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COMPARISON OF SIMULATION TOOLS FOR OPTIMIZATION AND EVALUATION OF GREEN BUILDING PERFORMANCE IN CHINA

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ABSTRACT

Green building is developing very rapidly worldwide, and evaluation/optimization of green building performance through simulation has become an important concern. In this paper, the significance of the simulation is pointed out through the comparison of simulation indicators required in the domestic and international green building evaluation standards, which includes building energy consumption, indoor and outdoor noise, lighting and thermal environment. Based on the survey of a number of China's domestic cases which have acquired green building identification, the condition of the use of simulation software is analysed, and some main problems in the simulation process are discussed in detail. Besides, tends towards the chosen of simulation tools for different simulation indicators in China are analysed taking building projects in the district of Shanghai as example. Finally, the standardization of building performance simulation was discussed in the study, expected to provide better technical supports to promote the application of simulation tools in the development process of green building in China.

INTRODUCTION

Green building maximizes conservation of resources (including energy, land, water and materials), protects the natural environment and minimizes pollution. It provides people with healthy, adaptive and efficient spaces during its life cycle and coexists in harmony with the natural environment.

The core of green building is to emphasize resource conservation and environmental protection, to emphasize the suitability of climate characteristics, geographical conditions, humanistic environment, and social development, to emphasize the optimal performance of the entire life cycle, to emphasize multi-field and multi-disciplinary integration optimization. To achieve the core idea of green building, scientific and rational planning and design of green building is the prerequisite.

In the next five to ten years, driven by policies and standards, China will face a rapid development of green building; By January 2013, the identified green building projects have accumulated more than 700, about 75 million square meters. Regarding to optimization and evaluation of the performance design of Green building in China, simulation of building energy consumption, indoor and outdoor sound, lighting and thermal environment are essential, accounting for about 35% of the total number of evaluation indicators. Therefore, no matter from the view of improving the building's green performance or the view of green performance evaluation, it needs to strengthen the application of simulation tools in actual projects.

In the previous research about building simulation (BS) tools, Shady et al. carried out a detailed study about the application of 10 early design simulation tools for net zero energy buildings, including e-Quest, etc. However, the selected software mainly concentrated on the aspect of energy consumption simulation (Shady et al., 2011). As for Building Energy Simulation Test (BESTEST) project conducted by the Model Evaluation and Improvement International Energy Agency (IEA) Experts Group, it is an in-depth study in the comparison of energy consumption simulation tools. In the BESTEST project, a method was developed for systematically testing whole-building energy simulation programs and diagnosing the sources of predictive disagreement, which can provide a more scientific standard in the comparison study and verifying energy consumption simulation tools. However, when it comes to the topic of green buildings, except for energy consumption simulation, other simulation focused on building performance is needed, including indoor and outdoor wind environment, lighting, noise, etc. Therefore, survey and analysis for the application of BS tools in these aspects are necessary.

By surveying a number of China's domestic cases which have acquired green building identification, this paper showed the statistics of score achieved in performance simulation standards and the use of simulation software, and summarized some problems existing in the simulation process. This paper had a comparative study of green building rating standards and the function of different simulation software, and discussed the standardization of building performance simulation in green building evaluation, finally expected to provide better technical support to promote the application of simulation tools in the development process of green building in China.

BUILDING PERFORMANCE SIMULATION IN GREEN BUILDING EVALUATION STANDARDS

International Standards

American LEED, German DGNB, Japanese CASBEE and British BREEAM are widely used in the international. These evaluation standards have relevant terms of evaluation for the performance of the building, including natural lighting, natural ventilation and building energy consumption. In addition, many aspects of the evaluation need simulations. This study firstly summarized the needs for simulation in each standard, listed in Table 1.

From the statistical results in Table 1, it can be seen that for building performance simulation requirements, CASBEE covers in the widest range and includes all the properties listed in the table, followed by DGNB and BREEAM, which have no requirements for Outdoor wind environment and Heat island intensity. The simulation evaluation items in LEED are relatively less. Meanwhile, it is shown that compared with their respective early version, the latest evaluation criteria added evaluation requirements of carbon emissions and LCA. For example, DGNB and CASBEE put forward LCA evaluation of carbon emissions. BREEAM also has requirements about carbon emissions in operation stage. China's CGBES also unceasingly strengthen the requirements of actual performance simulation.

