly cooling loads of all the rooms, and with the addition of the fresh air load and the load due to temperature rise at the air handling unit, air duct, water pump, chilled water pipe and water tank. Because some of the loads may vary during the 24 hours period in a day, it is necessary to calculate for each hour and see which one will give the largest block load. The amount of the load will also be affected by the running period of the air-conditioning installation. For intermittently operated air-conditioning systems, load calculation should consider the effect between pre-cooling/pre-heating and the storage of heat.

There are a lot of methods for the determination of building thermal storage and thermal physics, for example, the room response method [4], equivalent temperature difference method [5], harmonised wave decomposition method [6] and finite difference method [7]. Nowadays, the "transfer function method" developed by ASHRAE[1] based on the 1960's theories of Stephenson and Mitalas is most commonly used [8]. This method introduces the concept of coefficient, disturbance, response and transfer function in the control theory into the thermal load calculation of buildings. Because an iteration process is taken in this method, computers are usually required for the calculation process. With the development of microcomputers and software, more and more people have adopted the more complicated calculation methods. In cooling load calculation, there is no absolutely correct method for the computation because during the calculation process we have to make a lot of assumptions and the results of the calculation will be influenced by the quality of the assumptions. As Romine [9] has pointed out, cooling load calculation is both a "science" and an "art" that requires skills. To carry out the calculation effectively and accurately, one must be careful about the important parameters in the loads and try as far as possible to keep the assumptions close to reality.

2.2 Energy Calculation

The purpose of energy calculation is to estimate the annual energy consumption of buildings so as to provide information for energy and economic analysis which aims at improving the building design. There are many methods for estimating building energy consumption and in general they can be divided into two categories: steady-state and dynamic. Steady-state methods, such as effective heat transfer method, degree day method, bin method, temperature frequency method and full load coefficient method, are relatively simple to use, but they cannot provide information about the variation of energy consumption with the time and do not consider the effect of thermal storage in the building structure. Dynamic methods are more detailed and will usually require hourly calculations over the whole year for the analysis of annual load and energy consumption.

The calculation of energy consumption is similar to that of the thermal loads. The values of hourly air-conditioning loads throughout the year is the basis for dynamic energy calculation and analysis. The conditions during part load is often a key to energy efficiency of the system. The major difference between load and energy calculation is that energy calculation is based on average climatic conditions and building usage whereas load calculation uses extreme climatic conditions and usage for its estimation. Conversion from heat gains to cooling load can be carried out in two ways. One way is called "weighting factor method" and the other is called "heat balance method" [8, 10]. Comparatively speaking, heat balance method uses more detailed physical thermal models and intends to solve simultaneously the balanced condition of heat transfer and

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[1] ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers.

inside surface temperatures. Therefore, more calculations will be required and the computation will be more complicated.

After the hourly load calculations of the rooms, the energy consumption of the air-conditioning system will be determined. The "space heat extraction" (see Figure 1) is the cause of the air-conditioning energy consumption and it is affected by the characteristics of the control system and the air-conditioning equipment. The next step of the energy calculation is to estimate the annual energy consumption (such as electricity) of the air-side and water-side systems (also known as "secondary equipment"). Then, the annual energy and fuel consumption of the air-conditioning plant (also known as "primary equipment") will be determined. Often, it is also necessary to carry out economic analysis according to the local energy prices of the fuels. Dynamic simulation nowadays often use an approach called "LSPE" (load-system-plant-economics) for the process, as shown in Figure 2. This approach can allow calculation to be done consecutively and directly at each step, but because there are no feedbacks between each phase, it cannot ensure that the air-conditioning system may meet all the demands of the thermal loads.

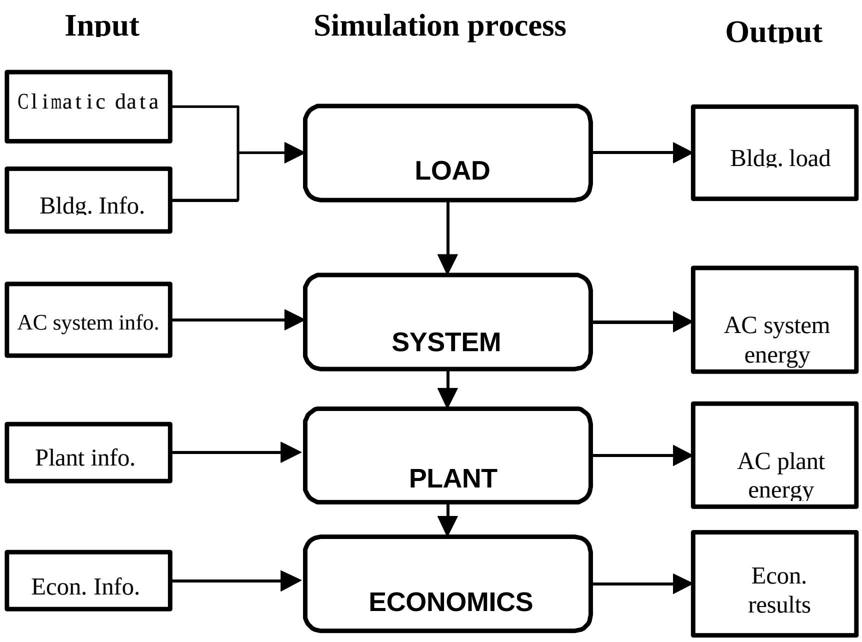

Figure 2 Load, system, plant and economics (LSPE) approach for consecutive calculation

