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LONG-TERM TREND IN THERMAL INDEX AND ITS IMPACT ON MORTALITY IN HONG KONG

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Summary

This study aims to examine the long-term trend in thermal index and its relationship with mortality in Hong Kong. In summer (May-September), the annual mean Net Effective Temperature (NET) and the annual mean daily maximum NET in Hong Kong are found to be increasing at a rate of 0.25 and 0.15 per decade respectively for 1983-2005. These increasing trends are likely to be due to a rise in temperature under global warming and urban development as well as a fall in wind speed due to high density urban development in Hong Kong. "Excess" deaths associated with hot weather are found to occur when the daily maximum NET exceeds 26. Using Poisson regression, it is estimated that the mean mortality associated with excessive heat would double per unit rise in NET beyond 26. Thus, if NET continues to rise under global warming, the mortality associated with excessive heat would increase.

In winter (November-March), the annual mean NET and the annual mean daily minimum NET have been increasing at a rate of 1.05 and 1.15 per decade respectively in the period 1983-2005. There are statistically significant negative-lagged correlations between the daily minimum NET and the daily mortality attributed to circulatory and respiratory diseases. In cold weather, "excess" deaths start to occur when the daily minimum NET is less than 14 and the mean mortality is estimated to increase by about 1.3-fold per unit fall in NET below 14. The elderly age group (≧ 65) is found to be more vulnerable to NET changes when compared to other age groups. Thus if NET continues to rise under global warming, the mortality due to circulatory and respiratory diseases in cold weather is expected to decrease.

Keywords
Mortality, Net Effective Temperature, Poisson Regression, Hong Kong.

1. Introduction

As an inter-disciplinary science, human biometeorology studies the relationship between atmospheric conditions and human well being. The existence of a relationship between climate and human health has long been noted since Hippocrates, a Greek physician at about 400 BC (WMO/WHO/UNEP, 2003). In recent years, the threat of global climate change has led to an increased interest in studying the effect of weather and climate on health (WMO 1999). An extensive literature (e.g. WMO/WHO/UNEP, 1996; WMO/WHO/UNEP, 2003) has pointed out that climate and climate change can directly or indirectly affect health.

Among the various weather elements, extreme hot and cold conditions have been shown to be the most significant ones in terms of human mortality and morbidity (WMO/WHO/UNEP, 1996; WMO, 1999). A typical example is the heat wave in the summer of 2003 that caused more than 21,000 deaths in southwestern Europe (WMO, 2004a).

Human beings are "warm-blooded", meaning that they maintain a uniform body temperature at 37°C despite variations in the thermal environment [HOUGHTON, 1985]. Within certain limits, thermal comfort can be maintained by appropriate thermoregulatory responses, and reflex actions such as sweating and shivering can be pursued without any detriment to health. However, temperatures exceeding the comfortable limits, both in the cold and hot ranges, substantially increase the risk of deaths (predominantly cardiopulmonary) [MARTENS, 1998]. This is especially true for the elderly and those with pre-existing heart, respiratory and chronic illness whose physiological thermoregulation mechanism is likely impaired.

Several mechanisms may explain the higher risk of thermal-induced mortality. The increased blood pressure, blood viscosity and heart rate associated with physiological adjustment to cold and hot weather may account for the increased mortality of diseases of the cardiovascular system [PAN et al, 1995]. Influenza may be indirectly attributed to cold-related mortality [KUNST et al, 1993] and pulmonary infections may increase through bronchoconstriction by breathing cold air [SCHAANNING et al, 1986].

Apart from temperature, the thermal comfort of humans is the result of the synergistic effect of other climatic components such as humidity and wind speed. To quantify these components, thermal indices were constructed for various combinations of them. Due to the great importance of thermal conditions for human well being, more than one hundred thermal indices are now known in literature (WMO, 2004b). Heat Index, Humidex, Windchill Index and Net Effective Temperature are some examples of commonly used indices.

