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ORIGINAL PAPER

# The development of the Hong Kong Heat Index for enhancing the heat stress information service of the Hong Kong Observatory

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**Abstract** This paper presents a study to develop a heat index, for use in hot and humid sub-tropical climate in Hong Kong. The study made use of hospitalization data and heat stress measurement data in Hong Kong from 2007 to 2011. The heat index, which is called Hong Kong Heat Index (HKHI), is calculated from the natural wet bulb temperature, the globe temperature, and the dry bulb temperature together with a set of coefficients applicable to the high humidity condition in the summer of Hong Kong. Analysis of the response of hospitalization rate to variation in HKHI and two other heat indices, namely Wet Bulb Globe Temperature (WBGT) and Net Effective Temperature (NET), revealed that HKHI performed generally better than WBGT and NET in reflecting the heat stress impact on excess hospitalization ratio in Hong Kong. Based on the study results, two reference criteria of HKHI were identified to establish a two-tier approach for the enhancement of the heat stress information service in Hong Kong.

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**Keywords** Heat stress · Heat index · Hot · Hospitalization · Wet bulb globe temperature

## Introduction

It has been well known that climate conditions can have tremendous impact on public health. Previous studies suggest that thermal stress under cold and hot weather conditions is strongly linked with higher mortality and hospitalization rates in Hong Kong, particularly among the elderly (Yip et al. 2007; Mok and Leung 2009; Goggins et al. 2013; Chan et al. 2013; Wong et al. 2014). For "heat stress," it refers to the effect of heat that would generate pressure or discomfort on the human body. Generally speaking, metabolism in the human body continuously generates heat energy which is lost through direct radiation, air conduction, and sweating. When the body carries out physical work, more heat energy will be generated internally. To maintain a healthy body temperature, the excessive heat needs to be transferred to external environment by sweating more to increase heat loss by evaporation through the skin. If the heat energy cannot be dissipated in time, the body temperature will continue to rise until the body temperature reaching a level which may trigger heatstroke become life-threatening (Kjellstrom et al. 2009). The four main meteorological factors which affect the "heat stress" perceived by humans are air temperature, relative humidity, wind speed, and solar radiation. High temperature would make it difficult for the body to lose heat by direction radiation. The higher the relative humidity, the more difficult it will be for heat loss by sweating. Low wind speed or calm wind condition would reduce evaporation of sweat and heat removal from the skin. Under direct sunshine, the solar radiation increases heat gain and body temperature would rise. When working or engaging in activities in outdoor environment, the heat stress results from the background temperature and humidity will be modulated or enhanced by short-term variations of the wind speed and solar radiation depending very much on the immediate surroundings and changes in the cloud amount. As such, in addition to commonly used air temperature and humidity, a heat index which also takes into account the effect of solar radiation and air movement will be useful in assessing the heat stress experienced by individuals engaging in outdoor activities, especially those who may not be able to remove themselves from the thermally uncomfortable environment, for example, because of sports activity, military or industrial discipline, etc.

In Hong Kong, with a sub-tropical climate, it is hot and humid in summer with afternoon temperature often exceeding 31 °C. There are on average about 10 very hot days in a year with the daily maximum temperature reaching 33 °C or above (HKO 2014). Under the combined effect of global warming and local urbanization, there is also a long-term increasing trend in the mean temperature and the annual number of very hot days in Hong Kong. Moreover, the dense urban development in Hong Kong also resulted in a significant long-term decrease in the local wind speed in the last few decades (Wong et al. 2011; Ginn et al. 2010; Chan et al. 2012a). The hot and humid summer conditions together with decreasing ventilation in some of the urban areas may have significant heat-related health impacts to the public, especially for the elderly, people with chronic diseases, outdoor workers, and those underprivileged who live in congested and poorly ventilated environment (Lam 2006). For examples, the study by Goggins et al. (2012) suggest that high mean temperatures and low mean wind speeds were significantly associated with higher daily mortality, especially in high urban heat island index regions of Hong Kong. The study by Chan et al. (2011) reveal that the frequency of health-related help-seeking calls by elderly started to increase when daily maximum temperature and daily mean relative humidity were greater than around 30–32 °C and 70–74 %, respectively. Regarding outdoor workers, Yi and Chan (2014a) have examined the impacts of heat stress on the construction workers in Hong Kong and suggest approaches to optimize the work pattern of them with different start and finish times to minimize the occurrence of heat stress on construction site. Looking ahead, extreme temperature projection in Hong Kong further suggests that the number of very hot days in Hong Kong is expected to increase significantly in the twenty-first century (Lee et al. 2011). A warmer climate with more extreme high temperature events in the future summers will likely further increase outdoor heat load and impair public health and productivity (Kjellstrom et al. 2009; Zander et al. 2015).

From public health point of view, an early warning system on heat stress should be in place to provide clear and understandable information to enhance the proper community responses to heat stress. In this regard, heat health warning systems have been developed in a number of countries and places to alert decision-makers and the general public to impending dangerous hot weather and for the implementation of a range of actions and measures to reduce the effects of hot-weather extremes on health. The definition of extreme heat and related health impact varies from one place to another and there is no absolute universal threshold of the heat health warning systems. Also, many local factors, such as demographic and socioeconomic characteristics, may also influence individual's ability to accommodate heat stress. As such, heat health warning systems are usually developed at the local/regional level based on data availability, human and technical resources, and local specific heat–health associations. Moreover, various types of heat or thermal comfort indices, ranging from simple biometeorological indices to complex human heat-budget models, have been adopted by different meteorological services to assess the heat stress. The heat index and the local health data are usually used to identify threshold values beyond which the effects of heat on health increase rapidly. Such threshold values are often used as a basis for issuing heat-related advisories or warnings to the public (WMO and WHO 2015).

