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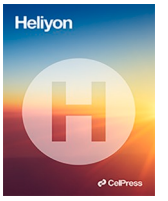

Research article

# Association of ambient temperature with social isolation among the community-dwelling Chinese older adults: A cross-sectional study in Hong Kong

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ABSTRACT

*Background:* The adverse health impacts of ambient temperature have been well-documented, encompassing not only the mortality and morbidity burden but also mood and mental health disorders. However, the relationship between temperature and social isolation remains unexplored. The objective of the current study was to investigate the potential associations between ambient temperature and social isolation among the aging population.

*Methods:* We took advantage of a cross-sectional survey conducted between January 2017 and November 2018 from a community service program special for older adults aged ≥60 who lived in a central community of Hong Kong. The personal social isolation was assessed by the validated Lubben Social Network Scale-6 (LSNS-6), with a score ranging from 0 to 30 and score of less than 12 indicating social isolation. The environmental exposures, including ambient temperature, sunshine hours, rainfalls, and air pollution, were obtained from the nearby monitoring stations. The association of ambient temperature with LSNS-6 score or social isolation was examined by the generalized linear models while adjusting the potential confounding from other environmental exposures and personal sociodemographic factors.

*Results:* Among the 1616 participants, the distribution of LSNS-6 score was approximately normal and the mean score was a bit higher on cool days than on hot days (13.0 vs. 12.2). Compared with cool temperatures (14.4–19.5$^{o}$C), the independent effect estimates of hot ambient temperatures (24.5–28.7$^{o}$C) was associated with a 2.38 (95%CI: 1.63–3.13) decrease in LSNS-6 score. Meanwhile, we observed statistically significant associations of sunshine exposure, gender, health status, marital status, living alone, religion, and housing type with LSNS-6 score or social isolation.

*Conclusions:* Our study revealed a clear association between ambient cool temperatures and reduced social isolation, as well as association between hot temperatures and social isolation among older Chinese adults residing in the urban community of Hong Kong.

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## 1. Introduction

Defined as having few social relationships or infrequent social connections with others, social isolation is a public health crisis. The factors associated with social isolation may include individual, community, and societal levels. Evidence of individual factors has been documented in the literature, including being age of 80 years and older, having low education levels, smoking, being male, lacking social support, not owning a home, having limited social participation, being unmarried, experiencing hearing loss, facing impairment in activities of daily living, having poor health status, experiencing cognitive decline, and depression [1,2]. Meanwhile, the relationship between health outcomes and social isolation may be bidirectional, as social isolation also acts as a risk factor for adverse physical and mental health outcomes [3,4]. Community- and societal-level factors contributing to social isolation in the older population have been reviewed, with neighborhood safety, access to public third places, and cultural practices being the most commonly identified factors [5].

The adverse health impacts of ambient temperature have been well-documented, encompassing not only the mortality burden [6,7] but also mood and mental health disorders [8–11]. Increased temperature and temperature variability were found to be associated with increased cases of suicide and suicidal behavior, hospital attendance or admission for mental illness, and poor community health and well-being [10]. Furthermore, the association between cold or hot temperature and mortality may be modified by social deprivation or isolation [12–14]. The higher social isolation level was found to amplify the vulnerability to heatwave-related mortality among the urban, city-dwelling, elderly population [15]. Therefore, intervention in social isolation may reduce mortality during heat waves in the aged population [16]. It has been demonstrated that interventions rooted in social connection are a concept widely applied in public health and social well-being interventions and should be applied as effective tools for adapting to hot weather conditions [17].

Environmental factors such as extreme weather, heat waves, cold spills, and heavy air pollution may influent the intent of outdoor activities and social connections, especially for vulnerable older people. The comfortable ambient temperature can encourage the elderly to spend more time outdoors, which can facilitate social bonding and strengthen relationships, leading to increased opportunities for social interaction and connection. However, the association between ambient temperature and social isolation remains unexplored. Hong Kong, located in southeastern China and Asia, experiences a subtropical climate that exhibits mild and temperate winters and hot and humid summers. Hong Kong is known as one of the most densely populated cities in the world, with around 7.4 million population living in a territory of 1104 square kilometers. Hong Kong is also facing a problem of population aging, with the proportion of individuals aged 65 and over reaching 20.3 % in 2021 [18]. The elderly is particularly vulnerable, facing a higher prevalence of physical and mental health issues and their social isolation may be more pronounced compared to younger adults. We took advantage of a cross-sectional survey collected from a community service program special for the elderly and assigned them the environmental exposures with the routinely monitored data of ambient temperature, sunshine hours, rainfall, and air pollution. The objective was to investigate potential associations between social isolation and ambient temperature. Findings from the current study may offer valuable insights to the government in developing a sustainable and inclusive society that addresses the needs of the aging population, thereby ensuring their well-being and enhancing their quality of life.

