Influence of the Air-Conditioning heat rejection on Microclimate and Cooling Loads of Residential Building in Shanghai

ABSTRACT

Heat rejection from air conditioners not only contribute the outside environment surrounding the buildings but also increase the cooling loads. Based on it, A novel methodology to fully-scale amend the weather data in summer season is proposed, as a means of quantizing the results. Two software, EnergyPlus and Fluent were employed in this study. Three variables were inputted into Fluent to get the relationship between the difference in outside temperature and the dry-bulb temperature, heat rejection and wind speed, thus can generate the regression equation. Based on the equation, we can get the effect of heat rejection on the environment surrounding the buildings and cooling load. The results showed that the heat rejection not only raise the outside temperature, but also increase the cooling loads.

KEYWORDS

Heat rejection, Cooling load, dry-bulb temperature

1. INTRODUCTION

We are living a rapid expansion urbanizing world. This truth urged research in interdisciplinarity fields concerned with living environment in cities and depletion of energy. The heat rejection from air conditioners (ACs) of urban areas not only rises the ambient temperature, but also increases the cooling loads of buildings （Akbari H，2001）.

To study the effect of the heat rejection from the ACs on the environment surrounding the buildings and the buildings load, M.Bojic(2002) have researched the effect of heat rejected from the window type air conditioners on the recessed space for the high-story residential buildings in Hong Kong . Chun-Ming Hsieh(2007) coupled the EnergyPlus with Windperfect discussed the feedback of the heating rejection to the cooling load ,found the cooling load increased 10.7% during 19:01 to 02:00 h on the following day. Mengtao Han(2010) evaluated two heat release modes and positions of air-conditioner units on the environment surrounding the buildings and the air-conditioner energy consumption for the public building in Wuhan.

Unfortunately, the study of heat rejection on building environment and the feedback to cooling load is merely carried on a certain moment and specific building. There are very little quantitative analysis methods for the building environment and cooling consumption for the whole cooling season. And the results of heat rejection to the surrounding environment can just be used in specified instance.

To clarify and resolve these problems with the aim of predicting the alter of the weather parameters and cooling load for a cooling season, we have established a novel methodology to estimate the impact of the rejection heat to the building environment and cooling consumption for the residential buildings in Shanghai.

2. METHODOLOGY

It is known to all that air-conditioners are widely used in modern life for the sake of the living comfort, and the influence is a cycle. When the dry-bulb temperature rise, the ACs open, lead to the heat exhausting, causing the variation of the air temperature and then further feedback to the exhaust heat, until the loop reaches equilibrium. In order to estimate the feedback of the heat rejection to the building environment and cooling load, two software, EnergyPlus building energy program and Fluent CFD software, are used in this study.

For the residential buildings, the type of the air-conditioners commonly used is the split-type air-conditioner in Shanghai and the air-conditioner condensers usually placed outside the room in the building, shown in Fig.1, while the fixed location is usually not clear. The influence of heat rejection on the surrounding building is not uniform, but the weather parameters used to the EnergyPlus to simulate the cooling load are unique. Solving these issues, a simplified numerical calculation method for heat rejection to create new weather files is proposed. Specifically, it is considered that the heat rejection from the condensers is equivalent to the heat rejection by the wall surface rather than to discuss the detailed condensers, which can as a variable parameter to generate the regression equation. Then the equation changes the summer weather file to simulate the change of cooling loads. However, this method is only for the condenser hanging outside the windows and cannot be verified in actuality.

Fig.1. Layout of the air-conditioner condenser for residential buildings

The technical route of the research is shown in Fig. 2. From the flow-chart, our methodology contains of two key procedure.

The first is to obtain the change of the building environment due to the heat rejection from the ACs that generates the new weather parameters. The important question, is how to obtain the new weather file at this problem. Because the Fluent merely simulate for a certain moment while what we need is the whole summer weather file to be used in EnergyPlus for the total cooling consumption. To solve it, a regression equation is proposed based on the outdoor dry-bulb temperature, wind speed and cooling load, and can use it to change weather file in cycle. The range of the wind speed and ambient dry-bulb temperature are obtained from the weather files, and the range of the cooling load is from the results of EnergPlus based on the typical meteorology year (*.epw).