In Hong Kong, the Hong Kong Observatory (HKO) had been issuing Very Hot Weather Warning (VHWW) to alert the public of the risk of heatstroke and sunburn due to very hot weather in Hong Kong since 2000 (HKO 2015). With a simple on/off mechanism, the VHWW has in general gained wide public acceptance and understanding in Hong Kong. It is also adopted as a criterion for opening of temporary heat shelters for needed people, exemption of motor vehicle idling as well as the conduction of some activities in the community. To assist in the forecast operation of the VHWW, Li and Chan (2000) developed a weather stress index (WSI) through the use of net effective temperature (NET), an index taking into account the effect of air temperature, wind speed, and relative humidity on human. By taking into account WSI (when it reaches or is expected to be higher than 97.5 %) and the forecast regional dry bulb temperature distribution, issuance of VHWW will be considered.

In 2007, a set of equipment developed by the HKO for automatic measurement of dry bulb temperature (**Ta**), natural wet bulb temperature (**Tnw**), and globe temperature (**Tg**) was installed at the King's Park (KP) (see location in Fig. 1). **Ta** is the ordinary air temperature measured by a thermometer shielded from direct sunshine. It is the standard temperature normally quoted in weather observations and forecasts. **Tnw** is measured by a thermometer covered with a wetted wick and exposed to sunshine. As the natural wet-bulb thermometer is not shielded, it thus represents the integrated effect of air temperature, humidity, wind, and solar radiation. **Tg** is the temperature measured by a thermometer installed inside a black hollow globe made of copper. The black globe, like the natural

**Fig. 1** Location of stations with heat stress measurement in Hong Kong


wet-bulb thermometer, is not shielded and thus it represents the integrated effects of air temperature, wind, and solar radiation. The **Ta**, **Tnw**, and **Tg** measurements together have the advantage of being a set of directly measurable parameters without the need of complex calculations from different weather elements. These are also considered as more representative in heat stress assessment than air temperature alone since the three parameters take account of air temperature, humidity, wind, and solar radiation (Willett and Sherwood 2012). Figure 2 shows the set up of the three thermometers of the heat stress measurement developed by the HKO. Subsequently, heat stress measurement equipment was set up in Sha Tin (SHA), Beas River (BR2), HKO Headquarters, and Kau Sai Chau (KSC). Figure 1 shows the locations of the five stations with heat stress measurement in Hong Kong. The **Ta**, **Tnw**, and **Tg** data collected by these thermometers were used in the research and development of a heat index suitable for the climate and environment of Hong Kong, with a view to enhancing HKO's services related to the hot weather.

One of the widely used heat indices derived from the **Ta**, **Tnw**, and **Tg** data is the Wet Bulb Globe Temperature (WBGT) which is defined as weighted average of **Ta**, **Tnw**, and **Tg** according to the equation below (Yaglou and Minard 1957; ISO 1989):

$$\mathrm{WBGT} = 0.7 \times \mathbf{Tnw} + 0.2 \times \mathbf{Tg} + 0.1 \times \mathbf{Ta} \qquad (1)$$

In the last few years, the **Ta**, **Tnw**, and **Tg** data measured at various stations in Hong Kong were adopted to compute WBGT for heat stress assessment in major outdoor events in Hong Kong, including the 2008 Olympics Equestrian Events and the 2012 Hong Kong Marathon (Wong and Lee 2008; Jeffcott et al. 2009). Moreover, some organizations, including the Hong Kong Sports Institute and the Kau Sai Chau Golf Course, also make reference to onsite measured WBGT in planning their activities. Nevertheless, the WBGT stated in Eq. (1) above was empirically developed by Yaglou and Minard (1956) as a practical heat index to substitute the effective temperature with solar radiation component taking into account. The weighting coefficient of the WBGT components was obtained based on the climate of the US Army and Marine Crops training camps in North America and the olive drab shades clothing of the soldiers. The applicability of the WBGT and relevant tolerance limits identified may vary significantly from place to place due to acclimatization, environment, clothing, activity, and population. Its effectiveness and validity in environment of high humidity, which is not uncommon in Hong Kong, have been challenged in some of the literature (Macpherson 1960; Minard 1964; Ramanathan and Belding 1973; Claassen and Kok 2007; Budd 2008). In particular, Budd (2008) highlighted the limitation of WBGT in reflecting the heat strain in case of high humidity and low air movements which is a main characteristic of urban climate in Hong Kong. Hence, to better represent the heat stress scenarios in Hong Kong, it is important to study the optimal combination of coefficients **Ta**, **Tnw**, and **Tg** based on the local specific heat–health associations for developing a heat index suitable for Hong Kong (Kuwabara et al. 2007).

