THE DESIGN OF A COMFORTABLE THERMAL ENVIRONMENT BY SIMULATION: A CASE STUDY

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ABSTRACT

In this paper, a 3-floors building with capacious spaces was introduced. It has unique shape and all-glass envelope, which worsens the thermotechnical performance of the envelope, deteriorates the indoor thermal comfort.

By simulation, the indoor thermal environment of this building can be obtained. Standard Effective Temperature (SET) was adopted to assess the thermal environment of the occupied zones in the building. Three cases were assessed and compared: the original design, the design with some ceiling sunshades and the design with some ceiling and sidewall sunshades. From the comparison, the appropriate building envelope design and air-conditioning system design schemes which satisfy human thermal comfort requirement were obtained.

From the case it can be found that, in the architectural design, the application of building simulation takes an important assistant effect. Sometimes this application may be indispensable.

INDEX TERMS

Building simulation; Architectural design; thermal environment assessment; building envelope; sunshade

INTRODUCTION

In modern architectural design, people usually pursue outstanding individuality and unique style. It increases the achievements of human changing the world, but meanwhile it also takes more difficulty on the architectural design, structural design and air-conditioning system design. For example, when we carry out conventional air-conditioning design methods on some buildings with strange shape or special envelope or elements, it may not be competent. In this condition, the building simulation technique becomes particularly important. By simulation, the detailed indoor thermal environment of the building can be predicted and assessed, the problems about the original architectural and system design can be found, so that corresponding system design and ameliorating scheme can be proposed. Then a comfortable and healthy environment or an environment which satisfies some certain working requirements can be produced.

In this paper, a 3-floors building with capacious spaces was introduced. It has unique shape and all-glass envelope, so as to become the symbol of that district. However, the application of so many glass structures worsens the thermotechnical performance of the envelope, which increases the energy consumption of heating and air-conditioning. Especially in the daytime of summer, the radiation heating load coming into the building increases a lot, which deteriorates the indoor thermal comfort. Thus, the simulation is required to analyze and assess the indoor environment and obtain the ameliorating scheme.

MODEL DESCRIPTION

According to actual building structure, the simulation model is simplified to a 3-floors building with capacious spaces, as shown in Figure 1. The software used in this work is PHOENICS. The grid setting is 120×275×40, and the mean mesh size is 0.1 meter. The crowd load and equipment load are distributed to each floor in accordance with the air-conditioning system design. And the air supply and exhaust openings are set as shown in Figure 2. According to the local climate condition, the typical outdoor design temperature is set to 35.6 °C, the solar radiation intensities are chosen from hourly data of typical day in Medpha (Yan et al. 2004). The heat transfer rates through the envelope are calculated from the correlative parameters, such as the heat transfer coefficient and shading coefficient of the envelope, and the solar radiation intensity.

The case at 12 o'clock with the strongest horizontal radiation intensity was simulated to obtain the indoor thermal comfort status at that time. It is not good because of the strong radiation intensity. So the case with some ceiling sunshades was simulated. It resolves the problem at 12 o'clock. But the ceiling sunshades have little help on blocking the strong western solar radiation at 16 o'clock. To deal with this matter, the case with some ceiling and sidewall sunshades was simulated. And, this design scheme satisfies the human thermal comfort requirement at the occupied zones in the building.

ASSESSMENT INDEX DESCRIPTION

To assess indoor thermal environment of the building with transparent envelope, the thermal comfort vote index should reflect the influences of not only the temperature, relative humidity, velocity, etc., but also the solar radiation. The conventional PMV index is not competent. The Standard Effective Temperature (SET) recommended by ASHRAE was adopted in this work. The SET is defined as "the equivalent air temperature of an isothermal environment at 50% rh in which a subject, while wearing clothing standardized for the activity concerned, has the same heat stress (skin temperature t_{sk}) and thermoregulatory strain (skin wettedness w) as in the actual environment" (ASHRAE 1996).

