



Visits to the accident and emergency department in hot season of a city with subtropical climate: association with heat stress and related meteorological variables

Pui Hing Chau¹ · Kevin Ka-Lun Lau² · Xing Xing Qian¹ · Hao Luo³ · Jean Woo⁴

Received: 5 January 2022 / Accepted: 8 July 2022 / Published online: 28 July 2022
© The Author(s) under exclusive licence to International Society of Biometeorology 2022

Abstract

Background Literature reporting the association between heat stress defined by universal thermal climate index (UTCI) and emergency department visits is mainly conducted in Europe. This study aimed to investigate the association between heat stress, as defined by the UTCI, and visits to the accident and emergency department (AED) in Hong Kong, which represents a subtropical climate region.

Methods A retrospective study involving 13,438,846 AED visits in the public sector from May 2000 to September 2016, excluding 2003 and 2009, was conducted in Hong Kong. Age-sex-specific ANCOVA models of daily AED rates on heat stress and prolonged heat stress, adjusting for air quality, prolonged poor air quality, typhoon, rainstorm, year, day of the week, public holiday, summer vacation, and fee charging, were used.

Results On a day with strong heat stress ($32.1\text{ °C} \leq \text{UTCI} \leq 38.0\text{ °C}$), the AED visit rate (per 100,000) increased by 0.9 (95% CI: 0.5, 1.3) and 1.7 (95% CI: 1.3, 2.1) for females and males aged 19–64 and 4.1 (95% CI: 2.7, 5.4) and 4.1 (95% CI: 2.6, 5.6) for females and males aged ≥ 65 , while keeping other variables constant. On a day with very strong heat stress ($38.1\text{ °C} \leq \text{UTCI} \leq 46.0\text{ °C}$), the corresponding rates increased by 0.6 (95% CI: 0.1, 1.2), 2.2 (95% CI: 1.7, 2.7), 4.9 (95% CI: 3.1, 6.7), and 4.7 (95% CI: 2.7, 6.6), respectively. The effect size of heat stress associated with AED visit rates was negligible among those aged ≤ 18 . Heat stress showed the greatest effect size for males aged 19–64 among all subgroups.

Conclusion Biothermal condition from heat stress was associated with the health of the citizens in a city with a subtropical climate and reflected in the increase of daily AED visit. Public health recommendations have been made accordingly for the prevention of heat-related AED visits.

Keywords Universal Thermal Climate Index (UTCI) · Accident and Emergency Department · Heat stress · Subtropical climate · Older adult · Hong Kong

Introduction

There has been a growing concern over global warming. By the end of the twenty-first century, the global average surface temperature will be very likely to rise by 1.0–5.7 °C (depending on the greenhouse gases emission scenario) compared to the pre-industrial period of 1850–1900 (Intergovernmental Panel on Climate Change 2021 & 2022). The heat-related adverse outcomes are associated with the working population who are exposed to occupational hazard (Gubernot et al., 2015). Meanwhile, the older adults are more vulnerable to the adverse effects of hot weather due to their weakened physiological responses (Meade et al. 2020). These may lead to greater healthcare utilization, including emergency department and inpatient admissions, and

✉ Pui Hing Chau
phchau@graduate.hku.hk

¹ School of Nursing, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong SAR, China

² Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, Luleå, Sweden

³ Department of Social Work and Social Administration, Faculty of Social Sciences, The University of Hong Kong, Hong Kong SAR, China

⁴ Department of Medicine and Therapeutics, Faculty of Medicine, The Chinese University of Hong Kong, Hong Kong SAR, China

mortality (Basu et al. 2012; Bishop-Williams et al. 2015; Li et al. 2015).

Traditionally, the effects of individual meteorological variables on health and healthcare utilization have been investigated. For instance, in a city with subtropical climate in Hong Kong, hospital admissions increased by 4.5% for every 1 °C increase above 29 °C in the hot season (Chan et al. 2013), and a rise in diurnal temperature range by 1 °C was associated with 2.5% increase in emergency asthma hospitalization (Qiu et al., 2015). In addition, a study showed that health-seeking behaviors among the older population started to increase when the maximum ambient temperature reached 30–32 °C (Chan et al. 2011). Positive associations between ambient temperature and morbidity and mortality during hot seasons have also been reported in other climate zones (Dessai 2002; Díaz et al. 2002; Wang et al. 2020; Ye et al. 2012).

As the thermal stress experienced by the human body cannot be explained by ambient temperature alone, there has been an increase in usage of composite indices that incorporate additional meteorological variables, such as relative humidity, wind speed, and radiant temperature, along with ambient temperature, into a single thermal index. In Europe, the associations of maximum apparent temperature with respiratory hospitalization among the older adults and with all-causes mortality have been revealed (Michelozzi et al. 2000; Baccini et al. 2008; Michelozzi et al. 2009). Various studies in Hong Kong have investigated the associations between health outcomes and these indices during the hot season. Although heat stroke mortality was reported to double when the net effective temperature (NET) increased by one unit above 26 °C (Leung et al. 2008), a significant relationship with all-cause mortality could not be shown with the Weather Stress Index (WSI) (Li & Chan 2000). Subsequently, a Hong Kong specific index, namely, the Hong Kong Heat Index, was developed based on its association with excess hospitalization to better reflect the situation (Lee et al. 2016). Although such an index has practical value in the local context, it may not be comparable to studies in other regions.

The Universal Thermal Climate Index (UTCI) was developed in 2009. This index is intended to assess outdoor thermal stress, with the advantage of being applicable to regions of different climates (Błażejczyk et al. 2010; Jendritzky et al. 2012). The UTCI is defined as “the isothermal air temperature of the reference condition that would elicit the same dynamic response of the physiological model” (Jendritzky et al., 2012). The UTCI incorporates ambient temperature, humidity, wind speed, and radiant temperature into a score based on a multivariate dynamic model, with higher scores indicating greater heat stress (Błażejczyk et al., 2013). The UTCI not only incorporates multiple meteorological variables in a non-linear way, but, more importantly, it also classifies thermal stress based on human physiological responses. Ten thermal stress classifications,

ranging from extreme cold stress ($UTCI \leq -40.0$ °C), to thermoneutral conditions ($UTCI$ between 9.1 and 26.0 °C), and extreme heat stress ($UTCI > 46.0$ °C), were proposed to describe the extreme weather stress experienced by humans (Błażejczyk et al., 2010). However, investigations regarding the association between thermal stress and health outcomes, particularly heat stress, have been mostly conducted in Europe, which generally has a temperate climate. For example, a study in the Czech Republic reported that when the UTCI reached 22 °C, cardiovascular mortality exceeded the mean value by 11.8% (Urban & Kyselý, 2014). A study in Poland reported increased asthma hospitalization among populations younger than 65 years of age for an UTCI between 26.1 and 32.0 °C compared to days with thermoneutral UTCI (Romaszko-Wojtowicz et al., 2020). Another study in Poland reported an increase in mortality by 10–20% for UTCI exceeding 32.0 °C and by 25–30% for UTCI exceeding 38.0 °C (Kuchcik et al., 2021). A study from Athens showed the odds of self-reported heat-related symptoms such as exhaustion, headache, dizziness, and breathing difficulties, increased by 4% per 1 °C increase in UTCI (Krüger, 2021). Among the few studies from Asia, a study conducted in Beijing, a city characterized by a hot summer and continental climate, showed that cerebral infarction emergency room visits among those aged 45 to 65 years increased by 64% on lag 0–2 days when the UTCI reached 38 °C (Ma et al. 2018). Another study in Bangladesh, a country with a tropical monsoon climate, showed that with every 1 °C increase in the UTCI above 34–35 °C, the all-cause mortality increased by 31.3% and the cardiovascular mortality increased by 20%. These relationships were more pronounced among men and those aged > 65 years (Burkart et al., 2014). There is limited amount of research on the health outcomes of heat stress, as defined by the UTCI in other climate zones.

Whether such associations exist in other climate zones, particularly in subtropical climate zones, remains uncertain. Long-term acclimatization could result in differences in the summer thermal comfort thresholds in different climate zones. For example, the population in Hong Kong, a city with a subtropical climate, reported a neutral to warm sensation at a higher UTCI range compared to the dynamic thermal sensation model (Lam & Lau 2018). Hence, there is a need to quantify the adverse health risks in terms of UTCI in subtropical climate zones during hot seasons. This study aimed to investigate the association between UTCI and visits to the accident and emergency department (AED) in a subtropical climate region, with Hong Kong as an illustration.

Method

Study design

This was a retrospective study based on administrative records.

Data sources

This study was performed using data on daily healthcare utilization in the public sector among the Hong Kong population from 2000 to 2016. The years 2003 and 2009 were excluded due to the occurrence of the SARS epidemic and swine flu pandemic, respectively, as the usual healthcare utilization pattern may have been affected. Healthcare utilization data were obtained from the Clinical Management System (CMS), a database of the Hospital Authority that records all hospital admission, and discharge data of patients from the public sector in Hong Kong. The data included the number of daily AED visits in all 18 accident and emergency units operated by the Hospital Authority, stratified by sex (female, male), and age (≤ 18 , 19–64, ≥ 65 years). In Hong Kong, those aged ≤ 18 years are generally classified as pediatric patients and those aged > 65 years as geriatric patients. To avoid non-linear relationships arising from whole-year data analyses, only data from the summer season were analyzed. In accordance with the literature, we used May to September to represent the hot season in Hong Kong (Chau et al. 2009; Lee et al. 2016), resulting in 2295 days in the analysis set.

The corresponding population data, stratified by sex and age groups, were obtained from the Census and Statistics Department of Hong Kong. The hourly meteorological data, including ambient temperature, relative humidity, wind speed, global solar radiation, and weather warning signals, including typhoons and rainstorms, were obtained from the Hong Kong Observatory (HKO). The daily general air quality health index (AQHI) (Wong et al. 2013) was obtained from the Environmental Protection Department. Indicator variables on public holidays and Sundays were generated according to the Hong Kong calendar.

