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TransDATA2: A Data Visualization Toolkit to Assist the High-Performance Building Design

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Abstract: With the development of the economic and low-carbon society, high-performance building (EPB) design plays a more and more important role in the architectural area. The performance of buildings usually includes the building energy consumption, building interior natural daylighting, building surface solar radiation and so on. To obtain a high-performance building in the design process, building performance simulation (BPS) and multiple objective optimizations (MOO) are becoming the main methods. Correspondingly, the BPS and MOO are based on the parametric tools like Grasshopper and Dynamo. However, these tools are lacking the data analysis module for designers to select the EPB more conveniently. This paper proposes a toolkit "transDATA2" developed based on the Grasshopper platform and Python language. At the end of this paper, four experiments were operated to verify the function of transDATA2 which showed that it could aid architects to design the high-performance buildings more efficiently and conveniently.

Key words: TransDATA2, BPS, MOO, EPB, Python language.

1. Introduction

With the development of the computational architectural design tools, more and more building designers could utilize the building performance simulation (BPS) and building performance multiple objective optimization (MOO) methods to design the high-performance building (EPB) like low-energy consumption, ideal building interior natural daylighting and suitable building surface solar radiation.

At the present stage, Grasshopper has been deeply favored by many designers, which plays an important role in parametric building design phase. It allows designers to operate the BPS and MOO using the plugin in Grasshopper-like Geco, Ladybug & Honeybee. However, the simulated data analysis tools in Grasshopper to aid BPS or MOO are rare and the existing tools like Parrot, Mr. Comfy and so on are not specially designed for BPS or MOO data visualization. As a result, this paper proposes a data analysis & visualization toolkit—transDATA2 based on Python language to assist the BPS and MOO analysis. It includes a set of Python language battery blocks to provide data analysis and decision support for BPS and MOO results to select the suitable design results. Different Python language battery blocks could assist a different kind of BPS or MOO simulated results which would be more convenient and accurate for architects to select the high-performance buildings design scheme (Fig. 1).

In term of the BPS, MOO, and data analysis & visualization tools in previous studies, they contributed a lot to the sustainable building design process. BPS is an important method to predict building performance

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in design process. And the MOO could aid designers to select the better scheme balancing the performance and the formation of buildings.

As for BPS, Popovici [1] used the ANSYS-Fluent tool to simulate the heating, ventilation, and air conditioning (HVAC) system of buildings and compared different situation of predicted mean vote (PMV) and percentage of projected dissatisfaction (PPD) to choose a better building design condition. Paule et al. [2] operated the dynamic simulation of both daylight and thermal performance based on DOAL+ software which allowed designers to make the final building design decision based on the building performance of dynamic systems such as electrochromic (EC) glazing. Artopoulos et al. [3] assessed that the efforts spent nowadays by designers, architects and engineers to integrate new solutions and technologies into the building architecture require new design methods. The case studies mentioned above showed that BPS could help understand the potential building performance (like building daylighting and energy performance) to enhance and increase the building energy-saving effect.

As for MOO, Touloupaki and Theodosiou [4] designed a workflow named nZEB based on the MOO algorithm to integrate the energy simulation in the design stage to minimize the lifecycle energy requirements. Harkouss et al. [5] designed the zero energy buildings based on MOO methods to help to minimize the thermal, electrical demands and life cycle cost (LCC). The case studies mentioned above showed that the MOO could help to improve the design scheme by assessing solutions of the Pareto front for designers to select the best design result.

As for data analysis & visualization tools, there are many other data visualization tools in current studies. Abdelalim et al. [6] proposed an integrated framework to estimate the building energy flows of which the Sankey diagram was used to show the data of the building-level energy flow. More recently, Papadopoulos and Kontokosta [7] developed a building energy performance grading method based on the machine learning and building data which could be shown on the form of the New York City-specific GREEN grading tool and provide the convenient visualization way for the building performance assessment.