The impacts of thermal stress on human mortality are well documented in higher latitude regions like Europe and North America [e.g. KOVATS et al, 2006; MARTENS, 1998]. Relatively little research has been done in tropical and subtropical areas. For Hong Kong, YAN [1997] analysed the thermal stress of climate by using the thermal indices - Apparent Temperature and CLO (a measure of comfort that provides an indication of the clothing required). LI et al [2000] devised a weather stress index (WSI) based on Net Effective Temperature and provided a case study on the comparison of WSI and daily mortality rate in January 1995. YAN [2000] studied the mortality seasonality as well as the relationship between monthly mortality and the meteorological variables in Hong Kong from 1980 to 1994. YIP et al [2006] analysed the long-term trends of six different kinds of thermal indices for Hong Kong. The present study aims to examine the statistical relationship between thermal index and daily mortality for Hong Kong due to various causes of death in summer (May to September) and winter (November to March) from 1995 to 2004 respectively. The vulnerability of different age groups to thermal stress is also investigated.

Poisson regression was employed to estimate the relative risk in mortality study for Valencia, Spain [BALLESTER et al, 1997] and for San Paulo, Brazil [SHAROVSKY et al, 2004]. The technique was also used to study the impact of ambient air pollution on public health in Hong Kong [WONG et al, 1997]. The present study makes use of this technique to estimate the change in mortality rate with the change in NET for various causes of death in Hong Kong.

2. Data and definition of thermal index

2.1 Meteorological and mortality data

Hourly temperature, relative humidity and wind speed recorded at the Hong Kong Observatory Headquarters are extracted for computing hourly values of the thermal index.

Daily mortality data for various causes of death (identified by ICD codes) in the 10-year period 1995-2004 are obtained from the Department of Health of Hong Kong. The data are classified under different age groups: child (＜15), young adult (15-34), middle age (35-64) and elderly (≧ 65).

In the present study, the mortality for all causes excluding external causes such as injury and poisoning (ALL), the mortality from the three major classes of disease Neoplasm (NEO), Circulatory (CIR), Respiratory (RES), as well as the mortality from Ischaemic Heart Diseases (IHD), Cerebrovascular diseases (CBD), Pneumonia and Influenza (PIF), Chronic Obstructive Pulmonary disease and allied (COP), Excessive Heat (EHEAT) and Excessive Cold (ECOLD) that are possibly related to thermal stress are examined. IHD and CBD are subsets of CIR whereas PIF and COP are subsets of RES. EHEAT commonly refers to heat stroke and ECOLD to hypothermia. Details of the diseases are found on the website of the Department of Health of Hong Kong [DEPARTMENT OF HEALTH, 2006].

2.2 Definition of the thermal index

YIP et al [2006] have analysed six commonly used thermal indices, namely Net Effective Temperature (NET), Apparent Temperature (Shade), Heat Index, Humidex, Windchill Index and Wet Bulb Globe Temperature that are applicable to Hong Kong, and found that they are highly correlated among themselves with correlation coefficients ranging from 0.78 to 0.94 in summer and 0.83 to about 1 in winter. They also found that these indices exhibited similar diurnal and seasonal variation patterns. Since the correlation among various indices is high, the present study only makes use of NET for analysis. Compared with other thermal indices, NET has the advantage of being applicable to both hot and cold situations [LI et al, 2000].

NET was first introduced and named Effective Temperature in 1937 [HENTSCHEL, 1986] to include the effects of relative humidity in hot weather. Later it was modified to include the effects of winds and thus extending its use in cold weather [HENTSCHEL, 1986]. NET is given by the formula:

$$NET = 37 - \frac{37 - T}{0.68 - 0.0014\,RH + 1/(1.76 + 1.4v^{0.75})} - 0.29T(1 - 0.01RH)$$

where T is the ambient air temperature (in °C), v the wind speed (in ms^{-1}) and RH the relative humidity (in %).

In cold weather, a lower NET means the weather is more stressful. In hot weather, the higher the NET, the more stressful is the weather. NET reflects the common perception that people tend to feel more stressful on hot and humid days with calm winds in summer and cold, windy and humid days in winter [LI et al, 2000].

3. Methodology

Similar to YAN [2000], the technique of analysis of variance (ANOVA) is employed to test if there is a seasonal variation in mortality due to various causes. ANOVA is a statistical technique which tests the difference of group means to see if the means of the groups formed by values of independent variable are different enough not to have occurred by chance.

Poisson regression is a commonly used method in epidemiologic analysis for rare count events [e.g. SELVIN, 2001]. In Poisson regression, given the independent variable X, it is assumed that the dependent variable Y, the number of occurrences of an event such as the number of deaths, has a Poisson distribution:

$$P(Y = k) = \frac{e^{-\mu}\mu^{k}}{k!} \quad , \qquad k = 0,1,2,.........$$

where the logarithm of the mean μ is a linear function of X given by:

$$\ln \mu = a + bX$$

The parameters a and b are estimated by maximum likelihood.