Dependent variable

The primary outcome was the all-cause daily AED visit rate (per 100,000 population). The age- and sex-specific rates were calculated by dividing the daily number of corresponding admissions by population, and then multiplying with 100,000.

Independent variables

UTCI was calculated based on ambient temperature, humidity, wind speed, and mean radiant temperature obtained from the HKO. The details of the adjustment to the meteorological variables were presented elsewhere (Lam & Lau 2018). In particular, wind speed was adjusted by the height of the weather station and black globe temperature was used to approximate the mean radiant temperature. The hourly UTCI

was calculated according to the Fortran code provided on the UTCI website (ISB Commission 6, 2014). The daily maximum UTCI was selected to reflect heat stress since human beings were hypothesized to be vulnerable to extreme weather conditions. According to the thresholds of the UTCI (Błażejczyk et al., 2010), thermoneutral conditions referred to UTCI between 9.1 and 26.0 °C, moderate heat stress referred to UTCI between 26.1 and 32.0 °C, strong heat stress referred to UTCI between 32.1 and 38.0 °C, and very strong heat stress referred to UTCI between 38.1 and 46.0 °C. In Hong Kong, none of the days in the analysis set was having extreme heat stress ($UTCI \geq 46.1$ °C). Thermoneutral condition and moderate heat stress were combined as a group because there were too few summer days in Hong Kong that could be considered thermoneutral. Thus, the daily maximum UTCI between 9.1 and 32.0 °C was categorized as thermoneutral to moderate heat stress condition. To reflect prolonged heat stress, the number of days of strong to very strong heat stress (32.1 °C \leq UTCI \leq 46.0 °C) over the past 7 days was computed as a continuous variable. A period of 7 days was considered because the association between hot weather and health outcomes was generally limited to a few days (Wang et al. 2021).

Since there is evidence in the literature supporting the influence of air quality on AED visits (Szyzkowicz, 2019), the AQHI, which is a health risk-based multi-pollutant index, was controlled in the model. The air quality was reflected by AQHI, which was calculated based on “the cumulative health risk attributable to the 3-h moving average concentrations of four air pollutants including ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and particulate matter (PM_{2.5}/PM₁₀)” (Environmental Protection Department 2020). According to the thresholds of the AQHI (Environmental Protection Department 2020), daily general AQHI between 4 and 10 was categorized as moderate to very high health risk, and between 1 and 3 was categorized as low health risk. During the study period, none of the days had a general AQHI exceeding 10, and there were 13 days with missing readings. Missing readings were replaced with the average of the readings immediately prior to and after the missing data. Furthermore, the number of days of air quality of moderate to very high health risk over the past 7 days was computed as a continuous variable to reflect prolonged poor air quality.

Typhoons have been associated with AED visits (Lin et al. 2013). Hence, the occurrence of typhoons was controlled in the model. In Hong Kong, there are five levels of typhoon warning signals (signal numbers 1, 3, 8, 9, and 10). When a typhoon is categorized as signal number 8, the wind is expected to reach the gale force. Therefore, in this study, an ordinal variable (none, signal number 3 or below, signal number 8 or above) was applied. There is also a rainstorm

warning system in Hong Kong, with three levels of warning, namely Amber, Red, and Black, in ascending order of severity. In this study, the rainstorm warning system was considered an ordinal variable (none, amber, red, and black).

While there were inconsistencies related to a holiday, day of the week, and AED utilization (Castner et al. 2016; Hahn et al. 2018), these were still controlled in the model as independent variables, with the aim of controlling for any possible influence. A binary variable, public holiday, was created according to the public holiday calendar of Hong Kong. The day of the week was included as the nominal variable. Summer vacation was defined as 15 July to 31 August as this was the most common period for summer vacation among primary and secondary school students. As the AED service was free of charge before December 2002 in Hong Kong, a binary variable indicating whether the service was free of charge was included. The year was also controlled as a continuous variable to cater to any potential trends in the population.

Data analysis

Data analyses were conducted for the six population subgroups based on sex and age separately. Descriptive statistics, including frequencies and percentages, were used to summarize the meteorological characteristics of the study days. For each subgroup, the analysis of covariance (ANCOVA) model was used to investigate the associations between the dependent and independent variables. AED visit rate was used as the dependent variable. Categorical independent variables were factors and continuous independent variables were covariates. Heat stress and prolonged heat stress were used as factor and covariate respectively. The models were also adjusted for air quality, prolonged poor air quality, typhoon warning, rainstorm warning, fee charging, public holiday, day of the week, and year by including them as factors or covariates as appropriate. For population aged ≤ 18 , summer vacation was also included as a factor. For covariates, the fitted coefficients referred to the change in the mean AED visit rate (per 100,000 population) per unit increase in the corresponding variables. For factors, the fitted coefficients were the comparison of means between different levels of the factors and its reference level, which was “thermoneutral conditions to moderate heat stress” for the factor heat stress, “low health risk” for the factor air quality, “Saturday” for the factor day of the week, “free of charge” for the factor fee of AED visit, and “no/none” for the remaining factors. Partial eta squared (η_p^2) was used to quantify the effect size (Cohen 1973), with 0.01 considered a small effect, 0.06 a medium effect and 0.14 a large effect, respectively. The model diagnostics of linearity and normality assumptions were checked. Variance inflation factor (VIF) was used to assess multicollinearity among the independent variables (factors were treated as dummy), with $VIF > 4$ indicating possible multicollinearity. All statistical analyses were performed

using SPSS version 25 (IBM Corp., Armonk, NY, USA). The significance level was set to 5%.

Results

Descriptive statistics

Figure 1 shows the percentage of days with different levels of heat stress in each month over the years 2000 to 2016. The number of days with different levels of heat stress during May to September of 2000 to 2016 is shown in Fig. 2. Comparing to thermoneutral or moderate heat stress, the chance of having a very strong heat stress day and strong heat stress day increased by 15.3% (Odds ratio (OR): 1.153, 95% CI: 1.123, 1.183) and 4.2% each year (OR: 1.042, 95% CI: 1.021, 1.063), respectively. Figure 3 shows the percentage of days with different levels of health risk related to air quality in each month over the years 2000 to 2016. The number of days with different levels of health risk related to air quality in May to September 2000 to 2016 is shown in Fig. 4. Comparing to low health risk, the chance of having a moderate to very high health risk did not show a significant trend (OR: 1.000, 95% CI: 0.983, 1.017).

The characteristics of the data from 2295 days between May 2000 and September 2016 (excluding the years 2003 and 2009) are presented in Table 1. Most of the studied days had strong heat stress (58.6%) or very strong heat stress (20.7%). Approximately 70.9% of the studied days had air quality associated with low health risk. Only 1.3% of the days had a typhoon warning signal number of eight or more. Only 1.8% and 0.6% of the days had rainstorm warning signals red and black, respectively. Less than 20% of the studied days were public holidays (including Sundays).

During the study period, 13,438,846 AED visits occurred. The population aged ≥ 65 years had the highest daily AED visit rate. Descriptive statistics of the age- and sex-specific AED visit rates are presented in Table 2. For females aged ≥ 65 years, the daily admission rates (per 100,000 population) ranged from 105.1 to 227.9, whereas the male counterparts had a range of 117.7 to 225.7. For females aged ≤ 18 years, the daily rates (per 100,000 population) ranged from 40.4 to 151.1 and from 51.1 to 179.1 for males aged ≤ 18 years. For those aged 19–64 years, the daily rates (per 100,000 population) ranged from 52.6 to 96.4 for females and 56.2 to 103.3 for males.

Association between heat stress and AED visit rates

ANCOVA models on AED visit rates were fitted for each age and sex subgroup. The fitted coefficients are listed in Tables 3 and 4, respectively. The model diagnostics did not violate the assumptions of the model. Heat stress was

Fig. 1 The percentage of days with different levels of heat stress in each month, 2000 to 2016

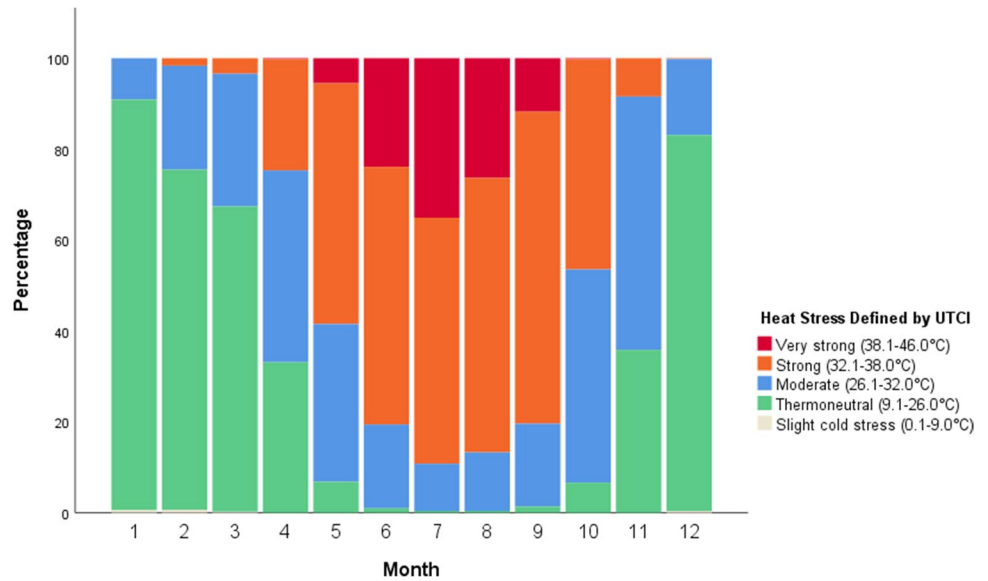
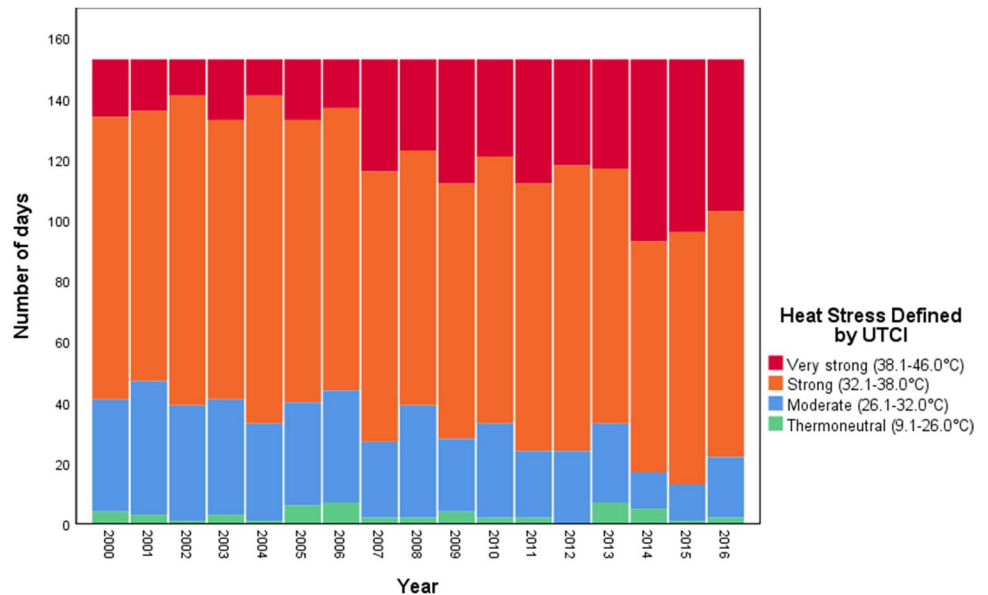