According to the ASHRAE standard, it is just acceptable to human body when SET is between 15 and 35 °C. But when SET is above 30 or below 20 °C, it may be uncomfortable to human body. So it's better to control the SET between 20 and 30 °C (Lin 2004). Taking the safety factor into account, in this work, the SET of 29 °C was chosen as the upper limit of the environment control aims.

RESULTS AND DISCUSSION

Due to page limitation, only the distributions of SET at the height of 1.5 meters of each floor (the place where people occupy in the building) were illustrated in the results.

Case 1: Without sunshades, at 12 o'clock

The results of the case without sunshades at 12 o'clock are shown in Figure 3(a)-(c). From the figures it can be seen that the SETs of most places of the first floor were below 29 °C, whereas the SETs of most places of the second and third floors were above 29 °C then caused uncomfortable. To avoid uncomfortable, some ameliorating means are needed. It will be difficult and with more energy consumption by changing the air-conditioning design scheme. So setting inner sunshades at the transparent envelope regions to weaken ingoing solar radiation is preferred.

The case with some ceiling sunshades was simulated. The reflecting factor of the sunshades is 0.65, the covering factor of which is 80%. It may resolve the problem at 12 o'clock. But the ceiling sunshades have little help on blocking the strong western solar radiation at 16 o'clock. So the case with some ceiling sunshades at 16 o'clock was also simulated to check whether it met the requirements at that time.

Case 2: With some ceiling sunshades, at 12 o'clock

Figure 4(a)-(c) shows that when setting some ceiling sunshades at 12 o'clock, the SETs of each floor were below 27 °C, and the first and second floors may need to reduce some cooling supply.

Case 2': With some ceiling sunshades, at 16 o'clock

Figure 5 shows that when setting some ceiling sunshades at 16 o'clock, the SETs of the first and second floors were below 28.5 °C, but the SETs of the third floor were about 29.5 °C, which might cause uncomfortable. So some sidewall sunshades are also recommended.

Case 3: With some ceiling and sidewall sunshades, at 16 o'clock

On the basis of case 2', some western and southern sidewall sunshades were considered to avoid western exposure. The sunshades settings are shown in Figure 6. The simulation result in Figure 7 shows that the SETs of the third floor were also satisfying the human thermal comfort requirement. So this scheme can be adopted as the ameliorating design scheme.

CONCLUSIONS

From the case study, it can be found that:

a. In order to decrease energy consumption of the building with many glass envelopes, setting sunshades at the transparent envelope regions to weaken ingoing solar radiation is preferred.

b. In architectural design, the application of building simulation takes an important assistant effect. Sometimes this application may be indispensable. Along with the raising of people's demands on the shape and functions of the building, building simulation analysis will gradually play a more and more important role in the architectural design.

ACKNOWLEDGEMENTS

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Yan D, Xie XN, Song FT and Jiang Y. 2004. "Building environment design simulation software DeST(1): an overview of developments and information of building simulation and DeST", *HV & AC* (China). 34 (7): 48-56.

