SIMULATION AND RESEARCH ON INDOOR ENVIRONMENT CONTROL MODE BASING ON THERMAL COMFORT: A CASE STUDY IN THE AVIATION BUILDING IN SANYA AIRPORT

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ABSTRACT

It is the goal of climate-adapting buildings to make used of the natural regularity to decrease indoor temperature and improve thermal comfort. In the aviation building in Sanya airport, the control mode of thermal environment—combination of natural ventilation, air modulation by mechanical fans and air-conditioning is promoted. The CFD software PHOENICS is employed to simulate the potential of natural ventilation and air modulation by mechanical fans in different plans under typical meteorological conditions of Sanya in summer. Finally, it is concluded that the wide usage of air modulation by mechanical fans in tropical zones can lead to lower energy consumption under the same indoor thermal comfort.

KEYWORDS

Control mode of thermal environment Indoor thermal comfort CFD Climate-adapting buildings

INTRODUCTION

The design method of climate-adapting buildings is based on the bioclimatology. It is also a method to reduce building energy consumption in natural conditions while keeping the indoor thermal comfort at the acceptable level. Victor Olgyay pointed out in his book "Design with Climate: Bioclimatic Approach to Architectural Regionalism"[1] that architects should pay more attention to the relationship among the local climate, building forms and constructional details. He promoted the idea that climate should be used to enrich the meaning of buildings and building science should be treated as the motivity to reach this goal. A lot of design methods and relative case studies were introduced by Arvind Krishan in his book.[2]

When practising in tropic zones, the usage of advantageous orientation, buffer zones, shading facilities and planting can maximize the cooling effect of natural environment and minimize the need of mechanical or man-made environment. Meanwhile, the utilization of proper thermal environment control mode can give attention to both nature and comfort while fetching up the deficiency of adjustment by the nature and improving or eliminating the uncomfortable zones. As a result, lower energy consumption is required to create a more comfortable indoor environment.

One of representable examples of climate-adapting buildings are the Chinese traditional buildings, especially the ones in south China. Tang Guohua, Lin Qibiao and Qiu Wenming etc.[4~6] analysed the relationship between native climate and the characteristics of local traditional buildings. Qiu Wenhang[7] employed climate adaptability in a projects. Meng Qinglin and his team[8] used passive evaporation technics to improve the indoor thermal comfort of a hotel.

As the fast development in computed calculation, simulation softwares are more and more widely utilized in design area. Shuzo Murakami[9] introduced the use of CFD in building environmental design. But, the combination of CFD software and climate-adapting design in tropic zones has been little reported in journals.

In this paper, the design of aviation building in Sanya Airport is taken as an example to demonstrate the procedure of enhancing design projects and relative thermal environment control mode based on the climate adaptability. At the same time, the computational simulation technology is also employed to assist architecture so as to find out the disadvantageous parts, bring forward the modified plans and finally estimate the validity of the control mode. Ultimately, a building with low energy consumption, high climate adaptability and excellent indoor thermal environment is constructed.

CONTROL MODE OF INDOOR THERMAL ENVIRONMENT

Evaluation Index of indoor thermal environment

The construction environment is quite different with the natural one. It is a kind of man-made environment with air-handling equipments composed by buildings and other structures. The following two indexes are utilized to evaluate whether the environment is a good one or not.

- Natural ventilation

It is estimated by the distribution and scale of the indoor weak wind fields. The wind speed in these fields is lower than 0.5 m/s. The indoor thermal environment would be worsened because of the low wind speed and inconsequent distribution. Therefore, the analysis of these fields can be helpful to find out the areas where natural ventilation is inefficient and mechanical air modulation or air-inducing is required.

- Thermal comfort of human body

This index, which estimates human thermal comfort is an integrated one, including wind speed, temperature, humidity and so on. ISO7730 recommends the system of PMV-PPD, as shown in Table 1. The value of PPD should be less than 10%, while PMV should be in the range of -1.0 to 1.0.