Fig. 2 The number of days with different levels of heat stress in May to September 2000 to 2016



unlikely to have multicollinearity with other variables (VIF ranges from 1.0 to 2.1), although the variable holiday was related to Sunday ($VIF > 5$).

The results showed that a day with strong to very strong heat stress was significantly associated with higher AED visit rates among all age and sex groups (p ranged from < 0.001 to 0.048). Heat stress attained a small-to-moderate effect size for males aged 19–64 years ($\eta_p^2 = 0.037$), a small effect size for females aged ≥ 65 years ($\eta_p^2 = 0.016$), and males aged ≥ 65 years ($\eta_p^2 = 0.014$), but negligible for those aged ≤ 18 years ($\eta_p^2 = 0.003$ for females and 0.005 for males) and females aged 19–64 years ($\eta_p^2 = 0.008$). After adjusting for other possible factors, on a day with strong heat stress, the AED visit rate (per 100,000) increased by 1.7 (95% CI: 1.3,

2.1) among males aged 19–64 years, 4.1 (95% CI: 2.7, 5.4) among females aged ≥ 65 years, and 4.1 (95% CI: 2.6, 5.6) for males aged ≥ 65 years, whereas on a day with very strong heat stress, such rates increased by 2.2 (95% CI: 1.7, 2.7), 4.9 (95% CI: 3.1, 6.7), and 4.7 (95% CI: 2.7, 6.6), respectively. The days with very strong heat stress was associated with more AED admissions as compared to days with strong heat stress, except for females aged 19–64 years.

Prolonged heat stress was associated with lower AED visit rates among those aged ≤ 18 years and those aged ≥ 65 years ($p < 0.001$ for all groups), but higher AED visit rate among those aged 19–64 years ($p = 0.007$ for females and $p < 0.001$ for males). For those aged ≤ 18 years, the AED visit rate (per 100,000)

Fig. 3 The percentage of days with different levels of health risk related to air quality in each month, 2000 to 2016

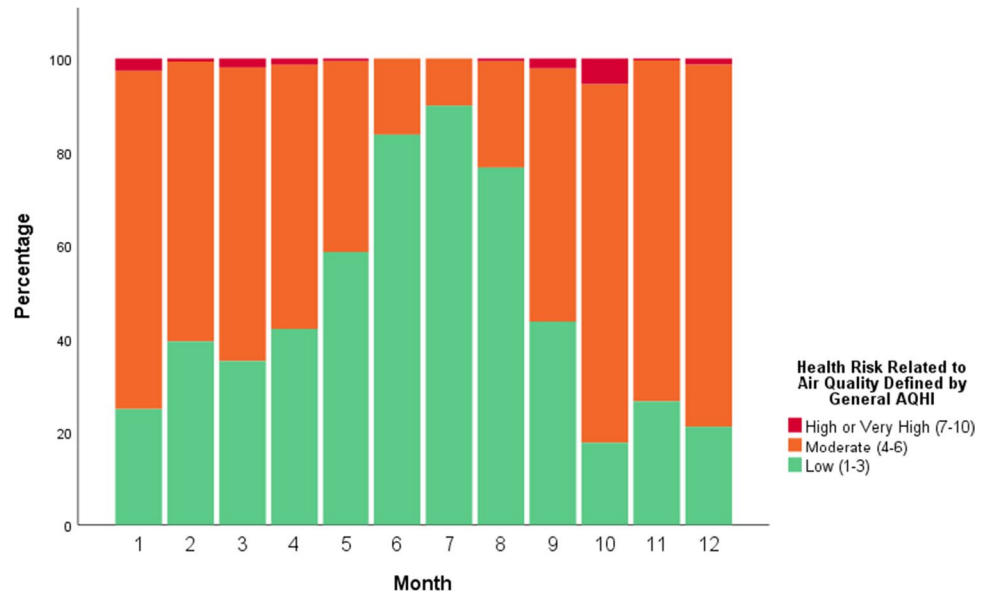
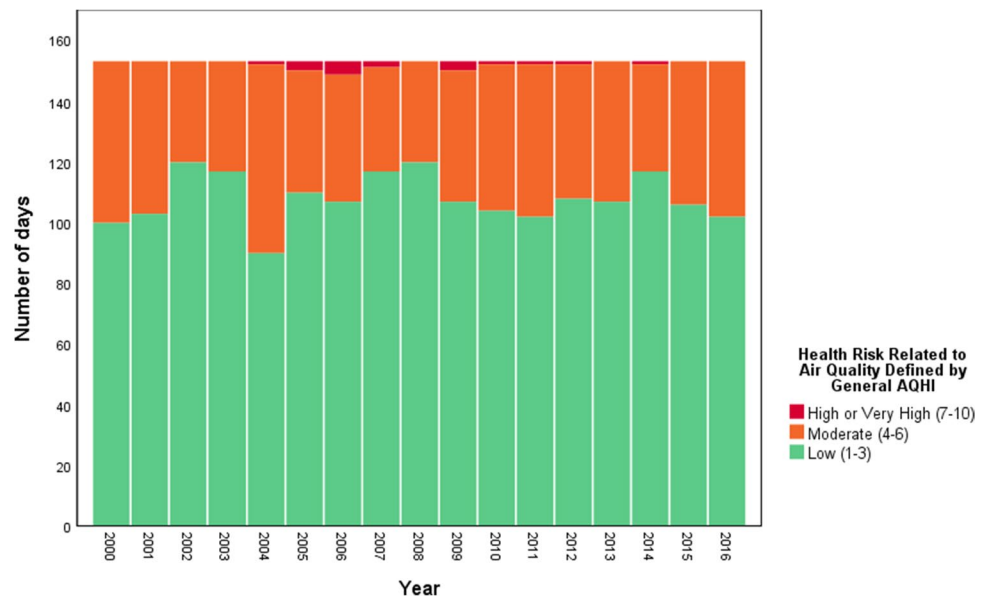


Fig. 4 The number of days with different levels of health risk related to air quality in May to September 2000 to 2016



decreased by 0.4 (95% CI: 0.2, 0.7) for females and 0.6 (95% CI: 0.3, 0.9) for males, for an additional day of heat stress following the past 7 days, the effect size ($\eta_p^2 = 0.005$ for females and 0.007 for males), though negligible, was greater than that from heat stress on the eighth day. Among those aged ≥ 65 years, the effect size from prolonged heat stress ($\eta_p^2 = 0.019$ for females and 0.012 for males) was comparable to that from heat stress on the eighth day. For an additional day of heat stress following the past 7 days, the AED visit rate (per 100,000) decreased by 1.1 (95% CI: 0.8, 1.4) for females aged ≥ 65 years and 0.9 (95% CI: 0.6, 1.3) for males aged ≥ 65 years. Among those aged 19–64, an additional day of heat stress following the past 7 days was associated with an increase in the AED visit

rate (per 100,000) (females: 0.1 (95% CI: 0.04, 0.2); males: 0.3 (95% CI: 0.2, 0.4)), with an effect size ($\eta_p^2 = 0.003$ for females and $\eta_p^2 = 0.021$ for males) slightly smaller than that for the eighth day.

