IMPROVEMENT ON THE PREDICTIVE MODEL OF URBAN AIR TEMPERATURE IN SUMMER

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Abstract

This paper presents the improvement of the CTTC model for predicting urban air temperatures based on the experiment data of Sep. 2008 in Guangzhou. Four improvements was proposed and the experimental validation was performed. The results show that the improved CTTC model can predict the urban air temperature more accurately than the original one. The improved model has great importance on the urban microclimate design and building energy conservation.

Key words: urban air temperature, CTTC model, green heat transfer correction factor

1. INTRODUCTION

The CTTC model was originally developed by Swaid and Hoffman, which is a lumped parameter predictive model for urban air temperatures. This present paper improves the original model to make it more exactly and applicable, especially for hot-humid region of China.

2. INTRODUCTION TO CTTC MODEL

2.1. The original CTTC model

Swaid and Hoffman proposed that the urban air temperature can be expressed as the sum of the contributions in energy balance:

\[ T_u(t) = T_b + \Delta T_{sol}(t) - \Delta T_{lw}(t) \]  

where \( T_b \) is base temperature, \( \Delta T_{sol}(t) \) is the contribution to air temperature variations of absorbed solar radiation by the urban canopy layer surface and \( \Delta T_{lw}(t) \) is the contribution to air temperature of the net outgoing long-wave radiation flux from the urban canopy surfaces to outer space.

2.2. The green CTTC model

The main effects of trees on urban air temperature are the effect on solar radiation, the effect on CTTC value and the effect on long-wave radiation. Considering the effect of the trees on solar radiation, Shashua-Bar and Hoffman believed that part of the solar radiation shaded by the trees were transferred to the ambient environment by convection and proposed a convection heat-exchange ratio, which is a ratio of the convection heat exchanged between the tree and the ambient air to the solar radiation on the surface of the tree. They mentioned that the effect of the trees on the long-wave radiation can be ignored.

3. DEFICIENCY OF THE EXISTING CTTC MODELS

The deficiencies of the existing CTTC models are:

1. Lack of accurate calculation of the surface temperature;
2. The contribution of the net outgoing long-wave radiation can not be calculated exactly;
3. The effect of the trees on long-wave radiation can not be ignored.

4. AN IMPROVEMENT OF THE CTTC MODEL

Based on the experimental studies in Sep. 2008 in Guangzhou, four improvements were proposed as followings.

4.1. The predictive model for surface temperature

The predictive model for surface temperature was proposed mainly based on the reaction coefficient model given by Ran et al.

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4.2. The improved model of $\Delta T_{lw}(t)$

The net Long-wave radiation was considered as the decrease of solar radiation, and followed the law of contribution of solar radiation:

$$\Delta T_{lw}(t) = \sum_{\lambda} (1/h) \Delta I_{lw}(\lambda) \times (1 - \exp((\lambda - t)/CTTC))$$

(2)

Where $h =$ overall heat transfer coefficient (W/m·K), $\Delta I_{lw}(\lambda) =$ step change in net outgoing long-wave radiation intensity (W/m²), $\lambda =$ time (h), $t =$ time (h).

4.3. The effect of the trees on long-wave radiation

The improved model proposed that in the tree area was the contribution to air temperature of the net outgoing long-wave radiation flux from ground surfaces to lower surface of the leaves of the tree. The temperature of leaves is approximately equal to ambient air temperature.

4.4. The green heat transfer correction factor

The green heat transfer correction factor was proposed in the present study to represent the integrated effect of convection heat exchange of green belt at time $t$ on $\Delta T_{sol}(t)$.

$$\Delta T_v(t) = (1 - f(1 - Ci(t))) A - \Delta T_{lw}(t) + \Delta T_{lw}(0)$$

(3)

$$1 - f(1 - Ci(t)) = \frac{A1}{A}$$

(4)

Where $Ci(t)$ is the green heat transfer correction factor, $A$ is $\Delta T_{sol}(t)$ at an open place, $A1$ is $\Delta T_{sol}(t)$ of green, $\Delta T_v(t)$ is the measured temperature change at time $t$ to the initial time.

Fig. 1 and 2 show the experimental result of mango tree and lawn according to the measurement in 12th Sep.

5. EXPERIMENTAL VALIDATION

The improved CTTC model was verified with the field measurements in a residential area in Guangzhou on 14th and 15th Oct in 2008, and the original model was also used for comparison (see Fig. 3 and 4).
Error analysis on the simulation and measured results are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Improved model</th>
<th>Original model</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum (℃)</td>
<td>34.25</td>
<td>34.7</td>
<td>34.38</td>
</tr>
<tr>
<td>Mean (℃)</td>
<td>30.75</td>
<td>31.02</td>
<td>31.13</td>
</tr>
<tr>
<td>Maximum error (℃)</td>
<td>0.97</td>
<td>1.37</td>
<td>0</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.991</td>
<td>0.936</td>
<td>0</td>
</tr>
<tr>
<td>Maximum error ratio</td>
<td>2.84%</td>
<td>4.43%</td>
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</tr>
<tr>
<td>Standard error</td>
<td>0.41</td>
<td>0.87</td>
<td>0</td>
</tr>
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</table>

It can be seen from Fig.3, Fig. 4 and Table 1 that the improved model can predict the urban air temperature more accurately than the original one.

6. CONCLUSIONS

The improved CTTC model can predict the urban air temperature more accurately than the original one. It can be applied for the prediction of the effects on urban air temperature of urban plan, building design, surface material, street distribution, green, and heat irritation due to human activities. It has great importance on the urban microclimate design and building energy conservation.

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