## 2. Materials and methods

### 2.1. Study design, setting, and participants

Between January 2017 and November 2018, a cross-sectional study employing face-to-face interviews and a structured questionnaire was carried out among individuals aged 60 years and above residing in a community within the Kowloon Central District of Hong Kong. This district is characterized by a high median age and is considered an aging district. The study specifically targeted participants who were either members or recipients of social services provided by three non-governmental organizations (NGOs) operating within the Kowloon Central District area. The focus was on individuals who typically lived alone or lacked sufficient family support [4]. We applied a convenient sampling with the assistance of the NGOs to conduct the survey. Individuals who had been diagnosed with dementia, or Parkinson's disease, or were mentally incapacitated to respond to the survey were excluded. A total of 2433 potentially eligible elder adults were approached and 1652 of them responded to the interview with a response rate of 67.9 %.

Subjects who participated in the study were voluntary. The initial verbal consent was obtained via telephone and the written consent was obtained before conducting the face-to-face interviews. The project was ethically approved by the Human Subjects Ethics Sub-Committee of the City University of Hong Kong (Reference No.: 2-4-201701_01).

### 2.2. Data collections

#### 2.2.1. Social isolation

We evaluated it using the Lubben Social Network Scale-6 (LSNS-6), a validated instrument specifically designed to measure social isolation in older adults. The LSNS-6 assesses the quantity and frequency of social interactions with both friends and family members, as well as the perceived level of social support derived from these relationships [19]. The LSNS-6 scale comprises two subscales: family and friends. The family subscale includes items such as "How many relatives do you see or hear from at least once a month?" The friend subscale includes items such as "How many friends do you feel at ease with, that you can talk about private matters?" Each subscale consists of three items, resulting in a total of six items. Participants rate each item on a 6-point Likert scale. The LSNS-6 score is

calculated by summing the equally weighted items, with a total score ranging from 0 to 30. Higher scores indicate a higher level of social support and greater social connection. A score of less than 12 means social isolation with a relatively low social connection and support [20]. Therefore, the LSNS-6 score was also categorized into a binary outcome variable to denote social isolation or not, that is, 1 for LSNS-6 $< 12$ meaning social isolation, and 0 for LSNS-6 $\geq 12$ meaning no social isolation. Thirty-six participants with missing values in LSNS-6 score were excluded, resulting in 1616 participants in the analyses.

#### 2.2.2. Environmental exposures

Daily 24-h mean temperature ($^{o}$C), daily sunshine hours, and rainfall (millimeters, mm) from December 2016 to November 2018 which covered the study period were obtained from the Hong Kong Observatory Headquarters which is the reference synoptic station for Hong Kong and located in central Kowloon (https://data.gov.hk/en-data/dataset/hk-hko-rss-daily-temperature-info-hko). Daily 24-hr mean concentrations (μg/m$^3$) of $PM_{2.5}$, $NO_2$, and $O_3$ were obtained from the Environmental Protection Department (https://cd.epic.epd.gov.hk/EPICDI/air/station/?lang=en) and averaged over two general monitoring stations (SSP and KC) which are located in the Kowloon Central District matching the residential area that the participants lived. We calculated the moving averages over the past month for each day and linked the ambient exposures with the survey data based on the survey date. We used moving averages in the past month to denote the environmental exposures, aligning with the social support/connection data that collected information during the same time period.

In light of the potential relationship between social isolation and the number of public holidays, we also identified the dates of public holidays and calculated the count of holidays occurring one month before the survey date for each participant.

#### 2.2.3. Sociodemographic characteristics

Demographic information of the participants was collected and compared, including age, gender, body mass index (BMI, kg/m$^2$), education level (categorized as not educated, primary, secondary, and degree or above), marital status (classified as married, widowed, divorced/separated/unmarried), current smoking and drinking status (categorized as never or ever), living arrangement (living alone or not), religious affiliation (yes or no), and type of housing (private or public, serving as a proxy for socioeconomic characteristics).