Association between air quality and AED visit rates

The results showed that a day with air quality of moderate to very high health risk was significantly associated with a higher AED visit rate among those aged ≤ 18 years only ($p = 0.002$ for females and $p < 0.001$ for males), but not for those aged 19–64 years and ≥ 65 years. In the adjusted model, on a day with air quality of moderate to very high health risk, the AED visit rate (per 100,000) increased by

Table 1 Characteristics of 2295 days in May to September of the period 2000 to 2016 (excluding 2003 and 2009)

Independent variables	Frequency	Percentage (%)
Daily maximum UCTI		
Thermoneutral conditions (9.1 to 26.0 °C)	45	2.0
Moderate heat stress (26.1 to 32.0 °C)	431	18.8
Strong heat stress (32.1 to 38.0 °C)	1345	58.6
Very strong heat stress (38.1 to 46.0 °C)	474	20.7
Extreme (≥ 46.1 °C)	0	0.0
Daily general AQHI		
Low health risk (score 1 to 3) [#]	1627	70.9
Moderate health risk (score 4 to 6) [#]	651	28.4
High health risk (score 7)	15	0.7
Very high health risk (score 8 to 10)	2	0.1
Serious health risk (score ≥ 10)	0	0.0
Highest typhoon warning signal during the day		
None	2112	92.0
Signal nos. 1 or 3	154	6.7
Signal nos. 8, 9, or 10	29	1.3
Highest rainstorm warning signal during the day		
None	2055	89.5
Amber	185	8.1
Red	42	1.8
Black	13	0.6
Day of the week		
Sun	328	14.3
Mon	327	14.2
Tue	328	14.3
Wed	328	14.3
Thu	329	14.3
Fri	328	14.3
Sat	327	14.2
Public holiday (include Sunday)		
No	1896	82.6
Yes	399	17.4

[#]The 13 days with missing data were imputed with the average value of the data on the days before and after that day, 11 days were imputed as low health risk, and 2 were imputed as moderate health risk

Table 2 Descriptive statistics of daily AED visit rates (per 100,000) on the 2295 days studied

Daily AED visit rate	Female ≤ 18	Male ≤ 18	Female 19–64	Male 19–64	Female ≥ 65	Male ≥ 65
Mean	75.2	91.8	66.9	71.8	158.6	169.1
Median	74.1	90.2	64.9	69.5	156.9	168.6
Minimum	40.4	51.1	52.6	56.2	105.1	117.7
Maximum	151.1	179.1	96.4	103.3	227.9	225.7
Standard deviation	14.8	18.3	7.4	7.8	17.2	15.8
Interquartile range	18.3	22.4	9.2	10.0	20.7	21.6

1.6 (95% CI: 0.6, 2.6) among females aged ≤ 18 years and by 2.8 (95% CI: 1.7, 4.0) among males aged ≤ 18 years. Such effect sizes were small for males ($\eta_p^2 = 0.010$) and negligible for females ($\eta_p^2 = 0.004$).

Prolonged poor air quality was associated with a lower AED visit rate among males aged 19–64 years ($p = 0.020$), the effect size was negligible ($\eta_p^2 = 0.002$). Insignificant associations were observed for other age and sex subgroups.

Table 3 ANCOVA models for daily AED admission rates (per 100,000) among females

Independent variables	Female ≤ 18				Female 19–64				Female ≥ 65			
	Coef	95% CI	P-value	η^2_p	Coef	95% CI	P-value	η^2_p	Coef	95% CI	P-value	η^2_p
Daily maximum UTCI	[ref]		0.048	0.003	[ref]		< 0.001	0.008	[ref]		< 0.001	0.016
Thermoneutral conditions to moderate heat stress												
Strong heat stress	1.2	(0.2, 2.3)	0.025	0.002	0.9	(0.5, 1.3)	< 0.001	0.008	4.1	(2.7, 5.4)	< 0.001	0.014
Very strong heat stress	1.6	(0.2, 3.1)	0.024	0.002	0.6	(0.1, 1.2)	0.030	0.002	4.9	(3.1, 6.7)	< 0.001	0.013
Number of days with strong to very strong heat stress in the past seven days	-0.4	(-0.7, -0.2)	0.001	0.005	0.1	(0.04, 0.2)	0.007	0.003	-1.1	(-1.4, -0.8)	< 0.001	0.019
Daily general AQHI												
Low health risk	[ref]		0.002	0.004	[ref]		0.119	0.001	[ref]		0.273	0.001
Moderate to very high health risk	1.6	(0.6, 2.6)			0.3	(-0.1, 0.7)			0.7	(-0.5, 1.9)		
Number of days with air quality of moderate to very high health risk in the past seven days	-0.1	(-0.3, 0.1)	0.556	< 0.001	-0.03	(-0.1, 0.05)	0.408	< 0.001	-0.1	(-0.4, 0.1)	0.304	< 0.001
Typhoon Signal			0.049	0.003			0.136	0.002			< 0.001	0.020
None	[ref]				[ref]				[ref]			
Nos. 1 or 3	0.5	(-1.1, 2.1)	0.515	< 0.001	-0.2	(-0.9, 0.4)	0.423	< 0.001	-2.1	(-4.1, -0.1)	0.038	0.002
Nos. 8, 9, or 10	4.4	(0.8, 8.0)	0.017	0.003	-1.3	(-2.7, 0.1)	0.062	0.002	-15.1	(-19.6, -10.6)	< 0.001	0.018
Rainstorm warning signal			0.017	0.004			0.244	0.002			< 0.001	0.009
None	[ref]				[ref]				[ref]			
Amber	-0.9	(-2.4, 0.6)	0.252	0.001	-0.5	(-1.0, 0.1)	0.127	0.001	-3.0	(-4.9, -1.1)	0.002	0.004
Red	-4.2	(-7.2, -1.2)	0.006	0.003	-0.8	(-1.9, 0.4)	0.178	0.001	-4.2	(-7.9, -0.4)	0.032	0.002
Black	-3.9	(-9.2, 1.4)	0.146	0.001	-0.7	(-2.8, 1.3)	0.471	< 0.001	-9.9	(-16.6, -3.1)	0.004	0.004
Year	0.7	(0.5, 0.8)	< 0.001	0.051	0.2	(0.2, 0.3)	< 0.001	0.035	-1.0	(-1.1, -0.8)	< 0.001	0.066
Day of the week			< 0.001	0.063			< 0.001	0.328			< 0.001	0.130
Sat	[ref]				[ref]				[ref]			
Sun	-1.9	(-4.6, 0.8)	0.164	0.001	2.7	(1.7, 3.7)	< 0.001	0.011	5.1	(1.7, 8.4)	0.003	0.004
Mon	2.7	(1.2, 4.1)	< 0.001	0.005	8.6	(8.0, 9.1)	< 0.001	0.278	15.6	(13.7, 17.5)	< 0.001	0.105
Tue	-3.2	(-4.7, -1.7)	< 0.001	0.008	2.9	(2.3, 3.4)	< 0.001	0.042	3.4	(1.5, 5.2)	< 0.001	0.006
Wed	-3.7	(-5.1, -2.2)	< 0.001	0.010	2.2	(1.6, 2.7)	< 0.001	0.024	2.6	(0.7, 4.4)	0.007	0.003
Thu	-4.7	(-6.2, -3.2)	< 0.001	0.017	1.4	(0.8, 2.0)	< 0.001	0.010	2.8	(0.9, 4.6)	0.004	0.004
Fri	-4.5	(-6.0, -3.0)	< 0.001	0.015	1.0	(0.4, 1.6)	< 0.001	0.005	2.9	(1.0, 4.7)	0.003	0.004

Table 3 (continued)

Independent variables	Female ≤ 18			Female 19–64			Female ≥ 65					
	Coef	95% CI	P-value	η_p^2	Coef	95% CI	P-value	η_p^2	Coef	95% CI	P-value	η_p^2
Public Holiday (include Sunday)												
No	[ref]				[ref]				[ref]			
Yes	12.7	(10.4, 15.0)	<0.001	0.048	1.3	(0.4, 2.1)	0.006	0.003	-8.4	(-11.3, -5.5)	<0.001	0.014
Summer vacation												
No	[ref]				NA				NA			
Yes	-14.3	(-15.2, -13.4)	<0.001	0.298								
Fee of AED visit												
Free of charge	[ref]				[ref]				[ref]			
Charged	-21.7	(-23.2, -20.3)	<0.001	0.282	-16.5	(-17.0, -15.9)	<0.001	0.604	-15.8	(-17.6, -14.0)	<0.001	0.115

Coef, coefficient; CI, confidence interval; η_p^2 , partial eta square; [ref], reference level; NA, not applicable

Association between other factors and AED visit rates

Among all other controlled factors, the AED visit fees had large impact on AED visits for all groups ($p < 0.001$ for all groups) except males aged ≥ 65 years. The AED visit rate was substantially lower in the charging period compared to the free of charge period. For those aged ≤ 18 years, during the charging period, AED visit rate (per 100,000) decreased by 21.7 (95% CI: 20.3, 23.2; $\eta_p^2 = 0.282$) for females and 26.8 (95% CI: 25.2, 28.5; $\eta_p^2 = 0.307$) for males. For those aged 19–64 years, such rates decreased by 16.5 (95% CI: 15.9, 17.0; $\eta_p^2 = 0.604$) for females and 16.7 (95% CI: 16.2, 17.2; $\eta_p^2 = 0.643$) for males. For females aged ≥ 65 years, such rate decreased by 15.8 (95% CI: 14.0, 17.6; $\eta_p^2 = 0.115$). For males aged ≥ 65 years, such rate increased by 4.8 (95% CI: 2.9, 6.8; $\eta_p^2 = 0.011$).

For those aged ≤ 18 years, summer vacation was associated with lower AED visits ($p < 0.001$ for all, $\eta_p^2 = 0.298$ for females and 0.344 for males), with AED visit rate (per 100,000) decreased by 14.3 (95% CI: 13.4, 15.2) for females and 18.4 (95% CI: 17.4, 19.5) for males during summer vacation.

There was a decreasing trend in the AED visit rate for those aged ≥ 65 years, but an increasing trend for those aged ≤ 18 years and 19–64 years. The day of the week was significant in all models, with the “Monday effect” observed in all subgroups ($\eta_p^2 = 0.005$ and 0.007 for females and males ≤ 18 years, respectively, and 0.105 to 0.336 for other subgroups). Although public holidays were significant in all models, the direction of the effect was different. All those aged ≤ 18 years and females aged 19–64 years had increased AED visits on public holidays, whereas males aged 19–64 years and all those aged ≥ 65 years had decreased visits on those days. However, it should be noted that the public holiday variable and Sunday had some extent of dependency ($VIF > 5$), fitted coefficients had to be interpreted with care. The impact of typhoons and rainstorms also varied across the different subgroups.