Besides, there are many other tools that could realize

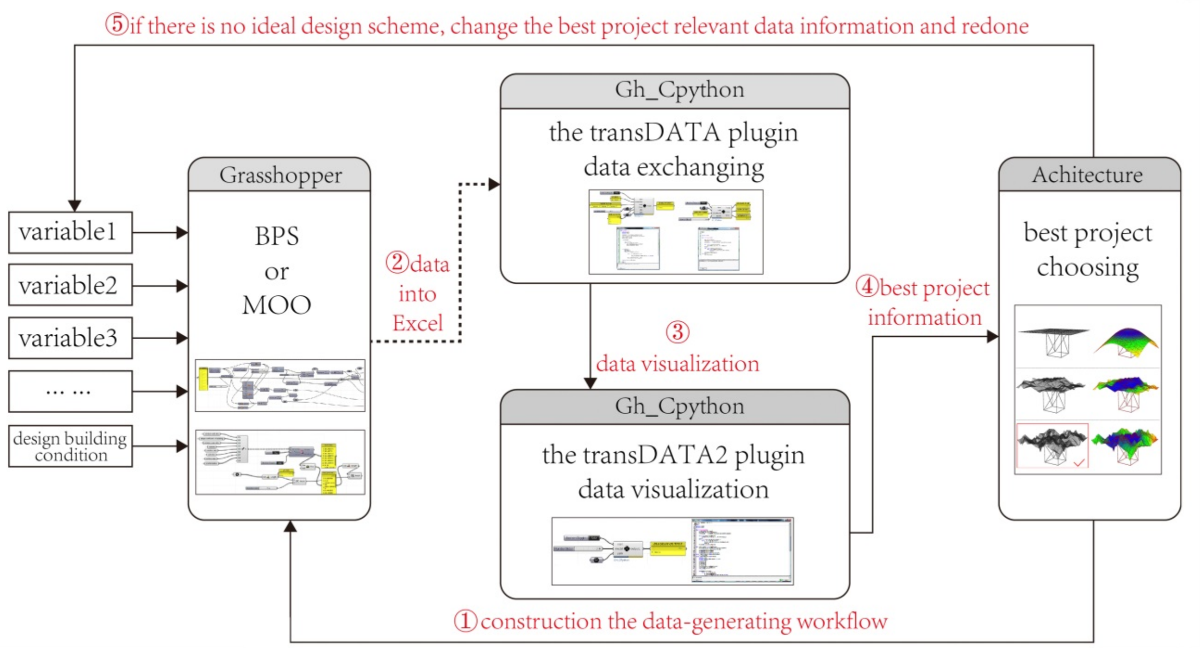

Fig. 1 The transDATA2 aided high-performance building design method.

the data visualization in the building design process which makes it easy for designers to select the ideal scheme. However, the category of the building performance is various and the current data analysis & visualization tools cannot meet the need of the different building performance analysis very well. As a result, this paper focuses on the features of different building performance and developed a toolkit—“transDATA2” in Grasshopper based on the Python language to assist the BPS or MOO simulated data analysis. The goal of the construction of the transDATA2 toolkit is aiming at the high-performance building design.

2. Methodology

The general BPS process mainly composed of the following steps: (1) gathering information; (2) modeling the parametric model; (3) importing the parametric modeling to the performance simulation engine to do the building performance simulation; (4) comparing different building simulation results; (5) collecting the simulation results; (6) designers select the ideal building design scheme. The building performance MOO process is similar to the BPS process. And what is different from BPS is that the MOO process would compose of the optimization step based on MOO algorithm like NSGA-II and SPEA-II et al. which could help designers to the exam if the building performance matches the high-performance condition and outputs the ideal building scheme. The development of the transDATA2 could help to make it easy for designers to compare different building performance condition and select the high-performance design scheme (Figs. 2 and 3).