The second is the feedback of heat rejection to the air conditioning cooling load because of the alter of the building environment. Specifically, using the new weather file(*.epw) from the above equation to calculation the variation of cooling load in EnergyPlus. A crucial issue is the iteration, the increased cooling load will augment the heat rejection in turn, so the equation will be used repeatedly until the balance is reached.

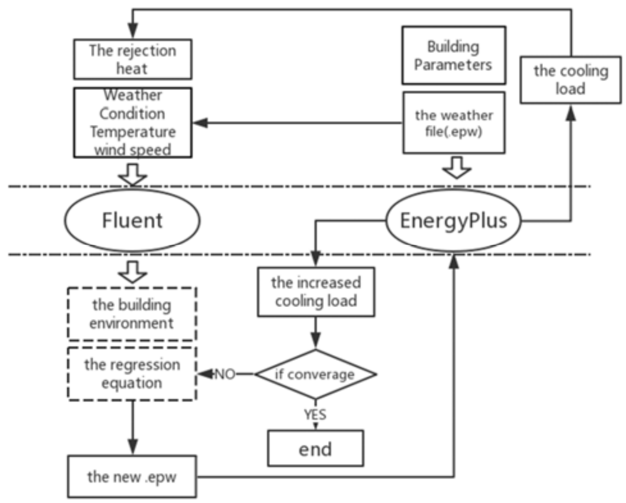


Fig.2. Technical route of the research

2.1. The basic inputs parameters in the Fluent

In order to get the new weather file(*.epw), the first step is to focus on the simulation of heat rejection for the building environment. Choosing the dry-bulb temperature as the dependent variable, described as dT. Three elements as the independent variables: (1)T_{dry}, the outdoor dry bulb temperature, ℃; (3) V, the wind velocity, m/s, which closely related to building environment and building load; (2) Q_{out}, the flux of heat rejection, W/㎡.

As for the number of independent variable levels, the selection is based on the design standard, meteorological parameters, the accuracy and time balance of the simulation software and common sense.

According to Energy conservation design standard for residential buildings JGJ134-2010, the cooling design temperature is above 26℃, considering the habits of the natives and the impact on heat island effect is obvious, taking 13 levels from 28℃ to 40℃. The wind speed get from the typical meteorological parameters (TMYs) is shown in Fig.3, ranging from 0m/s to 8 m/s, taking 4 levers, namely 0,1,3,5. The reason to choose the wind speed based on two aspects:1) the computation time; 2) the computation results, the dT not exceed 0.5℃ when the wind speed excess 5m/s. The selection of the heat rejection flux based is based on the cooling load, shown in formula (1), and the cooling load selects three levels, 50,100 and 150W/㎡, respectively, which is included in the range of the building cooling load simulated. A total of 156 cases in Fluent for all variables.

$$Q_{out} = \frac{1+COP}{COP} * Q_{cool} * \frac{S_{cool}}{S_{wall}} \tag{1}$$

Where Q_{out} is the heat flux from the wall surface, W/㎡; Q_{cool} is the building cooling load, W/㎡; S_{cool} is the net conditioned building area, ㎡; S_{wall} is the wall surface are, ㎡.

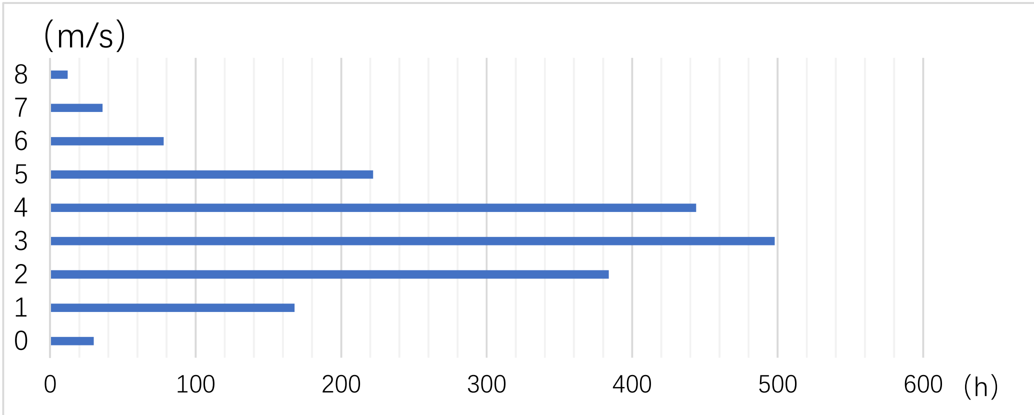


Fig.3. Frequency statistics of different wind speeds during cooling season in Shanghai

2.2.Geometry of the building and fluid field

From the above mentioned, the heat rejection from the building surface, the depicted geometry of the building is 30m, 30m and 100m, respectively, which can ignore the directions of wind to reduce the number of cases. The length of the fluid field is 4H + Block field + 10H; the width is 5H + Block field + 5H; and the height is 6H, where H is building's height. Based on the structured grids, the total grid count is 0.76 million. The area of finest mesh is around the building boundary, with the 0.2m*1m*3.3m for x, y, z direction.