While the simple one-tier, on/off mechanism of VHWW is effective and easy to understand, there has been growing expectation from the public for more heat stress information, in particular when the weather is rather hot, but not quite meeting the criteria for issuing the VHWW. Therefore, to further enhance the heat stress information service of Hong Kong, it is desirable to introduce a two-tier approach with a special

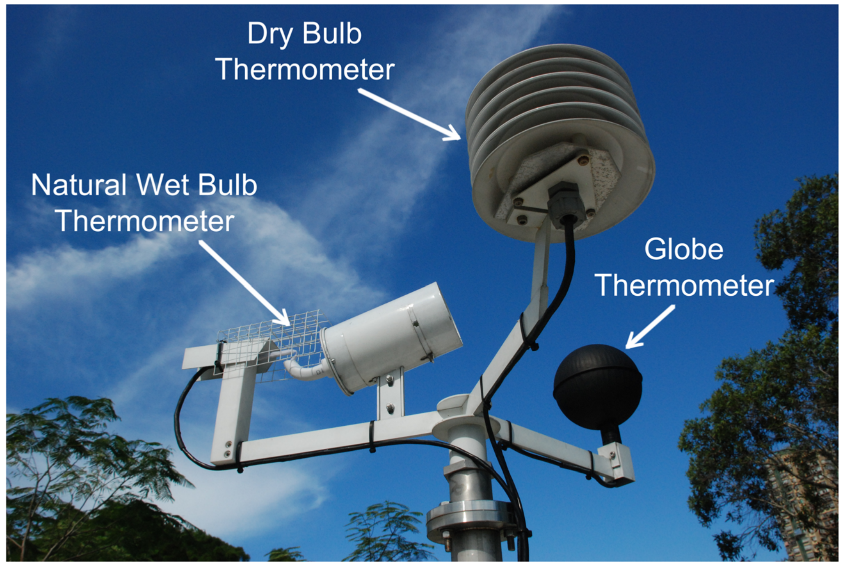



**Fig. 2** Heat stress measurement equipment developed by the Hong Kong Observatory

advisory for hot weather and a VHWW for very hot weather, so that the public can take due attention and timely precautions to prevent negative impacts from heat stress.

Different from the previous approach which mainly uses the extreme 2.5 % (97.5 percentile) of NET as the reference level, this study examined the change of hospitalization rate due to heat strain in response to **Ta**, **Tnw**, and **Tg** of Hong Kong to determine a new set of coefficients for **Ta**, **Tnw**, and **Tg** and to formulate the Hong Kong Heat Index (HKHI) which is optimal for Hong Kong climate. The public health response to HKHI was then analyzed to identify the two-tier reference criteria of HKHI for the issuance of special advisory of hot weather and VHWW, respectively.

## Data and analysis methods

The **Ta**, **Tnw**, and **Tg** data and the hospitalization data in Hong Kong during the period 2007–2011 were used in the study. The **Ta**, **Tnw**, and **Tg** data were obtained from the measurement at KP. The data at KP was used as KP is located very much at the center of Hong Kong and the temperature data there has very high correlations with measurements from the other four locations (see discussion in "Results and discussion" section). In Hong Kong, since about 99 % of the very hot days (daily maximum temperature at HKO headquarters ≥33.0 °C) occurred between May and September, the data obtained in these 5 months of the year were analyzed in this study. Moreover, 10-min running mean values of the temperature data were used in this study to avoid (i) transient jumpiness of shorter-term mean values, e.g., 1-min mean, and (ii) long time lag of longer-term mean, e.g., 1-h mean. This should in general strike a good balance between the two ends and better represent the heat stress experienced at the instance.

For hospitalization data, the Hospital Authority of Hong Kong maintains a citywide hospital database that covers all admissions to public hospitals, which represent 83 % of all admissions (Chan et al. 2013). Since this study is related to health effect due to heat stress, the hospitalization data were scrutinized to remove those due to accidental causes. From this database, data on routine hospital admissions was extracted by the following causes of hospitalization, as coded in the International statistical classification of diseases and related health problems, ninth revision (WHO 1978): all non-accidental hospitalization, all codes except 800–999; infectious diseases, codes 001–139, 320–323, and 614–616; cardiovascular diseases, codes 390–459; and respiratory diseases, codes 460–519. The non-accidental hospitalization data was then categorized into five age groups, namely (a) all ages; (b) children under 15; (c) adults aged between 15 and 59; (e) aged between 60 and 74; and (e) aged 75 or above.

From the time series of the daily hospitalization rate for all age groups in Fig. 3, there are notable year-to-year variations as well as clustering of hospitalization data in working days, Saturdays, Sundays, and public holidays. Such variations and clusters are likely due to various socio-economic factors which are not the focus of this study. In order to investigate the effect of heat stress on hospitalization rate, this study separately analyzed the heat stress data and hospitalization data for various day groups: (a) working days; (b) Saturdays; (c) Sundays; and (d) public holidays in each year. The data for each day group were then separately normalized to remove the annual variation and clustering effects and to compute the excess hospitalization ratio as described below. In each year and for each day group, the daily hospitalization rate corresponding to each percentile (in steps of 5 or 10 %, and with base period 2007–2011) of daily maximum HKHI (computation method of HKHI is described in the