The transDATA2 toolkit was constructed based on the Matplotlib library which mainly consists of a set of data visualization modules: the column graph module and the fold line graph module et al. All of the modules were constructed by installing the Python language into the GH_Cpython plugin in Grasshopper which is shown as the Grasshopper battery blocks. The workflow including transDATA2 toolkit mainly composes of 4 steps to operate the data analysis which includes the data generation step; data inputting step; data visualization step and data analysis step. As is shown in the Fig. 4, all of the modules in transDATA2 toolkit were used at the end of the BPS or MOO workflow. The following sections would introduce how different modules work in the high-performance building design workflow. And in this paper, we mainly talk about the column graph module, the fold

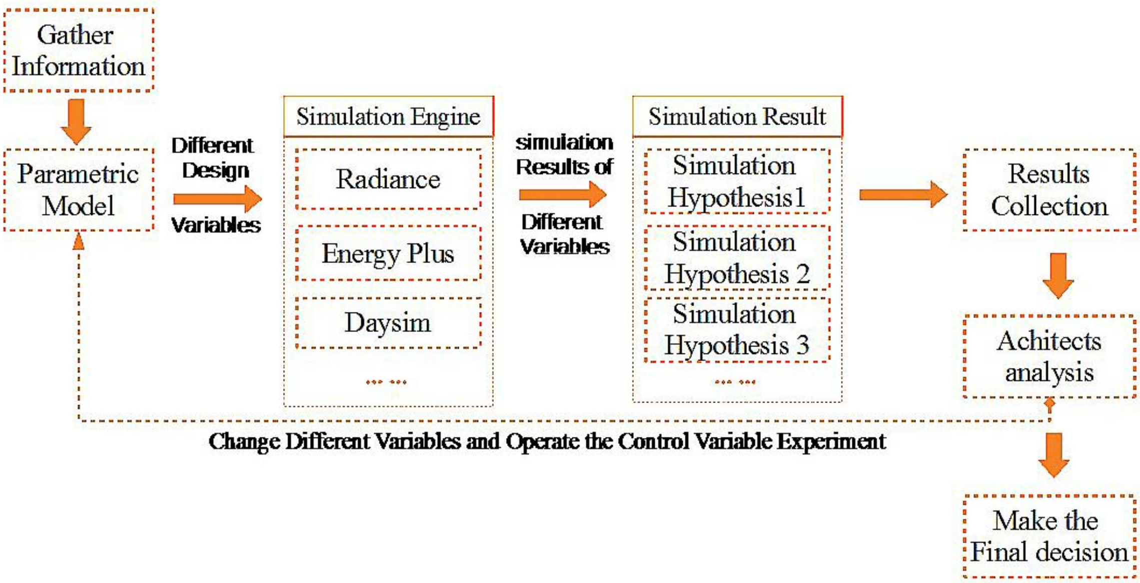

Fig. 2 BPS process with transDATA2.