2.3.Building design parameters

In order to validate the application of heat rejection, the height of structural height is 3.5m, the floors are 28 and the height is 98m in total, shown in Fig.4. The interior structure of the building divided into bedrooms, living rooms, kitchens, toilet and corridors, which shown in Fig.5.

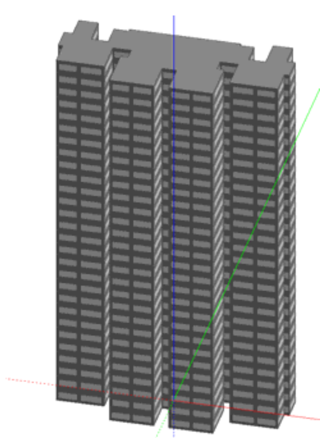


Fig.4. the shape of the building

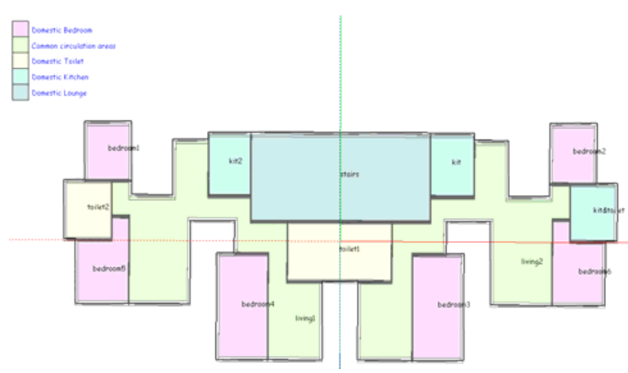
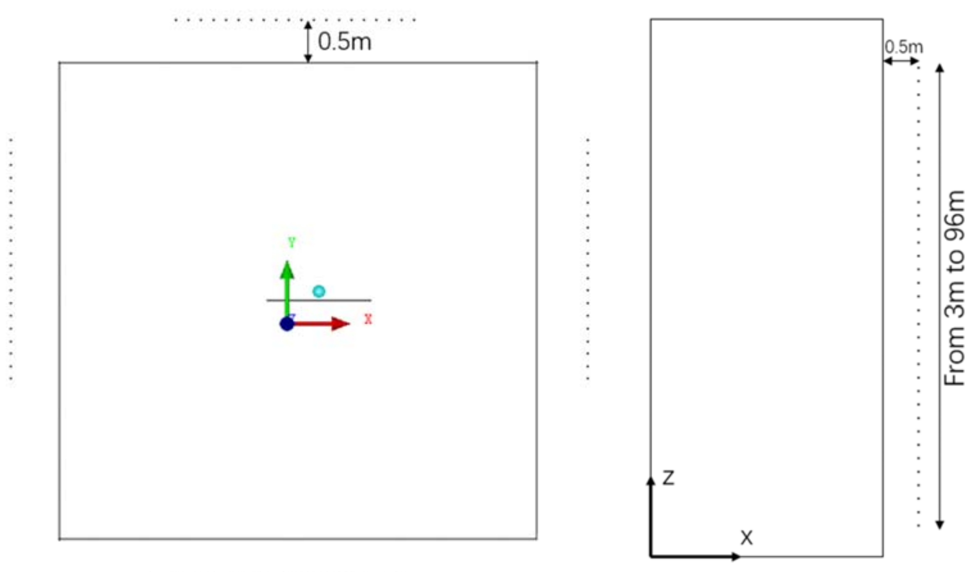


Fig.5. The architectural interiors

The setting of building material and window-wall ratio are according to the Energy conservation design standard for residential buildings JGJ134-2010 in China. The window-all ratio of residential building is 35% and the height of structural height is 3.5m. The U values of wall and roof are 1 and 0.75 $W/m^2 \cdot K$, respectively. Number of people, electric loads of lights and appliances are assumed to be proportional to the floor areas. The load of lightening and appliances is 5 and 5 W/m^2, respectively. The COP of the window type air conditioner is specified to be 2.80 and the temperature setting is 26℃ in this study. The schedule of people, light and appliance adopted the default data from the Design Builder, which provides advanced modelling tools in an easy-to-use interface used for EnergyPlus to build the model. The calculation period of air-conditioner is from 15 in June to 31 in August.

