Study on long-term calculation method of temperature in residential areas in hot and humid regions

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Abstract. This paper uses the improved green CTTC model to explore the selection method of background temperature for long-term continuous calculation. A new method to determine the background temperature is proposed, and the feasibility of the method is verified by tested. This method not only improves the prediction accuracy of the model due to external meteorological factors, but also applies to long-term continuous calculations of one week or more. The consistency index \( d = 0.991 \), RMSE=1.272°C, absolute error maximum=5.6°C, relative error maximum 23.8%. 0.2°C ~1.4°C is improved compared to the original calculation model.

1.Introduction

In hot and humid regions of China, the climate is hot and humid with abundant rain throughout the year, and the urban heat island effect is increasing year by year. Reasonable architectural design should be adopted to reduce the urban heat island as much as possible. Therefore, the evaluation tools for guiding the thermal environment of urban residential initial designed is important. At present, the more mature research in the lumped parameter model to guide the design planning and ensure the quality of the outdoor thermal environment in the initial stage of the project is the improved green CTTC model. This paper discusses the method of selecting the background temperature for the improved green CTTC model for long-term continuous calculation.
2. Research status

The original CTTC (Cluster Thermal Time Constant) model was first proposed by L. Shashua-Bar and M. E. Hoffman (1990) in solving the heat transfer of the envelope and calculating the internal temperature response of the room. The follow-up study takes into account the impact of green trees on the air temperature in residential areas and forms the green CTTC model (L. Shashua-Bar and M. E. Hoffman 2002). The suitable meteorological conditions for these models are fair-weather and clear day with wind speed less than 2 m/s (or light-to-moderate winds). The model considers the temperature of residential is determined by the effect of the rising temperature caused by solar radiation and the cooling caused by long-wave radiation on the background temperature, as equation (1).

\[
t_a = t_b + \Delta t_{sol} - \Delta t_{lw}
\]

Where, \(t_a\) is outdoor air temperature in residential area, °C; \(t_b\) is background temperature, °C; \(\Delta t_{sol}\) is the rising temperature caused by solar radiation, °C; \(\Delta t_{lw}\) is the cooling caused by long-wave radiation.

Among them, the selection of background temperature is the key, determined by the mesoscale meteorological conditions, there are generally two methods to determine: one is use the equation (1) to calculate; Another is taken the mean temperature of the whole day in the suburban meteorological station. The two selection methods have been used in the past studies, and the results agree well in summer clear weather.

The studies in humid and hot regions (L F Shu et al. 2010, Y F Zhang et al. 2014, J Wu et al. 2016) play an active role in the application of CTTC model. However, the above studies are mainly for one day (24 hour) calculations for sunny weather conditions in summer. Therefore, this paper will improve the existing model to achieve long-term scale (7 days, 168 hours) calculation and verify the accuracy of long-term scale model calculation through experimental research.

3. Methods

3.1. Background temperature calculation

The background temperature of the original model is taken the lowest temperature with minimum temperature rise of solar radiation in the whole day as \(t_{b0}\), calculated by equation (2). When the weather conditions are stable, the background temperature is stable on the day. However, in the long-term scale calculation, because the cold and warm peak transit or precipitation will cause the background temperature to change, this paper proposes two methods of value selection for \(t_b\), as shown in table 1.

Method 1 is taken the mean temperature of 6:00 to 5:00 the next day; Method 2 is taken the mean of the lowest temperature of first calculated day and the next calculated day.

| Calculation method | \(t_b = t_{a0} - \Delta t_{sol} + \Delta t_{lw}\) (2) |
|--------------------|--------------------------------------------------|
| Original method    | \(t_b = \sum t_{ai}/24 - \Delta t_{sol} + \Delta t_{lw}\) (3) |
| Method 1           | \(t_b = (t_{a0} + t_{a24+i+1})/2 - \Delta t_{sol} + \Delta t_{lw}\) (4) |

Table 1. Calculation method of background temperature.
Where, $t_{a0}$ is the lowest air temperature of the calculated day, usually takes the temperature at 6:00 a.m., °C; $t_{ai}$ is air temperature at every hour from 6:00 a.m. to 5:00 a.m. next day, °C; $t_{a24i+1}$ is the lowest air temperature of the next calculated day, °C; $\Delta t_{sol}$ and $\Delta t_{lw}$ reference to the references (J Wu, 2016).

3.2. Field measurements in sites
A series of field measurements were carried out in Nantie Living Area of Xixiangtang District, Nanning City, Guangxi Zhuang Autonomous Region. The buildings layout is determinant, the average height of the buildings are 24m, and the greening rate is 2%~28%. We selected 15 residential areas as ground stations and 1 high-altitude station. The test time is from July 2017 to June 2018. We selected 12th station as the test object in this paper, respectively utilizing the three methods above to calculate a week with rainfall in summer and transition season, the information as shown in table 2 and figure 1 (Satellite image from Google Earth).

| Test | Season | Date       | Mean Temp | Temp trend | Rainfall  |
|------|--------|------------|-----------|------------|----------|
| Test1 | summer | 2017/10/16~10/22 | 21.2°C  | rise      | 39.2mm (Continuous) |
| Test 2 | transition | 2018/1/8~1/14 | 12.5°C  | rise      | 17.0mm (Continuous) |
| Test 3 | transition | 2018/3/17~3/23 | 19.8°C  | down      | 28.4mm (Intermittent) |
| Test 4 | summer | 2018/6/10~6/16 | 24.8°C  | stable    | 36.4mm (Intermittent) |

![Figure 1. Description of test point layout.](image)

Delta ground station(2m from ground) ⭐ high-altitude station(30m from ground)

The measured physical quantities are near-earth air temperature, relative humidity, atmospheric pressure, windspeed, rainfall, solar radiation intensity, etc. Considering the regular layout of the residential area, the ground stations are arranged in the center of the residential, 2m from the ground, a temperature/humidity recording instrument and a simple weather station are placed, in order to avoid the influence of solar radiation, the temperature/humidity recording instrument is placed in a louvered box; the high-altitude station is 30m from the ground, as shown in figure 1.
3.3 Calculation Platform

This paper is based on the green residential parametric optimization design platform (J Wu, 2016), which uses the improved green CTTC model to calculate the temperature. The steps are as follows: 1. Community parametric modeling; 2. Calculation of boundary conditions. As shown in figure 2.