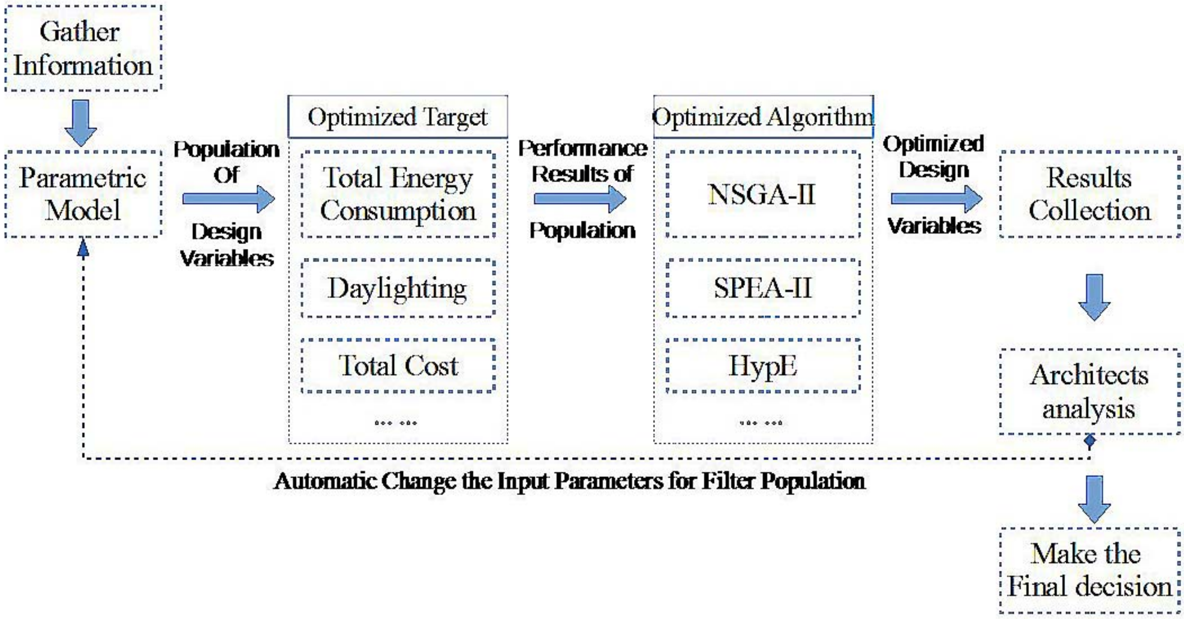

Fig. 3 MOO process with transDATA2.

line graph module, the pie chart module, and the violin chart module.

The column graph module was designed as the building performance database analysis part which is operated behind the BPS or MOO. This part was constructed by Python language in GH_Cpython plugin and its HUMAN UI was designed as follows: the start part was used for the control of the analysis module, the path part was used for inputting the simulated database path, the head part was used for inputting the head context of the database and the inputting column part was used for inputting the number of the analyzed column. After inputting all of this context mentioned above, a double column Python Figure could be shown in front of the Grasshopper plugin for designers to select one suitable design scheme. This module could be used for comparing building performance of different building design scheme.

The same as the column graph module, the fold line graph module was also constructed based on the Python language in GH_Cpython plugin. Its UI was composed of 4 parts: the start part, the path part, the head part, and the column part. And this module could be used for analyzing the building performance change trend of the BPS or MOO process.

The pie chart module constructed in Grasshopper includes two types. The first type was the single pie chart module which includes the start part and the path part. This module was mainly used for the performance analysis of one design scheme. The second type was the multi-pie chart module which was mainly used for the same building performance comparison of the different design scheme.

The violin chart module was designed similar to other modules whose input parameters include the start part, the path art, and the column part. And this module could be used for the data distribution analysis of different design scheme and provide more specific information about the BPS or MOO simulated results.

3. Experiment

To validate the different function of different modules in transDATA2 toolkit, we designed four BPS and MOO experiments based on the transDATA2 plugin. The first case was designed to test the usage of the column graph module in the BPS process to select the ideal office building design scheme with suitable solar radiation in summer and winter. The second case was designed to test the usage of the fold line graph module in MOO process to select the ideal farmhouse building design scheme with the high-quality daylighting condition. The third case was designed to test the usage of the pie chart module in MOO process to select the low-energy consumption office building design scheme in severe cold region. And the final case was designed to test the usage of the violin chart module in BPS process to help designers analyze the solar radiation on the building surface in summer and select the low-solar radiation building design scheme.

3.1 TransDATA2 Aiding the Office Building Design with Suitable Surface Solar Radiation

To confirm the function of the column graph module in tranDATA2 toolkit, three office buildings with different building plans were constructed in Grasshopper. According to the requirement of the "Energy Efficiency Design Standard for Public Buildings GB50189-2015" in China, the window to wall ratio (WWR) of the office buildings constructed in the severe cold region should be less than 0.6. The WWR of three buildings constructed in this experiment was that the north WWR was 0.3, the south WWR was 0.6, the west WWR was 0.3 and the east WWR was 0.6. The three building models were put into Honeybee & Ladybug plugin in Grasshopper to operate the BPS of the annual solar radiation on the building surface.

After the simulation of three office buildings, the simulation results could be output into the Excel by transDATA2 plugin. Then, the building performance database could be imported into the column graph module in the tranDATA2 toolkit. By setting the Excel path and the column number of the data analysis module, the annual solar radiation on the building surface of three different office buildings scheme could be shown on the Python Figure. From the python figure, we could easily compare the annual solar radiation of different building schemes and gain the information from the figure that the lowest solar radiation in summer was the L plane office building while the highest annual solar radiation in winter was the hexagonal plane office building. Balancing the solar radiation on a building surface, we would like to select the triangular plane office building as the final high-performance office building design.