Table 1 Relationship between PMV and subjective feeling

PMV	**+3**	**+2**	**+1**	**0**	**-1**	**-2**	**-3**
Subjective Feeling	hot	warm	slightly warm	neutral comfort	slightly cool	cool	cold

Energy-efficient control mode of indoor thermal environment

In order to maintain the thermal comfort, it is necessary to dominate thermal environment through controlling the indoor physical parameters, such as wind speed and temperature. Generally, natural ventilation and air conditioning are used. In the project of Sanya Airport, mechanical air modulation is also taken into account so as to reduce the operation time or replace air-conditioning equipments.

Based on the computational simulation technology, the measures of better orientation, allocation plans and sectional holes are preferentially considered to employ natural ventilation, especially in the areas of high human density. In the weak wind fields of high temperature or human density, fans are set to modulate air flow. It can be assured that the indoor thermal environment is kept in comfort at 85% of the total working time in summer by these two measures. To some other rooms with higher demands or parts that can not achieve comfort only by the two measures, air-conditioning sets are installed as supplement. Finally, the combination of natural ventilation, mechanical air modulation and air-conditioning is formed as an energy-saving control mode of indoor thermal environment.

In this mode, the modulation of mechanical fans works as the continuation of natural ventilation and complement of air-conditioning. The turning of paddles accelerates the speed of spot air flow. As a result, under the same condition of temperature and humidity, the value of PMV decreases to the level of comfort. Therefore, it is an economical method to maintain indoor thermal comfort with lower power consumption.

CASE STUDY

Sanya Airport is located in the southern part of China. The new aviation building, next to the old one, holds 47700 ㎡ with the total construction area of 9590 ㎡. The architecture sketch and model in computational simulation are shown in Figure1.

Analysis of meteorological data

According to the meteorologic database of the TMY in the DOE (Department Of Energy, USA), wind speed and outdoor temperature from 8 a.m. to 9 p.m. in June 1st to September 30th are analyzed, totally 1586 hours. The frequency and percentage in the whole summer is calculated so as to guide the design and input as the boundary conditions in CFD simulation.

➢ Wind speed

According to the statistics in TMY, the dominant air flow direction in Sanya is southwest. The wind speed mainly distributes from 1.0m/s to 4.12m/s. The frequency is shown in Figure 2.

The wind speeds with high frequency are 3.09m/s (321hours), 2.06m/s (317 hours), 4.12m/s (217 hours), 1.54m/s (158 hours) and 1.03m/s (124 hours). The frequency of wind speeds above 2.06m/s is around 75%, so these values are able to present the dominant speeds.

➢ Outdoor temperature

The hourly outdoor temperature in Sanya ranges from 24~33℃ in summer, with one wave crest, as shown in Figure3. The temperature values with high frequency are 29.4℃(198hours), 30.6℃(192hours), 30 ℃ (159hours) and 31.1 ℃ (155hours). The frequency of temperature values below 32℃ are around 92.6%, so these values are able to present the dominant temperature in summer.