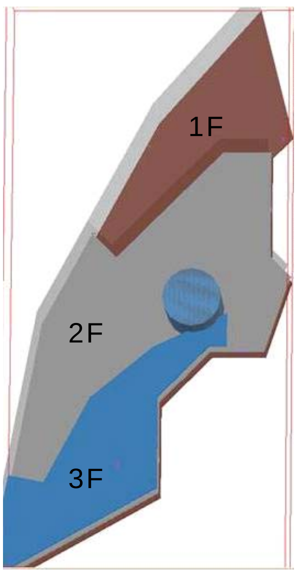

Figure 1. Simulation model of the building

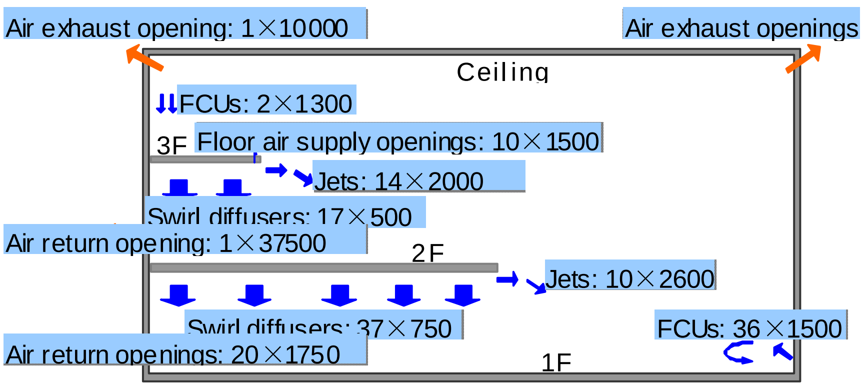

Figure 2. Sketch map of the openings and their air exchange volumes (m^3/h) in the simulation