Let μ_{x+1} and μ_x be the values of μ when X equal to $x+1$ and x respectively. From the above equation, it can be derived that

$$\mu_{x+1} = \mu_x e^{b}$$

The term e^b is called the rate ratio (RR) or relative risk and represents the change in the mean value of Y per unit increase in X. Similarly the term e^{-b} (the reciprocal of rate ratio e^b) is the change in the mean value of Y per unit decrease in X.

In this study, the 95% confidence interval (CI) of the rate ratio for the mortality of each cause with respect to unit change in NET is estimated by using the statistical and power analysis software NCSS.

4. Results

4.1 Net Effective Temperature

Long-term trend analyses of annual mean NET were carried out by YIP et al [2006] for 1983-2004 using linear regression and t-test. This study updates the trend to 1983-2005. It is found that NET increased at a rate of 1.05 per decade and 0.25 per decade in winter and summer respectively (Figure 1). By linear regression, the mean daily minimum NET in winter and the mean daily maximum NET in summer are found to be increasing at a rate of 1.15 per decade and 0.15 per decade respectively. These increasing trends in NET are likely to be due to a rise in temperature under global warming and urban development [LEUNG et al, 2004a] as well as a fall in wind speed due to high density urban development in Hong Kong [LEUNG et al, 2004b].

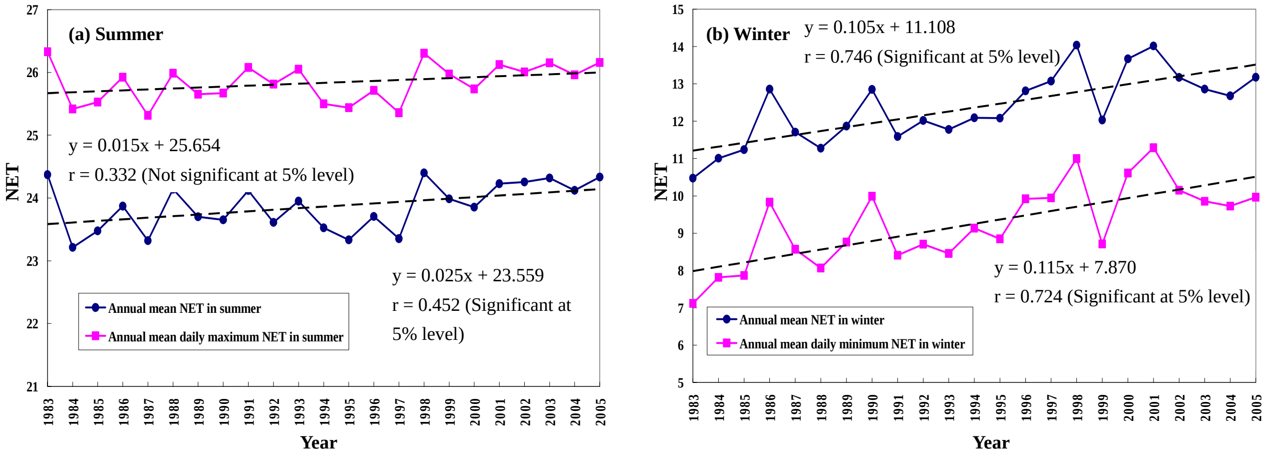


Fig. 1. Time series of (a) annual mean NET and annual mean daily maximum NET in summer, and (b) annual mean NET and annual mean daily minimum NET in winter for 1983-2005.

4.2 *Mortality*

In 1995-2004, the three major causes NEO, CIR and RES comprised about 33%, 26% and 18% respectively of the total mortality in Hong Kong, comparable with the 29.2%, 28.8% and 16.8% for 1980-1994 found by YAN [2000].

Except for NEO, COP and EHEAT, mortality peaks for all other causes are generally observed in December to February. For ECOLD, mortality only existed in November to March and for EHEAT, mortality only existed in July to September. Results of ANOVA (Table 1) show that all the causes except NEO and EHEAT exhibited seasonality at 5% significance level. The scarcity of data in mortality for EHEAT may be a reason for its non-significance at 5% level. For the reason above, NEO is excluded from subsequent analyses.