There were some missing values in sociodemographic factors. The number of missing values in BMI, marital status, education level, smoking status, drinking status, and religion status were 47, 6, 23, 7, 12, and 47, respectively. The missing values in each variable were treated as a separate category while adjusting for their potential confounding effects in the multivariate regression models. This approach allowed us to retain the sample size and maintain statistical power in our analysis, thereby avoiding data loss.

The health status of each participant was represented as an overall health score ranging from 0 to 100 based on self-reported physical function and mental health, which has been generated in our previous study [4]. We further categorized it as Poor/Moderate/Good health status, using tertiles as the cut-off points. 113 missing values in health scores were also treated as a separate category.

### 2.3. Statistical analysis

The distribution of the LSNS-6 score and ambient temperature exposure in the past month were checked by histograms. Two independent samples T-test is used for continuous variables and the Chi-square test is used for categorical variables to compare the difference of environmental exposures between two groups with high and low ambient temperature exposure using median temperature (24.53$^{o}$C) over the study period as the cutoff to denote the cool-warm and hot days respectively or compare the difference of sociodemographic characteristics between two groups with and without social isolation using the LSNS_6 score of 12 as the cutoff.

The association of ambient temperature with LSNS-6 score or social isolation was examined by the generalized linear models (GLM) while adjusting the potential confounding from other environmental exposures and personal sociodemographic factors. As airborne pollutants ($PM_{2.5}$, $NO_2$, and $O_3$) may be associated with poor health thus leading to social isolation [3], we included outdoor air pollutants in the model for adjustment. As the sunshine hours, rainfall, and the number of public holidays may confound the relationship between social connection levels and ambient temperature, we also include them in the model for adjustment. The covariates left in the final model were selected based on the backward stepwise approach [4].

The exposure-response relationship between ambient temperature exposure and social isolation was plotted by including a smoothing term with a degree of freedom of 4 for temperature in the generalized additive model [21]. The residuals of the final multivariate model were assessed using various diagnostic techniques, including residual plots, partial autocorrelation function (PACF), and normal quantile-quantile (Q-Q) plots [22]. The potential nonlinear effect of ambient temperature moving averaged over the past month on the indicators of social support/connection was examined by categorizing the temperature into four groups using quartiles as the cut-off points and named them as Cool days ($\geq$14.42 & $<$ 19.52$^{o}$C), Warm days ($\geq$19.52 & $<$ 24.53$^{o}$C), Hot days ($\geq$24.53 & $<$ 28.73$^{o}$C), and Very hot days ($\geq$28.73 & $\leq$ 29.93$^{o}$C). We used the 1st group (Cool days) as the reference according to the shape of the exposure-response curve which was associated with the highest LSNS-6 score or lowest odds of social isolation. Temperature as a continuous variable was also examined in the model as a sensitivity analysis.

As we have confirmed the association between LSNS-6 score and overall health status in our previous study [4], we further conducted sensitivity analysis by excluding 113 participants with missing values in health status score and included it as a continuous variable for adjustment in the model.

The effect estimates were presented as an absolute change in LSNS-6 score or an odds ratio (OR) for social isolation that was associated with environmental exposures or sociodemographic factors with a corresponding 95 % confidence interval (CI). Temperature as a categorical or continuous variable was included in the model separately. The significance test was 2-sided and a p-value

<0.05 was considered to be statistically significant. Data processing and analyses were conducted in R version 4.3.0 (R Foundation for Statistical Computing, Vienna, Austria).

## 3. Results

Among the 1616 participants who answered the questions related to social support and were included in the study, the distribution of LSNS-6 score was almost normal (Fig. 1A) and the mean score was a bit higher (13.0 ± 5.3) on the cool-warm days with ambient temperature <24.53°C than the hot days with temperature ≥24.53°C (12.2 ± 5.3). The hot days showed more average sunshine hours (5.9 vs. 5.3), and significantly more rainfalls (10.0 vs. 0.9 mm) than cool days. The main air pollutants' concentrations and the number of public holidays tended to be greater on cool-warm days than on hot days (Table 1). Out of the participants, 66.3 % were female, ranging in age from 61 to 104, with an average age of 80.9 years old. The participants had a mean BMI of 23.3 kg/m$^2$, with a standard deviation (SD) of 3.8. The average overall health score was 74.2 (SD: 18.7). Among the participants, 39.9 % were married, 47 % were widowed, and 51.2 % lived alone. Regarding education level, 90.5 % had completed secondary education or below. Additionally, 21.3 % reported a history of smoking, while 13.4 % reported a history of drinking. Of the participants, 57.4 % had religious affiliations, and 66.2 % resided in public housing (Table 1).