Table 1
Simulation Needs in International Green Building Evaluation Standards

	LEED	DGNB	CASBEE	BREEAM	CGBES
Outdoor wind			○		○
Heat island			○		○
Natural Ventilation	○	○	○	○	○
Daylighting	○	○	○	○	○
Sunshine			○		○
Thermal Comfort	○	○	○	○	○
Energy Consumption	○	○	○	○	○
Carbon Emissions		○	○	○	
LCA		○	○	○	
Noise		○	○	○	○

Domestic Case Studies

In China's National green building standard- C3-star, most aspects of building performance, including indoor wind environment, energy consumption, lighting and noise level, are required to be evaluated through simulation. In current standard, there are about 14 principles related to these simulations, which are listed below:

1. **Land saving and outdoor environment**, there are requirements for simulations of lighting, noise and heat island effect. It is demanded that the heat island effect should not exceed 1.5℃. For outdoor environment, the wind velocity should below 5m/s in pedestrian area.
2. **Energy saving and utilization,** there are requirements for simulations of building envelope, ventilation and energy consumption. The energy consumption in air condition or heating should not exceed 80% of the value demanded in the local building energy saving standards. The use of renewable energy source should take more than 10% in total energy consumption.
3. **Indoor environment**, there are requirements for simulations of daylight and lighting, indoor ventilation. In buildings like office building and hotel, the daylight factor in 75% of their main function area should comply for the requirements in GB/T50033.

Many principles in Green building evaluation should be conducted through simulation. Therefore, on the bases of 57 projects (32 for residential construction, 49 for public building) achieving green building certification during 2009 and 2010, we count up the use of simulation tools in these evaluation. Statistics are shown in the Table 2.

Table 2
Simulations Conducted in Existing Cases

	Residential	Public	Simulation Tools
Outdoor Wind	84%	96%	Fluent(62%) Phonices(19%) Airpark(5%) Starccm(5%)
Heat Island	16%	-	Fluent SPOTE STAR-CD
Natural Ventilation	56%	80%	Fluent(80%) Phonices(10%) Starccm(10%)
Energy Consumption	44%	64%	Dest(80%) Equest(20%)
Daylight	63%	76%	Ecotect(85%) VE(7%) Ecotect＋Radiance(8%)
Noise	-	-	Cadna/A

It can be inferred from the statistics that simulation for the outdoor wind environment is used the most with the frequency up to 90% in residential and public construction; The rate of natural ventilation simulation is 70%, and 68% for lighting simulation, followed by the rate of energy consumption, which is 54%. Few of residential construction have simulation for heat island effect.

As for software application, mainstream tools in the world are not wildly used in these existing cases. For building energy consumption simulation, IES, DesignBuilder and TRANSYS are rarely used. The same situation for Daysim, a daylight simulation tool which can simulate the whole year hourly dynamic daylight. While in CFD simulation, many international mainstream software are well used, such as Phoenics and Fluent.

Simulation focus for different star rated public and residential green building projects are shown in Fig 1 and Fig 2 respectively. It can be found that, due to the different point rewarding policies for each star-rating level, 3-star green building has a relatively stricter requirement for indoor environment and energy consumption simulation. 2-star is the next. While most 1-star green building only focus on ventilation simulation.

Compared with pulic buildings, the design of residential buildings is relatively simple. In addition, Articles of required measures for residential buildings counts for a larger percent than those of optimization requirement in C3-star green building standard. Thus, optimization through numerical simulation analysis is less in general.