Table 1. Results of significance testing for seasonality of mortality using ANOVA

Cause of death	F-statistic	P value	Significance at 5% level
ALL	11.808	0.003	YES
NEO	0.028	0.993	NO
CIR	10.349	0.004	YES
IHD	9.155	0.006	YES
CBD	10.327	0.004	YES
RES	17.081	0.001	YES
PIF	22.580	0.000	YES
COP	6.676	0.014	YES
EHEAT	1.792	0.227	NO
ECOLD	6.077	0.019	YES

4.3 *Relationship between NET and mortality*

4.3.1 *Inter-annual relationship*

Figure 2a shows the time series of annual mean daily mortality for ALL and annual mean daily maximum NET in summer. The time series of annual mean daily mortality for ALL and annual mean minimum NET in winter are plotted in Figure 2b. It can be seen that the mortality is in general "out of phase" with the NET in winter. However, no similar relationship between mortality and NET in summer is observed except that the maxima of both time series occurred in 1998, the warmest year in Hong Kong since record began in 1885.

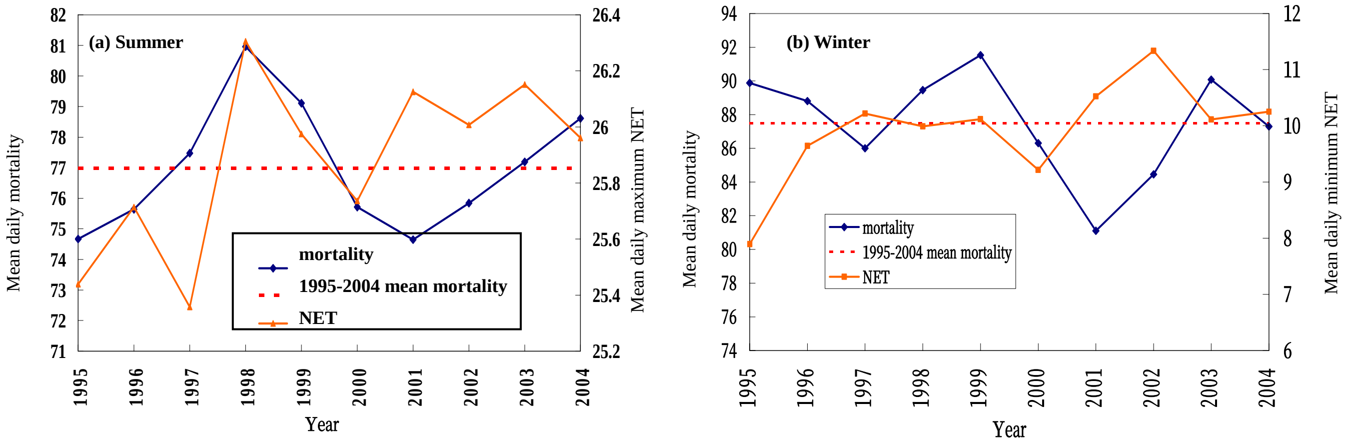


Fig. 2 Time series of (a) annual mean daily mortality for ALL and annual mean daily maximum NET in summer, and (b) annual mean daily mortality for ALL and annual mean daily minimum NET in winter.

4.3.2 *Intra-annual relationship*

To filter out short-term fluctuations, 31-day moving average of daily mortality, daily minimum NET/temperature in winter and daily maximum NET/temperature in summer are computed. The results are shown in Figure 3. In the Figure, excess mortality in each day refers to the departure of mortality on that day from the mean mortality averaged for the whole winter or summer. Similarly, excess NET/temperature in each day refers to the departure of NET/temperature on that day from the mean NET/temperature averaged over the whole winter or summer.

The peaks of excess mortality in winter for various causes occurred in mid-February to early March, generally close to the troughs of excess NET/temperature which occurred in mid-February (Figure 3a). Excess mortality for ALL, CIR and RES are higher at 9.3, 3.8 and 3.4 respectively as compared with 0.1 to 1.7 for other causes. In summer, however, the excess mortality was not the greatest near the peak of excess NET/temperature in July and August. The greatest mortality in summer occurred in early May (Figure 3b).