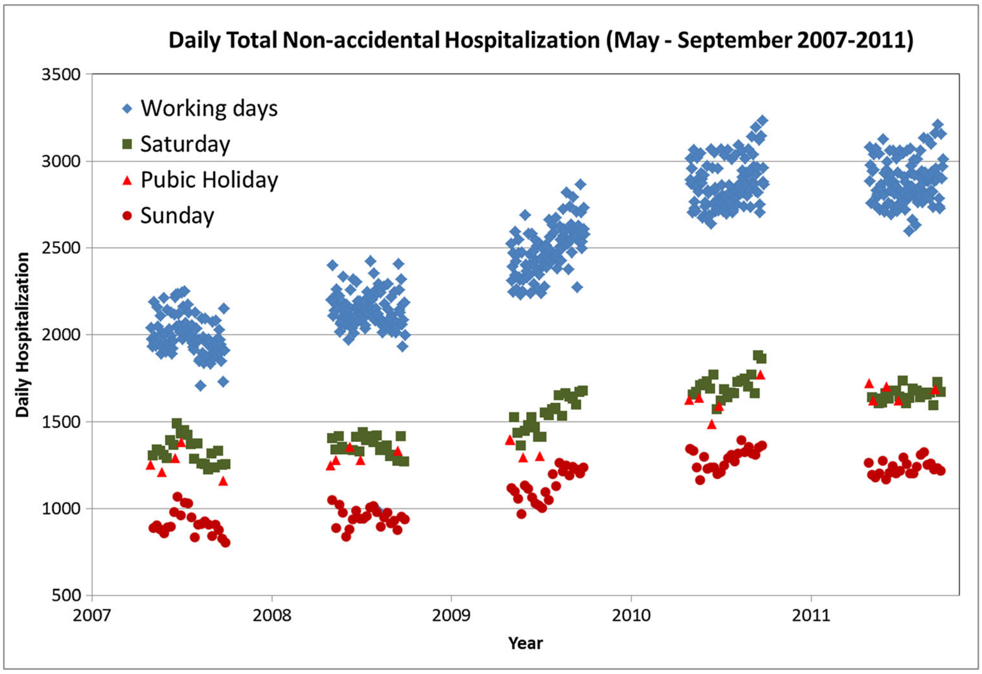



**Fig. 3** Time series of the daily hospitalization rate during May–September from 2007 to 2011

paragraph below) was first obtained. This daily hospitalization rate for that percentile was then divided by the mean hospitalization rate of the day group for that year to give the excess hospitalization ratio.

In this study, the HKHI is expressed in a form similar to that of WBGT but with a different set of coefficients for **Ta**, **Tnw**, and **Tg**:

$$\mathrm{HKHI} = a \times \mathbf{Tnw} + b \times \mathbf{Tg} + c \times \mathbf{Ta} \qquad (2)$$

With a view to identifying an optimal combination of coefficients ($a$, $b$, and $c$), all possible combinations of coefficients $a$, $b$, and $c$ (each in searching steps of 0.05 between 0 and 1) were made to calculate the respective HKHIs for each age group. The optimal HKHI equation is the one with the combination of coefficients that shows (a) the largest excess hospitalization ratio at 90th percentile; and (b) the excess hospitalization ratio demonstrating an exposure-response relationship in every age group. The excess hospitalization ratio at 90th percentile is adopted since many climate and health studies take this as a threshold in defining heat waves or extreme high temperature events (e.g., DeGaetano et al. 2002; Beniston and Diaz 2004; D'Ippoliti et al. 2010). Also, the study intends to attain an optimal index that exhibits the exposure-response relationship (i.e., exposure-response curve usually depicts the relationship between the magnitude of a physical agent (e.g., heat stress) and the corresponding risk of response (e.g., excess hospitalization ratio) from the subject) for different age groups. Moreover, previous studies suggest the association between high temperatures and mortality was acute and of short period in Hong Kong (Yi and Chan 2014b; Chan et al. 2011; Goggins et al. 2012). In this connection, we examined the effects of the current day's exposure on hospitalization rate in this study.

## Results and discussion

### New coefficients for HKHI

Based on the method described in "Data and analysis methods" section, the set of coefficients that resulted in the largest excess hospitalization ratio at 90th percentile and the excess hospitalization ratio demonstrating an exposure-response relationship in every age group were 0.8, 0.05, and 0.15 for **Tnw**, **Tg**, and **Ta**, respectively. As such, the HKHI is expressed as:

$$\mathrm{HKHI} = 0.8 \times \mathbf{Tnw} + 0.05 \times \mathbf{Tg} + 0.15 \times \mathbf{Ta}$$

According to the above equation, the unit of HKHI is degree Celsius which may sometimes be easily mixed up with that of air temperature which is commonly used in public weather forecast and misinterpreted by workers and decision makers. Such a concern was also brought up by D'Ambrosio Alfano et al. (2014) in their review of the application of WBGT in last 60 years. To avoid confusion, hereafter, the HKHI will be treated as a dimensionless index and the unit will not be presented in the rest of the paper. From the public weather forecast perspective, this simplified approach could also be adopted to help public to distinguish between HKHI and air temperature.

When compared with the expression of WBGT, the coefficient of **Tnw** in HKHI (0.8) is larger than that of WBGT (0.7). This is not surprising as Hong Kong is located in the subtropical region with relatively high humidity. This result generally agreed with other publications in emphasizing the importance of the weightings of **Tnw** to reflect the heat tolerance level (Goldman et al. 1965; Kerslake 1972; Moran et al. 1998; Kuwabara et al. 2007).