The distribution of moving average temperature in the past month was left-skewed (Fig. 1B). The residuals of the final multivariate model were diagnosed in Fig. 2. The residual plot and PACF plot exhibited no noticeable patterns and autocorrelation in the residuals. Furthermore, the Q-Q plot demonstrated the normality of standardized deviance residuals, providing evidence that all potential confounding factors in the variation of the LSNS-6 score were effectively accounted for.

The exposure-response curves for the relationship of ambient temperature with LSNS-6 score and social isolation showed the non-linear effects of temperature, indicating the lowest effect estimate of temperature at around 27°C (Fig. 3). While categorizing the temperature into four groups (Cool/Warm/Hot/Very hot days) using quartiles as the cut-off points and the 1st group (Cool days) as the reference, we observed a statistically significant decreased LSNS-6 score of 1.54 (95 % CI: 0.80–2.28) on Hot days and 0.97 (95 % CI: 0.24–1.70) on Very hot days (Table 2). In the univariate model, we also observed that less rainfall and participants with higher air pollution exposures, female, better health status, higher BMI, or having religions tended to be associated with higher LSNS-6 scores, while participants of Divorced/Separated/Unmarried, ever smoking or drinking, living alone, or living in public houses were associated with lower LSNS-6 levels (Table 2). The association of social isolation with sunshine hours was not statistically significant in the univariate model. The association of social isolation with the number of public holidays was not found.

With adjusting for the potential confounding from other environmental exposures and personal sociodemographic factors in the multivariate model (Table 3), the independent association of hot ambient temperature kept statistical significance with a 2.38 (95%CI: 1.63–3.13) decrease in LSNS-6 score. On average, every 5°C increments in temperature was associated with a 1.11 (95 % CI: 0.67–1.56) decrease in LSNS-6 score. The associations of LSNS-6 score with air pollution exposures, rainfall, BMI, and ever smoking or drinking lost statistical significance. Meanwhile, we observed the statistically significant associations of sunshine exposure, gender, health status, marital status, living alone, religion, and housing type with LSNS-6 score. One hour increase in sunshine exposure was associated with a 0.28 (95 % CI: 0.06–0.50) increment in the LSNS-6 score. Female and married participants with better health status, holding religions, and living in private houses tended to have a higher LSNS-6 score of 0.73–2.22. Categorizing LSNS-6 score into yes/no social isolation and using the multivariate binary logistic regression model observed the very consistent associations of social isolation with ambient hot temperatures and the sociodemographic factors (Tables 2 and 3). Sensitivity analysis by excluding the 113 participants with missing values in health status score only changed the results in the associations very slightly (Table 4).

