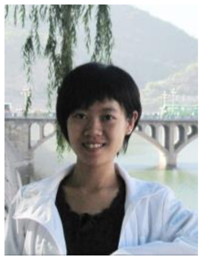

Microclimate Regulation by Trees in a Subtropical High-Density Urban Environment during Sunny and Cloudy Weather

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1. Introduction

The hot, humid summers of subtropical Hong Kong cause thermal discomfort. This discomfort is further intensified by the urban heat island (UHI) effect on heavily built-up areas (Goggins *et al.*, 2012). Urban greenery has been proposed as a microclimate regulation mechanism; nonetheless, the thermal impact of such greenery on the high-density urban environment has seldom been reported in literature (Wong and Chen, 2005). Moreover, few urban climatic studies have been conducted on hot climates, especially hot-humid climates (Roth, 2007). Thus, research on site-specific planning for tree-planting in a built environment under a hot-humid climate are needed to clarify greenery design in (sub)tropical regions.

Studies on tropical and subtropical areas indicate that sky view factor (SVF) influences the thermal performance of building groups (Mills, 1997), and significantly affects the outdoor thermal comfort of residents (Krüger *et al.*, 2011; Lin *et al.*, 2010). In addition, a 1% reduction in SVF reduces daytime UHI intensity by 1%–4% in subtropical Hong Kong (Giridharan *et al.*, 2004). The cooling effects of trees on the urban environment are interrelated with the impacts of building morphology (Shashua-Bar *et al.*, 2009). Therefore, the thermal behavior of urban trees must be investigated with different SVFs. Due to the high humidity in the subtropics, "cloudy" is the dominant weather type in large parts of such regions (Giridharan *et al.*, 2008); hence, the current study evaluates the cooling effects of urban trees in both sunny and cloudy weather to address the critical and prevailing issues related to pedestrian comfort in subtropical cities (Fig. 1).

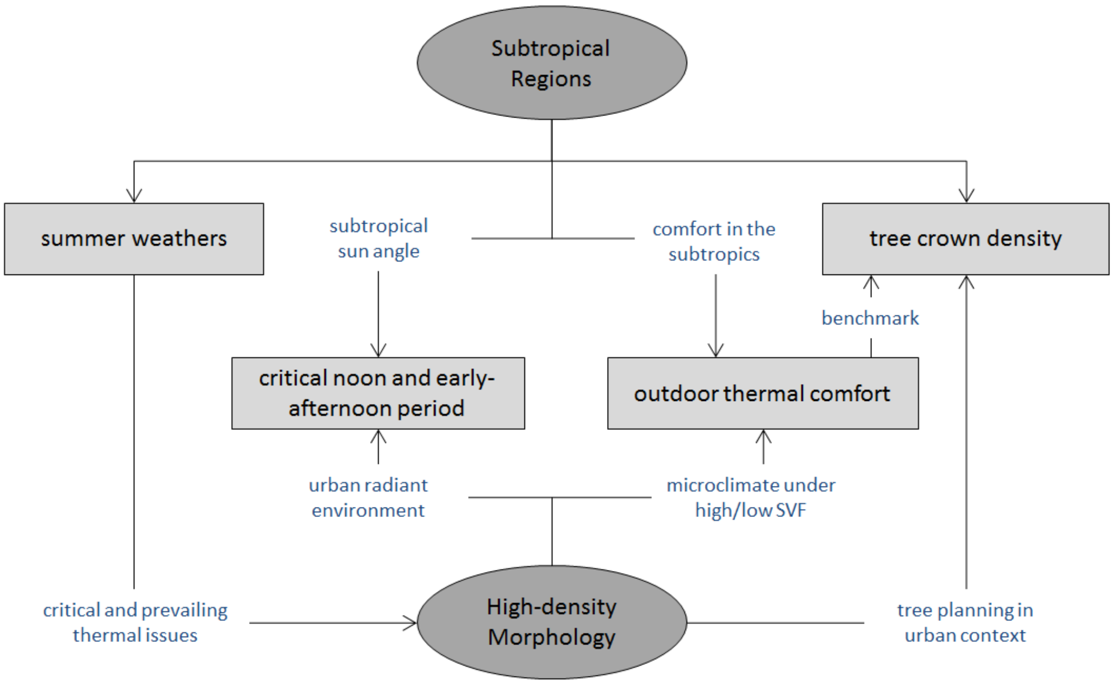

Fig. 1 Key words and context of the study

2. Methodology

A field survey is conducted to determine the thermal effect of trees in the urban areas of Hong Kong with SVFs ranging from 0.2 to 0.8. Physical environmental variables are measured under a tree canopy and on a nearby exposed reference point positioned at a height of 1.5 m (Armson *et al.*, 2012; Konarska *et al.*, 2014). Downward solar radiation, ground surface temperature, air temperature, relative humidity, wind speed, and global temperature are measured with a TESTO measuring instrument and an FLIR thermography camera (Fig. 2). Furthermore, T_{mrt} values are calculated with reference to the measured data (Thorsson *et al.*, 2007); the measurements were taken from 12:30 to 14:00 under sunny and cloudy weather in July and August 2014. For data representativeness, weather criteria were set for the data collecting: the sky condition should remain constant 30-60mins before measurement and during the measuring period (referencing the records of Hong Kong Observatory); and to exclude the interference of upwind signals, only data collected under weak wind condition (wind speed <1.5m/s) would be used for analysis.