## HKHI thresholds

Table 1 lists the excess hospitalization ratios in working days for different percentiles of daily maximum HKHI for various age groups. Figure 4 shows the variation of mean excess hospitalization ratio with percentiles of daily maximum HKHI (in red), NET (in green), and WBGT (in blue). HKHI performed better than WBGT and NET in terms of excess hospitalization ratio for most age groups, exhibiting better exposure-response relationship. It is also evident that the excess hospitalization ratio rises rapidly when HKHI is above the 90th percentile (30.3). This is well in line with other climate and health studies (DeGaetano et al. 2002; Beniston and Diaz 2004; D'Ippoliti et al. 2010; Lin et al. 2012; Van Zutphen et al. 2012), which also take the 90th percentile threshold in defining heat waves or extreme high temperature events. For example, in the EU's EuroHEAT project (WHO 2007), the 90th percentile is used as the threshold for extreme heat. Hence, the 90th percentile of HKHI is considered justified to be taken as a threshold for warning the public of excessive heat stress when considering the issuance of VHWW. It was noted that, in terms of excess hospitalization ratio, the 90th percentile of HKHI generally outperformed NET which is currently one of the criteria for considering the issuance of VHWW. As the HKHI has incorporated directly or indirectly all the meteorological elements for NET, HKHI could be considered as a better reference index than NET in the operation of VHWW.

Figure 4 also shows that the excess hospitalization ratio starts to pick up its rising rate at around the 60th or 70th percentiles, corresponding to the HKHI of around 29.5. This value of HKHI can serve as a precursor of marginally very hot condition and be considered as one of the criteria for alerting the public of increasing health risk due to heat stress with a reasonable lead time before the occurrence of very hot weather. Other parameters to consider in issuing special advisory include the maximum temperatures at HKO and at other regional automatic weather stations. With the results from the above analysis, the existing heat stress information service, which consists of only the on-off mechanism of issuing VHWW, could be enhanced by adopting a two-tier approach as depicted below:

> Tier 1—issuing a Hot Weather Special Advisory for hot weather, which will be based on HKHI (with threshold of 29.5: round to the nearest multiple of 0.5 of the 70th

**Table 1** Excess hospitalization ratio in working days for different percentiles of daily maximum Hong Kong Heat Index (HKHI) for various age groups during the period May–September from 2007 to 2011

| | Excess hospitalization ratio | | | | |
|---|---|---|---|---|---|
| | All non-accidental group | Age below 14 | Age between 15 and 59 | Age between 60 and 74 | Age 75 or above |
| 95 % tile: Daily maximum HKHI=30.5 | 1.049 | 1.096 | 1.050 | 1.053 | 1.031 |
| 90 % tile: Daily maximum HKHI=30.3 | 1.032 | 1.052 | 1.035 | 1.031 | 1.025 |
| 85 % tile: Daily maximum HKHI=30.1 | 1.020 | 1.028 | 1.021 | 1.018 | 1.018 |
| 80 % tile: Daily maximum HKHI=30.0 | 1.017 | 1.023 | 1.020 | 1.013 | 1.015 |
| 70 % tile: Daily maximum HKHI=29.6 | 1.016 | 1.019 | 1.019 | 1.011 | 1.013 |
| 60 % tile: Daily maximum HKHI=29.3 | 1.015 | 1.020 | 1.017 | 1.011 | 1.013 |
| 50 % tile: Daily maximum HKHI=29.0 | 1.012 | 1.014 | 1.015 | 1.010 | 1.010 |
| 40 % tile: Daily maximum HKHI=28.5 | 1.011 | 1.011 | 1.014 | 1.009 | 1.008 |
| 30 % tile: Daily maximum HKHI=27.8 | 1.009 | 1.008 | 1.011 | 1.008 | 1.006 |
| 20 % tile: Daily maximum HKHI=26.8 | 1.007 | 1.006 | 1.009 | 1.007 | 1.005 |
| 10 % tile: Daily maximum HKHI=25.6 | 1.002 | 1.003 | 1.003 | 1.002 | 1.001 |