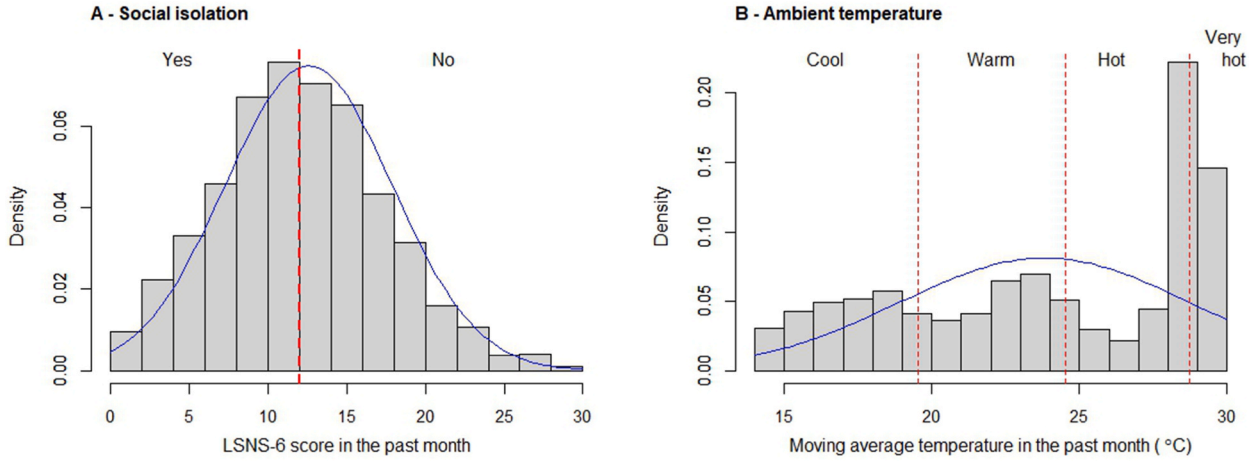


**Fig. 1.** Distribution of LSNS-6 score and ambient temperature.
Notes: The red dash line in A) is the cut-off at 12 to categorize the LSNS-6 score into two groups with social isolation or not; and the red dash lines in B) are the quartiles as the cut-off points to categorize the ambient temperature into 4 groups.

**Table 1**
Environmental exposures and sociodemographic characteristics of the participants (N = 1616).

| Environmental exposures | Total (N = 1616) | Ambient Temperature[a] | | |
|---|---|---|---|---|
| | | Cool-warm days (<24.53 °C) (N = 808) | Hot days (≥24.53 °C) (N = 808) | P-value[b] |
| **LSNS-6 score**, *mean ± SD* | 12.6 ± 5.3 | 13.1 ± 5.2 | 12.1 ± 5.4 | **< 0.001** |
| **Ambient air pollution** | | | | |
| $PM_{2.5}$ (μg/$m^3$) | 22.0 ± 6.0 | 26.8 ± 2.7 | 17.2 ± 4.3 | **< 0.001** |
| $NO_2$ (μg/$m^3$) | 46.7 ± 6.2 | 49.0 ± 3.5 | 44.4 ± 7.4 | **< 0.001** |
| $O_3$ (μg/$m^3$) | 64.7 ± 16.3 | 72.4 ± 8.8 | 56.9 ± 18.2 | **< 0.001** |
| **Sunshine** (hours), *mean ± SD* | 5.6 ± 1.2 | 5.2 ± 1.1 | 6.0 ± 1.1 | **< 0.001** |
| **Rainfall** (mm), *mean ± SD* | 5.5 ± 6.6 | 0.9 ± 0.6 | 10.0 ± 6.8 | **< 0.001** |
| **Public Holidays in the past month** | | | | **< 0.001** |
| 0 day | 531 (32.9) | 289 (35.8) | 242 (30.0) | |
| 1–2 days | 557 (34.5) | 159 (19.7) | 398 (49.3) | |
| 3–5 days | 528 (32.7) | 360 (44.6) | 168 (20.8) | |
| **Sociodemographic characteristics** | **Total (N=1616)** | **Social Isolation Yes (LSNS-6<12) (N=669)** | **No (LSNS-6≥12) (N=947)** | **P-value** [b] |
| **Age** (years old), *mean ± SD* | 80.9 ± 7.3 | 81.0 ± 7.7 | 80.7 ± 6.9 | 0.405 |
| **Gender**, *n (%)* | | | | **< 0.001** |
| Female | 1071 (66.3) | 381 (57.0) | 690 (72.9) | |
| Male | 544 (33.1) | 287 (42.9) | 257 (27.1) | |
| **BMI** (Kg/$m^2$), *mean ± SD* | 23.3 ± 3.8 | 23.0 ± 3.9 | 23.5 ± 3.8 | **0.016** |
| **Overall health status score**, *mean ± SD* | 74.2 ± 18.7 | 71.4 ± 20.1 | 76.1 ± 17.5 | **< 0.001** |
| **Marital status**, *n (%)* | | | | **< 0.001** |
| Married | 645 (39.9) | 244 (36.5) | 401 (42.3) | |
| Widowed | 756 (46.8) | 294 (43.9) | 462 (48.8) | |
| Divorced/Separated/Unmarried | 209 (12.9) | 128 (19.1) | 81 (8.6) | |
| **Education level**, *n (%)* | | | | 0.326 |
| Not educated | 358 (22.2) | 144 (21.5) | 214 (22.6) | |
| Primary | 752 (46.5) | 319 (47.7) | 433 (45.7) | |
| Secondary | 353 (21.8) | 134 (20.0) | 219 (23.1) | |
| Degree or above | 98 (6.1) | 48 (7.2) | 50 (5.3) | |
| Other | 32 (2.0) | 14 (2.1) | 18 (1.9) | |
| **Ever smoking**, *n (%)* | | | | **< 0.001** |
| No | 1265 (78.3) | 483 (72.2) | 782 (82.6) | |
| Yes | 344 (21.3) | 180 (26.9) | 164 (17.3) | |
| **Ever drinking**, *n (%)* | | | | **0.003** |
| No | 1387 (85.8) | 553 (82.7) | 834 (88.1) | |
| Yes | 217 (13.4) | 110 (16.4) | 107 (11.3) | |
| **Living alone**, *n (%)* | | | | **0.011** |
| No | 786 (48.6) | 300 (44.8) | 486 (51.3) | |
| Yes | 828 (51.2) | 369 (55.2) | 459 (48.5) | |
| **Religion**, *n (%)* | | | | **< 0.001** |
| No religion | 642 (39.7) | 308 (46.0) | 334 (35.3) | |
| Had religion | 927 (57.4) | 339 (50.7) | 588 (62.1) | |
| **Housing type**, *n (%)* | | | | **< 0.001** |
| Private | 547 (33.8) | 182 (27.2) | 365 (38.5) | |
| Public | 1069 (66.2) | 487 (72.8) | 582 (61.5) | |

