

Calculation method for the effect of heat rejection of split-type air conditioner on thermal environment and building energy demand for neighbourhood-level

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Abstract. The purpose of this research is to propose a simple and fast method to evaluate the effect of heat rejection of split-type air conditioner on the thermal environment surrounding the building and the building cooling demand to provide guidance for architectural design in the urban planning stage. In this paper, we first determined the factors that affect or are affected by heat rejection as heat dissipation, wind speed, and ambient air temperature, which as inputs to the CFD to build the regression model of the temperature rise. Then, the regression model is coupled with the energy consumption simulation software EnergyPlus to estimate the building cooling increase. The result of taking a typical residential building as a reference show that the maximum temperature rise and cooling demand increase with the values of 1.86°C and 17%.

Keywords: Heat rejection; Ambient temperature; Wind speed; Building cooling energy.

1 Introduction

Recent years have been a significantly increase in building energy requirement for developing of the urbanization and improving requirements for thermal comfort [1,2]. At the urban or neighbourhood level, considering the buildings in urban context more important than regrading them as stand-alone for accurately predicting building energy demand [3]. Especially for the summer, the heat island effect in cities has been severely deteriorated with worsening thermal environment by the continuous growth of building energy consumption [4]. Furthermore, the deteriorating thermal environment affect the city buildings by increasing the energy consumption and electric power necessary for cooling needs [5]. Consequently, there is a vicious circle between the built-environment and building energy consumption, and heat rejection from the air-conditioner is the main way of building energy demand. To deal with this situation, scholars have focused on air conditioners energy consumption to reduce this consumption and increase energy-efficiency to make the urban environment better.

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Because of the advantages of simple structure, flexible operation, and smooth appearance, split-type air conditioners are broadly applied in households and offices. Split-type air conditioners take in air near the condenser and reject heat to the outside with a fan, which is a process of sensible heating; that is, heat is added to the air without changing its relative humidity [6]. A stream of studies has been explored on factors that affect the heat rejection of air conditioners, mitigate strategies to reduce heat rejection, and its effect on thermal environment and building energy consumption.

As we all know, heat rejection from the fan is equals to the building load and the power consumption of the air conditioner, which can be obtained from the building load and the COP (coefficient of Performance, used to calculate the power consumption of the unit). The wind that has a significant effect for the accumulation of the heat from the fan near the building under the condition that the heat rejection and outdoor ambient temperature are kept constant [7]. Chun-Ming Hsieh proposed that the specific installation location of the outdoor unit is every floor or every third floor of the building to reduce the impact of the heat rejection on the thermal environment and building load [8].

Heat rejection from the fan generate a rise for the ambient air temperature rise near the fan surrounding the building that affects the performance of air conditioner and the building cooling demand. With the higher temperature around the outdoor condenser unit, more energy consumption of the air conditioner will produce [9]. Temperature rise adjacent to the building envelope affected by the location of the condenser unit where the highest can reach by 3.1°C in Wuhan at 14:00 for an office building [7]. Coupling CFD and EnergyPlus, Chun-Ming Hsieh [10] argued that the temperature rise can increase 1.89°C surrounding the building which cause and additional 10% for the building cooling demand for a typical high-rise residential building in Taiwan in summer night.

The previous studies that heat rejection of split-type air conditioners are based on the built architecture, which obviously does not take the heat reject for the building or the buildings on a neighbourhood-level in the planning stage into account. In addition, the time scale from the above research is short so that the evaluation of heat rejection on the environment and building energy in the whole summer cannot available. To deal with these tricky, we propose a simple, convenient, and fast calculation method that build a regression model for the temperature rise, and then obtain the building cooling demand increase by revising the original weather data used as inputs to energy simulation software.

2 Methodology

This research establishes a regression model with numerical simulation in CFD used to revise the original weather data for building energy simulation and calculation to predict the impact of heat reject on a long-term scale. The research process can be schematized into the following steps:

- 1) propose the assumption that the heat rejection of the air conditioner is equivalent to the heat dissipation from four walls of the building;
- 2) design numerical simulation cases based on the factors that affect the heat rejection and their variation range;
- 3) establish a regression model of the temperature rise (described by dT) according to the above calculation results;
- 4) calculate the effect of heat rejection on thermal environment and building cooling energy demand for a typical residential building.

2.1 Assumption

The weather file, where the parameters such as temperature, humidity, and solar radiation are the constant values that change over time is used for building energy consumption simulation. The temperature rise caused by heat reject just increase the partial temperature that needs to be processed, for example, to make an average, to get the effects on thermal environment and building energy demand. We argue that the temperature rises from heat rejection of the condenser units is distribute uniformly in the air adjacent to building envelope on the neighbourhood level. Based on the above, we propose the assumption that the heat rejection is equal to the heat dissipation of the four walls of the building, which is calculated as equation (1):

$$Q_w = (1+COP)/COP * Q_c * S_c/S_w \quad (1)$$

Where: Q_w is the heat dissipation of the wall, W/m^2 ; COP is the coefficient of performance of the split-type air conditioner; Q_c is the building cooling load, W/m^2 ; S_c is the net conditioned area, m^2 ; S_w is the wall surface area, m^2 .