In this experiment, the column graph module in

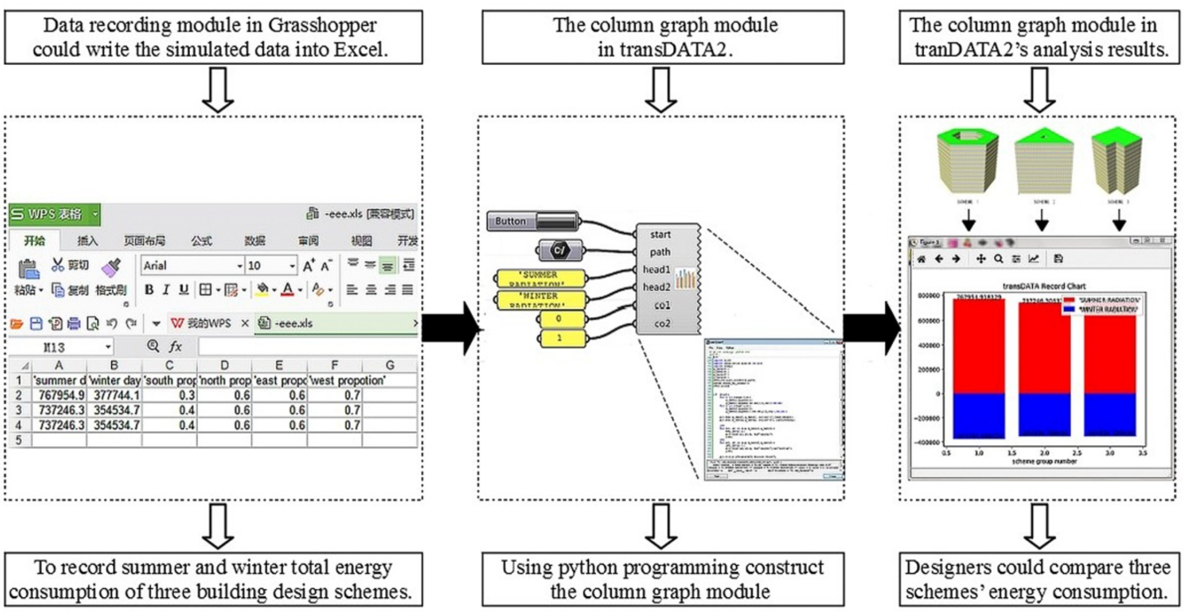

Fig. 4 The column graph module analysis result.

transDATA2 toolkit could help to transform the BPS data into Python Figure and make it easy for designers to compare the annual solar radiation on the building surface of different design schemes. Besides, this experiment was operated only on behalf of the analysis of the BPS results. If the office building design scheme was used for the MOO process, the column graph module operation was similar to the BPS analysis results.

3.2 TransDATA2 Aiding the Low-Energy Building Design in the MOO Process

To confirm the pie chart module in the transDATA2 toolkit, we used the farmhouse case study to operate the building energy consumption analysis. The MOO process of the building energy consumption composed of the lighting energy consumption, heating energy consumption and cooling energy consumption. The optimized variables of the case study were the dimension of the window and the height of the farmhouse. This case study was carried out in the summer of June 23. And the MOO energy simulated results would be recorded into Excel which was shown in the first part of Fig. 5.

In the MOO process, we defined the dimension range of the building windows was 0.5 m-1.5 m, the range of the house height was 3.6 m-5.4 m. After setting the design parameters of the Octopus plugin in Grasshopper, we start the MOO process and the simulated data would be recorded into Excel automatically. Then, the Excel data would be exported into the pie chart module. And the transDATA2 chose the final three optimized schemes to realize the data visualization. As we could see from the Python Figure, the lowest heating energy consumption was scheme 1 which was 34%; the lowest heating lighting consumption was scheme 3 which was 15% and the lowest cooling energy consumption was scheme 2 which was 22%.