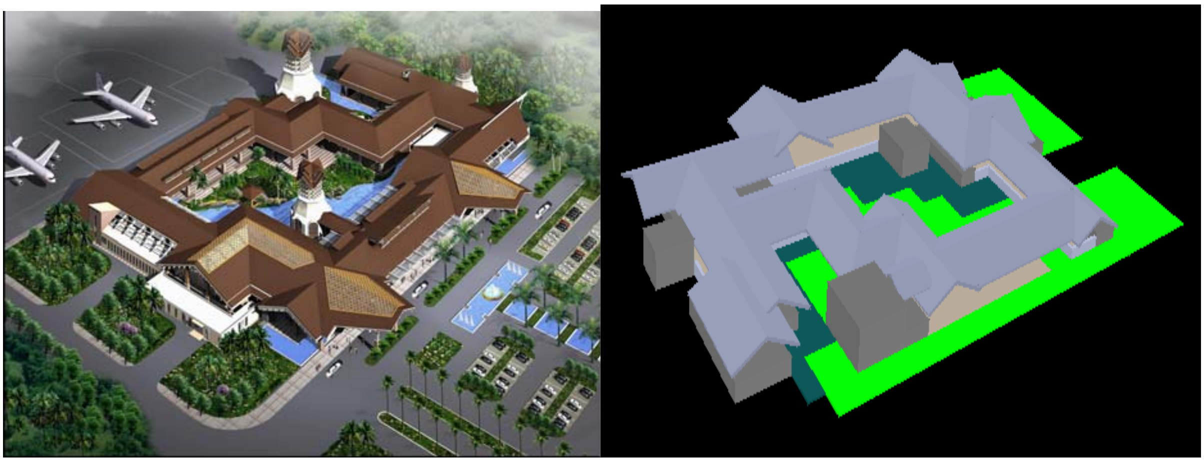


Figure 1 Architecture Sketch and Simulation model

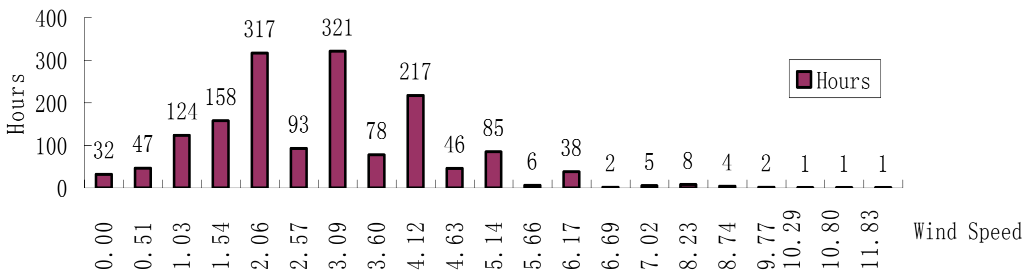


Figure2 Frequency of Wind Speed

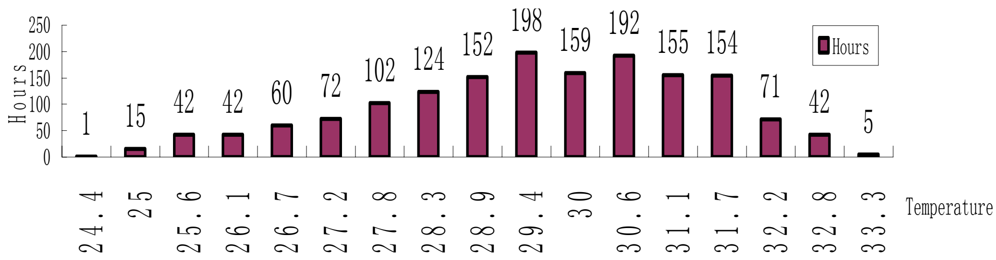


Figure 3 Frequency of Temperature

Simulation

Climate adaptability is carefully considered in the stage of plan. According to the results of simulation to draft plans,following improvements are taken,:

✧ Pitched roof with domers to employ winds from outer space, shown as figure 1 .

✧ 1.2m-height openings between windows and eaves to import draught and daylights, shown as figure 5 and 6

✧ Lakes and grassplots around or inside the building to reduce the temperature of outer space, shown as figure 7.

✧ 1m-height openings from the groudn in all the indoor glass dividers, shown as figure 5

Figure 5. Elevation view

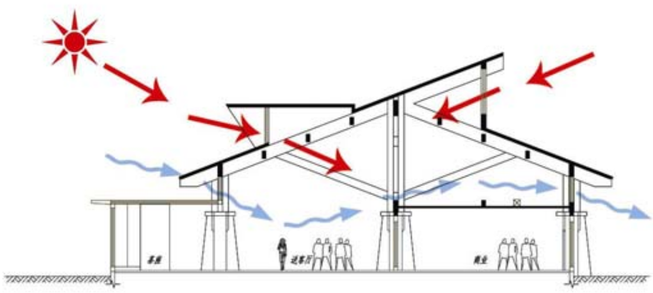
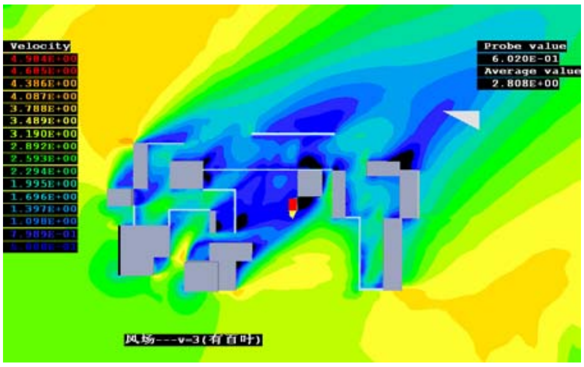