Discussions

Based on hospital administration records, this study demonstrated significant associations between the daily AED visit rate and heat stress as defined by UTCI, using Hong Kong as an example of a subtropical climate. This study not only contributed to expand our knowledge by providing evidence that such associations exist in subtropical climates, but also highlighted that the strength of these associations varied across different age- and sex-specific population subgroups. Furthermore, the association with prolonged heat

stress correlated differently in both direction and strength with the AED visit rate among the different subgroups.

Heat stress can be defined by a number of indicators, ranging from ambient temperature to composite indices. In this study, the UTCI was used to define heat stress. A previous local study suggested that the UTCI is capable of determining the thermal stress experienced by the human body (Cheung & Hart 2014). In the current study, we found that in the period studied, almost 80% of the days were considered to have strong or very strong heat stress. Despite the common occurrence of heat stress, significant associations with AED visits have been reported.

Our study showed that heat stress was more influential in adult males and the older population (small-to-moderate effect size ($\eta_p^2=0.037$) for males aged 19–64 years and small effect size ($\eta_p^2=0.016$ and 0.014) for females and males aged ≥ 65 years), but negligible effect size in children and adult females (for females and males aged ≤ 18 years ($\eta_p^2=0.003$ and 0.005) and females aged 19–64 years ($\eta_p^2=0.008$)). Our findings that AED visits among adult males showed the strongest association with heat stress was consistent with the review that adults showed stronger association than the older adults, particularly AED visits related to dysrhythmia, ischemic heart disease, and hypotension (Basu et al., 2012). In Spain, it was reported that the heat-related mortality was observed for middle-aged males but not females (Díaz et al., 2006). It was consistent with our results in the way that males aged 19–64 exhibited larger effect size than their female counterparts, although, in our study, both gender showed significant associations with heat stress.

The working population, aged 19–64 years, may have been working outdoors, for instance, those engaged in the construction and logistics industries. Heat stress in workplaces would cause heat exhaustion and heat stroke if proper precautions are not implemented (Kjellstrom et al., 2020). The excessive heat stress faced by the construction workers has been reviewed by Rowlinson et al. (2014). In Hong Kong, nearly 10% of the working population is in the construction industry, along with several other industries requiring outdoor workers. A study reported that about 17.5% of the work in the hot summer months of the Hong Kong construction workers were at high risk and 34.2% at moderate risk, and the heart rate during the work period mostly belonged to 55–69% maximum heart rate (Yi & Chan 2017). The physical work capacity showed significant reduction by 78% when wet bulb globe temperature reached 40 °C (Foster et al. 2021). Moreover, a study conducted in Beijing reported that emergency admissions related to cerebral infarction had the strongest association with heat stress among those aged 45–64 years, when UTCI reached 38 °C, such occurrence increased by 64% (Ma et al. 2018). In the case of young adults, an increase in their AED visits may be related to

their higher frequency of engagement in outdoor activities, which exposes them to a greater risk of emergency conditions. According to a behavioral risk factor survey in Hong Kong, 3.6% of young adults aged 18 to 24 years experienced a heat stroke in 2015 (Bacon-Shone 2016).

In older adults, the adverse health outcomes from heat stress could be explained by their weakened ability to detect heat and trigger appropriate behavioral and physiological reactions for body temperature regulation. Similarly, those with comorbidities and under medication may also have a reduced ability to detect and respond to heat (Kenny et al. 2010). In a subtropical climate region, thermoregulation becomes more challenging during hot and humid summers, wherein heat is less likely to escape from the human body through radiation and evaporation. Failure in thermoregulation induces various cardiovascular responses and changes in fluid regulation, thus resulting in a higher risk of adverse health events, such as heat stroke, acute myocardial infarction, thrombosis, ischemic stroke, electrolyte imbalances, and acute kidney injury (Meade et al. 2020). These acute conditions require emergency health services.

In children, their underdeveloped thermoregulatory system and higher metabolic rate may render them vulnerable to heat stress; an association between heat waves and several cause-specific morbidities, such as renal disease, respiratory disease, electrolyte imbalance, and fever, has been reported in the literature (Xu et al. 2014). However, our study did not show a significant association between AED visits and heat stress among children. Possible reasons may include the use of all-cause AED visits instead of cause-specific ones, and the control of air pollution and other factors as variables. Further research is warranted to investigate these inconsistencies.

Literature showed the prolonged heat wave in Poland, with midday UTCI means at three standard deviations above that of the period of 1951–2018, increased the total mortality and strong heat-related mortality by 10% and 5-folds in June 2019, respectively, as compared to 2010–2018 (Błażejczyk et al. 2022). We found that prolonged heat, defined by the total number of days with strong to very strong heat stress over 7 days, showed varied correlations with AED visits for different age groups. Males aged 19–64 years had small-to-moderate effect size ($\eta_p^2=0.021$), females and males aged ≥ 65 years had small effect size ($\eta_p^2=0.019$ and 0.012), but negligible effect size for females and males aged ≤ 18 years ($\eta_p^2=0.005$ and 0.007) and females aged 19–64 years ($\eta_p^2=0.003$). While prolonged heat was associated with fewer AED visits among older adults and children, it was associated with more AED visits among adults aged 18–64 years. The negative correlation may be explained by the survival of the fittest concept (i.e., those who were weaker may have already become sick earlier during the 7 days), which is likely for the case of the older adults and children.

Table 4 ANCOVA models for daily AED admission rates (per 100,000) among males

Independent variables	Male ≤18				Male 19–64				Male ≥65			
	Coef	95% CI	P-value	η_p^2	Coef	95% CI	P-value	η_p^2	Coef	95% CI	P-value	η_p^2
Daily maximum UTCI	[ref]		0.005	0.005	[ref]		< 0.001	0.037	[ref]		< 0.001	0.014
Thermonutral conditions to moderate heat stress												
Strong heat stress	1.9	(0.6, 3.2)	0.003	0.004	1.7	(1.3, 2.1)	< 0.001	0.032	4.1	(2.6, 5.6)	< 0.001	0.013
Very strong heat stress	2.6	(0.9, 4.2)	0.002	0.004	2.2	(1.7, 2.7)	< 0.001	0.030	4.7	(2.7, 6.6)	< 0.001	0.010
Number of days with strong to very strong heat stress in the past seven days	-0.6	(-0.9, -0.3)	< 0.001	0.007	0.3	(0.2, 0.4)	< 0.001	0.021	-0.9	(-1.3, -0.6)	< 0.001	0.012
Daily general AQHI												
Low health risk	[ref]								[ref]			
Moderate to very high health risk	2.8	(1.7, 4.0)	< 0.001	0.010	0.01	(-0.3, 0.4)	0.949	<0.001	0.01	(-1.3, 1.3)	0.987	<0.001
Number of days with air quality of moderate to very high health risk in the past 7 days	-0.01	(-0.3, 0.2)	0.950	<0.001	-0.1	(-0.2, -0.01)	0.020	0.002	-0.1	(-0.3, 0.2)	0.707	<0.001
Typhoon signal												
None	[ref]		0.125	0.002	[ref]		< 0.001	0.007	[ref]		< 0.001	0.020
Nos. 1 or 3	0.7	(-1.1, 2.6)	0.455	<0.001	-0.2	(-0.8, 0.3)	0.393	<0.001	-1.4	(-3.5, 0.7)	0.201	0.001
Nos. 8, 9, or 10	4.1	(-0.1, 8.3)	0.053	0.002	-2.7	(-3.9, -1.4)	< 0.001	0.007	-16.6	(-21.5, -11.8)	< 0.001	0.020
Rainstorm warning signal												
None	[ref]		< 0.001	0.010	[ref]		0.008	0.005	[ref]		0.003	0.006
Amber	-1.9	(-3.7, -0.2)	0.032	0.002	-0.7	(-1.2, -0.1)	0.015	0.003	-2.7	(-4.7, -0.7)	0.009	0.003
Red	-6.9	(-10.4, -3.4)	< 0.001	0.007	-0.7	(-1.7, 0.4)	0.232	0.001	-4.4	(-8.4, -0.4)	0.033	0.002
Black	-6.9	(-13.1, -0.8)	0.027	0.002	-2.3	(-4.2, -0.4)	0.018	0.002	-7.3	(-14.5, -0.2)	0.044	0.002
Year	0.6	(0.5, 0.7)	< 0.001	0.031	0.1	(0.01, 0.1)	0.008	0.003	-1.1	(-1.3, -1.0)	< 0.001	0.078
Day of the week												
Sat	[ref]		< 0.001	0.064	[ref]		< 0.001	0.400	[ref]		< 0.001	0.164
Sun	-1.5	(-4.7, 1.6)	0.330	<0.001	2.9	(2.0, 3.9)	< 0.001	0.015	5.7	(2.1, 9.3)	0.002	0.004
Mon	3.6	(1.9, 5.3)	< 0.001	0.007	9.2	(8.6, 9.7)	< 0.001	0.336	20.0	(18.0, 22.0)	< 0.001	0.146
Tue	-3.3	(-5.0, -1.5)	< 0.001	0.006	3.3	(2.7, 3.8)	< 0.001	0.061	7.0	(5.0, 9.0)	< 0.001	0.021
Wed	-4.8	(-6.6, -3.1)	< 0.001	0.013	1.7	(1.2, 2.2)	< 0.001	0.017	3.8	(1.8, 5.8)	< 0.001	0.006
Thu	-5.1	(-6.8, -3.4)	< 0.001	0.015	1.5	(0.9, 2.0)	< 0.001	0.013	6.4	(4.5, 8.4)	< 0.001	0.017
Fri	-4.2	(-5.9, -2.5)	< 0.001	0.010	0.9	(0.4, 1.4)	0.001	0.005	6.2	(4.2, 8.2)	< 0.001	0.016

Table 4 (continued)

