Application of button-size temperature sensors for micro-climate study of the urban environment of Hong Kong

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Abstract

The availability of high density in-situ weather observations is indispensable for the study of urban climate. In 2017, the Hong Kong Observatory (HKO) installed button-size temperature sensors in more than 30 different urban sites within an areal extent of around 4 km x 4 km over the Kowloon peninsula at the centre of Hong Kong. Those sites included green parks, seaside areas, hilltops, roadsides, buildings, etc. The objective is to study the temperature variations on a microscale (a few km in distance) under various meteorological scenarios for better understanding of the urban climate of Hong Kong.

This paper summarizes the technological advantages of using small size temperature sensors to enable fast establishment of a dense temperature observation network within the urban area of Hong Kong. The sensor's characteristics, data sampling rate, radiation shield used for housing the sensors, the exposures of measurement sites, etc. are also described. Analysis and discussions on the temperature data collected in a few interesting episodes are made. Possible future work to further enhance the study of urban climate for smart city development will also be described.

1. Introduction

It has been well known from previous studies that urbanization has contributed to the change of urban climate. In Hong Kong, a long-term rise of the annual mean temperature was observed with a rate of 0.12 ℃/decade (HKO, 2017; Lam, 2011) and the rate of rise has been increasing in recent decades (HKO, 2017; Li et al., 2015). In order to enhance further understanding of the urban climate of Hong Kong, HKO established a dense temperature observation network in the urban area of Hong Kong in early 2017 for studying the spatial distribution and temporal variations of temperatures over a microscale (within a few km) under different meteorological scenarios.

2. Methodology

2.1 Selection of measuring sites and temperature sensor

The temperature observation network comprises 32 measuring sites covering an area of around 4 km x 4 km over the Kowloon peninsula at the centre of Hong Kong (Figure 1). The measuring sites are established in green parks, seaside areas, hilltops, roadsides, buildings, etc. so that a diversity of site environment can be achieved to study the different degrees of urban influences on temperature measurements. The exposure at each measuring site is assessed based on (a) WMO's siting classification scheme (WMO, 2014), and (b) sky view factor (SVF), which is basically the portion of the sky that can be observed at the site. SVF can indicate the amount of solar radiation received at the site (Peng et al., 2017). To estimate the SVF of a measuring site, an upward looking fish eye lens photograph was taken at the site and the areal extent of sky view in the photo was thus calculated for determining the SVF (Figure 2). The assessment results of all stations are shown in Appendix 1.

Equipment-wise, button-size temperature sensors (hereafter, i-button sensors) with light weight and easy deployment are used for air temperature measurements. Each i-button sensor is housed in a rugged stainless steel package which is highly resistance to environmental hazards. Each sensor is calibrated in a temperature chamber traceable to the National Institute of Standards and Technology (NIST) and its measurement accuracy is better than ±0.5℃ with range from -10℃ to +65℃. Each i-button sensor is supplied with internal battery and no external power supply is required for its operation. Temperature data are sampled every 5 minutes so that each i-button sensor is able to achieve sustained operation of more than one year.

2.2 Radiation shield for temperature sensor

Radiation shields consisting of 8 layers of plastic plates are employed for housing the i-button sensors [Figure 3 (a)]. To assess the ventilation performance of the 8-layer radiation shield, three i-button sensors were installed separately in a 8-layer shield, Stevenson screen box and Thatched Shed at the Hong Kong Observatory Headquarters (HKOHq). Temperatures measured by the i-button sensors in these three different types of shields were compared with those measured by platinum resistance thermometers placed inside Stevenson screen box and Thatched Shed [Figure 3 (b)]. Figure 4 shows the comparison results of temperatures recorded on a sunny day of 20 August 2017. It can be observed that temperatures recorded by the i-button sensor in 8-layer shield were generally higher than those recorded by platinum resistance thermometers and i-button sensors in Stevenson screen box and Thatched Shed. This was primarily due to better ventilation of the Thatched Shed while that of 8-layer shield was the least ventilated among the three different shields. The mean absolute difference and the maximum difference between i-button sensor in 8-layer shield and a conventional setup of platinum resistance thermometer in Stevenson screen box were around 0.4℃ and 1.3℃ respectively. The above comparison results provide useful benchmarking reference when assessing the accuracy of temperatures recorded by the i-button network.

3. Observations

The distribution pattern of temperatures as measured by the i-button network depends primarily on a number of factors including solar radiation (function of SVF), ventilation conditions over the Kowloon peninsula (functions of wind strength and building topography) and anthropogenic heat sources such as air-conditioners and traffic over the region. In particular, shading effect and air ventilation are two major components controlled by the urban morphology that can influence microclimate (Peng et al., 2017). A number of interesting hot episodes in the period of May – July 2017 under different weather scenarios are described below.

3.1 Easterly and westerly wind regimes

On 11 May 2017, light to moderate easterlies prevailed over the Kowloon peninsula (Figure 5) but winds turned to generally westerlies the next day (Figure 6). The HKO's Star Ferry wind station situated at the southern tip of the Kowloon peninsula (see Figure 1 for its location) with good exposure to winds from the east and the west well indicated the above change of wind regimes. Under easterlies, temperatures over the eastern flank of the Kowloon peninsula were relatively lower due to better ventilation and a lack of apparent heat sources upstream while temperatures at HKO and A3 stations were relatively higher (Figure 7). The distribution pattern reversed and relatively lower temperatures were recorded at HKO and A3 stations when generally westerlies prevailed over the Kowloon peninsula on 12 May 2017 (Figure 8). In both cases, an area of high temperatures could be located to the southwest of HKO.

As HKO is almost situated at the central position of the Kowloon peninsula, a comparison of temperatures recorded at stations locating to the east (T3, T4) and west (A3) of HKO based on the case of 11-12 May 2017 was conducted to identify the ventilation capability of easterly and westerly winds over the region near HKO (Figure 9). It was noted that when easterlies prevailed on 11 May 2017, i-button temperatures recorded at HKO, A3 and T4 were higher than those at seaside stations T3 and T17 by roughly about 2-3℃. When westerly winds prevailed the next day, i-button temperatures recorded at T4 and even T3 seaside station were higher than those at HKO by roughly around 0.5-1℃. The wind station at HKO near the i-button sensor with wind sensor height of around 1.3 m above ground recorded a daily mean wind speed of about 0.1 m/s on 11 May 2017 and it was six times higher (0.6 m/s) on 12 May 2017 (lower panel in Figure 9), showing higher wind strengthen at HKO for winds from the west. The above results suggested that under easterlies on 11 May 2017, the buildings to the east of HKO might cause blocking or introduce artificial heat sources that raised not only the temperatures at HKO but also the A3 station which was around 300 m west-southwest of HKO (Figure 10). Under westerlies on 12 May 2017, HKO experienced less influence by urban heat sources and probably better ventilation due to green areas to the west of HKO so that lower temperatures were recorded there compared with those recorded at stations on its eastern side.