With the help of the pie chart module in transDATA2, the building energy consumption analysis of the MOO process becomes easy and convenient to compare a different kind of energy consumption of the different building design scheme. The pie chart comparison method could be more popular than the data comparison method so that designers could select the ideal design scheme efficiently.

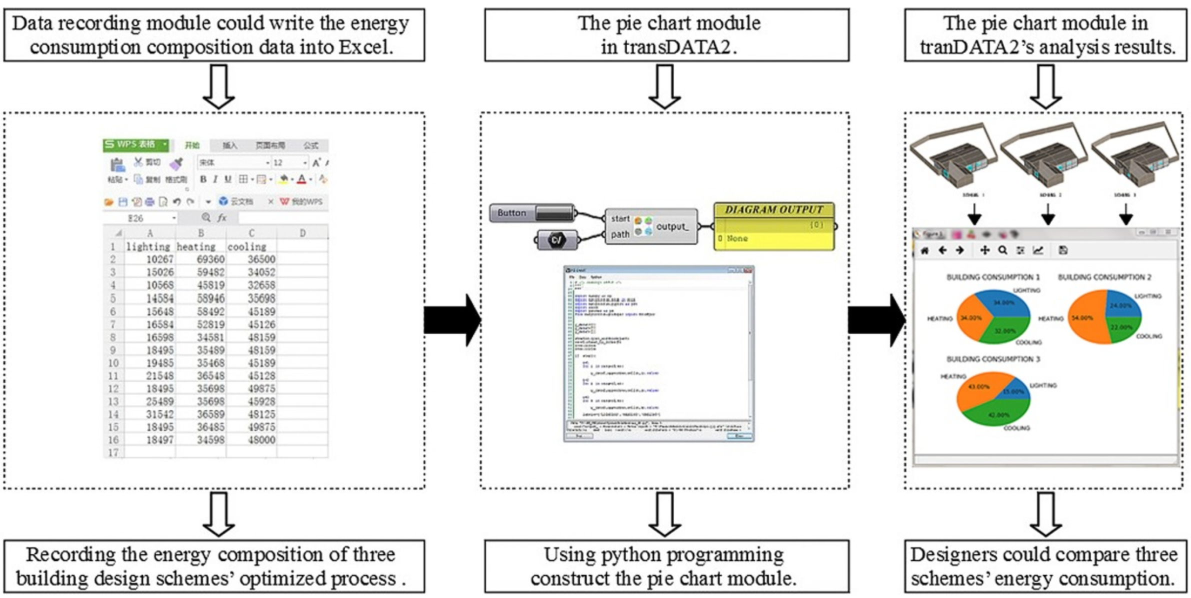

Fig. 5 The pie chart module analysis result.

3.3 TransDATA2 Aiding the Analysis of the Building Surface Solar Radiation of Different Schemes

To confirm the violin chart module in transDATA2 toolkit, we developed an office building design scheme in cold region to test if transDATA2 plugin could help to analyze the solar radiation on the building surface in summer and winter. The building set was listed as follows: the basic dimension of the building plane was 20 m × 20 m; the height of the office building was 50 m; the number of the building storey was 12. We designed a parametric office building skin for the indoor sun shading and the building surface unit rotates from the bottom of the window frame. The building shading construction rotates angle was designed into three groups which include 10°, 20°, 30°. After the construction of the office building model, we conducted the building solar radiation simulation of the office buildings. Each group was analyzed from the 8 o'clock to 16 o'clock in the summer of June 23 and in the winter of December 23. The simulation results would be recorded into Excel which would be analyzed in the violin chart module in the transDATA2 plugin to analyze and summarize the distribution of solar radiation on the surface of the building in winter or summer.