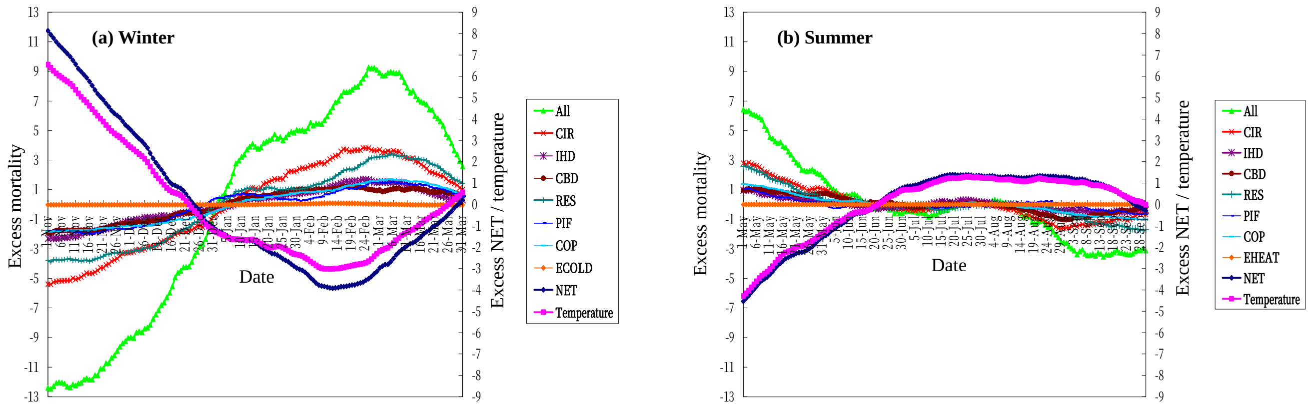


Fig. 3. Intra-annual relationship between (a) excess mortality and excess minimum NET/Temperature in winter, and (b) excess mortality and excess maximum NET/Temperature in summer.

4.3.3 *Daily relationship*

(a) Correlation analysis

Lagged correlation analyses between daily mortality for various causes and daily maximum NET in summer are carried out. The daily mortality of a particular day is correlated respectively to the daily maximum NET of the same day (lag 0), the daily maximum NET of the day before (lag 1), the daily maximum NET two days before (lag 2), etc. Correlation for EHEAT is not performed since the total number of deaths is small. Similarly, the lagged correlation analyses between daily mortality and daily minimum NET in winter are also conducted.

Results show that the lagged correlation coefficients between daily mortality for the various causes under study and daily maximum NET in summer are all small with magnitude less than 0.1, indicating the lack of significant correlation between the daily mortality and the daily maximum NET in contrast to the significant relationship found in most temperate regions. On the other hand, the lagged correlation coefficients between daily mortality and daily minimum NET are larger with magnitude ranging from 0.15 to 0.49, and almost all are significant at the 5% level (Table 2). All the correlation coefficients are negative showing that in general, the lower the NET, the higher the mortality. Except for IHD, the magnitude of correlation coefficients for various causes of death is the greatest at lag 3 and 4. Table 2 also shows that the daily mortality is in general slightly better correlated to daily minimum NET than daily minimum temperature. This indicates the closer relationship between mortality and NET than mortality and temperature.

Table 2. Lagged correlations between daily mortality and daily minimum NET, and also between daily mortality and daily minimum temperature in winter. Those values marked with * are statistically significant at 5% level

	Daily minimum NET						Daily minimum temperature					
	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
All	-0.29*	-0.36*	-0.44*	-0.46*	-0.49*	-0.48*	-0.27*	-0.35*	-0.43*	-0.47*	-0.49*	-0.48*
CIR	-0.32*	-0.37*	-0.41*	-0.44*	-0.44*	-0.44*	-0.29*	-0.35*	-0.39*	-0.41*	-0.42*	-0.41*
IHD	-0.21*	-0.25*	-0.29*	-0.32*	-0.31*	-0.33*	-0.20*	-0.24*	-0.27*	-0.29*	-0.30*	-0.31*
CBD	-0.22*	-0.25*	-0.28*	-0.30*	-0.30*	-0.29*	-0.19*	-0.23*	-0.23*	-0.24*	-0.24*	-0.21*
RES	-0.21*	-0.26*	-0.30*	-0.33*	-0.37*	-0.36*	-0.18*	-0.23*	-0.27*	-0.31*	-0.34*	-0.34*
PIF	-0.15*	-0.17*	-0.21*	-0.23*	-0.25*	-0.24*	-0.13*	-0.16*	-0.20*	-0.22*	-0.25*	-0.25*
COP	-0.15*	-0.23*	-0.26*	-0.28*	-0.32*	-0.32*	-0.15*	-0.19*	-0.22*	-0.26*	-0.29*	-0.29*
ECOLD	-0.26	-0.27	-0.24	-0.39*	-0.21	-0.24	-0.26	-0.32*	-0.23	-0.37*	-0.21	-0.22