A similar case with apparent temperature difference over the eastern and western sides of the Kowloon peninsula occurred in the period of 28-30 July 2017 (Figure 11). Winds over the Victoria Harbour just to the south of the Kowloon peninsula were generally easterlies on 28 July 2017 but gradually backed to the west and northwest on 29 July 2017 and further to the southwest later on 30 July 2017. The daily mean wind speeds recorded by the wind station at HKO near the i-button sensor on the 3-day period of 28-30 July 2017 were 0.1 m/s, 0.6 m/s and 0.8 m/s respectively (lower panel in Figure 11), indicating again higher wind strength at HKO for winds from the west. With winds from the east and due to building effect, temperatures at HKO, T4 and A3 were relatively higher than those at T3 seaside station by about 3-4℃. With less influence by urban heat sources and probably better ventilation, temperatures at HKO and A3 fell by 2-3℃ on 29-30 July when winds changed to westerlies.

3.2 Roadside stations

The three roadside stations T9, T7, T8 with SVF of 0.38, 0.27, 0.12 respectively are located in a north-south orientated Nathan Road which is a major road with busy traffic over the Kowloon peninsula. In the period of 5-11 June 2017 when winds over the Kowloon peninsula were generally from the south to southeast, it was observed that temperatures recorded at station T7 were systematically higher than those at T8 and T9 (Figure 12). The lower temperatures at T8 might be explained by the shading effects of nearby tall buildings as it had a lower SVF. Also, with T8 locating closer to the seaside, it might be better ventilated than T7 and T9 under south to southeasterlies. The reason why T7 having a lower SVF but yet higher temperatures were recorded there than those at T8 and T9 might be attributed to more traffic flow at T7 as it was located near an intersection point of two main roads with busy traffic.

3.3 Hilltop stations

The three hilltop stations are KP, T26 and T28 with heights of around 67m, 71m and 76m above the mean sea level (msl) respectively (Appendix 1). In the period of 25-26 July 2017 when winds over the Kowloon peninsula were generally from the east, temperatures at KP were higher than those at T26 and T28 (Figure 13) although the three stations were all quite exposed (SVF ≥ 0.6). Under easterlies, KP was situated at a more downstream location compared with T26 and T28 so that the influence of heat sources upstream and probably lower ventilation were expected at KP. These might be the causes of higher temperatures at KP.

On 29-30 July 2017, local winds were generally westerlies with the presence of haze. There was a weak inversion in the lower atmosphere near 100 m [Figure 14 (a)]. The visibility over the Victoria Harbour just south of the Kowloon peninsula once fell below 5,000 m in this 2-day period [Figure 14 (b)]. Temperatures at hilltop sites including KP, T26 and T28 had similar variations in these two days, suggesting a rather homogeneous layer of air near the surface with not apparent regional temperature differences.

4. Discussion

The east-west street canyons are significant wind corridors over the Kowloon peninsula (Peng et. al, 2017) as there are mountains to the north and south of the peninsula. The observations as described in Section 3.1 above show that when easterlies prevail, temperatures at HKO and stations to the west of HKO are relatively higher. On the contrary when westerlies prevail, HKO experiences less influence of urban heat sources upstream and probably better ventilation compared with those stations to its east including the seaside station. As a result, relatively lower temperatures are recorded at HKO and A3. Under weak easterlies, it is interesting to note that the buildings to the east of HKO causes higher temperatures at HKO and also A3 station which is located around 300 m further to the west.

For roadside stations, it is reasonable that higher temperatures are recorded there because of the busy traffic. Among the three roadside stations along the Nathan Road, the comparison of temperatures between T7, T8 and T9 suggests that heat sources from nearby vehicles may be an important factor.

For the three hilltop sites with similar heights, the station recording lower temperatures seems to be the one that is located upstream of the wind flow and hence less susceptible to the influence of urban heat sources and probably better ventilation. Under easterlies, higher temperatures are recorded at the King's Park station. This might be explained by longer distance of around 2 km from the seaside to the east and probably reduced wind flow due to more building blockage. For stable meteorological conditions and the build-up of haze near the surface, temperatures recorded at the hilltop sites are close to each other.

5. Future work

To have better understanding of the urban climate, Computational Fluid Dynamic (CFD) models may be utilized to study the ventilation conditions over the Kowloon peninsula under different weather scenarios. Furthermore, remote sensing technology such as the use of thermal weather cameras can be applied to acquire a finer resolution of the heat distribution over the Kowloon peninsula. This should help evaluate the areal extent of urban heat island.

Since i-button is a passive sensor, real-time temperature data transmission is not feasible. This can be enhanced by devising a new set of equipment such as Arduino-based automatic weather station or other smart weather sensors making use of the Internet-of-things technology so that real-time temperature measurements can be sent via wireless communication means back to

HKOHq for prompt analysis. This also ties in with the growing emphasis on smart city development where urban weather and environmental information can be made readily available for various research and operational applications.

6. Conclusion

The i-button temperature network provided valuable data set for studying the urban micro-climate. Due to the natural topography and urban morphology in Hong Kong, the east-west orientated wind corridor is a major characteristic affecting the ventilation conditions over the Kowloon peninsula. The present study has identified several scenarios that the temperature distribution over the Kowloon peninsula would be quite the opposite with different wind flow patterns, in particular easterlies and westerlies. Under easterlies, temperatures over the eastern flank of the peninsula were lower due to lack of apparent heat sources upstream and probably better ventilation but higher temperatures were recorded downstream. Under westerlies, the temperature distribution pattern is basically reversed. For roadside stations, traffic flow is an important factor affecting the rise of temperatures. For hilltop sites, lower temperatures are recorded if the site is located on an upstream position with respect to the prevailing wind direction.