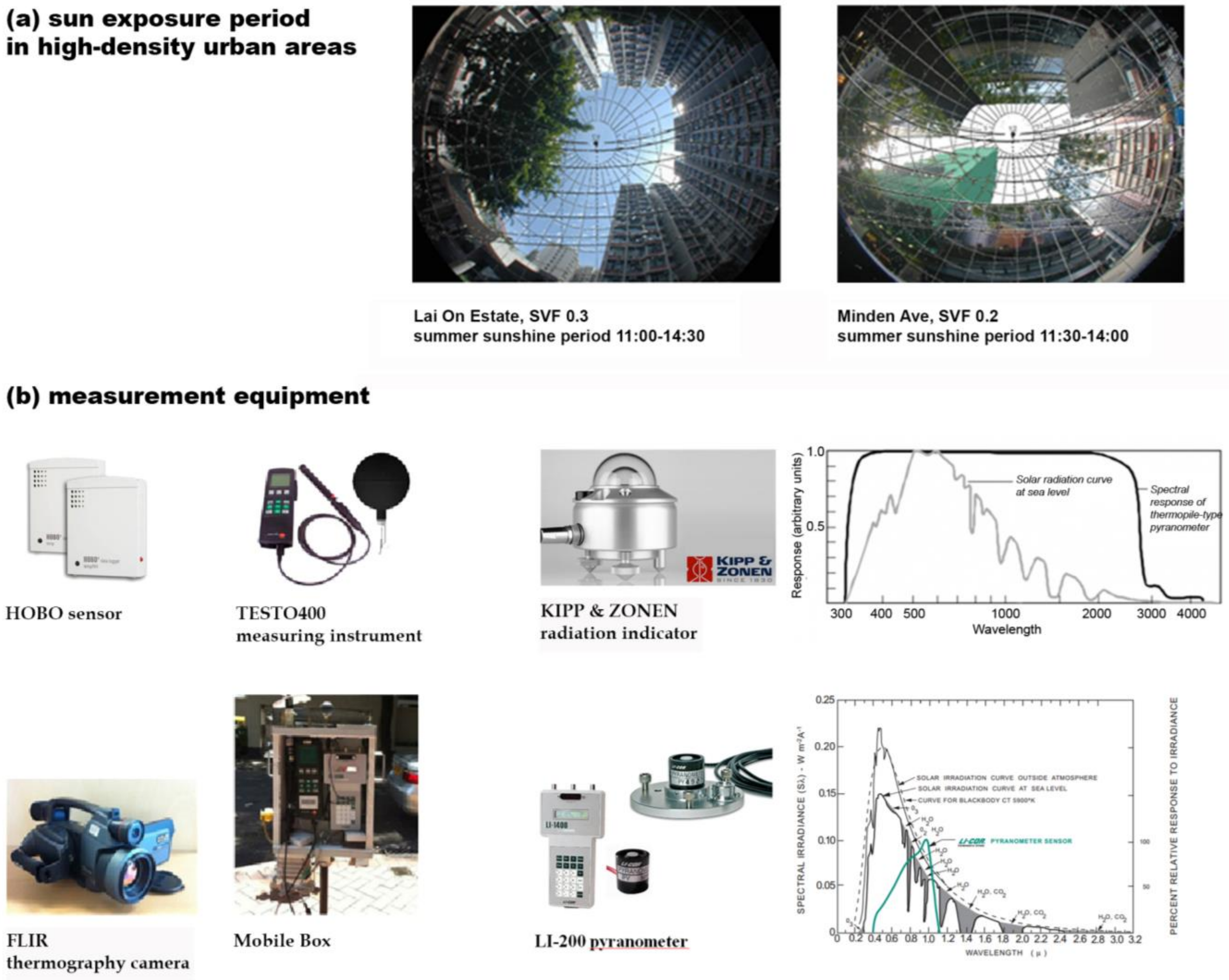

Fig. 2 Sun exposure period in high-dense urban environment (a) and measurement equipment (b)

On the basis of the field survey results, numerical modeling is performed with Hong Kong meteorology data to test the cooling effect of urban trees on high-density urban settings in typical summer and cloudy weather. The microclimate regulation and improvement in outdoor comfort provided by the trees are analyzed with reference to the before and after scenarios. The three-dimensional microclimate model ENVI-met 3.1 is used for the modeling study; this model is an effective simulation tool for urban climate study (Ali-Toudert and Mayer, 2006; Ng *et al.*, 2012). Moreover, the accuracy of ENVI-met in terms of modeling the urban environment under Hong Kong's climatic conditions has been verified (Ng *et al.*, 2012). In the model domain, 75-m and 25-m high building blocks were set up to simulate low-SVF (SVF = 0.2–0.3) and high-SVF (SVF = 0.5–0.6) environments in high-density urban areas.