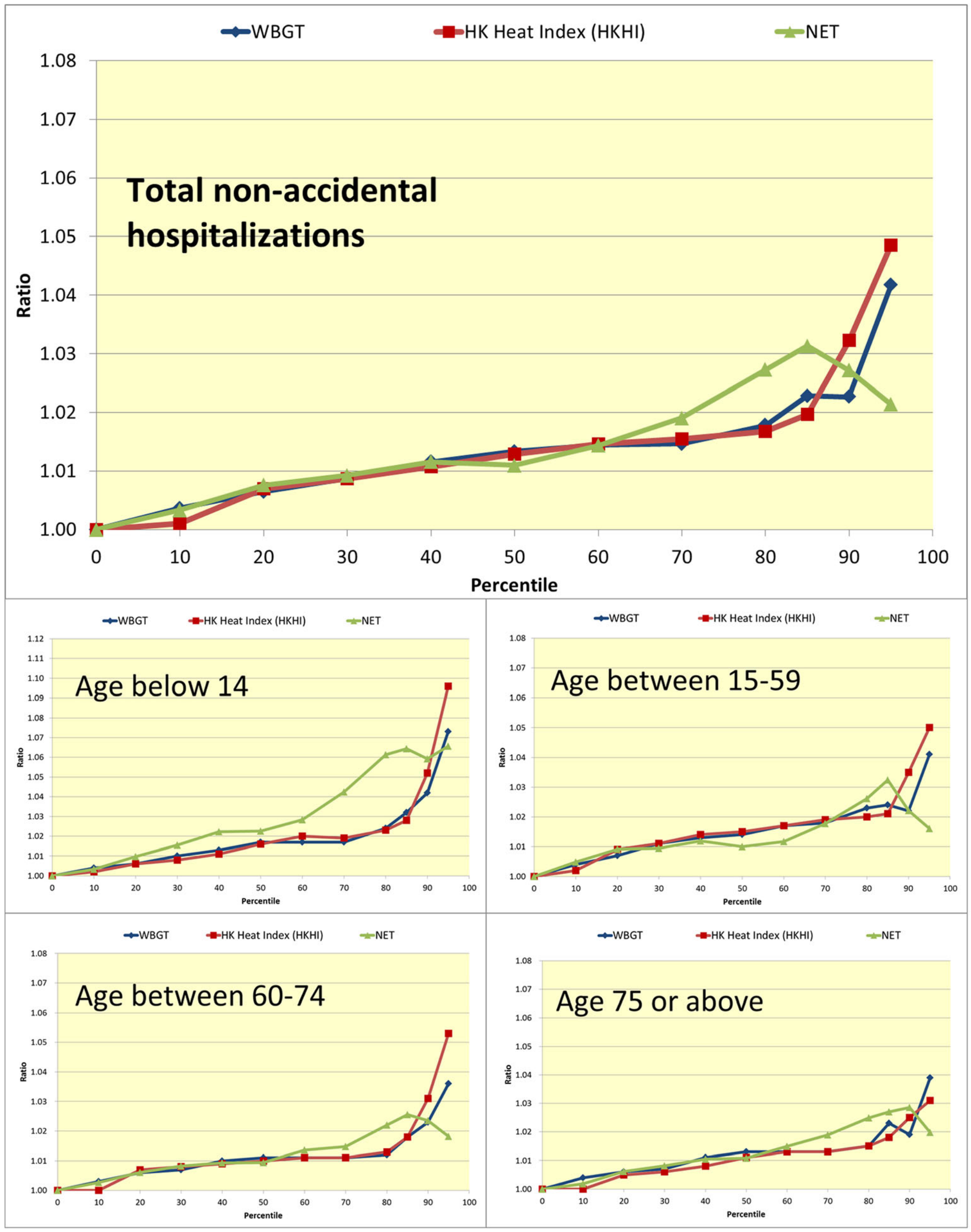



**Fig. 4** Excess hospitalization ratio with different percentiles of daily maximum Hong Kong Heat Index (working days during May–September from 2007 to 2011)

percentile value of 29.6 for operational convenience) in addition to dry bulb temperatures at HKO and at other regional automatic weather stations

Tier 2—issuing of VHWW, which will be based on HKHI (with threshold of 30.5: round to the nearest multiple of 0.5 of the 90th percentile value of 30.3 for operational convenience) in addition to dry bulb temperatures at HKO and at other regional automatic weather stations

The new criteria of issuing VHWW, which incorporated the above proposed reference criterion of HKHI at 30.5, is in general comparable with the original criteria for VHWW. Based on the record between 2007 and 2011, there was around 27.2 days per year meeting the new criteria for VHWW, close to the 25.2 days per year for the original criteria.

## Sub-group responses

As a range of physiological health effects associated with high ambient temperatures, including dehydration, overwhelming of thermoregulatory compensation system, and excessive physiological responses such as increased heart rate and metabolic rate, are commonly documented in the existing literature, this study also attempted to analyze different categories of hospitalization such as infectious disease, cardiovascular disease,