7. Acknowledgements

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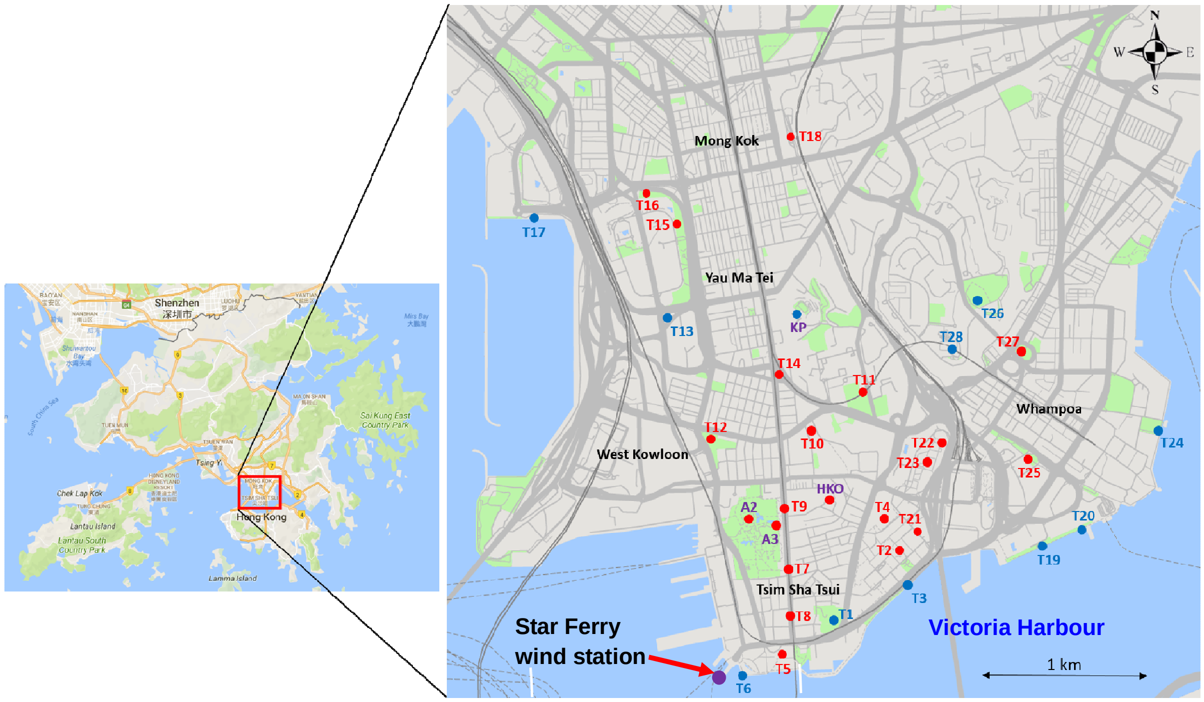


Figure 1 i-button temperature observation network over the Kowloon peninsula. Sites with good exposure (sky view factor, SVF > 0.5) are shown in blue dots. Sites with SVF ≤ 0.5 are shown in red dots. HKO and KP represent stations at Hong Kong Observatory Headquarters and King's Park Meteorological Station respectively. Those sites with station names highlighted in purple including HKO, KP, A2 and A3 are "Controlled Stations" where i-button sensors in 8-layer shield and platinum resistance thermometers in Stevenson screen box are installed at those sites.

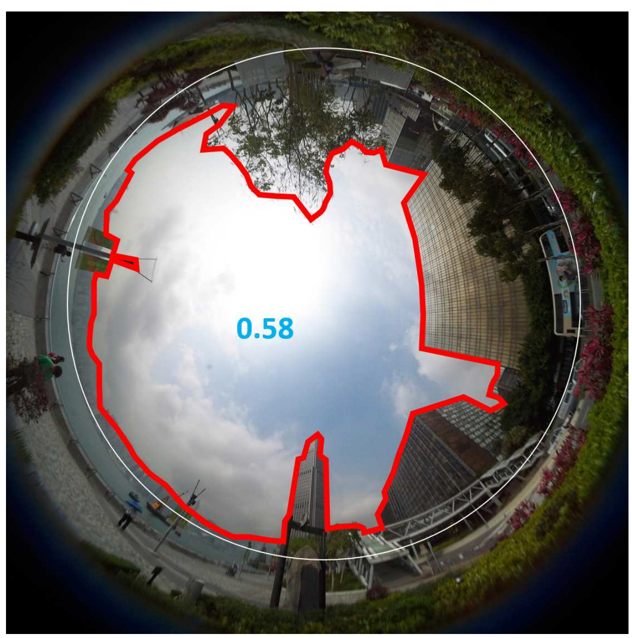


Figure 2 Sky View Factor (SVF) is determined by estimating the amount of unobstructed sky (ratio between the area within the red line boundary and the whole hemispheric plane, which is around 0.58 for the measuring site shown in the figure) of the surrounding environment.

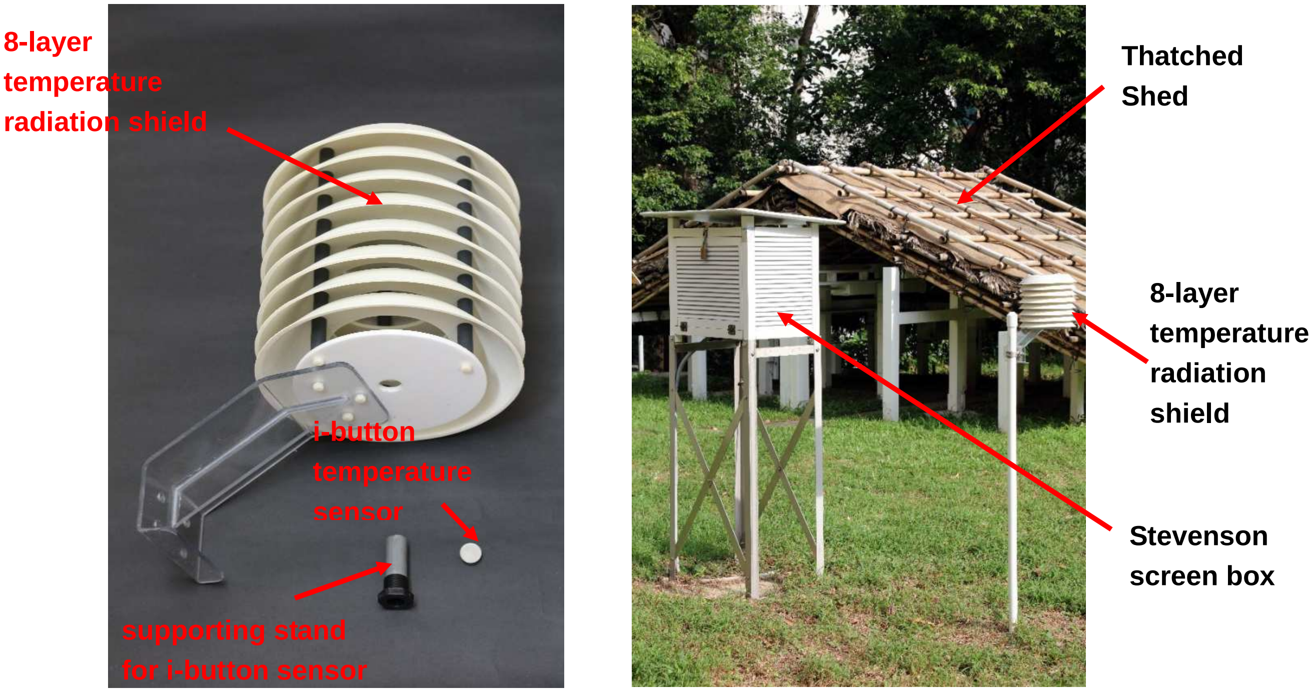


Figure 3 i-button temperature sensor and the 8-layer temperature radiation shield (left panel). The station at the Hong Kong Observatory Headquarters where temperature measurements made by i-button sensors installed inside 8-layer radiation shield, Stevenson screen box and Thatched Shed as well as platinum resistance thermometers installed inside Stevenson screen box and Thatched Shed (right panel).