[a] Ambient temperature moving average in the past month of the survey day was categorized into cool-warm and hot days, using median as the cut-off point.

[b] Two independent samples T-test is used for continuous variable and Chi-square test is used for categorical variables to compare the difference of environmental exposures between two groups with high and low ambient temperature, or compare the difference of sociodemographic characteristics between two groups with social isolation or not. P-value<0.05 is in bold.

## 4. Discussion

In the current study linking the data of a cross-sectional survey with environmental exposures, we identified an independent association between ambient cool temperature and reduced social isolation, as well as association between hot temperature and increased odds of social isolation among the community-dwelling Chinese older adults in Hong Kong, after accounting for air pollution, sunshine hours, rainfall, and personal sociodemographic factors.

### *4.1. Interpret the main findings*

The observed association between ambient cool temperature and a higher LSNS-6 score or reduced social isolation is an interesting finding that contributes to our understanding of social dynamics in specific contexts. Hong Kong experiences a sub-tropical climate,

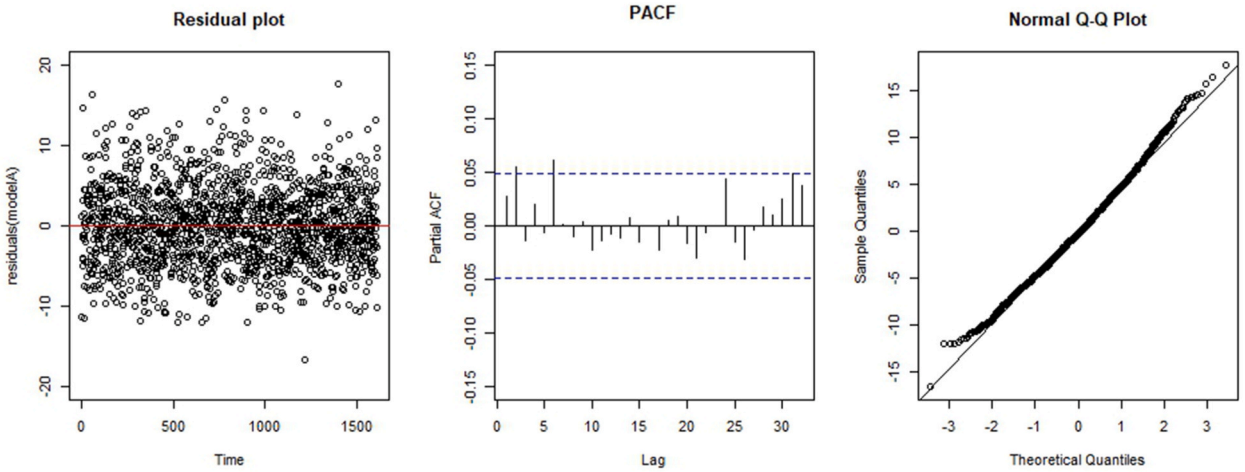


**Fig. 2.** Diagnostic plots for the residuals of the final model.

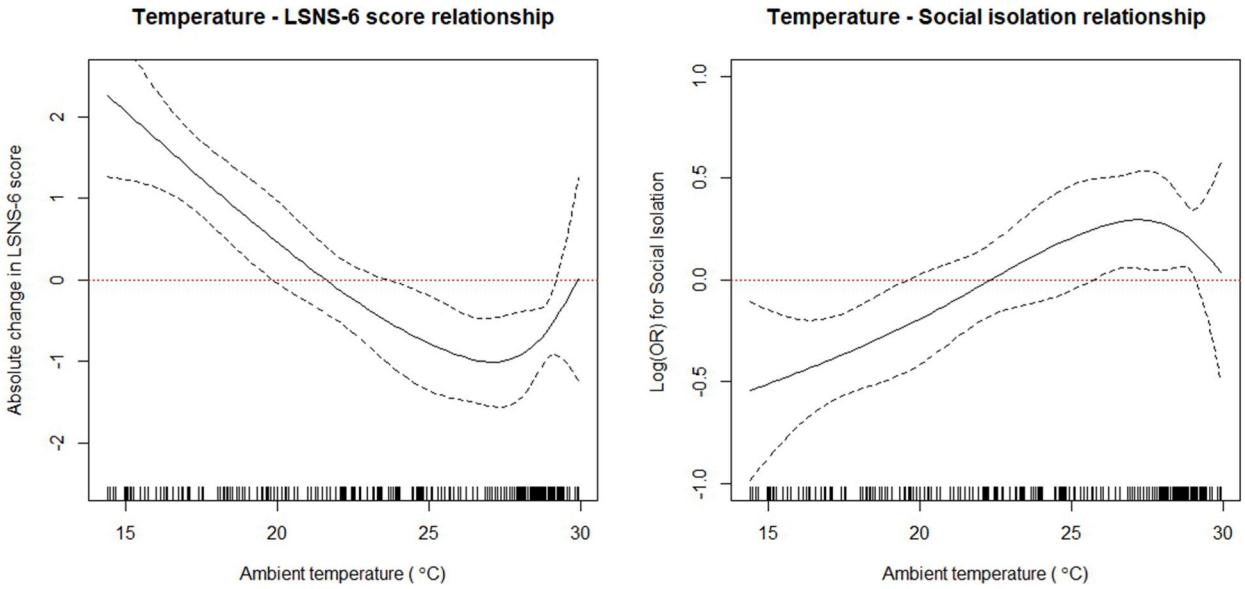


**Fig. 3.** Exposure-response curve for the relationship of ambient temperature with LSNS-6 score and social isolation, respectively.