(b) Risk analysis

The Poisson regression mentioned in Section 3 is applied to the mortality and NET data. No statistically significant relationship is found between daily mortality and daily maximum NET in summer for all the causes of death under study except EHEAT (Table 3). In winter, the relationship between daily mortality and daily minimum NET are statistically significant for all the causes of death (Table 3). These results are consistent with results from correlation analysis in Section 4.3.3 (a).

Table 3. 95% confidence interval (CI) estimates of rate ratios (RR) for various causes of deaths in summer and winter at lag 0.

Season	Cause of death	RR	95% CI	p value	Significance at 5% level
Summer	All	1.001	0.998 - 1.004	0.344	NO
	CIR	0.997	0.991 - 1.003	0.344	NO
	IHD	0.996	0.986 - 1.005	0.391	NO
	CBD	0.997	0.988 - 1.005	0.440	NO
	RES	1.001	0.993 - 1.008	0.814	NO
	PIF	1.004	0.994 - 1.013	0.427	NO
	COP	0.998	0.985 - 1.010	0.691	NO
	EHEAT	2.163	1.102 - 4.244	0.025	YES
Winter	All	0.990	0.988 – 0.991	<0.001	YES
	CIR	0.980	0.977 – 0.982	<0.001	YES
	IHD	0.980	0.977 – 0.984	<0.001	YES
	CBD	0.982	0.979 – 0.986	<0.001	YES
	RES	0.984	0.982 – 0.987	<0.001	YES
	PIF	0.987	0.983 – 0.991	<0.001	YES
	COP	0.980	0.976 – 0.985	<0.001	YES
	ECOLD	0.782	0.727 – 0.841	<0.001	YES

Similar to the estimation of mortality risk with temperature in the literature [e.g, MARTENS, 1998; BALLESTER et al, 1997], the 95% confidence interval (CI) of the change in the mean mortality per unit change in NET is estimated. In summer, the rate ratio (see Section 3) of EHEAT is 2.163 (Table 3) meaning that for a unit increase in NET, the mean mortality will be increased by about two-fold. In winter, the rate ratios are all smaller than 1 (Table 3), indicating the lower the NET, the higher the mortality. The increase in mean mortality per unit decrease in NET is the highest for ECOLD (reciprocal of rate ratio = 1/0.782 = 1.279), and slightly higher for the circulatory related causes (reciprocal of rate ratio = 1/0.980 = 1.020) than the respiratory related causes (reciprocal of rate ratio = 1/0.984 = 1.016).

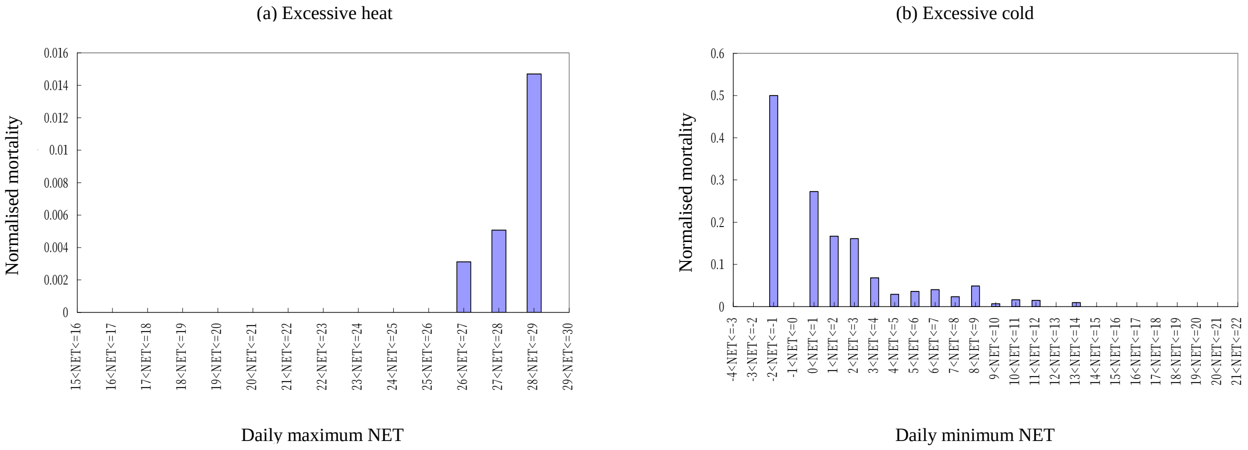
Table 4. 95% confidence interval (CI) estimates of rate ratios (RR) for various causes of deaths in winter under different age groups at lag 0.