3. Result and discussion

3.1 Measurement result

Site measurements were taken in the urban areas of Hong Kong with different SVF values during the hot summer months of 2014. The measured data indicated that the net tree effects were significantly related to SVF. This result can be interpreted from two perspectives: first, similar levels of cooling by the trees were observed under similar SVF levels (Fig. 4). Given dense trees with a solar transmission range of 0.06–0.08, the cooling in T_{mrt} were 21.7 °C and 21.6 °C in urban sites with 0.5 SVF. By contrast, these temperatures were 17.5 °C and 17.0 °C in urban sites with 0.7 SVF during sunny days. Second, the cooling magnitudes of the trees differed significantly in urban environments with high and low SVFs in both sunny and cloudy conditions. Specifically, the net cooling effects on T_{mrt} under high and low SVFs varied by 7° in sunny conditions. Under cloudy conditions, this difference increased to 12 °C. The observed data showed that the cooling effects of urban trees were particularly significant during sunny days with respect to both global temperature and T_{mrt}. On the other hand, the influence of building morphology on the cooling of trees was more evident in cloudy condition.

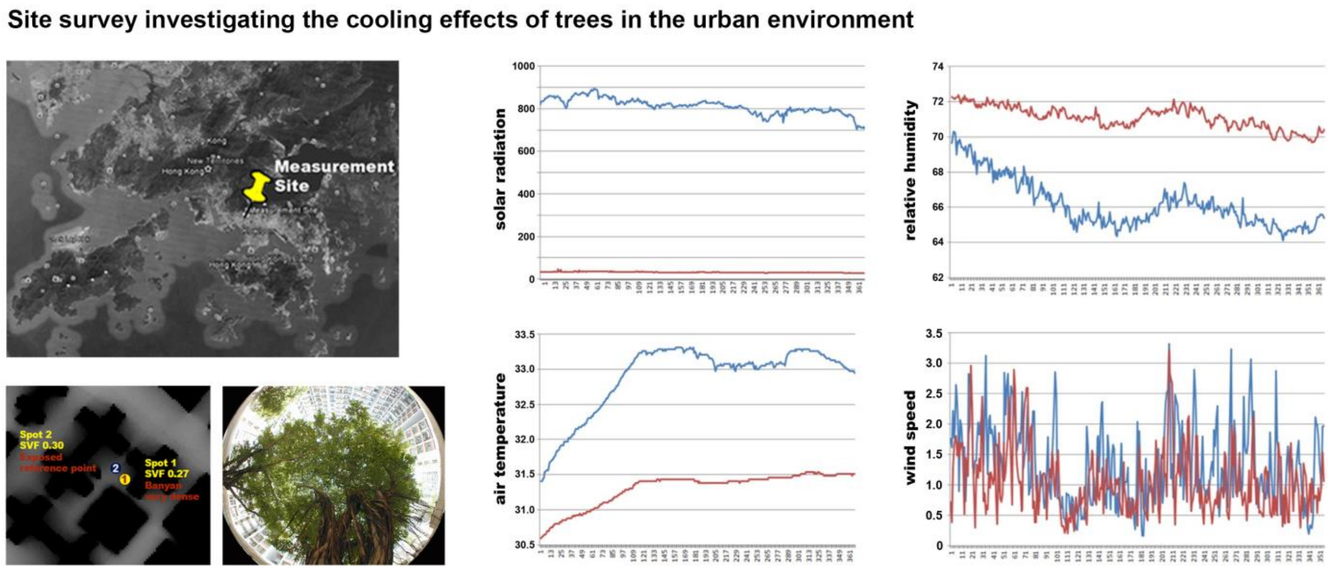

Fig. 3 Site measurement studying the effects of trees on microclimate in urban environment