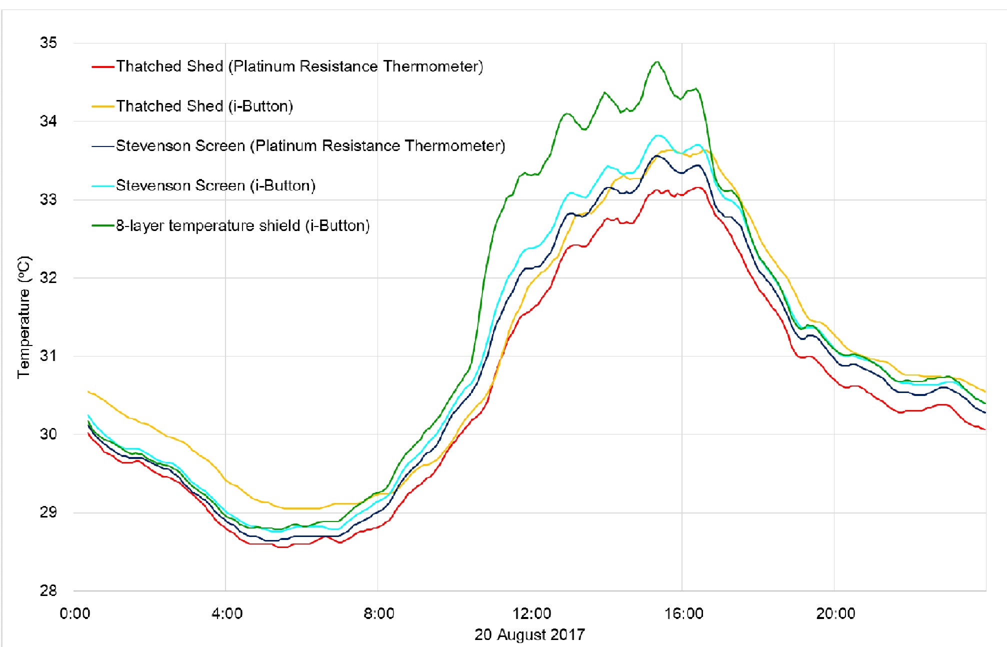


Figure 4 Comparison of temperatures measured by i-button sensors and platinum resistance thermometers placed inside 8-layer radiation shield, Stevenson screen box and Thatched Shed.

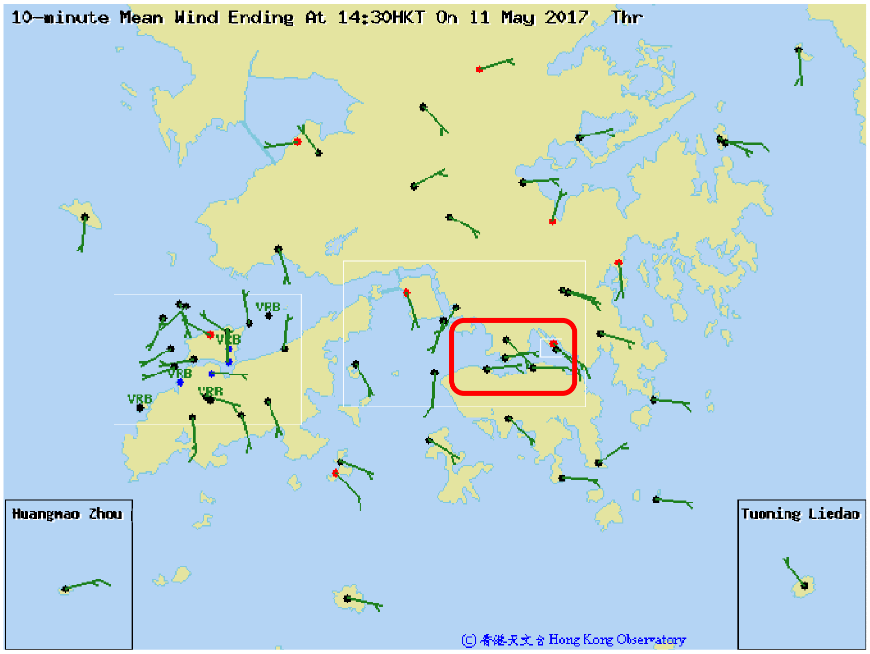


Figure 5 The wind flow conditions over Hong Kong at 2:30 p.m. on 11 May 2017 with easterlies generally prevailing over the Kowloon peninsula (red rectangle).

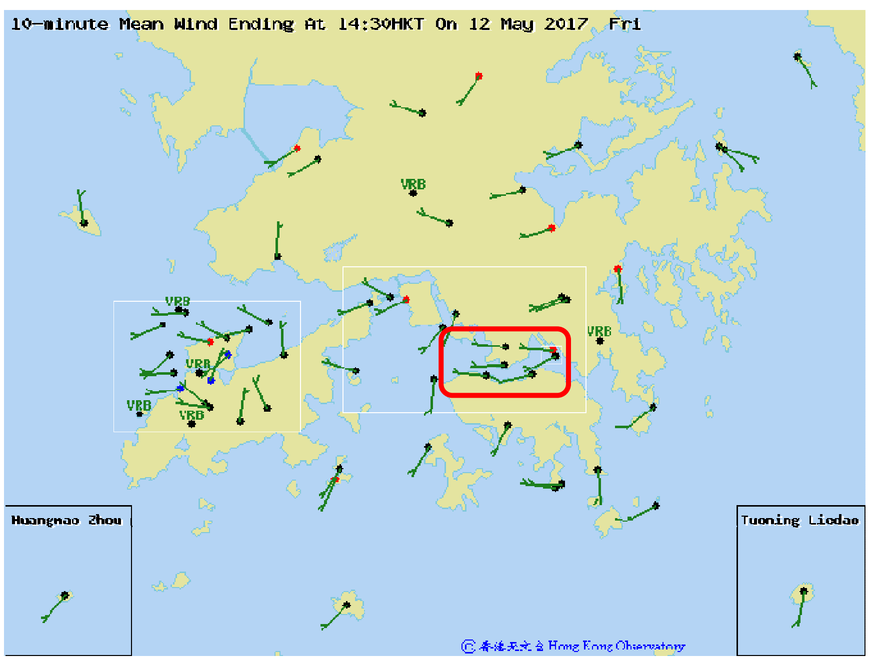


Figure 6 The wind flow conditions over Hong Kong at 2:30 p.m. on 12 May 2017 with westerlies generally prevailing over the Kowloon peninsula (red rectangle).