![Calculation platform and Model generation](image)

Figure 2. Calculation platform and Model generation.

4. Results

From July 2017 to June 2018, the highest temperature is 34°C in July and the lowest temperature is 8°C in January; there were 137 rainy days, including 92 light rain days; 29 moderate rain days; 14 heavy rain days; 2 heavy rain days, temperature fluctuations, rainfall obvious. Weather is often accompanied by rapid cooling and rapid warming after rain, as shown in figure 3.

![Temperature and rainfall during the test period](image)

Figure 3. Temperature and rainfall during the test period.

4.1 Solar Radiation Intensity and Rainfall

The test period are shown in figure 4 and figure 5. Take Test 1 (From Oct. 16, 2017 to Oct. 22, 2017) as an example, the maximum daily solar radiation intensity appeared at 12:00, 856.6 W/m² on 19th, and the minimum appeared at 6:00, 3.8 W/m² on 16th. The maximum rainfall appeared in 17th, 21:00, 4.8 mm.
Figure 4. Solar radiation intensity and rainfall.
5. Calculation result and analysis

5.1. Calculation results
Figure 6 shows the measurement and calculation results of air temperature in four research periods selected by this research. It can be seen from the diagram that the variation trend of air temperature calculated by three methods is basically the same as that of measured air temperature, but the errors between calculated results and measured results are also different in different periods. There is a certain relationship between the size of error and rainfall: The error of continuous rainfall period is small and intermittent rainfall error is larger; In the transition period after rain, the error increased obviously, and it began to decrease gradually without rainfall. Further quantitative analysis will be carried out according to the different rainfall conditions.
5.2. Error Analysis

The study period is divided into four periods according to rainfall: continuous rainfall period (1), transition period (2), stable period (3) without rainfall and intermittent rainfall period (4). In Test 4, there is rainfall for more than half a week, so we take the result of Test 4 as an example for further analysis.

In the period of rainfall, the coincidence between the three methods and the measured values is higher, the difference between the original method and the measured value is 0–0.5°C, the Method 1 differs from the measured value by 0–0.8°C, The Method 2 differs from the measured value by 0–0.3°C; In the transition period after the rain, the error begins to increase, the Original method and Method 2 are lower than the measured value, the Method 1 is higher than the measured value, the difference between the Original method and the measured one is 0.1–2.2°C, the difference between method 1 and actual measurement is 0.2–2.1°C, the difference between method 2 and actual measurement is 0.4–1.3°C; In the stationary period after the rain, the error between the Original method and the measured value is gradually reduced, the difference between Day4 is 0.1–1.9°C, and the error is 0–0.9°C when it is Day7, the Method 1 has a large error, which is different from the measured error by 1.1–3.7°C, the Method 2 is the best, the error is 0.2–1.4°C, during this period, the maximum error of the three calculation methods appeared in Day6 at 2:00 p.m.

In the three methods of these tests, the Method 1 has the largest error, the Original method is the second, and the Method 2 has the smallest error. The Original method's consistency index d=0.987, RMSE=1.530°C, absolute error maximum=5.8°C, relative error maximum 42.0%; The Method 1's consistency index d=0.971, RMSE=2.372°C, absolute error maximum=7.8°C, relative error maximum 30.0%; The Method 2's consistency index d=0.991, RMSE=1.272°C, absolute error maximum=5.6°C, relative error maximum 23.8%, As shown in the table 3.
Table 3. Error analysis.

| Method         | consistency index d | RMSE (°C) | absolute error maximum(°C) | relative error maximum(%) |
|----------------|---------------------|-----------|----------------------------|----------------------------|
| Original method| 0.987               | 1.530     | 5.8                        | 42.0                       |
| Method 1       | 0.971               | 2.372     | 7.8                        | 30.0                       |
| Method 2       | 0.991               | 1.272     | 5.6                        | 23.8                       |

6. Conclusion

Based on the improved green CTTC model, a new method that suitable for a week or more continuous calculation is adopted to determine the background temperature. The conclusion as below:

1. The new method to calculate background temperature can effectively reduce errors and improve accuracy. The tests prove that taking the mean temperature of the minimum temperature(6:00a.m) in the first day and the minimum temperature(6:00a.m) in the next day in continuous calculation is work, especially in the transition season with large temperature difference, the effect is remarkable. The consistency index d=0.991, RMSE=1.272°C, absolute error maximum=5.6°C, relative error maximum 23.8%. 0.2°C ~1.4 °C is improved compared to the original calculation model.

2. Surface cooling and evaporation caused by rainfall days have an effect on air temperature. The improved green CTTC model adopted in this paper does not consider relevant factors. Only the modification of background temperature selection method cannot reflect the temperature change during and after rainfall. the calculation method will be further revised in the next study.

Reference

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