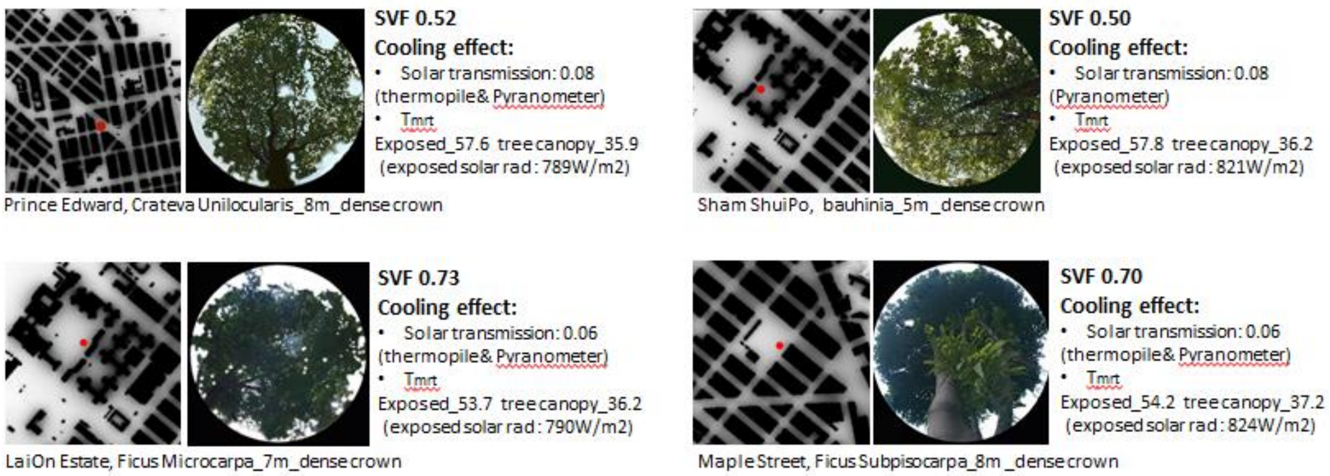

Fig. 4 same levels of cooling by trees were observed under similar levels of SVF

3.2 Modelling study

In the modeling study, the effects of trees under the typical summer cloudy weather were assessed referencing to the base case and the the before and after comparison. The findings showed that for a given crown density, the shading effects of street trees differed in low-SVF and high-SVF cases. In the low-SVF case, these effects exhibited considerable spatial diversity. In a high-SVF urban environment, T_{mrt} was reduced by 16 °C under the shading of dense trees. The cooling magnitude of T_{mrt} varied from 1 °C to 14 °C in the low-SVF case. Ng and Cheng (2012) studied outdoor thermal comfort in the hot-humid subtropical urban environment and concluded that the comfort range for PET was 27-29°C and for T_{mrt} was below 34 °C. The modeling study showed that with tree planted in low SVF environment, T_{mrt} under tree canopy dropped to 34 °C and PET value is cooled down to 29.2 °C; very close to the outdoor comfort threshold in the hot-humid subtropics (fig. 5). As cloudy weather dominates the summer period in the subtropics, the results of the study indicate that tree planting would substantially improve outdoor thermal comfort in the high-density urban environment in the regions.

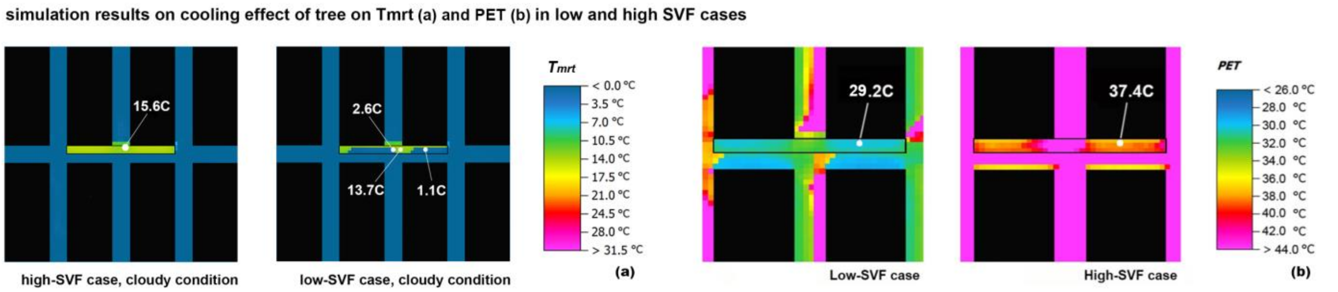

Fig. 5 simulation results on the cooling effect of tree on T_{mrt} and PET in low and high SVF cases in cloudy weather

4. Summary

The study investigated the cooling effect of urban trees under low- and high-SVF environments through site measurement and simulation study. The results indicate that the effects of tree planting on urban sites are SVF-related. Moreover, the cooling effects on T_{mrt} are similar when trees are planted in urban areas with similar SVF values. In addition, the difference in the cooling magnitudes of high-SVF and low-SVF sites is significant. Findings from the modeling study also indicate that the cooling effects of trees reduce T_{mrt} and PET values in the low-SVF case to the comfortable ranges under cloudy weather. The results of this study offer better understanding of urban tree behavior in built environments; such information may also help planners to develop site-specific tree planting plans for the city.

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