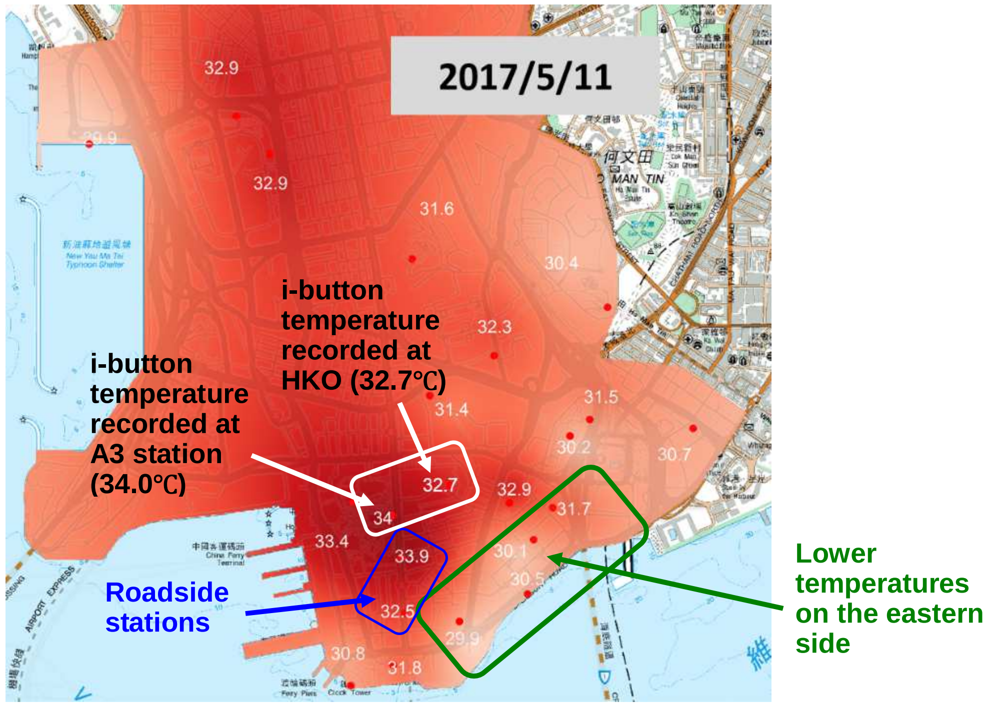


Figure 7 Temperature distribution over the Kowloon peninsula at 2:30 p.m. on 11 May 2017.

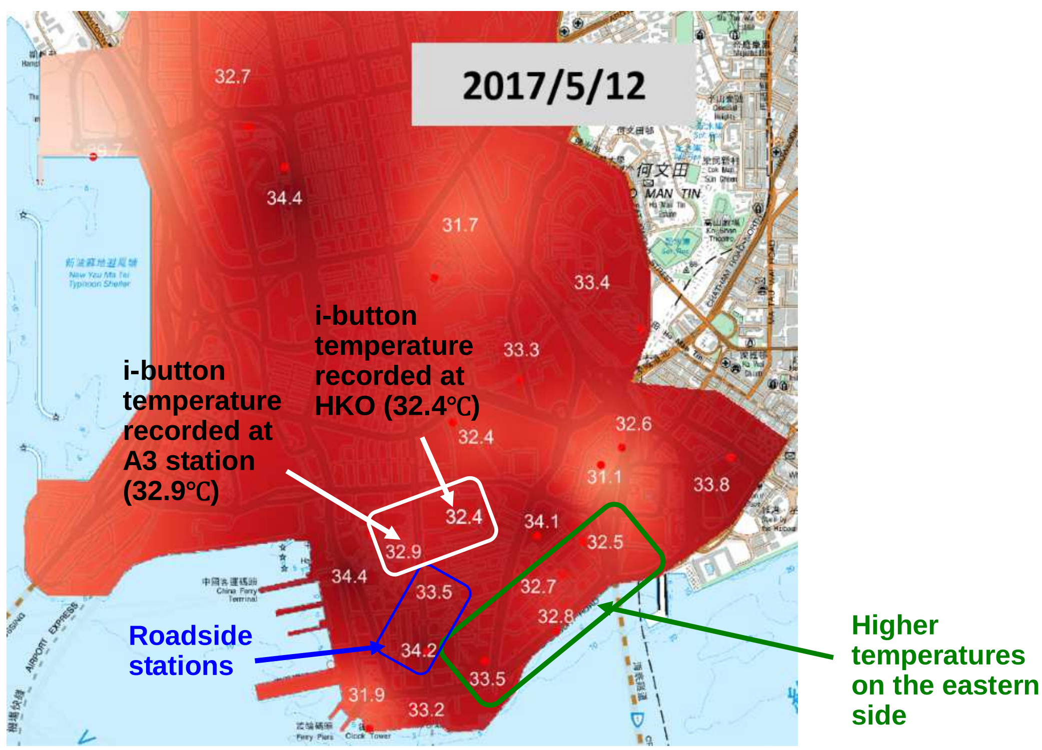


Figure 8 Temperature distribution over the Kowloon peninsula at 2:30 p.m. on 12 May 2017.