3. Building Energy Simulation

Building energy simulation by definition is the use of computer simulation methods for the analysis of energy efficiency and building loads. It includes air-conditioning and other building installations such as lighting and electrical systems.

3.1 Basic Information

The information that building energy simulation requires is basically the same as energy calculation. Before carrying out the simulation, one must collect information about the local climatic criteria, building design, air-conditioning system and control method. The local outdoor climatic conditions over a year is an important piece of information and it is better to have the hourly values of the climatic data. Building energy simulation usually requires 10 to 13 sets of weather parameters including solar radiation, temperature, humidity, wind speed, wind direction, cloud amount, atmospheric pressure and so on. This data is often recorded in a typical year [12]. If the weather data for a particular location is not available, it may take a lot of efforts to collect and establish this data.

The dynamic simulation of building energy consumption focuses on the hourly variations of the outdoor climatic conditions and the indoor design criteria about temperature and humidity. The air-conditioning loads and energy consumption for 8760 hours in a year or for several years are determined. Beside the part-load energy consumption, the maximum load over the year(s) will also be included. Usually, we are more interested in the energy consumption of the air-conditioning system, but in fact the dynamic simulation can also estimate at the same time the energy consumption of other building systems, such as lighting, electrical system and lifts. Figure 3 shows the major components of building energy simulation. Within the simulation system there are four major models, namely, building model, air-conditioning system model, air-conditioning plant model and control system model.

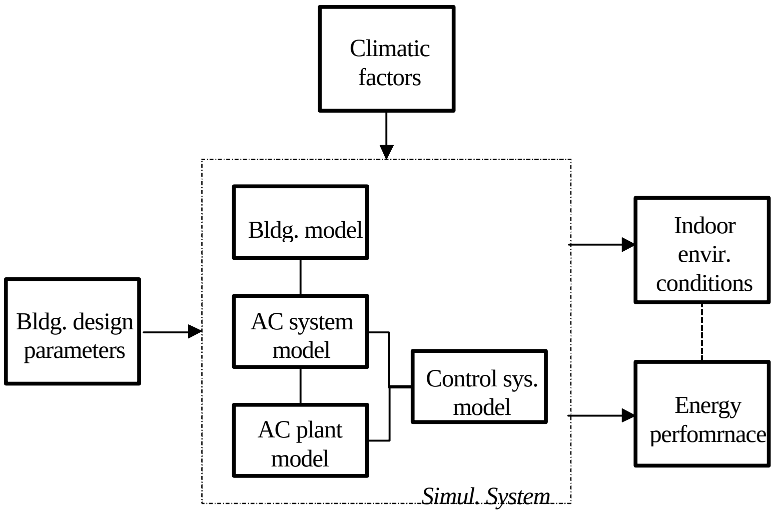

Figure 3 Major components of building energy simulation

3.2 Simulation Tools

Simulation tools are the computer software and programs used for the energy calculation. At present there are many different types of simulation software; each of them have their own characteristics and they are also developing continuously. Some simulation tools are sophisticated and complicated and are usually used for research purpose in the past, such as DOE-2, BLAST and ESP-r. In recent years, with the fast development of computing technology, they are beginning to be noticed by average building designers. On the other hand, there are some simulation tools developed by commercial companies and they are easier to use and have integrated design load calculation within their package, for example, HAP and TRACE 600. These programs are more widely accepted by engineers but the calculation process is usually simplified and their commercial background may also affect the independence of the tools.

Building simulation software has developed very fast in recent years and new programs and versions are coming up frequently. To keep abreast of the development, you may look at the "Building Energy Tools Directory" developed by the US Department of Energy. The web site address is "http://www.eren.doe.gov/buildings/tools_directory/". At the same time, you may also consult about the activities of the International Building Performance Simulation Association (IBPSA), and their web site address is: "http://next1.mae.okstate.edu:80/ibpsa/". The recent developments of the simulation tools are focusing on the enrichment of information and promotion of its application. Major research areas about the tools include:

(a) addition of heat balance procedure to consider the interactions among the load, system and plant so as to improve the present sequential calculation approach and weighting factor method;

(b) improvement of the information on the energy consumption of indoor equipment and this is resulted from the more accurate results from experiments and testing;

(c) improvement of the transfer function method and the investigation of heat transfer theories and mathematical techniques, such as finite difference method, finite element method and neural network method;

(d) expansion of the building climatic database (including hourly data, typical years and design extremes);

(e) development of simulation modules for new equipment and design methods (such as thermal storage system and solar system); and

(f) the use of stochastic weather model for the analysis of building thermal environment.