Figure 6. Wind and daylighting routes through pithced roof and openings

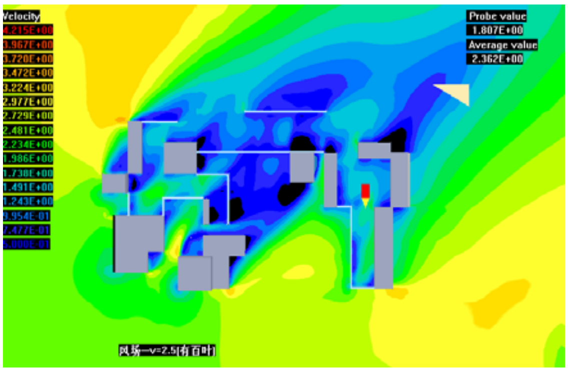
Figure 7. Final plan of the aviation building

- Natural ventilation

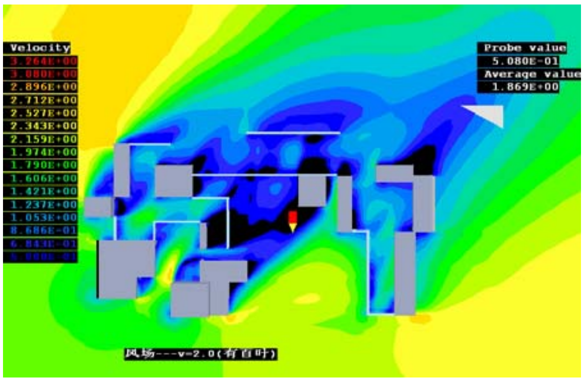
The simulation results of indoor 1.5m high in the condition of different incoming flow velocity are shown in Figure 8. The black parts in the figures stand for weak wind fields. They mainly distribute in café and pavement. Their area percentages to the whole building are shown in Table 2. According to the table, the percentage of 1.5m/s is around 20%. To these areas, fans are required to set.