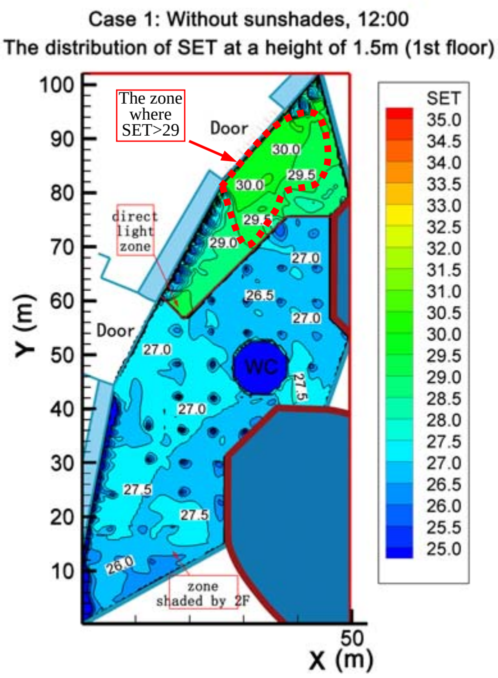

Figure 3(a). The SET of 1st floor in case 1

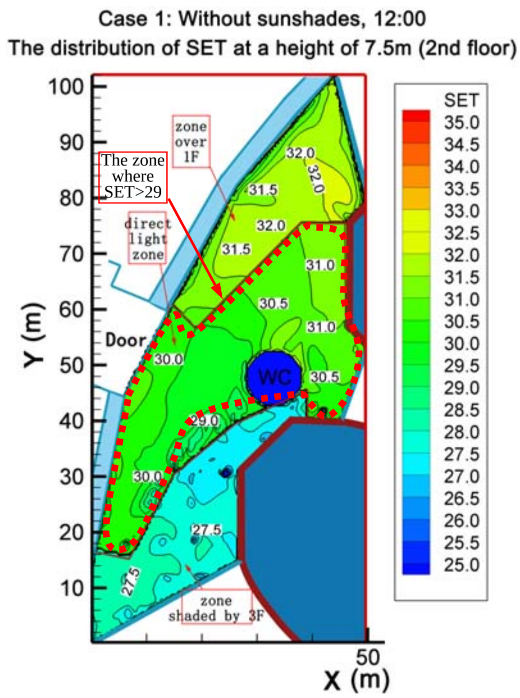

Figure 3(b). The SET of 2nd floor in case 1

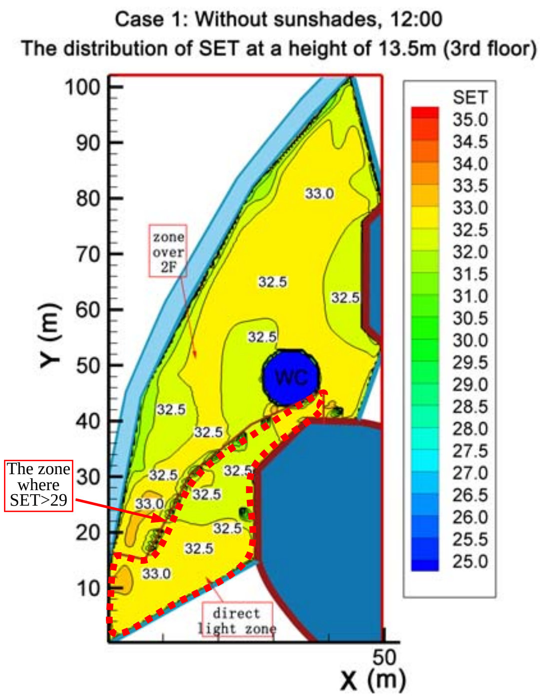

Figure 3(c). The SET of 3rd floor in case 1

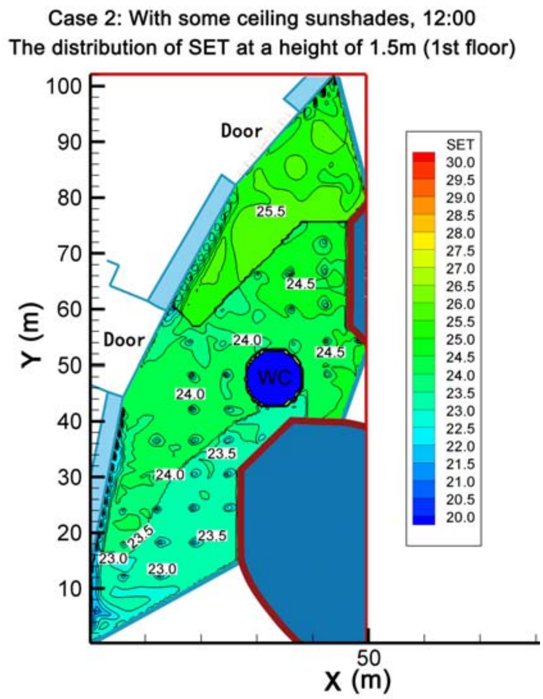

Figure 4(a). The SET of 1st floor in case 2

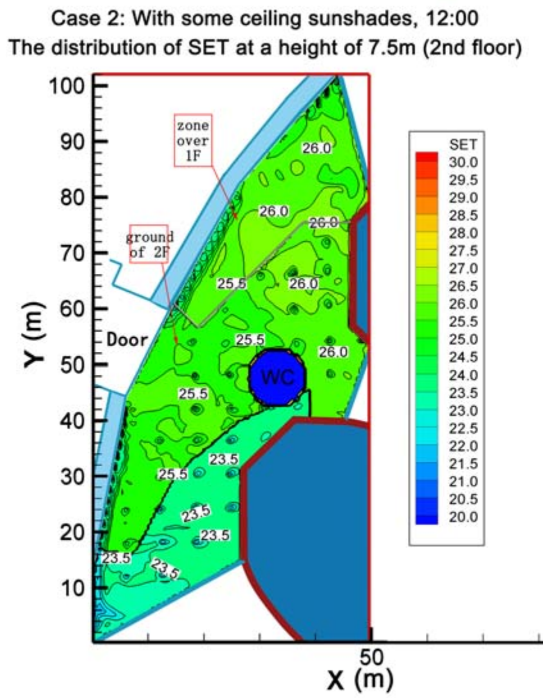