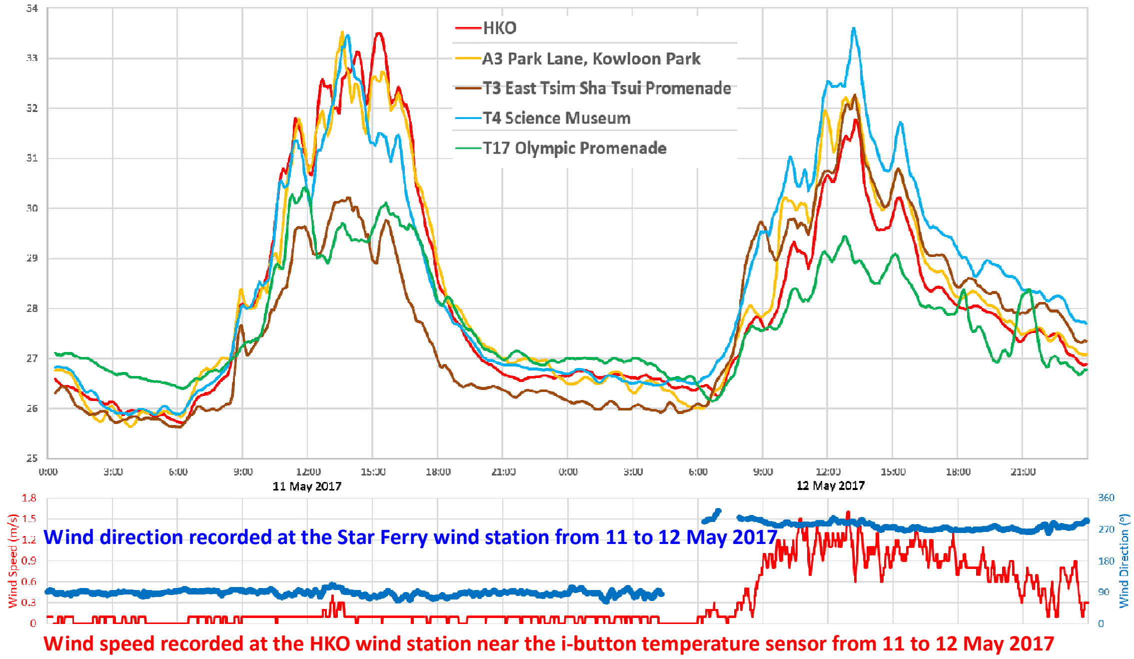


Figure 9 Time series of temperatures recorded at HKO, A3, T3, T4 and T17 stations on 11 and 12 May 2017 (upper panel). Times series of wind direction recorded at the Star Ferry wind station (blue line) and wind speed recorded at the HKO wind station* (red line) on 11 and 12 May 2017 (lower panel) **Sensor height around 1.3 m above ground*.

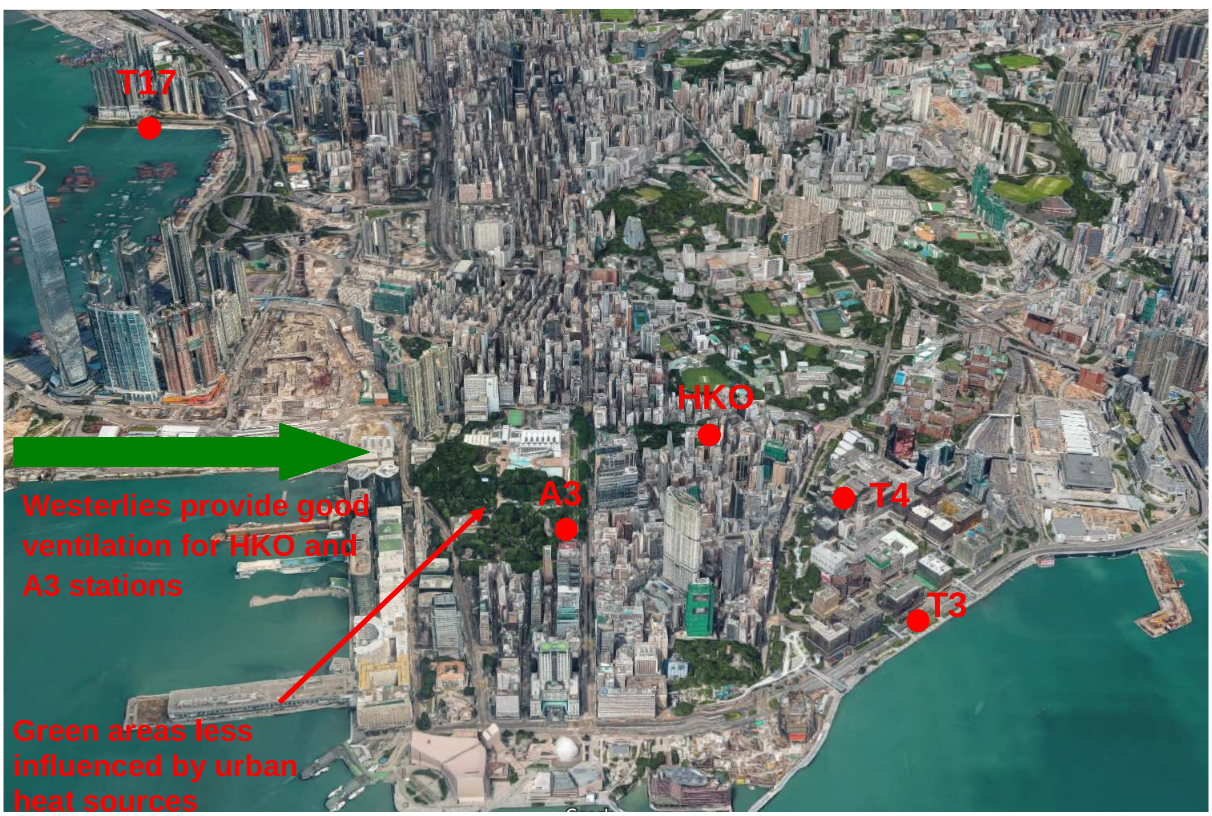


Figure 10 Google map showing the locations of the HKO, A3, T3, T4 and T17 stations. With respect to HKO, the green areas to the west of HKO are less influenced by urban heat sources and provide better ventilation when westerlies prevail (green arrow).