2.2 Inputs parameters and range for CFD

We have already known that heat rejection is a basic influencing factor depend on the building cooling energy demand will be as the first input for the CFD, described as Q_w . The wind speed that affect the temperature rise of the air adjacent to the building envelope is critical from the previous studies as the second input, described as V_0 . Besides, the ambient air temperature influenced by the temperature rise is the third input, described as T_a .

2.3.1 The value of Q_w

According to equation (1), the value of Q_w that related to the COP, building cooling load, building cooling area, and building wall area is determined. For a special air conditioner, the COP is a constant, the building cooling load is calculated from the EnergyPlus with the original weather file, and the other two parameters, building cooling area and building wall area, need to be defined.

The length and width of the building used to the numerical simulation are the same 30m that avoid the influence of wind direction on the temperature rise for different side of the wall and consider the problem of the temperature rise values of the air adjacent to the building envelope. The building height of building is 100m for the same reason of the values.

The COP of the air conditioner used in this research is 2.8. There are four levels for cooling energy load on the basis of empirical analysis, which are $20W/m^2$, $50W/m^2$, $100W/m^2$, and $150W/m^2$. As a result, the heat dissipation of the wall is $67.6W/m^2$, $169W/m^2$, $339W/m^2$, and $508W/m^2$.

2.3.2 The value of V_0

The value of wind speed is also four levels referring to wind speed frequency chart of weather file in Shanghai (Fig.1), which is $0m/s$, $1m/s$, $3m/s$, and $5m/s$.

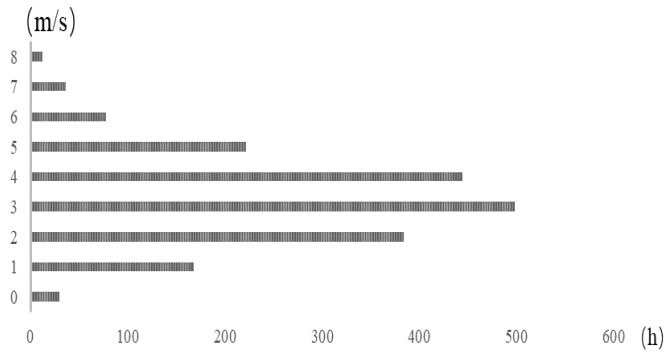


Fig. 1. Frequency chart of wind speed in Shanghai.

2.3.3 The value of Ta

Based on the set temperature of the air conditioner is 26°C, the value of Ta takes a total of 13 levels that ranges from 28 to 40 °C for each degree.

Then, we arrange the values of the three input variables and get the total calculation cases. In summary, the values for inputs parameters in the CFD and the total number of cases are as shown in Table1.

Table 1. Setting input parameters and their range.

Qw (W/m²)	Ta (°C)	V0 (m/s)	Cases
67.6 169 339 508	28	0 1 3 5	208
	29		
	30		
	31		
	32		
	33		
	34		
	35		
	36		
	37		
	38		
	39		
	40		

2.3 Boundary conditions in Fluent

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. The sets of boundary condition in Fluent as shown in Table2.

Table 2. Boundary conditions for Fluent.

Turbulence model	Steady standard k-e model
Momentum	First order upwind
Turbulent kinetic energy	First order upwind
Turbulent dissipation energy	First order upwind

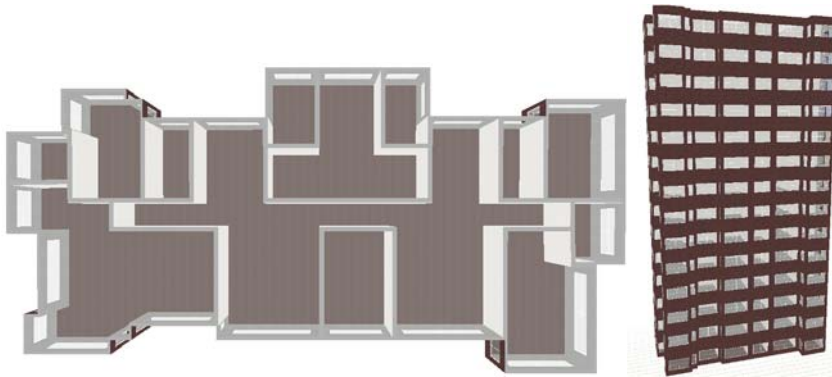


Fig. 3. Floor plans and elevations of the typical building.

A typical 14-story residential building in Shanghai of China was used to calculate the impact of heat rejection on temperature rise adjacent to the building envelope and building cooling energy increase adopting the regression model. The setting of thermal parameters of the external walls, windows and roofs, and internal heat gains of equipment, lighting and people takes local building energy efficiency design standards as a reference.

3 Results

3.1 Results of the numerical simulation

The results of temperature rise under different inputs as shown in Figure 4 that have been handled from Fluent.