During the BPS process, we carried out the solar radiation simulation on three office building surface at a different time of a day. The simulated data of three office buildings would be recorded into Excel and then import the Excel into the transDATA2 plugin to operate the data visualization using the violin chart module. As we could see from Fig. 6, the summer solar radiation of three groups office buildings was distributed more uniform which was between the range of 200 kWh/m^2-450 kWh/m^2 while the winter radiation was more uneven which was between the range of 100-650 kWh/m^2. Besides, the most simulated values of the office buildings on a summer day are 200 kWh/m^2 while in the winter day the most values were 150 kWh/m^2.

With the help of the violin chart module in transDATA2 plugin, the solar radiation simulation results of the office building surface would be recorded into Excel and realized the data visualization based on the transDATA2 toolkit. It could help to provide designers the Python Figure to analyze the solar radiation distribution on the building surface in a summer

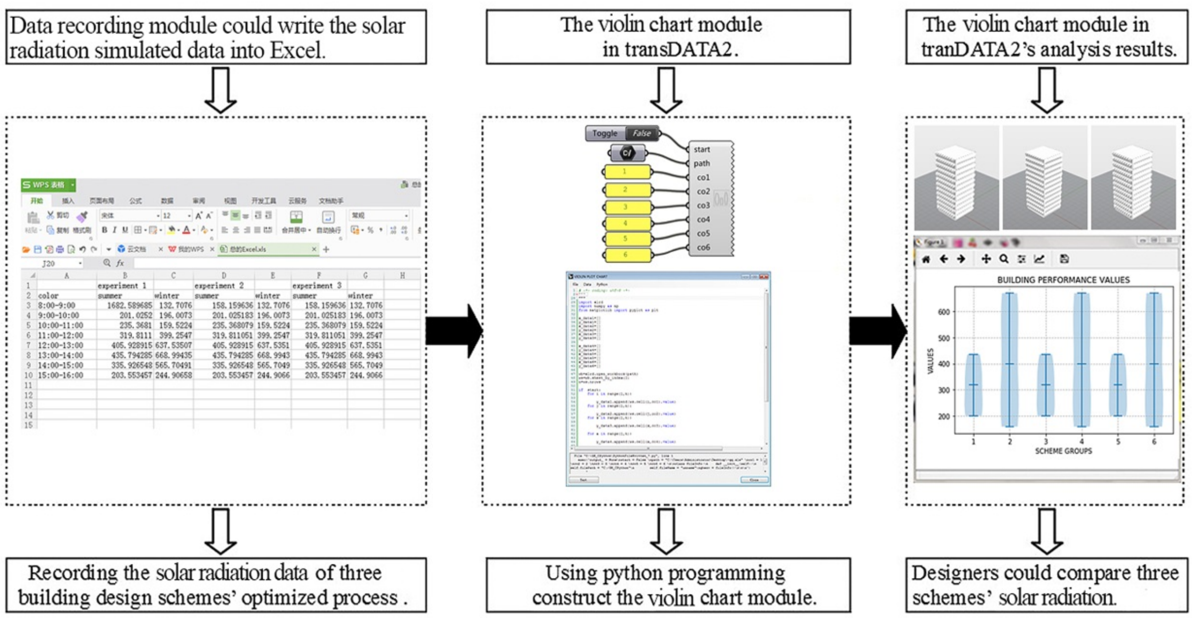

Fig. 6 The violin chart module analysis result.

day or a winter day so that designers could select the suitable design scheme with the low solar radiation distribution in a winter day and the high solar radiation distribution in the summer day.

4. Conclusion and Future Expectation

Compared with the previous data analysis method, the four experiments operated in this paper showed the different data visualization modules in transDATA2 which could omit the complex analysis steps based on the traditional tools like SPSS or Excel and enhanced the selection efficiency of high-performance building scheme. Different data visualization methods could also be used to interpret the simulation results of building performance in different ways.

With the aid of transDATA2 toolkit, it would be more convenient for designers to select the different high-performance building and guarantee the performance quality of the selected design scheme based on the Grasshopper platform.

In the future, we could construct more data visualization modules such as artist graph, bar chart, scatter plot graph and so on to increase the data analysis category and methods so that designers could use the transDATA2 to operate more kinds of sustainable and high-performance building design.

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