Because building structure has thermal storage characteristics, if the load calculation is carried out hourly, normally there should be no problem with the stability of the thermal system. At present, a quasi-steady state simulation method is usually employed for air-conditioning system and plant and it is assumed that within an hour the system should be stable enough and the change will occur only between the hours. This is usually valid for the calculation of general cases, but if the characteristics of some air-conditioning control systems are to be studied accurately, it may need to do the calculations in a smaller interval, such as a minute or a second.

3.3 Simulation Procedure

Before commencing a simulation analysis, one must select the appropriate simulation software. This may be a quite difficult task because there are many software available in the market and it is not easy to compare them. Selection of simulation software should consider your particular requirements and strength. It is important to understand that building energy simulation, like cooling load calculation, is not absolutely accurately and its "accuracy" and reliability will depend on the skill of the user and the number of assumptions. Training of the program user is very important and should be considered and planned carefully [13]. The procedure of building energy simulation is not simple and there are a lot of factors to consider. Architects and engineers may not able to master it without proper training beforehand. In general, the procedure of the simulation will be as follows [14]:

(a) mastering of the simulation tools;

(b) description of the building design and the assumptions;

(c) preparing of the simulation inputs;

(d) carrying out of the simulation; and

(e) interpretation of the simulation results.

The aim of the energy simulation is to help designers understand the relationship between design and energy performance. It is important not to be confused by the numerous data and not to forget to look carefully at the nature of the basic problem.

4. Application to Air-conditioning Design

With the various disciplines in the building industry gradually adopting computer-aided design, the environment for integrated building design is developing and the air-conditioning load and energy calculation is integrated with other building design works. This is beneficial to the promotion of building energy simulation.

4.1 Improve Load and Energy Calculations

The application of building energy simulation could improve the accuracy of air-conditioning load and energy calculations, and help optimise building and air-conditioning design schemes. Through annual dynamic load analysis, we may find out the frequency distribution of the system loads and select the appropriate equipment capacity and number to match the demand so as to keep the system and its equipment running at high efficiency level.

Building designers are often limited by time and resources, and they usually can only use simple and quick method for analysing and solving the design problems. During the outline design stage, because the building design may often change and the building structure and materials may still not decided, designers can only use rough calculation method for their analysis. At the detailed design stage, designers may then adjust their data based on actual information and then calculate carefully the load and energy consumption again. If building energy simulation models can be set up in early design stage, it will help designers understand the relationship between design and energy performance and make the correct design decisions. At a later design stage, the simulation results may provide detailed information for assessing the performance of the building and its air-conditioning design. When the building is completed, building simulation may also be used to assist the energy management and operation of the building.

4.2 Analysis of Different Design Techniques

According to the function, building energy simulation software may be classified into three major categories: (a) whole-building simulation, (b) lighting and daylighting simulation, and (c) component-based simulation. At present, there are many whole-building simulation software in the market including those programs mentioned in the previous section; they model the energy consumption of the building as a whole. Lighting and daylighting simulation software (such as ADELINE and RADIANCE) focuses on the design of lighting and daylighting systems; they estimate the lighting effect and provide related information and images to visualise the design. Component-based software is usually designed for a specific system, such as solar architecture and system simulation. Nowadays, there are some software which uses a "kernel-based" approach to design the simulation environment and make software development and application more convenient. Some whole-building simulation packages are also building up components and daylighting modules.

Some new technologies for building energy efficiency and air-conditioning, such as daylighting, natural ventilation, solar energy systems, ice storage systems, often require the use of simulation methods for their analysis to study their characteristics and economic efficiency. Beside energy consumption, building energy simulation can also be used for the analysis and comparison of indoor environmental conditions and air-conditioning equipment [1, 7].

4.3 Building Energy Efficiency Standards

Nowadays, the development and implementation of building energy efficiency standards is more complicated than the older ones which are often prescriptive in nature and energy simulation software is often required for developing them [15]. Through the comparison and analysis of energy targets, one can determine whether the efficiency requirement has been satisfied or not. The future trend of building energy efficiency standards is to adopt a "performance-based" approach and it will require heavily on the support of simulation techniques. Air-conditioning design should include energy simulation in the design process so as to facilitate the development of building energy standards.

5. Conclusion

During the past two decades building energy simulation has developed a set of systems and has gradually accepted by designers. Simulation methods can provide analytical power for the study and improvement of building performance; at the same time, we must understand its properties and review the traditional building design procedure. Building energy simulation is closely related to air-conditioning design. If a better building energy efficiency is to be achieved, building energy simulation should be promoted wider in air-conditioning design.

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