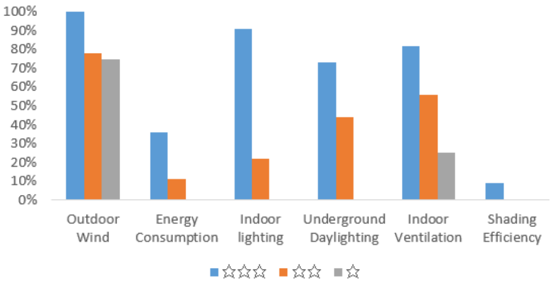

Fig 1 Simulation focus for different star-rating public buildings

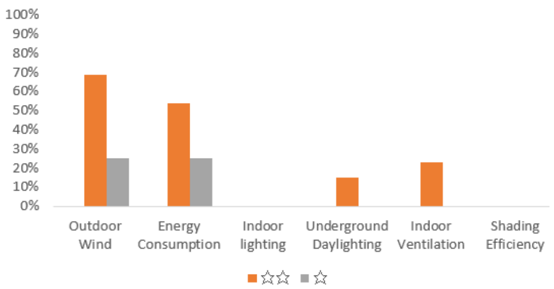

Fig 2 Simulation focus for different star-rating residential buildings

In order to know the use frequency in people with different professional background, such as architect designer and HVAC engineer, we listed 5 factors considered while using the simulation software, which are Intelligence, Usability, Interoperability, Speed, Accuracy. With these factors, we made a questionnaire and asked people in different areas to order those factors. Factor that is most important will be given 5 credits while the lowest important will have 1 credit. We have 85 people done the questionnaire and the result is shown in Figure 3.

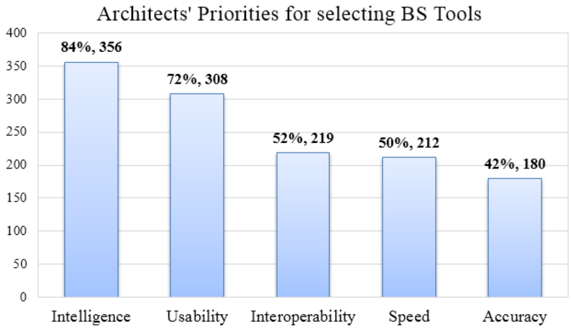

Figure 3 Architects' Priorities for Selecting BS Tools

Results show that intelligence is the most significant factor considered while choosing simulation software, and usability is in the second place. Other factors are less considered. In the stage of simulation, designers will most value that whether the software is easy to operate and whether it has the functions needed in some simulation. While in schematic design phase, scheme comparison and judgment of the trend are more significant, while the accuracy of the simulation software is not so important.

RESULTS

In this chapter, functions of different BS tools are surveyed and summarized. Meanwhile, existing problems of current BS tools application, and sensitivity of performance simulation results to a variety of factors are analysed.

BS Tools Functions

For different building evaluation standards, the application of building simulation tools is required in many aspects of building performance evaluation at present. In addition, it can be found that different simulation require different BS tools, even for some specific performance simulation, various BS tools can be used. Therefore, the functions of common BS tools at present are investigated and listed in Table 3.

From the statistics, the simulation software can be roughly divided into two categories. The first category is to demonstrate a special performance simulation. For example, the Phoenics and the Fluent can only perform CFD related simulation, while the Radiance and the Daysim can only do lighting simulation.

Table 3
Results of the BS Tools Functions

	Outdoor wind	Heat island	Natural ventilation	Daylighting	Energy consumption	Carbon emissions	Noise	Climate Analysis	Economic
Phoenics	○	○	○						
Fluent	○	○	○						
Airpak	○		○						
STAR-CD	○	○							
SPOTE		○							
Contamw			○						
DeST					○			○	
PKPM					○				
Energyplus			○	○	○			○	
eQUEST					○	○		○	○
DOE-2			○		○			○	
Ecotect				○	○		○	○	
DesignBuilder			○	○	○	○		○	○
IES	○	○	○	○	○	○		○	○
Radiance				○					
Daysim				○					
Cadna-A							○		

The other category of software is full-function integrated. For example, the IES and the DesignBuilder can perform many different aspects of simulation including energy consumption, lighting, ventilation, and carbon emissions. The current trend of the BS tools' development is towards to comprehensive integration, so that the uniformity and accuracy of the calculation can be ensured by integrating varied types of performance simulation on the same platform, and the work efficiency can be largely improved due to the avoidance of repeated modelling in different software.