Independent variables	Male ≤ 18				Male 19–64				Male ≥ 65			
	Coef	95% CI	P-value	η_p^2	Coef	95% CI	P-value	η_p^2	Coef	95% CI	P-value	η_p^2
Public Holiday (include Sunday)												
No	[ref]				[ref]				[ref]			
Yes	15.2	(12.5, 17.9)	< 0.001	0.051	-2.3	(-3.1, -1.5)	< 0.001	0.013	-10.7	(-13.8, -7.6)	< 0.001	0.020
Summer vacation												
No	[ref]				NA				NA			
Yes	-18.4	(-19.5, -17.4)	< 0.001	0.344								
Fee of AED visit												
Free of charge	[ref]				[ref]				[ref]			
Charged	-26.8	(-28.5, -25.2)	< 0.001	0.307	-16.7	(-17.2, -16.2)	< 0.001	0.643	4.8	(2.9, 6.8)	< 0.001	0.011

Coef, coefficient; CI, confidence interval; η_p^2 , partial eta square; [ref], reference level; NA, not applicable

Due to their lower capacity in thermoregulation, they may be hospitalized once facing heat stress. Those who could survive prolonged heat stress are likely to be healthier. For adults, while they could stand longer heat stress, each day of heat stress did post additional risks to them. Therefore, the longer the period for which they were exposed to heat stress, the higher the risk of acute health events. Previous studies also reported a relatively smaller effect of prolonged stress-induced mortality compared to heat stress on a particular day. For instance, Gasparrini and Armstrong (2011) reported that after four consecutive heat stress day, the added risk of mortality was only 0.2–0.8%, whereas the main effect was 4.9–8.0%. Another local study reported that at least five non-consecutive Hot Days and Hot Nights within a week was associated with a 15.6% increase in all-cause mortality at lag 0–1 but a 2% decrease at lag 2–3 (Ho et al. 2017). In Brisbane, a city with a subtropical climate, a 50.6% increase in ambulance attendances was shown to be associated with a 9.5 °C increase above the ambient temperature of 29 °C, but prolonged heat stress from heat waves had a significant but smaller effect (18.8% increase) compared to acute heat stress (Turner et al. 2013). Focusing on mortality among older adults in Europe, long heat wave had larger effect than short heat wave (D’Ippoliti et al., 2010). On the other hand, it was reported that in Europe, heat-related mortality rose rapidly with heat stress and the lag effect was only about one (Błażejczyk & McGregor, 2008; Laschewski & Jendritzky 2002). Nevertheless, prolonged heat stress could be confounded by lagged effects, as reported in the literature (Ye et al. 2012). Further research is warranted to examine the associations and, more importantly, to explore the underlying mechanisms.

The potential risk factors were controlled in the models. While the AED visit fees, day of the week, public holidays, and years had an influential impact on the rate of AED visits, heat stress and/or prolonged heat stress remained significant after controlling for these factors. The impact of air quality on AED visits was minimal for adults and older adults. Although a multi-city study in China found that the association between mortality and air pollution was amplified by high temperatures, a 10 µg/m³ increase in PM_{2.5} was found to associate with 0.33–0.52%, 0.39–0.98%, and 1.32–2.25% increase in cardiovascular mortality when the daily ambient temperature as at < 10th, 10th–90th, and > 90th percentiles (Zhang et al. 2020). On the other hand, a study conducted in Beijing suggested that the association between air pollutants and respiratory emergency department visits was significantly stronger on moderately cold days (relative risk being 1.006 for 10 µg/m³ increase in PM_{2.5}) than that on cold days (relative risk being 1.004), but insignificant differences on moderately hot days and hot days (Song et al. 2021). As our study period only included summers, the effects of air quality may not have been so obvious. In contrast,

among children, air quality had an effect size ($\eta_p^2=0.004$ for females and 0.010 for males) comparable to that from heat stress ($\eta_p^2=0.003$ for females and 0.005 for males). This may be because over 70% of AED visits among pediatric patients were influenza related (Kwong et al., 2009), and thus, air pollution is more likely to be a trigger.

Our findings were consistent with local evidence supporting the association between hot ambient temperatures. For instance, the relative risk for respiratory-related hospitalization on a day with ambient temperature > 90th percentile (29.5 °C) and > 99th percentile (30.6 °C) was estimated to be 1.06 and 1.14 respectively (Sun et al. 2019); the cumulative relative risk of asthma hospitalization for lags 0–3 days was 1.2 for a day with ambient temperature of 30 °C as compared to 27 °C (Lam et al. 2016); increase of 10 hot degree days (sum of daily ambient temperature in degree above 29.3 °C) in a year was associated with around 2% increase in the annual age-standardized mortality (Goggins et al., 2015). However, perceived thermal comfort can vary depending on the humidity, wind speed, and radiation. Hence, the effect size of hot weather based on ambient temperature may be more suitable in the local context. On the other hand, UTCI has the advantage of considering thermal stress in the development of thresholds. Hence, it is supposed to be applicable to different climate zones, and the effect size of hot weather based on the UTCI could be generalizable to other climate zones.

According to the Hospital Authority statistics, there were 2,048,039 AED admissions in year 2020, giving a daily average of 5596. Based on the 2020 population and our estimated AED visit rate, it is expected that on a day with strong heat stress, we may have an additional 137 AED admissions, compared to days with thermoneutral to moderate heat stress conditions; whereas on a day with very strong heat stress, we may have an additional 156 AED admissions. This means a 2.4 to 2.8% surge in the daily AED usage. In terms of service provision, emergency departments may be generally well prepared for days when heat stress is expected to occur. A local study predicted that there would be more days with strong heat stress in the future (Cheung & Hart 2014). It was projected that the proportion of days with strong heat stress would increase from 20.6% in 1971–2000 to 26.2–31.8% in 2046–2065, and the proportion of days with very strong heat stress would increase from 0.1% in 1971–2000 to 0.3–2.1% in 2046–2065. The urban heat island effect worsen the situation. The urban heat island duration was found increasing during 1990–2015 from 13.59 to 17.47 h in built-up areas in Hong Kong, as a result of urbanization and human activities associated with population growth (Chen & Jeong 2018). Local urbanization, in particular the reduction of greenery coverage, development of new towns, and extensive reclamation in coastal urban areas accounts for the increasing trend of urban temperature (Lau & Ng 2013). It was also

reported that the temperature of the impervious land surface in megacities of Southeast Asia was 3 °C hotter than green space, on average (Estoque et al., 2017). Thus, the adverse effects of heat stress cannot be neglected. Nevertheless, as the UTCI was not readily available from the HKO or most of the other observatories, the release of this information during the weather forecast or its incorporation into the weather warning system is recommended.

From a public health perspective, awareness of the influence of heat stress should be raised among the population. In Hong Kong, a hot weather warning system was launched in year 2000. When the extreme hot weather reached the specific threshold, the HKO would issue the Very Hot Weather Warning. Related precautions to prevent heat-related adverse outcomes were provided in the HKO website (Hong Kong Observatory 2021a). It was found that days with absence of such warning was associated with an increase of about 1.2 deaths from ischemic heart disease and 1.0 death from stroke among the older adults per day (Chau et al. 2009). In September 2021, the HKO added more precautionary measures to the website to address the special needs of older adults and those with chronic illnesses (Hong Kong Observatory 2021b). Besides alerting the public, the warning also served to alert relevant government departments and non-governmental organizations to take suitable actions. Moreover, if the threshold for issuing the Very Hot Weather Warning was not met, yet the situation could already trigger adverse health outcomes, the HKO would issue Hot Weather Special Advisory to alert the public and the stakeholders to take early precautions. In the USA, with improved heat warning systems and increased public awareness, decline in heat vulnerability had once been reported; however, a reverse trend was observed recently, particularly among the vulnerable groups (Sheridan et al. 2021). It is important to re-explore effective strategies to ameliorate the adverse health effects from heat stress, in addition to reviewing the thresholds that triggered the warnings to make sure that it could well reflect the latest situations in terms of global warning and heat island effect.

While older people are less likely to engage in outdoor activities during hot days, keeping their home cool at a low cost is important. Proper housing design with passive cooling strategies, such as direction of windows and ventilation, cool materials used in buildings, can prevent heat from entering and allowing heat dissipating with minimal energy load is particularly important for the South Asian regions (Sharma et al. 2022). In Japan, usage of sun-shade (in form of a white polyester tarpaulin) was reported to reduce at least 1 h of unsafe heat exposure during the day (Otani & Lee, 2022). In Hong Kong, open spaces purposefully designed with more breeze and shades were found to reduce outdoor thermal stress by 2 °C (in terms of UTCI) and attract more social activities, as well as more frequent

and longer duration of stay in these spaces by older people in Hong Kong (Huang et al. 2020). Free public areas equipped with meaningful activities, such as libraries and town halls, would also be ideal for the older population, both to stay away from heat stress and boost social participation. These measures often involve administrative and policy stakeholders to support the infrastructure and to raise public awareness and promote education through effective information dissemination channels.

The adult population may be engaged in outdoor activities such as outdoor work. Their health risk and physical work capacity have also been underscored (Kjellstrom et al., 2020). Therefore, awareness of occupational safety in terms of preventing heat-related adverse events is important. Developing early warning and forecast system for heat should form part of the heat action plans as an administrative tool to increase people's preparedness against extreme heat events (Sharma et al. 2022). Preventive measures such as reducing work intensity, taking frequent breaks, improving ventilation, cooling clothing, cold water immersion, heat acclimation, cold fluid intake are reported to be effective to mitigate occupational heat stress (Morris et al. 2020). Teaching public strategies to be resilient during heat stress is of utmost importance in the era of global warming. For outdoor leisure activities, a reduction in risky behaviors should be advocated among young adults, such as avoiding hiking during times of significant heat stress. Furthermore, proper health-seeking behaviors, such as seeking emergency care after a heat stroke, should be included as an additional public education topic.