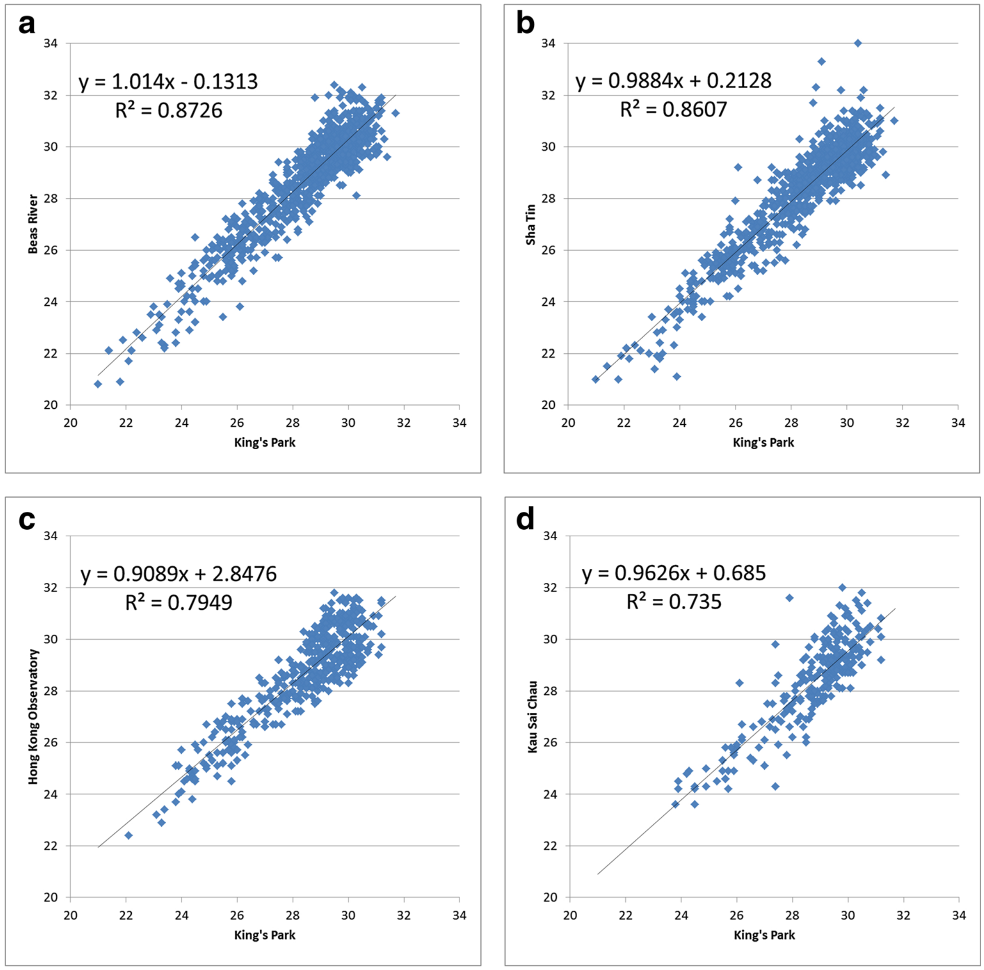



**Fig. 5** Correlation of daily maximum Hong Kong Heat Index at different stations **a** Beas River and King's Park; **b** Sha Tin and King's Park; **c** Hong Kong Observatory and King's Park; **d** Kau Sai Chau and King's Park

and respiratory disease. The excess hospitalization ratios associated with the 90th percentile of HKHI were 1.022 for infectious disease, 1.020 for cardiovascular diseases, and 1.021 for respiratory diseases, respectively. In particular, the ratio for cardiovascular diseases even rises rapidly to 1.052 at 95th percentile of HKHI. Those with cardiovascular diseases were more sensitive to very hot days. For other category of diseases, the effect of the high HKHI is not particularly evident. Furthermore, the study analyzed different data sets for Saturdays, Sundays, and public holidays for various age groups. While the sample sizes are relatively smaller, the results (not shown) for Saturdays, Sundays, and public holidays as well as age groups also in general concur with the above observations.

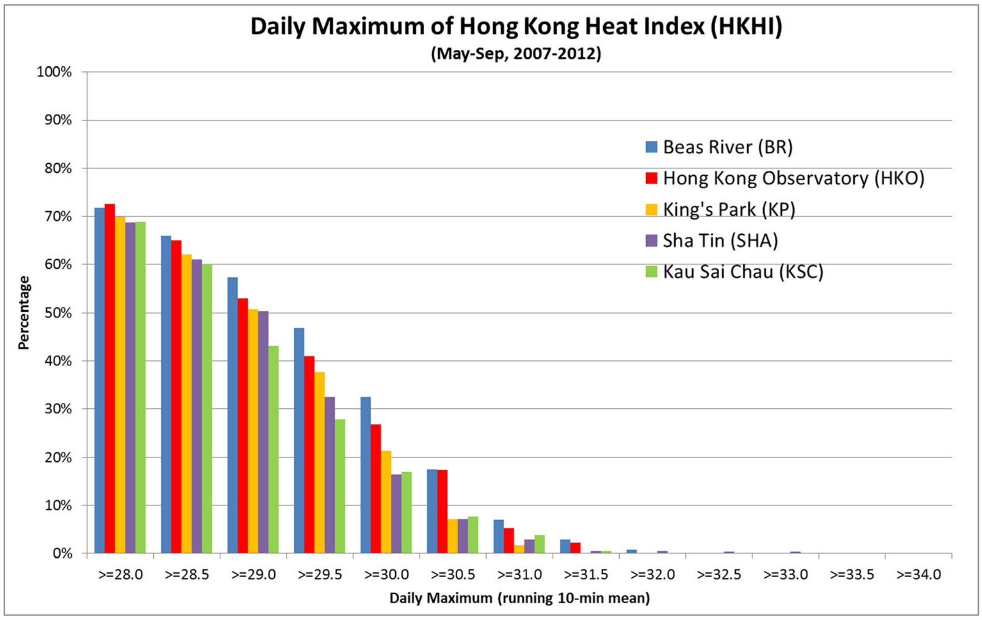
## Regional differences

With the complex topography and land uses in Hong Kong, it is not uncommon to observe spatial differences of HKHI at instances, for example, due to shading effect of clouds. The present study is an analysis of territory wide hospitalization data. Spatial variations are not taken into account. Notwithstanding this, the daily maximum HKHI at the five locations with heat stress measurement in Hong Kong are highly correlated with each other (Fig. 5). There are also high correlations between Beas River, Sha Tin, and Kau Sai Chau with $R^2$ ranging from 0.7 to 0.89 (figures not shown). Moreover, it was found that HKHI at KP was roughly among the average of those at other four measurement locations (Fig. 6). It is envisaged that similar conclusion can be drawn from analysis making use of average HKHI data from the other locations. This supports the use of HKHI data at KP as the reference for enhanced heat stress information service. From operation point of view, it is more convenient to adopt HKHI data at a single station than at multiple stations. Given the small size of Hong Kong, using HKHI data from such a central location as KP is justifiable.