BS Tools Matrix

The results of the case study above have shown that BS tools have been widely applied in green building evaluation recently in China, as many evaluation indicators need to be calculated by simulation tools. However, there are still some problems in the simulation process lacking of standardization. In the actual simulation process, there are big differences of the simulation settings in different cases. The settings are various in many aspects such as building up the model, boundary condition, analysis grid, and calculation accuracy setting, which will greatly affect the accuracy of the simulation results and the comparison between different cases. In this study, these problems and differences in simulation process were analysed and classified based on the results of the case study and the survey of designers.

From the results of Table 4, it can be found that there are different problems for different simulation among which some aspects are only influential for a specific simulation while some aspects are common problems for almost all kinds of building performance simulation. According to the statistical results, the following aspects are the most important problems need to be noticed:

Table 4
Results of the BS Tools Matrix

	Outdoor wind	Heat island	Natural ventilation	Energy Consumption	Day lighting	Noise
Model Simplification	★★★	★★	★★★	★★★	★★★	★★
Surrounding Buildings	★			★	★	★
Calculation Domain	★	★★				★
Analysis Grid	★★★	★★★	★★★		★★	★★
City Weather Data	★		★	★★		
Boundary Condition	★★	★★★	★★	★	★	★★★
Material Parameters	★	★★			★★	★★
Indoor Parameters			★	★★★		
Calculation Model	★		★		★	
Calculation Accuracy	★★		★★	★	★★	★★
Calculation Convergence	★★	★★	★★			

DISCUSSION AND CONCLUSIONS

Main problems of BS tools in use

Based on the above conclusion, this chapter focuses on discussion of main common problems existing in current BS tools application, and includes some typical case study.

1. **Model simplification:** from Table 4 it can be found that almost all kinds of simulation will be related to the problem of building up the model and the simplification. This aspect is including how to simplify the building model reasonably, how to dealing with the various types of building components inside and outside and also the surrounding buildings. For example, there are no such provisions of simplified building model to what extent is reasonable in the outdoor wind simulation, and the same situation exists in natural ventilation when creating the window

model of the building while the opening area and form of which is determined by experience.

For example, when modelling indoor daylighting, whether ground is included in the model will have great influence on the calculation results. To verify, model as Figure 4 shows is established and DA (Daylight Autonomy) distribution is calculated by Daysim to make a comparative study of model with and without ground. From the calculation results (shown in Figure 5A~5B), it can be found out that, with the presence of ground, indoor daylighting is enhanced due to the reflection of ground. Especially for the interior zone, average of DA increases by 6% compared with no ground.