3. RESULTS

It is important to handle the results from the Fluent, because there are three reasons can cause different results: (1) the model in the CFD is square, so the edge effect due to wind lead to the difference between the middle and the ends on the nodes; (2) the distance from the wall bring the difference in x and y axis; (3) the buoyancy cause the discrepancy in height.
As shown in Fig.6, we choose the 20 nodes in the middle of the X and Y axes at 0.5m away from the wall as the average values, then do the average from 3m to 96m.



In the Top viewport, the solid lines represent the building In the Front viewpoint

Fig.5. the selected node from the model grids

3.1 The results from the CFD

The temperature rise from Fluent is shown in Table 1, from the result, we can knew the wind speed and rejection heat flux have a great impact to the dT, and dry-bulb temperature regularity isn't obvious merely can be ignored. But because of the principle of thermal physics, the dry-bulb temperature must in the equation.

Table 1, the temperature rises results from the Fluent

dT(℃)	v=0m/s			v=1m/s		
dry-bulb Temp (℃)	Q_out=169W/㎡	Q_out=339W/㎡	Q_out=508W/㎡	Q_out=169W/㎡	Q_out=339W/㎡	Q_out=508W/㎡
28	2.42	3.85	5.06	1.94	2.25	3.16
29	2.43	3.87	5.08	1.95	2.32	3.22
30	2.44	3.93	5.08	1.81	2.27	3.16
31	2.45	3.91	5.07	1.88	2.21	3.25
32	2.46	3.94	5.09	1.89	2.25	3.34
33	2.47	3.92	5.15	1.91	2.25	3.29
34	2.47	3.92	5.17	1.85	2.22	3.27
35	2.47	3.93	5.17	1.95	2.33	3.26
36	2.48	3.97	5.22	1.89	2.23	3.24
37	2.48	4.00	5.21	1.90	2.25	3.26
38	2.47	4.00	5.24	1.96	2.40	3.27
39	2.51	4.01	5.26	1.97	2.33	3.31
40	2.52	4.03	5.27	1.95	2.88	3.35
dT(℃)	v=3m/s			v=5m/s		
dry-bulb Temp (℃)	Q_out=169W/㎡	Q_out=339W/㎡	Q_out=508W/㎡	Q_out=169W/㎡	Q_out=339W/㎡	Q_out=508W/㎡
28	0.85	1.76	2.68	0.53	1.10	1.57
29	0.83	1.57	2.49	0.56	1.13	1.59
30	0.85	1.69	2.53	0.57	1.09	1.61
31	0.88	1.84	2.45	0.50	1.10	1.71
32	0.84	1.65	2.37	0.52	1.12	1.56
33	0.89	1.64	2.55	0.53	1.05	1.66
34	0.89	1.77	2.50	0.54	1.07	1.66
35	0.88	1.71	2.48	0.52	1.01	1.60
36	0.88	1.65	2.41	0.53	1.03	1.61
37	0.86	1.68	2.43	0.52	1.09	1.71
38	0.91	1.71	2.48	0.51	1.10	1.62
39	0.87	1.71	2.39	0.54	1.11	1.69
40	0.87	1.72	2.51	0.52	1.09	1.66

From the above, the minimum temperature rise is 0.5℃, and less 0.5 as the random error determined the range of wind speed. The maximum dT is 5.27℃ when the wind speed is 0 m/s, the heat flux is 508W/㎡ and the dry-bulb temp is 40℃.