## Response to hot and dry condition

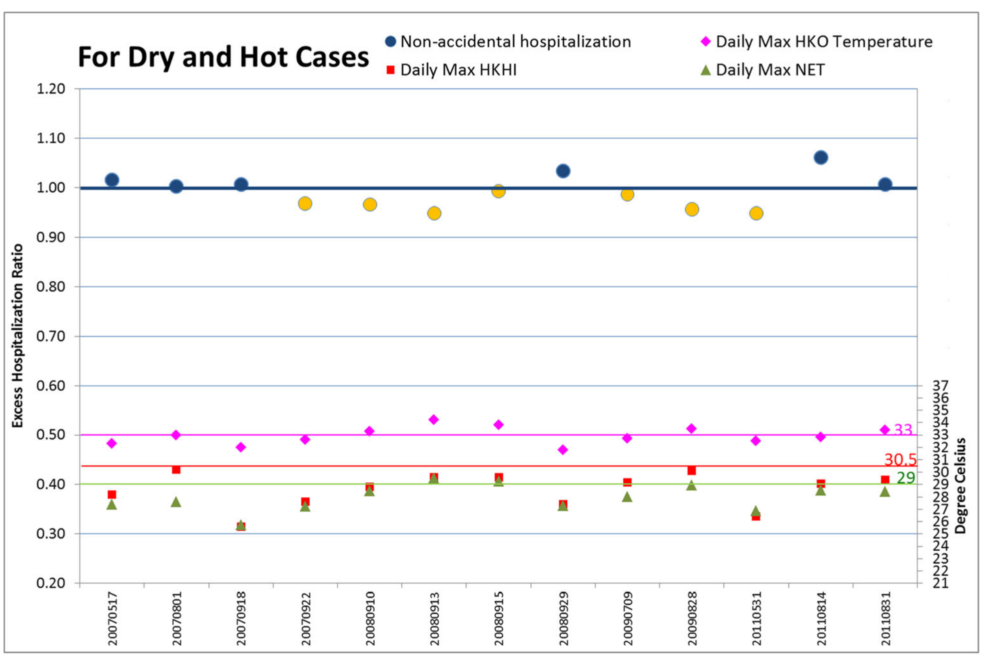
Besides hot and humid condition, Hong Kong occasionally experiences hot and dry weather in between May and September, especially on those days preceding the approach

**Fig. 6** Percentiles of daily maximum Hong Kong Heat Index at different stations




of a tropical cyclone. In order to investigate how HKHI performs in hot and dry cases, excess hospitalization ratios for all hot and dry days, which are defined as those days with daily maximum temperatures at HKO ≥31.5 °C and the daily minimum relative humidity at HKO ≤50 % (less than 5 percentile), during 2007–2011, are extracted for further analysis. There were only 13 hot and dry cases in the 5-year period (Fig. 7). Except for the two cases on 29 August 2008 and 14 August 2011, the excess hospitalization ratios of the remaining 11 cases were less than 1.016. That means the daily hospitalization values of most of the hot and dry cases (11 out of 13) are close to the corresponding yearly average hospitalization. Moreover, the values of daily maximum HKHI of these 13 cases were less than 30.5 °C, that is below the thresholds for considering the VHWW. However, NET exceeded the threshold of 29.0 °C for issuing VHWW in the original criteria (which corresponds to WSI of 97.5 % as mentioned above) in two cases (13 and 15 September 2008). The results reveal that HKHI is slightly better than NET in reflecting the hospitalization ratio under hot and dry situations. However, since hot and dry condition is not a common event in summer in Hong Kong with limited cases for investigation, more cases and further studies may still be required to confirm the performance of HKHI in this aspect.

**Fig. 7** Relatively low excess hospitalization for hot and dry cases (HKO daily maximum temperature ≥31.5 °C and daily minimum relative humidity ≤50 % (less than 5 percentile)) with corresponding HKHI below 30.5 during 2007–2011



## Conclusion and future work

In this study, by making use of local heat stress data and hospitalization data, the HKHI, which consists of a set of optimized coefficients for **Tnw**, **Tg**, and **Ta**, was developed to reflect local heat stress condition and to facilitate the issuance of early alert of hot weather in Hong Kong. Retrospective analysis also indicates that the HKHI performed better than WBGT and NET in reflecting the health risk under high temperature conditions as indicated by the exposure-response of the excess hospitalization ratio for most age groups. Based on the response of hospitalization rate to the HKHI, the criteria of HKHI were also identified for the two-tier approach of the heat stress information service. The findings of this study provide the scientific basis for the development of the new HKHI and the enhancement of the existing heat stress information services by introducing the two-tier approach with a special advisory for hot weather and a VHWW for very hot weather.

In summer 2014, the enhancement of the heat stress information service has been rolled out as a trial to promote the public to take due attention and timely precautions to prevent negative impacts from heat stress. A review of the service will be carried out after obtaining user's feedback and comments on the usefulness and applicability of the service. As an ongoing research, it will be beneficial to conduct further studies to verify the performance of the HKHI, further compare it with other commonly used heat indices, and to refine the proposed criteria for heat stress information service in Hong Kong when more health data is available in the coming years. Moreover, day and night-time conditions are equally important for understanding the heat-related health impacts, the merit of considering night time or minimum temperature as part of the heat stress information services may be a relevant subject of further research.

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