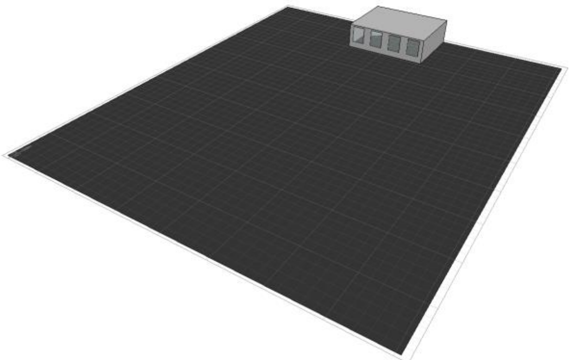

Fig 4 Model for daylighting calculation

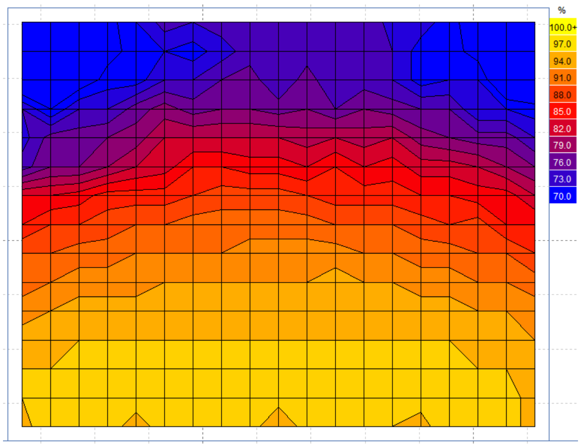

Fig 5A DA distribution with ground

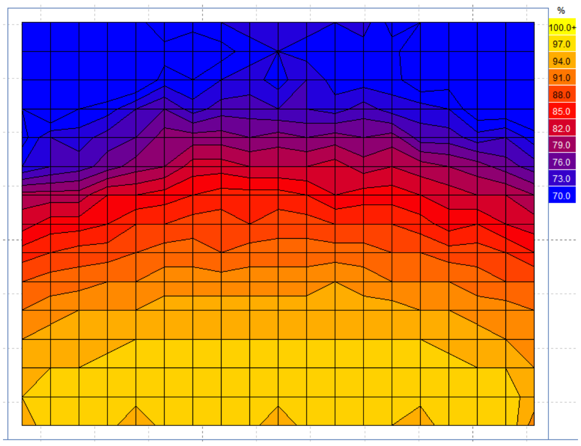

Fig 5B DA distribution without ground

2. **Analysis grid:** the analysis grid is required in most of the current simulation software such as CFD simulation, natural lighting simulation and noise level simulation. Currently, there are no standards and guidelines about the size, number and location of the grid setting which have a significant impact on the final calculated results. One obvious example is that in the CFD simulation, where too much grid will affect the calculation time while too little grid will reduce the calculation accuracy. As shown in Figure 6A and Figure 6B, the building models in the two cases are the same one, as well as the simulation parameters except the analysis grid setting which in Figure 6A is 70-75-20 for x-y-z axis respectively, while in Figure 6B is 34-37-10. The difference of the wind flow direction is obvious between the two cases. The average wind speed around the building is 2.7 m/s for case A, and for case B is just 2.3 m/s, which is 14.8% lower than that of case A.

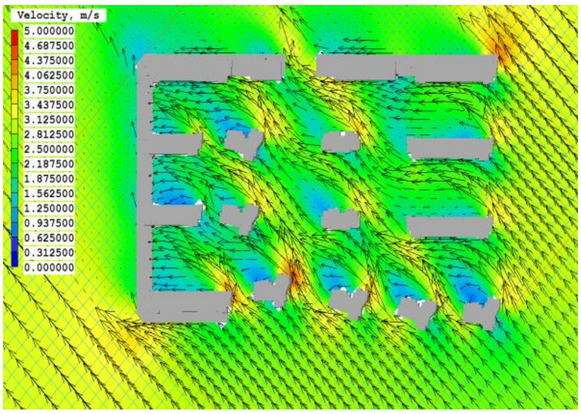

Figure 6A Grid Setting is as 70-75-20

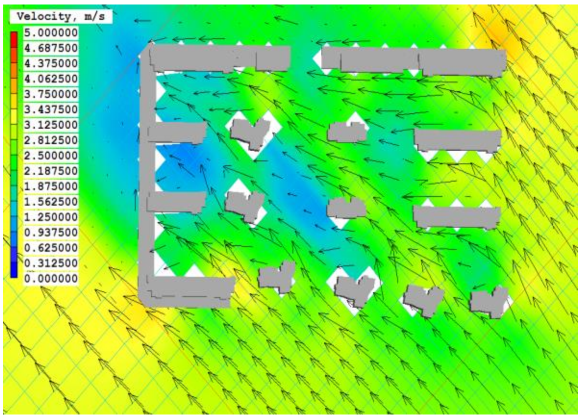

Figure 6B Grid Setting is as 34-37-10

Through the calculation model below, influence of 3 different meshing (79×33×36, 59×24×27, 38×16×18) to the results are analysed, including verical wind speed distribution and x-velocity component in rear flow fields of periptery. From the results shown in Figure 7A~7C and Figure 8, it can be seen that analysis grid will have direct influence on calculated wind flow distribution and wind speed. Especially for low-height area, sensitivity of calculated wind speed to grid is higher.