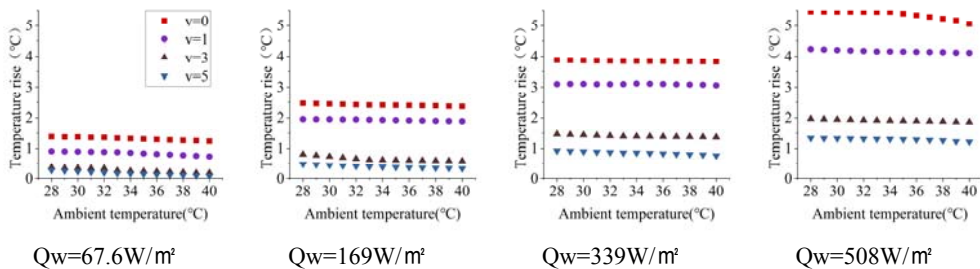


Fig. 4. Results of temperature rise under different inputs.

As discussed above, heat dissipation of the wall is the primarily factor to cause the temperature rise and wind speed plays a key role to dissipate heat and reduce heat island, which can be clearly seen from Figure 4. The maximum temperature rise is 5.46°C when heat dissipation of wall is 508W/m² and wind speed is 0m/s, and the minimum is 0.08°C under the condition that heat dissipation is 67.6W/m² and wind speed is 5m/s.

3.2 Establish regression model

In this paper, SPSS (Statistical Product and Service Solution) is used to build the regression model between the inputs of heat dissipation of wall, ambient air temperature, and wind speed and the output of temperature rise, as shown in equation (3).

$$dT=1.914-0.0118*Ta+0.00569*Qw-0.526*V_0 \tag{3}$$

The adjusted R-square of this model is 0.88, which means that 88% of the dependent variable are explained by the independent variables; and the F value is 489 meaning the hypothesis test has passed, so the model has certain credibility.

3.3 Results of heat rejection on thermal environment and building cooling energy demand

The effect of heat rejection on the layer adjacent to the building envelope and cooling energy demand of the building was iteratively calculated using the above model and EnergyPlus. We call the simulation with the original weather file as the first calculation, and a total of three calculations have reached the convergence condition described in 2.5. The hourly temperature rise and cooling energy increase that got from the last calculation is shown in Figure 5 and Figure 6.

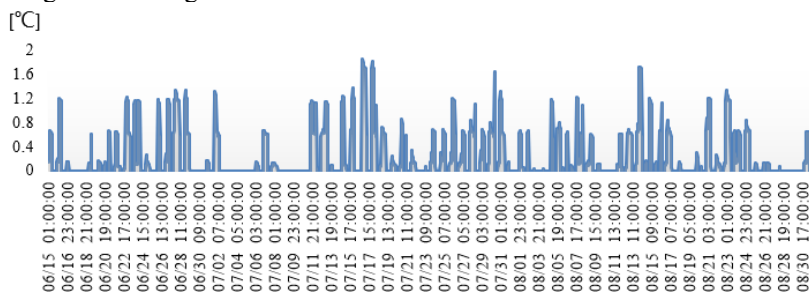


Fig. 5. Hourly temperature rise caused by the heat rejection.

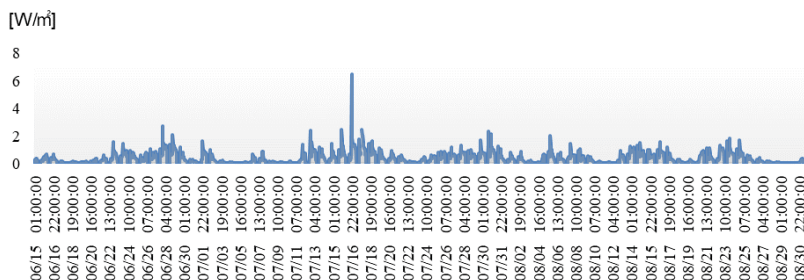


Fig. 6. Hourly cooling energy demand increase caused by the heat rejection.

The hourly temperature rise surrounding the building is diverse can be seen from the Figure 5 due to the inputs, resulting cooling energy increase to change over time. The maximum temperature rise is 1.86°C, and the average is 0.2°C. The maximum cooling energy increase is 6.96W/m², which is an increase of 17% compared to the cooling energy with the original weather data, and the total cooling increase is 0.53kWh/m².

4 Conclusion

With the increasing urbanization and building energy demand, the built environment has become particularly important no matter for the prediction of building energy demand or reduction of heat island. This paper proposes a novel calculation method for the impact of heat rejection on the thermal environment and building cooling demand on a large spatial

and long-time scale. A regression model for calculating the temperature rise is established with the numerical simulation on the basis of heat rejection of air conditioner is equivalent to the heat dissipation of wall. The coupled calculation method of the model and EnergyPlus results in a typical residential building with a temperature rise of up to 1.86°C and a cooling load increase of 17%.

It is reasonable and referential to use the model to evaluate the impact of heat rejection of split-type conditioners on the thermal environment surrounding the building and the cooling demand of the building on a neighbourhood scale. It is meaningful to study the impact of heat rejection, which can be used in the building plan and design stage to provide advice for better environment and lower energy consumption. Besides, there are still some uncertainties that may affect the results, such as the value of COP, which is a constant of 2.8 and further research is encouraged to analyse its impact on the results.

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