Figure 4(b). The SET of 2nd floor in case 2

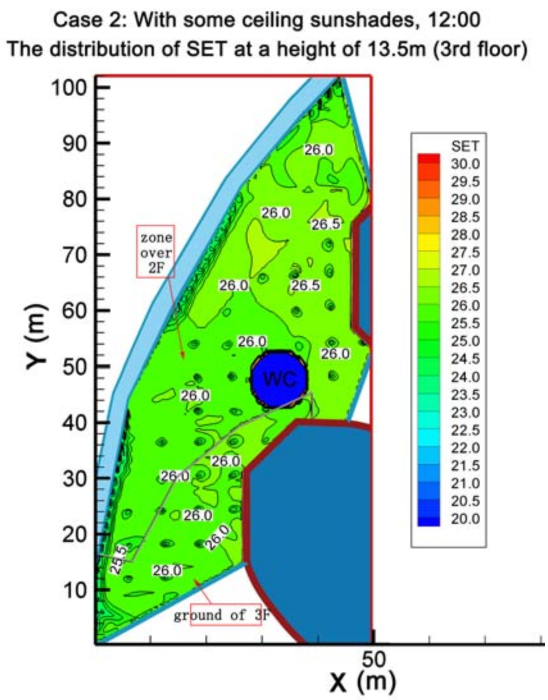

Figure 4(c). The SET of 3rd floor in case 2

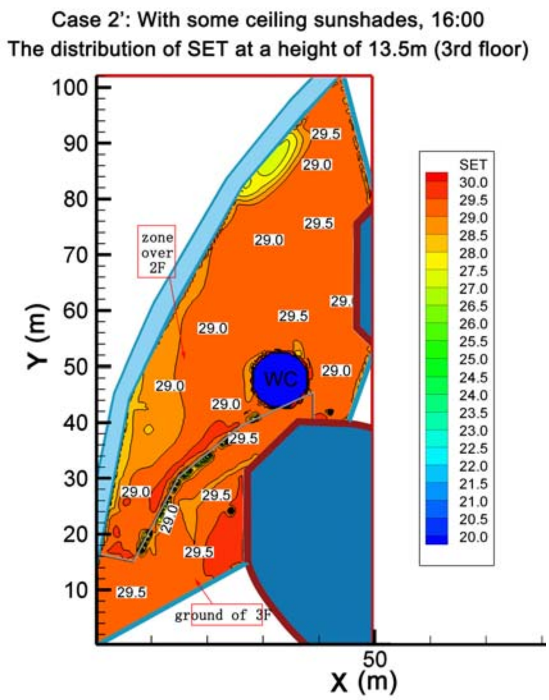

Figure 5. The SET of 3rd floor in case 2'

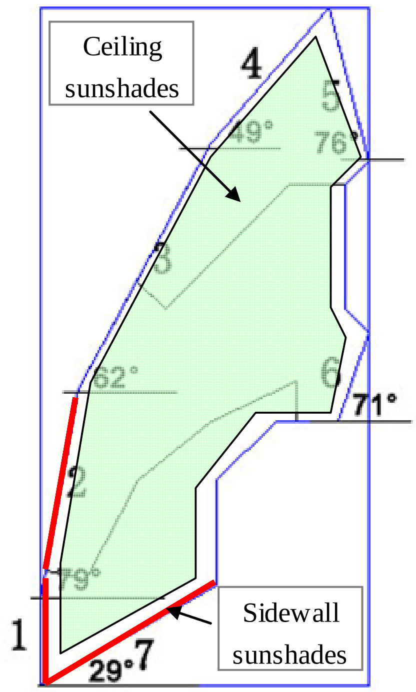

Figure 6. The sunshades setting in case 3

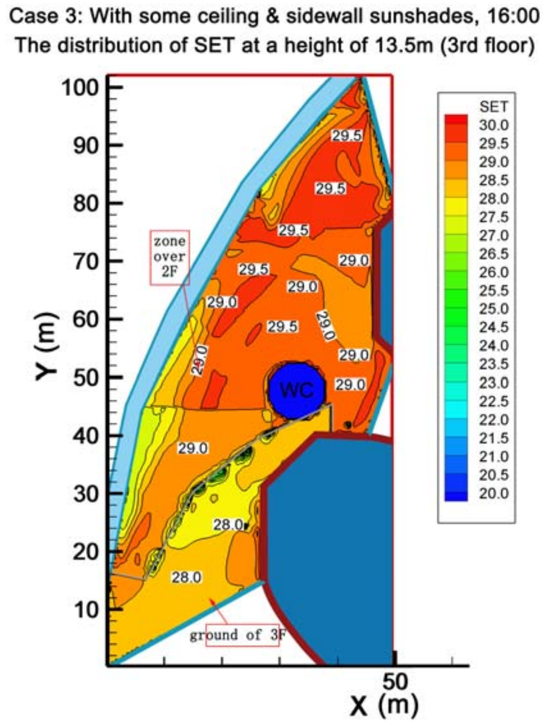

Figure 7. The SET of 3rd floor in case 3