3.2 Impacts of heat rejection on the surrounding buildings

The range of dT from the CFD is from 0.5 to 5.27, which is the basis for choosing the 5m/s as the maximum wind speed. This is because when the speed wind is bigger, the dT will not more than 0.5, and less than 0.5 was as the calculation error in this paper. After running by SPSS, obtained the nonlinear regression equation, and correlation coefficients of dry-blub temperature, heat rejection, wind speed and the square of wind speed are 0.06, 0.05, -1.06 and 0.11, respectively. Based on the data, the regression equation described by the following equation:

$$\mathrm{dT} = 1.81 + 0.06 \times T_{dry} + 0.05 \times Q_{out} - 1.06 \times V + 0.11 \times V^2 \tag{2}$$

Using the equation to the verification model of 28 floors, it has been recycled three times to achieve equilibrium. The final dT surrounding the building is shown in Fig.6, from which the maximum temperature increased can reach 3.7°C at 2:00 p.m on July 30th with the condition of T_{dry} is 29.6°C and the V is 0. The average temperature for the summer is 0.88°C, having a great contribution to the heat island effect.

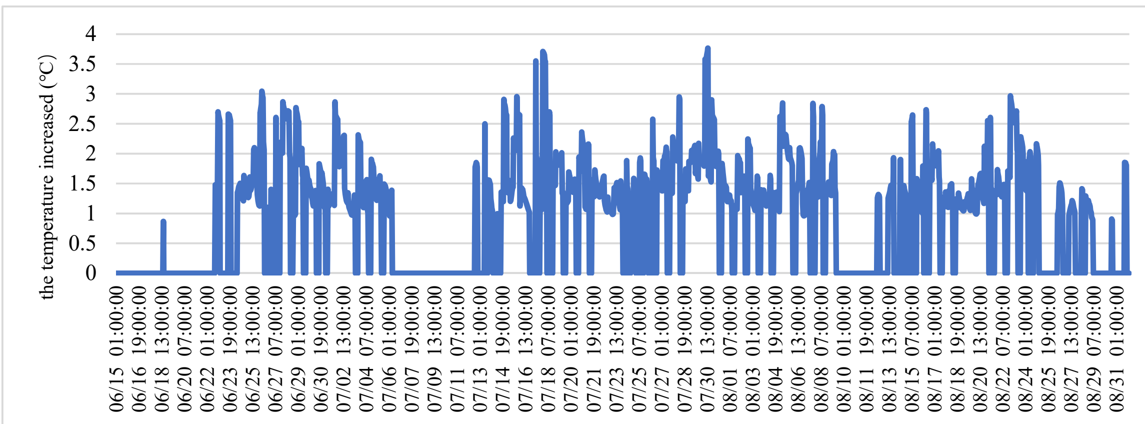


Fig.6. The final temperature increased around the building for the whole summer

3.3 Feedback of heat rejection to cooling load

Choosing two aspects to compare the feedback of heat rejection to cooling load: (1) the maximum cooling load on the design day; (2) the sum of hourly cooling load for the whole summer, namely cooling consumption, and both presented by increased percentage.

We choose the July 15th as design day, the maximum cooling load time appears at 3 p.m, and the increased percentage is 14.73%. the cooling time in summer is from June 15th to August 31th, the increased cooling load is 14.79%.

4. DISCUSSION

In this paper, the novel methodology exists lots of uncertainties and could not verification in a practical building, so just discussing the former

For In the CFD, there are two main doubtful points: (1) selecting a typical square building with a height is 100m to simulate regression equation, when applied to different heights or shapes, it will not suitable; (2) not considering the change of wind speed with height, because we just thought it was a rough method to quantify the heat rejection.

For the verification of cooling load in the EnergyPlus, the selection of design parameters for the building can lead to great discrepancy, such as window-wall ratio, schedule of people, lights and facilities, and even the heat transfer coefficient of materials. Therefore, the analysis of sensitivity of architectural design parameters is lacking.

5. SUMMARY AND IMPLICATIONS

The present paper discusses the feedback of heat rejection to the environment surrounding the buildings. The heat rejection from air conditioners not only increased the air temperature outside but also increased cooling load can reach 14.79%, will consume more energy to cool down the buildings.

In this paper, a novel methodology was proposed to calculation the increased cooling load for the whole summer. Generating the regression equation is the key component, in which temperature rise as the dependent variable, outside dry-blub temperature, heat rejection flux and the wind speed as the independent variables.

The influence of heat rejection to the environment of surrounding building expressed in the outside temperature and the highest rise is 3.7℃ in hot, windless summer. The feedback to cooling load reflected in the increase of the cooling consumption for the cooling season, and the percentage can reach 14.79%.

This methodology can be further applied in a community not just for a building. But we must solve the problem that the regression equation is not suitable for different height buildings in a community.

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