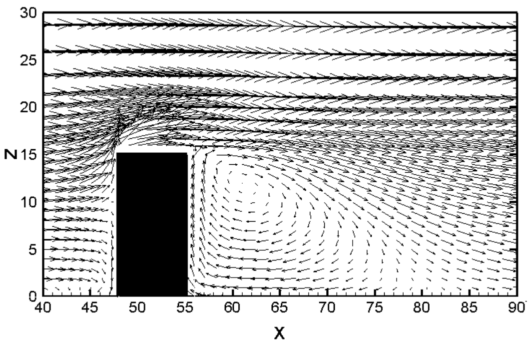

Fig 7A Wind speed distribution, analysis grid: 79×33×36

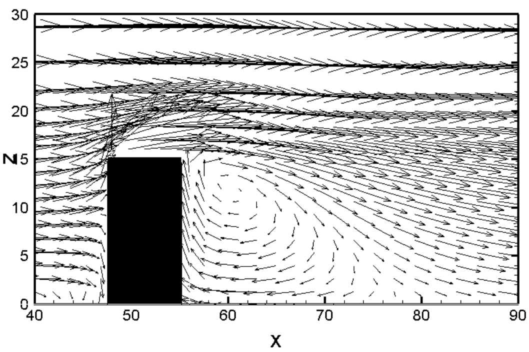

Fig 7B Wind speed distribution, analysis grid: 59×24×27

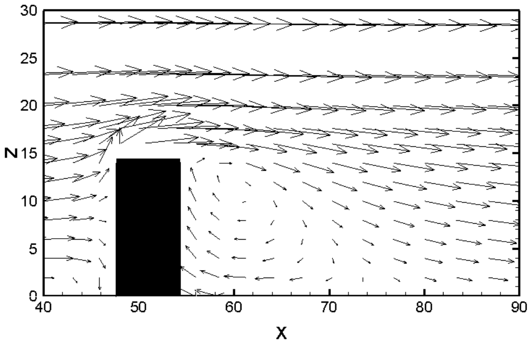

Fig 7C Wind speed distribution, analysis grid: 38×16×18

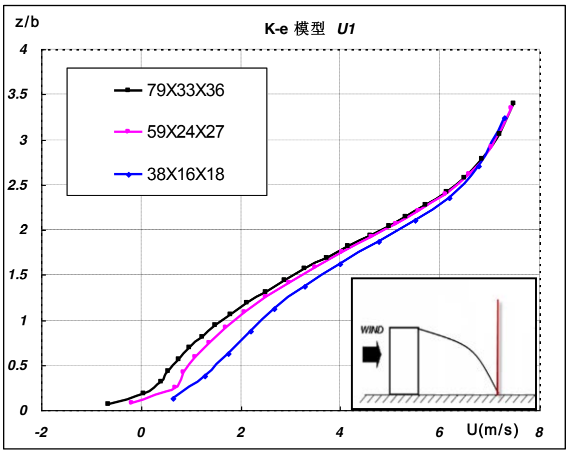

Fig 8 Variation of wind speed in vertical direction under 3 different analysis grids

The same situation also exsits in daylighting simulation for the analysis grid setting. As is shown in Figure 9A and Figure 9B, the only difference of the simulation setting is the analysis grid, which in case A is as 10-10 for x-y axis respectively, while in case B is 50-50. And the average daylighting factor is 5.85% for case A, and for case B is 5.30%, which is 9.4% lower than that of case A.