For all population subgroups, they would be benefited from better urban design. Increasing the percentage of community greenery and blue-green spaces have been widely adopted and promoted measures to regulate heat, noise, and pollution (Filho et al., 2021; Pascal et al. 2021; Krüger 2021). Tall urban vegetation showed positive impact on thermal comfort through shading and evapotranspiration, bringing down thermal exposure and UTCI by up to 10.5 °C (Lehnert et al. 2021). Increasing urban water bodies and blue infrastructures promotes evaporative cooling and reduces urban heat island effects (Krüger, 2021; Sharma et al. 2022). Yet, these infrastructures would better be carefully designed and fitted into city planning to maximum the effectiveness (Kolokotsa et al. 2022). Infrastructural modifications including building materials to increase surface albedo and decrease heat absorption are also mitigation measures (Krüger, 2021; Sharma et al. 2022).

From a research perspective, more in-depth investigations on the association between heat stress and health while controlling for individual-level socio-demographic and health conditions are needed. Other threshold values for defining heat stress, say by using the 90th-percentile or 95th-percentile of UTCI, may be explored. Furthermore, as individuals

may be exposed to different heat stresses depending on the surrounding environment, studies based on microclimate information would better reflect the specific association of a particular environment with heat stress. While all-cause AED visits could cover both direct and indirect health outcomes from heat, cause-specific AED visits should be explored in the future to determine differential impacts.

The strength of this study is the use of longitudinal administrative data across 15 years in the analyses, covering the majority of AED visits in Hong Kong. However, as one of the variables in the UTCI formula, the black globe temperature was not available in Hong Kong until 2014; thus, a proxy of global solar radiation was used. The use of hourly maximum UTCI might also differ from that based on 1 min or 10-min basis. Future studies should repeat the same analysis with different calculations of the UTCI when more data of healthcare utilization are available. As aggregated data were obtained, individual-level data were not available. Thus, age-standardized rates could not be used, and individual-level risk factors could not be controlled. For example, as the UTCI describes outdoor weather conditions, the results might not reflect genuine associations if the individual stayed indoors. Moreover, individual perceptions of thermal comfort could not be investigated because of the nature of the aggregated data. The confounding risks of prolonged and delayed effects may not be distinguishable. A sensitivity analysis was conducted by replacing the cumulative number of days of heat stress and poor air quality over 7 days with a lag of 1–7 for heat stress and poor air quality indicators. The results showed that the model fit, as revealed by the adjusted *R* square, did not improve. While previous studies have shown that the association between hot weather and AED visits varies by age and causes of visits (Basu et al., 2012), our aggregated data did not allow us to analyze cause-specific relationships. Although there could be autocorrelation in the AED rates, we did not include the autoregressive terms in the models as the past rates were also related to the weather. Future studies could use time series approach such as transfer function (Chau et al. 2020). Finally, this study was based on observational data; therefore, only associations could be investigated, rather than causations.

In conclusion, biothermal condition from heat stress was associated with the health of the citizens in a city with a subtropical climate and reflected in the increase of daily AED visit. The associations varied across different age and sex subgroups. Based on these findings, public health recommendations have been made for the prevention of heat-related AED visits.

Acknowledgements The work described in this paper was supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. R4046-18).

Author contribution Conceptualization: Pui Hing CHAU, Kevin Ka-Lun LAU; data curation: Kevin Ka-Lun LAU; formal analysis: Pui Hing CHAU, Xing Xing QIAN; methodology: Pui Hing CHAU, Hao LUO; resources: Kevin Ka-Lun LAU; software: Pui Hing CHAU, Xing Xing QIAN; writing—original draft: Pui Hing CHAU; writing—review and editing: Pui Hing CHAU, Kevin Ka-Lun LAU, Xing Xing QIAN, Hao LUO, Jean WOO.

Funding This work was supported by the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. R4046-18).

Declarations

Ethics approval and consent to participate Ethical approval was granted by the Institutional Review Board of the University of Hong Kong/Hospital Authority, Hong Kong West Cluster (reference number UW19-388).

Consent for publication Not applicable.

Data availability Not applicable.

Competing interests The authors declare no competing interests.

References

- Baccini M, Biggeri A, Accetta G, Kosatsky T, Katsouyanni K, Analitis A, Anderson HR, Bisanti L, D'Ippoliti D, Danova J, Forsberg B, Medina S, Paldy A, Rabcenko D, Schindler C, Michelozzi P (2008) Heat effects on mortality in 15 European cities. *Epidemiol Cambridge Mass* 19(5):711–719
- Bacon-Shone, J. (2016). Behavioural Risk Factor Survey April 2015. Retrieved from www.chp.gov.hk/files/pdf/brfs_2015apr_en.pdf
- Basu R, Pearson D, Malig B, Broadwin R, Green R (2012) The effect of high ambient temperature on emergency room visits. *Epidemiology* 23(6):813–820. <https://doi.org/10.1097/EDE.0b013e31826b7f97>
- Bishop-Williams KE, Berke O, Pearl DL, Kelton DF (2015) A spatial analysis of heat stress related emergency room visits in rural Southern Ontario during heat waves. *BMC Emerg Med* 15:17
- Błażejczyk K, & McGregor G. (2008) Mortality in European cities and its relations to biothermal conditions. *Klimat i bioklimat miast*, Wydawnictwo Uniwersytetu Łódzkiego 313–324
- Błażejczyk K, Broede P, Fiala D, Havenith G, Holmér I, Jendritzky G, . . . Kunert, A. (2010). Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. *Miscellanea Geographica* 14(1) 91–102
- Błażejczyk K, Jendritzky G, Bröde P, Fiala D, Havenith G, Epstein Y, . . . Kampmann B. (2013) An introduction to the universal thermal climate index (UTCI) *Geogr Pol* 86 1 5 10
- Błażejczyk K, Twardosz R, Wałach P, Czarnecka K, Błażejczyk A (2022) Heat strain and mortality effects of prolonged central European heat wave—an example of June 2019 in Poland. *Int J Biometeorol* 66(1):149–161
- Burkart K, Breitner S, Schneider A, Khan MM, Krämer A, Endlicher W (2014) An analysis of heat effects in different subpopulations of Bangladesh. *Int J Biometeorol* 58(2):227–237
- Castner J, Yin Y, Loomis D, Hewner S (2016) Medical Mondays: ED utilization for medicaid recipients depends on the day of the week, season, and holidays. *J Emerg Nurs* 42(4):317–324
- Chan EY, Goggins WB, Kim JJ, Griffiths S, Ma TK (2011) Help-seeking behavior during elevated temperature in Chinese population. *J Urban Health* 88(4):637–650
- Chan EY, Goggins WB, Yue JS, Lee P (2013) Hospital admissions as a function of temperature, other weather phenomena and pollution levels in an urban setting in China. *Bull World Health Organ* 91(8):576–584
- Chau PH, Chan KC, Woo J (2009) Hot weather warning might help to reduce elderly mortality in Hong Kong. *Int J Biometeorol* 53(5):461–468
- Chau PH, Yip PSF, Lau HYE, Ip YT, Law FYW, Ho RTH, Leung AYM, Wong JYH, Woo J (2020) Hot weather and suicide deaths among older adults in Hong Kong, 1976–2014: a retrospective study. *Int J Environ Res Public Health* 17(10):3449
- Chen X, Jeong SJ (2018) Shifting the urban heat island clock in a megacity: a case study of Hong Kong. *Environ Res Lett* 13(1):014014
- Cheung CS, Hart MA (2014) Climate change and thermal comfort in Hong Kong. *Int J Biometeorol* 58(2):137–148
- Cohen J (1973) Eta-squared and partial eta-squared in fixed factor ANOVA designs. *Educ Psychol Measur* 33(1):107–112
- Dessai S (2002) Heat stress and mortality in Lisbon part I. model construction and validation. *Int J Biometeorol* 47(1):6–12
- Díaz J, García R, Velázquez de Castro F, Hernández E, López C, Otero A (2002) Effects of extremely hot days on people older than 65 years in Seville (Spain) from 1986 to 1997. *Int J Biometeorol* 46(3):145–149
- Díaz J, Linares C, Tobías A (2006) Impact of extreme temperatures on daily mortality in Madrid (Spain) among the 45–64 age-group. *Int J Biometeorol* 50(6):342–348
- D'Ippoliti D, Michelozzi P, Marino C, de'Donato F, Menne B, Katsouyanni K, Kirchmayer U, Analitis A, Medina-Ramón M, Paldy A, Atkinson R, Kovats S, Bisanti L, Schneider A, Lefranc A, Iñiguez C, Perucci CA (2010) The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environ Health* 9:37
- Environmental Protection Department. (2020). What is the Air Quality Health Index (AQHI)?. Retrieved from https://www.aqhi.gov.hk/en/what-is-aqhi/faqs.html#e_01
- Estoque RC, Murayama Y, Myint SW (2017) Effects of landscape composition and pattern on land surface temperature: an urban heat island study in the megacities of Southeast Asia. *Sci Total Environ* 577:349–359
- Filho WL, Wolf F, Castro-Díaz R, Li C, Ojeh VN, Gutiérrez N, Nagy GJ, Savic S, Natenzon CE, Al-lmin AQ, Maruna M, Bönecke J (2021) Addressing the urban heat islands effect: a cross-country assessment of the role of green infrastructure. *Sustainability* 13(2):753
- Foster J, Smallcombe JW, Hodder S, Jay O, Flouris AD, Nybo L, Havenith G (2021) An advanced empirical model for quantifying the impact of heat and climate change on human physical work capacity. *Int J Biometeorol* 65(7):1215–1229
- Gasparrini A, Armstrong B (2011) The impact of heat waves on mortality. *Epidemiology* 22(1):68–73
- Goggins WB, Yang C, Hokama T, Law LS, Chan EY (2015) Using annual data to estimate the public health impact of extreme temperatures. *Am J Epidemiol* 182(1):80–87
- Gubernot DM, Anderson GB, Hunting KL (2015) Characterizing occupational heat-related mortality in the United States, 2000–2010: an analysis using the Census of Fatal Occupational Injuries database. *Am J Ind Med* 58(2):203–211