Cause of death	Age	RR	95% CI	p value	Significance at 5% level
All	<15	0.984	0.971 – 0.998	0.024	YES
	15 – 34	0.982	0.971 – 0.992	<0.001	YES
	35 – 64	0.996	0.992 – 0.999	0.009	YES
	>=65	0.989	0.987 – 0.990	<0.001	YES
CIR	<15	0.863	0.712 – 1.047	0.136	NO
	15 – 34	0.970	0.940 – 1.001	0.061	NO
	35 – 64	0.982	0.975 – 0.990	<0.001	YES
	>=65	0.980	0.977 – 0.983	<0.001	YES
IHD	<15	0.999	0.723 – 1.379	0.994	NO
	15 – 34	0.980	0.901 – 1.066	0.643	NO
	35 – 64	0.984	0.972 – 0.995	0.006	YES
	>=65	0.981	0.977 – 0.986	<0.001	YES
CBD	<15	0.978	0.852 – 1.122	0.749	NO
	15 – 34	0.993	0.939 - 1.051	0.814	NO
	35 – 64	0.985	0.975 – 0.995	0.0038	YES
	>=65	0.982	0.978 – 0.986	<0.001	YES
RES	<15	0.973	0.933 – 1.015	0.202	NO
	15 – 34	0.978	0.944 – 1.012	0.203	NO
	35 – 64	0.977	0.966 – 0.987	<0.001	YES
	>=65	0.985	0.982 – 0.990	<0.001	YES
PIF	<15	0.981	0.933 – 1.032	0.464	NO
	15 – 34	0.980	0.939 – 1.022	0.341	NO
	35 – 64	0.976	0.962 – 0.991	0.001	YES
	>=65	0.988	0.984 – 0.993	<0.001	YES
COP	<15	0.863	0.712 – 1.047	0.136	NO
	15 – 34	0.982	0.908 – 1.601	0.641	NO
	35 – 64	0.978	0.961 – 0.996	0.014	YES
	>=65	0.984	0.978 – 0.990	<0.001	YES
ECOLD	<15*	--	--	--	--
	15 – 34	1.021	0.647 - 1.613	0.927	NO
	35 – 64	0.781	0.612 – 0.998	0.048	YES
	>=65	0.776	0.718 – 0.838	<0.001	YES

* No ECOLD mortality occurred for the age group <15.

Results from the Poisson regression for different age groups in winter are listed in Table 4. For all the causes, the significance level (p values) are less than 0.001 for the elderly (age ≧ 65) and are the smallest among the four age groups. This indicates the closer relationship between mortality and NET for the elderly than other age groups. Discounting those rate ratios that are not statistically significant, the increase in mean mortality per unit decease in NET (reciprocal of rate ratios) are higher for the elderly than other age groups for ECOLD and circulatory related causes of death.

The distributions of mortality for EHEAT under different daily maximum NET categories in summer, and that for ECOLD under different daily minimum NET categories in winter are shown respectively in Figure 4a and 4b. Both distributions are normalized by dividing the mortality by the corresponding frequency of occurrence of the NET category. From Figure 4a, deaths associated with EHEAT start to occur when the daily maximum NET exceeds 26 and the normalized mortality increases sharply thereafter as NET increases. Thus the mortality associated with EHEAT is expected to rise with the trend of increasing NET. Due to the scarcity of mortality for EHEAT, further age-specific analysis is not carried out.



(a) Excessive heat

(b) Excessive cold

Fig. 4. The distribution of mortality for various (a) daily maximum NET categories in summer and (b) daily minimum NET categories in winter.