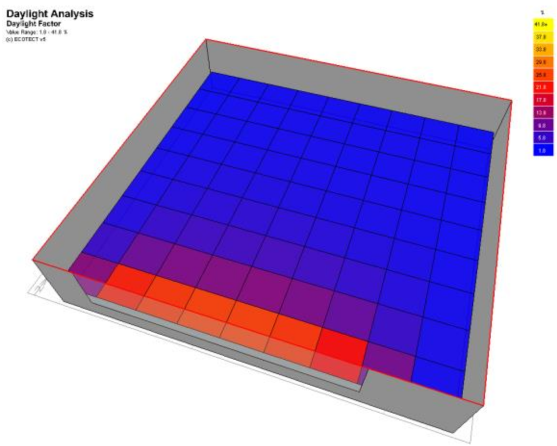

Figure 9A Grid Setting is as 10-10

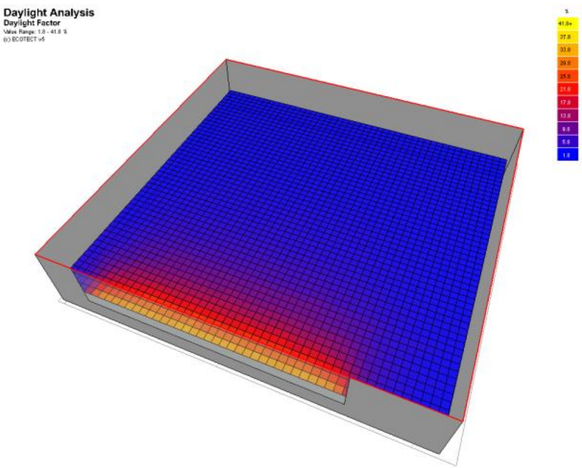

Figure 9B Grid Setting is as 50-50

3. **Calculation accuracy:** is not specified in the current evaluation standard which will also affect the final results greatly in most BS tools. For example, the judgment of the calculation results in the CFD simulation for wind environment is largely depending on the experience of the exports. And the simulation accuracy of daylighting as well as the simulation step of the energy simulation is not specified at present.Similarly, taking daylighting simulation as example, when using Daysim to calculate daylighting level, times of relection need to be set. This study focuses on the difference between 2 times of reflection and 5 times of reflection. From the results shown in Figure 10A~10B, difference of DA distributions is very clear, expecially for interior zone. DA average using 5 times of reflection is 86.1%, while DA average using 2 times of reflection is 66.7%, which decreases by 22.5%.

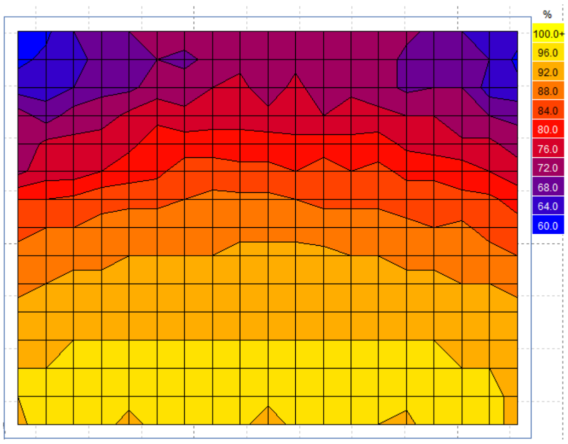

Fig 10A DA distribution, reflection time: 5

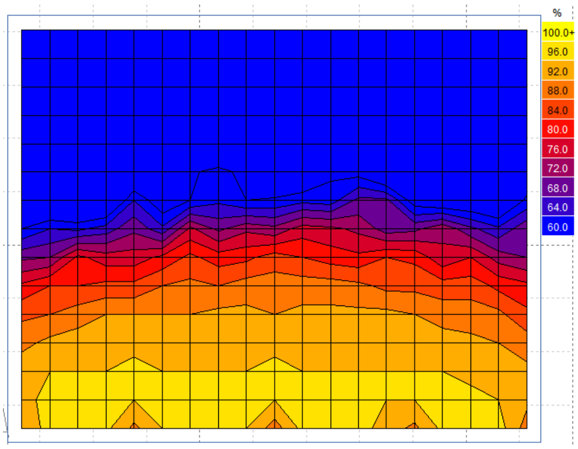

Fig 10B DA distribution, reflection time: 2

4. **Simulation parameters**: various kinds of parameters need to be set in the BS tools and will affect the results directly. At present, the specification of the parameter setting in building energy simulation is relatively comprehensive compared with other types of simulation. But there are still some parameters which is important to the energy simulation are not specified, such as infiltration rate of the building envelope, natural ventilation, and the control of artificial lighting. And there are less specifications for the other types of simulation. For example, the transmittance and cleanliness of the glass is not specified in the daylighting simulation, as well as the reflectance of the wall, roof and floor in the room.

Conclusion

From the summary of the actual simulation process, it can be seen that there are still many variances in different cases during the simulation. Therefore, there is an urgent need for appropriate regulations and standardization of the building performance simulation. Summarized by case analysis, the simulation can be standardized from the following aspects:

- The standardization of building and simplifying models, how to build a reasonable simulation model;
- The standardization of the analysis grid settings, including the size, number and position of the grid;
- The standardization of the boundary condition setting;
- The standardization of the setting of the various simulation parameters, to ensure the consistency of the input condition;
- The standardization of the calculation accuracy, to ensure the accuracy of the results;

- The standardization of the output results of the performance simulation, to ensure that the results can be evaluated, as well as comparable.

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