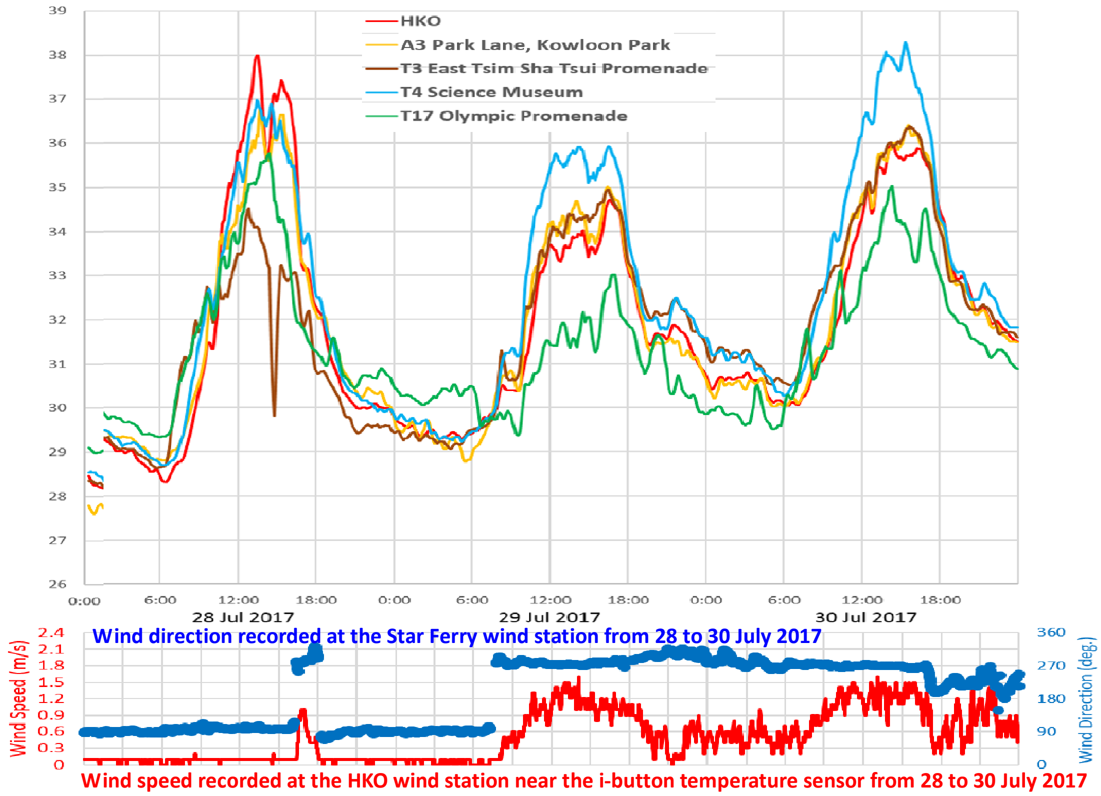


Figure 11 Time series of temperatures recorded at HKO, A3, T3, T4 and T17 stations from 28 to 30 July 2017 (upper panel). Times series of wind direction recorded at the Star Ferry wind station (blue line) and wind speed recorded at the HKO wind station* (red line) from 28 to 30 July 2017 (lower panel) **Sensor height around 1.3 m above ground*.

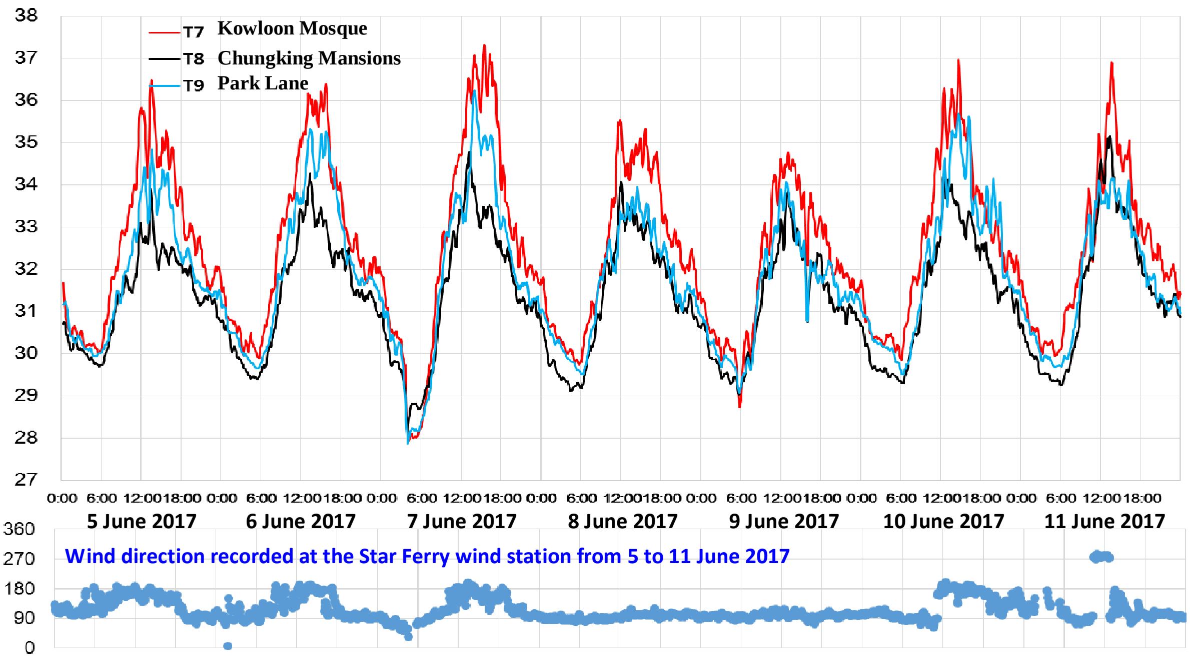


Figure 12 Time series of temperatures recorded at T7, T8 and T9 stations from 5 to 11 June 2017 (upper panel). Times series of wind direction recorded at the Star Ferry wind station from 5 to 11 June 2017 (lower panel).