Deaths associated with ECOLD begin to occur when the daily minimum NET is less than 14 and the normalized mortality increases sharply thereafter as NET decreases from 3 onwards (Figure 4b). The distribution of mortality under various NET categories for various age groups is shown in Figure 5. This distribution is normalized by dividing the mortality by the corresponding frequency of occurrence of NET category and also the corresponding population of the age group. It can be seen that the age group ≧ 65 is more vulnerable to NET changes than other age groups.

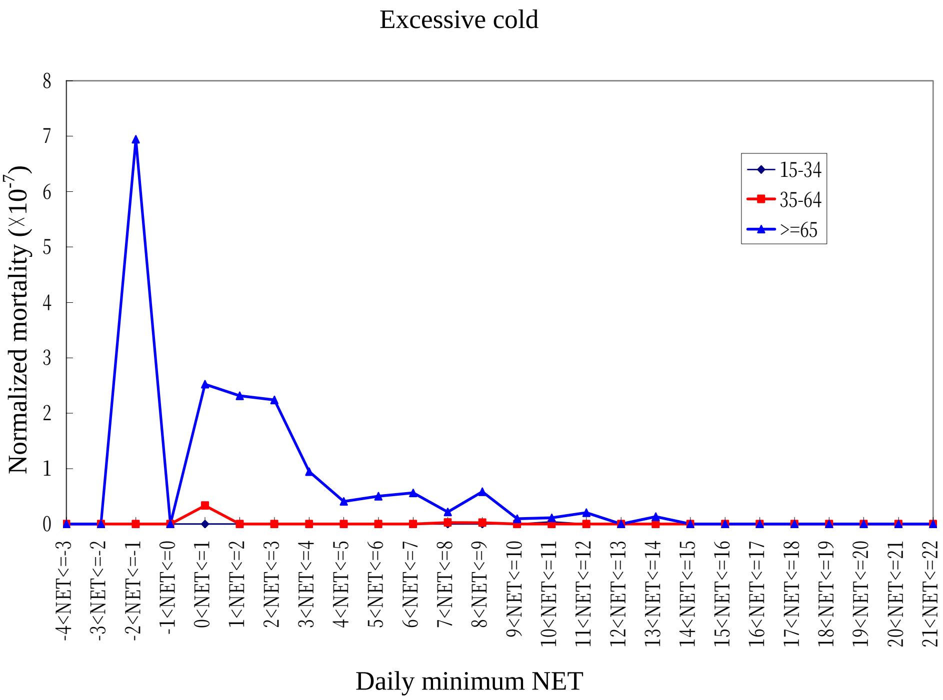


Fig 5. The distribution of ECOLD mortality for various age groups under different daily minimum NET categories in winter. Mortality is zero for the age group under 15.

5. Conclusions

Statistically significant seasonality exists in mortality from ALL, CIR, RES, IHD, CBD, PIF, COP and ECOLD, but not for NEO.

In summer (May to September), the death associated with EHEAT start to occur when the daily maximum NET exceeds 26 and the normalized mortality increases sharply thereafter as NET increases. The mean mortality estimated from Poisson regression is about a 2-fold increase per unit rise in NET beyond 26. The daily mortality for ALL, CIR, RES, IHD, CBD, PIF and COP are not statistically correlated to the daily maximum NET in summer. This finding is in contrast to those in most temperate regions.

In winter (November to March), there are statistically significant lagged correlations between the daily minimum NET and the daily mortality associated with each of ALL, CIR, RES, IHD, CVD, PIF, COP and ECOLD. Higher mortality generally corresponds to lower NET. The highest magnitudes of lagged correlations for the various causes under study are around lag 3 and 4 days. The increase in mortality per unit decrease in NET is found to be the highest for ECOLD, and slightly higher for circulatory causes than respiratory causes. Deaths associated with ECOLD start to occur when the daily minimum NET is less than 14, and the normalized mortality increases sharply thereafter as NET decreases from 3 onwards. The mean mortality estimated from Poisson regression is about 1.3-fold increase per unit fall in NET beyond 14. The age group ≧ 65 is found to be more vulnerable to NET changes than other age groups.

With the increasing trend of NET in Hong Kong under global warming, the mortality associated with EHEAT is expected to increase while the mortality associated with ECOLD is expected to decrease in future.

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