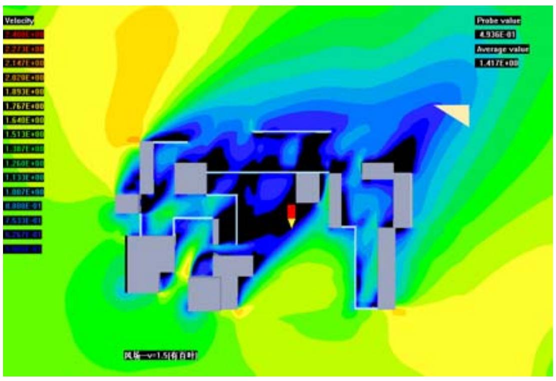
Incoming flow velocity: 3.0m/s



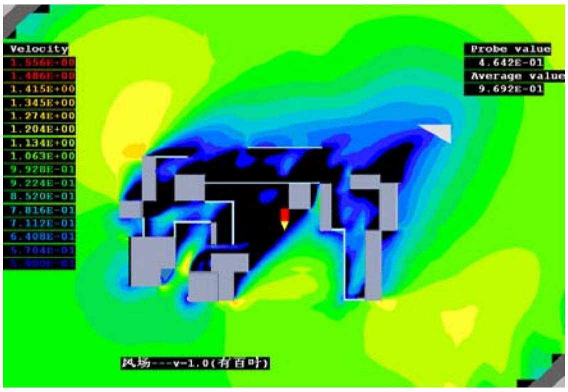
Incoming flow velocity: 2.5m/s



Incoming flow velocity: 2.0m/s



Incoming flow velocity: 1.5m/s

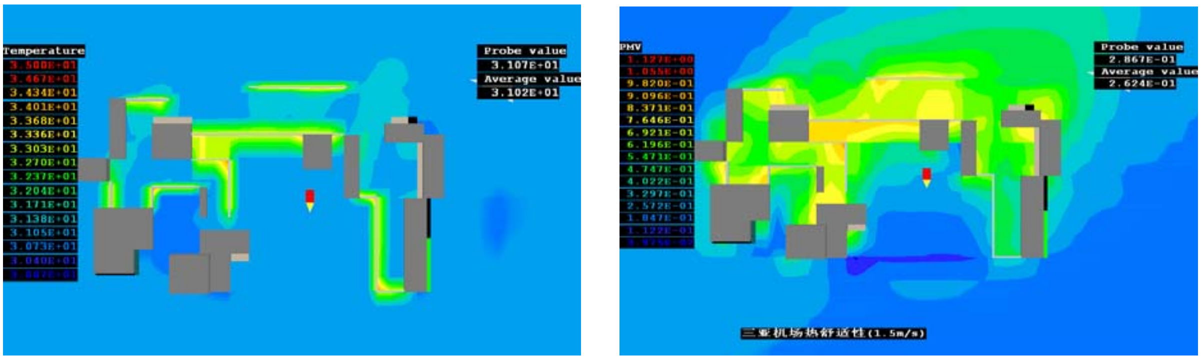


Incoming flow velocity: 1.0m/s

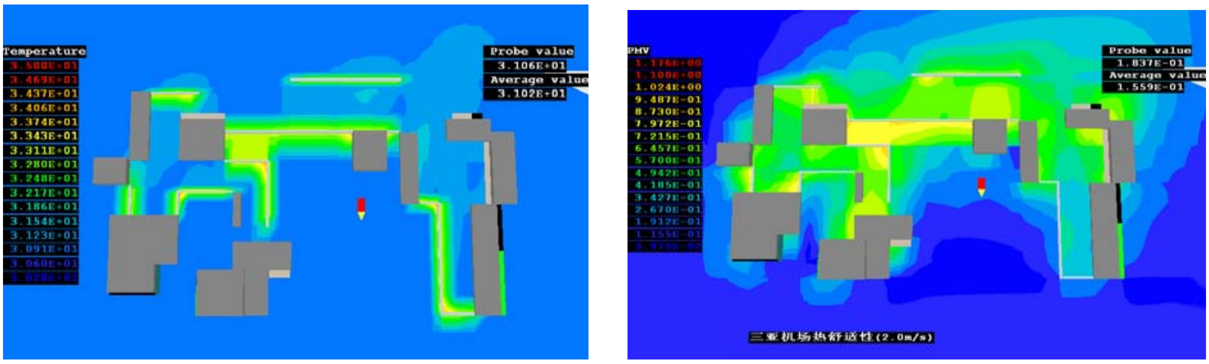
Figure 8 Simulation Results of Natural Ventilation with different incoming flow velocity

Table 2 Area Percentage of Weak Wind Field in Different Incoming Wind Speed

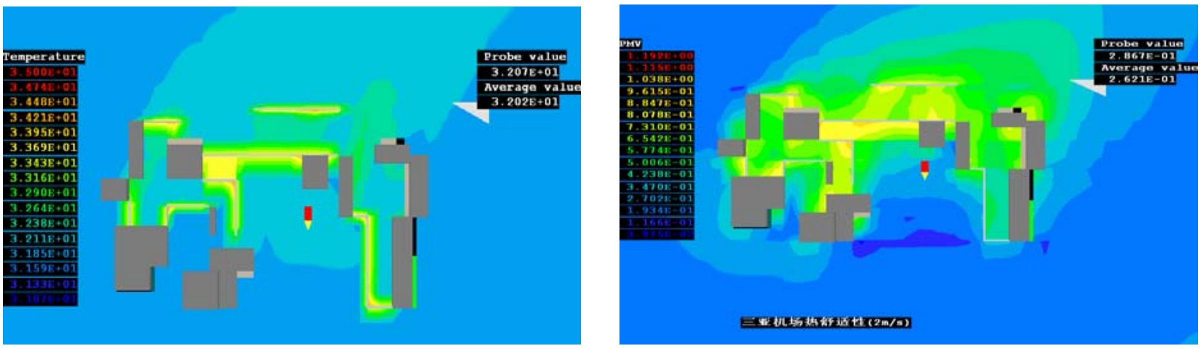
Speed(m/s)	**3.0**	**2.5**	**2.0**	**1.5**	**1.0**
Percentage	7.22%	9.45%	14.02%	20.37%	40.98%