- Hahn B, Zuckerman B, Durakovic M, Demissie S (2018) The relationship between emergency department volume and patient complexity. *Am J Emerg Med* 36(3):366–369
- Ho HC, Lau KK, Ren C, Ng E (2017) Characterizing prolonged heat effects on mortality in a sub-tropical high-density city, Hong Kong. *Int J Biometeorol* 61(11):1935–1944
- Hong Kong Observatory. (2021a). Cold and very hot weather warnings. Retrieved from <https://www.hko.gov.hk/en/ws/service/warning/coldhot.htm>
- Hong Kong Observatory. (2021b). The observatory enhances the very hot weather warning service through partnerships. Retrieved from <https://www.hko.gov.hk/en/Whats-New/106355/The-Observatory-Enhances-the-Very-Hot-Weather-Warning-Service-through-Partnerships>
- Huang J, Chen Y, Jones P, Hao T. (2020). Heat stress and outdoor activities in open spaces of public housing estates in Hong Kong: a perspective of the elderly community. *Indoor and Built Environ* 1420326X20950448
- Intergovernmental Panel on Climate Change. (2021). *Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf
- Intergovernmental Panel on Climate Change. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from <https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/>
- ISB Commission 6. (2014). UTCI Universal Thermal Climate Index documents. Retrieved from http://www.utci.org/utci_doku.php
- Jendritzky G, de Dear R, Havenith G (2012) UTCI—why another thermal index? *Int J Biometeorol* 56(3):421–428
- Kenny GP, Yardley J, Brown C, Sigal RJ, Jay O (2010) Heat stress in older individuals and patients with common chronic diseases. *Canadian Med Ass J* 182(10):1053–1060
- Kjellstrom T, Oppermann E, & Lee JKW. (2020). Climate change, occupational heat stress, human health, and socioeconomic factors. *Handbook of Socioeconomic Determinants of Occupational Health*, 71–89
- Kolokotsa D, Lilli K, Gobakis K, Mavriagiannaki A, Haddad S, Garsasbi S, Mohajer HRH, Paolini R, Vasilakopoulou K, Bartsaghi C, Prasad D, Santamouris M (2022) Analyzing the impact of urban planning and building typologies in urban heat island mitigation. *Buildings* 12(5):537
- Krüger EL. (2021) Applications of the Universal Thermal Climate Index UTCI in Biometeorology: Latest developments and case studies (Vol. 4). Springer Nature
- Kuchcik M, Błażejczyk K, Halaś A (2021) Long-term changes in hazardous heat and cold stress in humans: multi-city study in Poland. *Int J Biometeorol* 9:1567–1578
- Kwong KL, Lung D, Wong SN, Que TL, Kwong NS (2009) Influenza-related hospitalisations in children. *J Paediatr Child Health* 45(11):660–664
- Lam CKC, Lau KK (2018) Effect of long-term acclimatization on summer thermal comfort in outdoor spaces: a comparative study between Melbourne and Hong Kong. *Int J Biometeorol* 62(7):1311–1324
- Lam HC, Li AM, Chan EY, Goggins WB 3rd (2016) The short-term association between asthma hospitalisations, ambient temperature, other meteorological factors and air pollutants in Hong Kong: a time-series study. *Thorax* 71(12):1097–1109
- Laschewski G, Jendritzky G (2002) Effects of the thermal environment on human health: an investigation of 30 years of daily mortality data from SW Germany. *Climate Res* 21(1):91–103
- Lau KL, Ng E (2013) An investigation of urbanization effect on urban and rural Hong Kong using a 40-year extended temperature record. *Landsc Urban Plan* 114:42–52
- Lee KL, Chan YH, Lee TC, Goggins WB, Chan EY (2016) The development of the Hong Kong Heat Index for enhancing the heat stress information service of the Hong Kong Observatory. *Int J Biometeorol* 60(7):1029–1039
- Lehnert M, Tokar V, Jurek M, Geletič J (2021) Summer thermal comfort in Czech cities: measured effects of blue and green features in city centres. *Int J Biometeorol* 65(8):1277–1289
- Leung Y, Yip K, Yeung K (2008) Relationship between thermal index and mortality in Hong Kong. *Meteorol Appl* 15:399–409
- Li P, Chan S (2000) Application of a weather stress index for alerting the public to stressful weather in Hong Kong. *Meteorol Appl* 7:369–375
- Li M, Gu S, Bi P, Yang J, Liu Q (2015) Heat waves and morbidity: current knowledge and further direction—a comprehensive literature review. *Int J Environ Res Public Health* 12(5):5256–5283
- Lin CH, Hou SK, Shih FF, Su S (2013) The effect of tropical cyclones (typhoons) on emergency department visits. *J Emerg Med* 45(3):372–379
- Ma P, Zhou J, Wang S, Li T, Fan X, Fan J, Xie J (2018) Differences of hemorrhagic and ischemic strokes in age spectra and responses to climatic thermal conditions. *Sci Total Environ* 644:1573–1579
- Meade RD, Akerman AP, Notley SR, McGinn R, Poirier P, Gosselin P, Kenny GP (2020) Physiological factors characterizing heat-vulnerable older adults: a narrative review. *Environ Int* 144:105909
- Michelozzi P, Fano V, Forastiere F, Barca A, Kalkstein LS, Perucci CA (2000) Weather conditions and elderly mortality in Rome during summer. *Bull World Meteorol Org* 49(4):348–355
- Michelozzi P, Accetta G, De Sario M, D'Ippoliti D., Marino, C, Baccini, M, Biggeri, A, Anderson, HR, Katsouyanni, K, Ballester, F, Bisanti, L., Cadum, E, Forsberg, B, Forastiere, F, Goodman, PG, Hojs, A, Kirchmayer, U, Medina, S, Paldy, A, Schindler, C., ... PHEWE Collaborative Group (2009). High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. *American J Respir Critical Care Med*, 179(5), 383–389
- Morris NB, Jay O, Flouris AD, Casanueva A, Gao C, Foster J, Havenith G, Nybo L (2020) Sustainable solutions to mitigate occupational heat strain - an umbrella review of physiological effects and global health perspectives. *Environ Health* 19(1):95
- Otani H, Lee J (2022) The use of sun-shade on safe heat exposure limit on a sunny summer day: a modelling study in Japan. *Int J Biometeorol* 66(4):731–740
- Pascal M, Gorla S, Wagner V, Sabastia M, Guillet A, Cordeau E, Maucclair C, Host S (2021) Greening is a promising but likely insufficient adaptation strategy to limit the health impacts of extreme heat. *Environ Int* 151:106441
- Qiu H, Yu IT, Tse LA, Chan EY, Wong TW, Tian L (2015) Greater temperature variation within a day associated with increased emergency hospital admissions for asthma. *Sci Total Environ* 505:508–513
- Romaszko-Wojtowicz A, Cymes I, Dragańska E, Doboszyńska A, Romaszko J, Glińska-Lewczuk K (2020) Relationship between biometeorological factors and the number of hospitalizations due to asthma. *Sci Rep* 10(1):9593
- Rowlinson S, YunyanJia A, Li B, ChuanjingJu C (2014) Management of climatic heat stress risk in construction: a review of practices, methodologies, and future research. *Accid Anal Prev* 66:187–198
- Sharma A, Andhikaputra G, Wang YC (2022) Heatwaves in South Asia: characterization, consequences on human health, and adaptation strategies. *Atmosphere* 13(5):734
- Sheridan SC, Dixon PG, Kalkstein AJ, Allen MJ (2021) Recent trends in heat-related mortality in the United States: an update through 2018. *Weather Clim Soc* 13(1):95–106

- Song X, Jiang L, Wang S, Tian J, Yang K, Wang X., . . . Zhang N. (2021) The impact of main air pollutants on respiratory emergency department visits and the modification effects of temperature in Beijing China *Environ Sci Pollut Res* 28 6 6990–7000
- Sun S, Cao W, Mason TG, Ran J, Qiu H, Li J, . . . Tian L. (2019) Increased susceptibility to heat for respiratory hospitalizations in Hong Kong *Sci Total Environ* 666 197–204
- Szyszkowicz M (2019) The Air Quality Health Index and all emergency department visits. *Environ Sci Pollut Res* 26(24):24357–24361
- Turner LR, Connell D, Tong S (2013) The effect of heat waves on ambulance attendances in Brisbane. *Aust Prehospital Disaster Med* 28(5):482–487
- Urban A, Kyselý J (2014) Comparison of UTCI with other thermal indices in the assessment of heat and cold effects on cardiovascular mortality in the Czech Republic. *Int J Environ Res Public Health* 11(1):952–967
- Wang Y, Liu, Y, Ye, D, Li, N, Bi, P., Tong, S., . . . Yao, X. (2020) High temperatures and emergency department visits in 18 sites with different climatic characteristics in China: Risk assessment and attributable fraction identification *Environment International* 136 105486
- Wang, P., Zhang, X., Hashizume, M., Goggins, W. B., & Luo, C. (2021). A systematic review on lagged associations in climate-health studies. *Int J Epidemiol*
- Wong TW, Tam WWS, Yu ITS, Lau AKH, Pang SW, Wong AHS (2013) Developing a risk-based Air Quality Health Index. *Atmos Environ* 76:52–58
- Xu Z, Sheffield PE, Su H, Wang X, Bi Y, Tong S (2014) The impact of heat waves on children's health: a systematic review. *Int J Biometeorol* 58(2):239–247
- Ye X, Wolff R, Yu W, Vaneckova P, Pan X, Tong S (2012) Ambient temperature and morbidity: a review of epidemiological evidence. *Environ Health Perspect* 120(1):19–28
- Yi W, Chan A (2017) Effects of heat stress on construction labor productivity in Hong Kong: a case study of rebar workers. *Int J Environ Res Public Health* 14(9):1055
- Zhang Y, Wang S, Zhang X, Ni C, Zhang J, Zheng C (2020) Temperature modulation of the adverse consequences on human mortality due to exposure to fine particulates: a study of multiple cities in China. *Environ Res* 185:109353