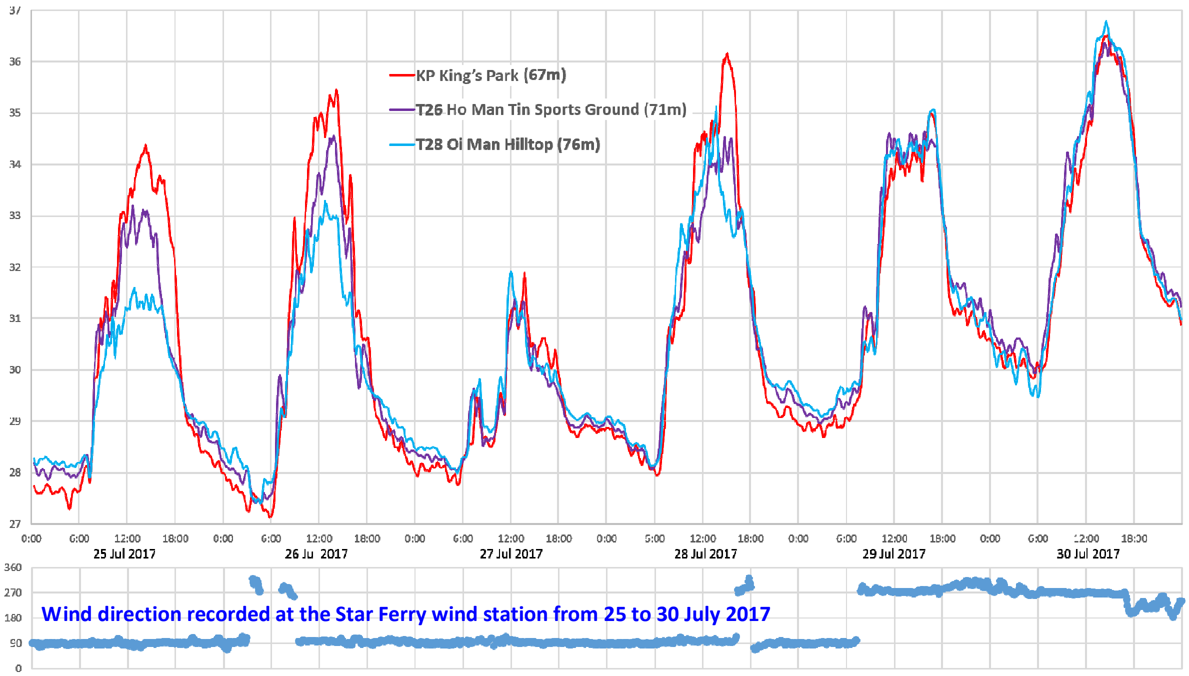
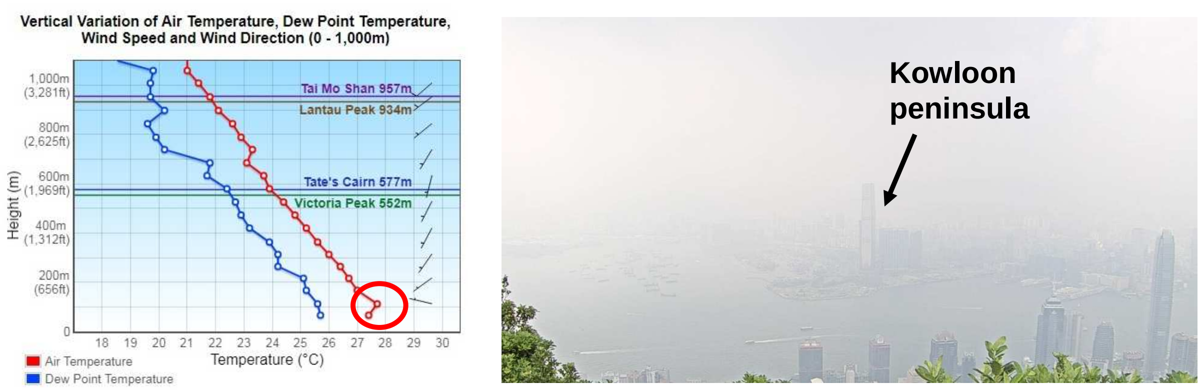


Figure 13 Time series of temperatures recorded at KP, T26 and T28 stations from 25 to 30 July 2017 (upper panel) [station heights are shown in brackets]. Times series of wind direction recorded at the Star Ferry wind station from 25 to 30 July 2017 (lower panel).



(a) (b)

Figure 14 Vertical variation of air temperature, dew point temperature and winds in the lower atmosphere (0 - 1,000 m in height) on 29 July 2017 with the red circle showing a weak inversion near 100 m (left panel). Weather photo taken from Victoria Peak (looking towards the north-northeast) at 2:30 p.m. on 29 July 2017 showing hazy conditions over the Kowloon peninsula (right panel).

List of i-button temperature stations

Station Code	Station Name (latitude and longitude of temperature station in brackets)	Station Height	WMO Site Classification		Sky View Factor (SVF)
			Heat Source	Projected Shade	
HKO	HKO Headquarters *(22°18'07" 114°10'27")*	33 m	3	5	0.31
A2	Kowloon Park Central *(22°18'03" 114°10'11")*	27 m	2	4	0.46
A3	Park Lane, Kowloon Park *(22°18'02" 114°10'17")*	19 m	4	5	0.46
KP	King's Park Meteorological Station *(22°18'43" 114°10'22")*	67 m	1	1	0.61
T1	Signal Hill Garden *(22°17'45" 114°10'29")*	37 m	2	5	0.50
T2	East Tsim Sha Tsui Centenary Garden *(22°17'58" 114°10'41")*	6 m	4	5	0.27
T3	East Tsim Sha Tsui Promenade *(22°17'49" 114°10'41")*	6 m	3	4	0.58
T4	Science Museum *(22°18'03" 114°10'37")*	11 m	4	4	0.45
T5	Space Museum *(22°17'38" 114°10'17")*	6 m	5	5	0.34
T6	Cultural Centre *(22°17'35" 114°10'10")*	10 m	2	4	0.73
T7	Nathan Road near Kowloon Mosque *(22°17'53" 114°10'19")*	9 m	5	5	0.27
T8	Nathan Road near Chungking Mansions *(22°17'46" 114°10'20")*	6 m	5	5	0.12
T9	Nathan Road near Park Lane *(22°18'05" 114°10'18")*	11 m	5	5	0.38
T10	Kowloon Cricket Club *(22°18'20" 114°10'24")*	10 m	2	4	0.38
T11	Club de Recreio *(22°18'27" 114°10'35")*	11 m	3	4	0.49
T12	Koon Chung King George V Memorial Park *(22°18'19" 114°10'03")*	8 m	2	4	0.33
T13	Junction Road *(22°18'41" 114°09' 54")*	6 m	3	2	0.58
T14	Gascoigne Road/Nathan Road Garden *(22°18'31" 114°10'17")*	9 m	4	5	0.32
T15	Cherry Street Park Tennis Court *(22°18'58" 114°09'57")*	7 m	3	4	0.48
T16	Cherry Street Park North *(22°19'05" 114°09'50")*	6 m	3	4	0.39
T17	Olympic Promenade *(22°19'00" 114°09'26")*	6 m	2	2	0.56
T18	Luen Wan Street outside Mong Kok East Station *(22°19'16" 114°10'19")*	14 m	5	5	0.39
T19	Tsim Sha Tsui Promenade *(22°17'59" 114°11'11")*	6 m	2	4	0.63
T20	Hung Hom Pier Promenade *(22°18'02" 114°11'19")*	6 m	3	4	0.51
T21	Hong Tat Path Garden *(22°18'03" 114°10'45")*	7 m	4	5	0.23
T22	Core T Podium of Polytechnic University *(22°18'17" 114°10'51")*	15 m	5	5	0.47
T23	Lawn inside Polytechnic University *(22°18'14" 114°10'48")*	6.0m	4	5	0.17
T24	Tai Wan Shan *(22°18'20" 114°11'35")*	5.3m	4	4	0.60
T25	Hung Lai Road *(22°18'15" 114°11'09")*	5.2m	5	5	0.27
T26	Ho Man Tin Sports Ground *(22°18'44" 114°10'57")*	71 m	2	4	0.60
T27	Fat Kwong Street Garden No.1 *(22°18'35" 114°11'07")*	20 m	2	3	0.35
T28	Oi Man Hilltop (*22°18'35" 114°10'54")*	76 m	1	2	0.77