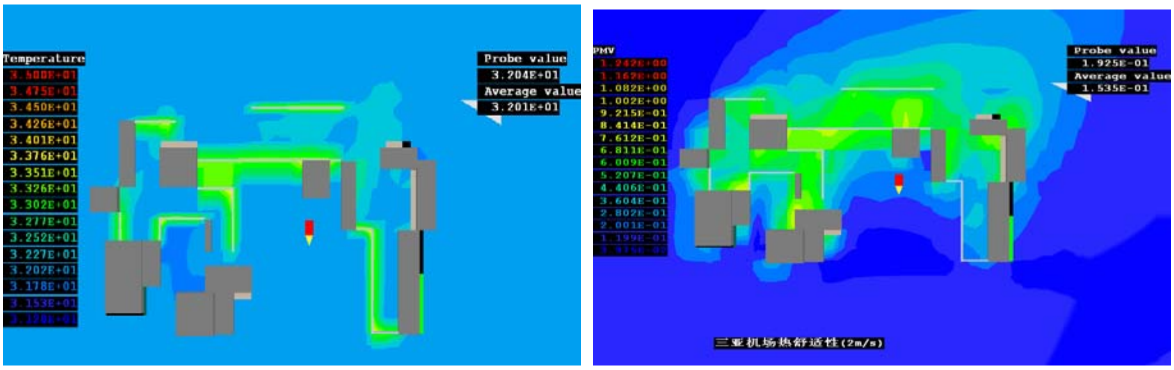
Condition1:Outdoor Temperature 31 ℃, incoming flow velocity 1.5 m/s



Condition2:Outdoor Temperature 31 ℃, incoming flow velocity 2.0 m/s



Condition3:Outdoor Temperature 32 ℃, incoming flow velocity 1.5 m/s



Condition 4:Outdoor Temperature 31 ℃, incoming flow velocity 2.0 m/s

Figure 9 Distributions of Indoor Temperature and PMV

➢ Distribution of Indoor Temperature and PMV

Under different combination of outdoor temperature and wind speed, the distribution of indoor temperature and PMV in the level of 1.5m high is simulated, as shown in Figure 9 with 4 different outdoor conditions. From these figures, the temperature around glass walls is higher than the average value of environment, especially the windows in café. The temperature is 2℃ higher. In order to prevent spot overheating, blinds, curtains and other shading facilities inside are recommended. The PMV value in the whole building differs from 0 to 1.0, but there are no spots where PMV is higher than 1.0. Thus, the control mode of thermal environment, mainly utilizing natural ventilation and mechanical fans, is feasible. In the terminal conditions of simulation, the frequency of temperatures lower than 32℃ is around 92.6%, while the wind speed higher than 1.50m/s is 83%. As a result, the simulation conditions can represent the condition of whole summer.

CONCLUSION

Based on computational simulation technology, the thermal environment control mode—combination of natural ventilation, mechanical air modulation and air conditioning has been successfully used in the design of climate adaptability. Natural ventilation, distribution of indoor temperature and PMV are simulated. The results of them guide the amendment of plan in turn.

The special control mode can adapt to the tropical climate in saving the electricity of air-conditioning equipments under the same thermal comfort level. It is an exploration and innovation in the design method of climate adaptability.

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