which tends to be temperate conditions for approximately half of the year. The winter months are characterized by pleasant breezes, ample sunshine, and comfortable temperatures, while the summer months are hot and humid and need air conditioning to maintain comfort. In the current study, we divided the ambient temperature into four quartile groups to examine its relationship with social connection among older adults. We defined the first quartile group as "cool days," which encompassed temperatures ranging from 14.4 to 19.5 °C and coincided with the comfortable winter months. We found that during these cool days, older adults exhibited the highest LSNS_6 score level, indicating a stronger social connection. Conversely, the third quartile group, representing hotter temperatures ranging from 24.5 to 28.7 °C, was associated with the lowest LSNS-6 score and highest odds of social isolation among the older adult population. During the hot days, heat-related physical discomfort, fatigue, and dehydration may discourage social interactions and contribute to social isolation, especially among vulnerable populations like the elderly [23]. Our study focused on a specific group of older adults, with an average age of 81 years, who were receiving homecare services. This population, characterized by advanced age, demonstrated the lowest social connection during the hot days.

### *4.2. Compare with the evidence in the literature on temperature and social isolation*

There is strong evidence in the literature to support the adverse health impact of extreme hot and cold temperatures on mortality burden [6,7], the incidence of both cardiorespiratory diseases [24–26] and mental illnesses [9–11]. The effect of social isolation is

**Table 2**
Association of environmental exposures and sociodemographic characteristics of the participants with LSNS-6 score or social isolation – the univariate generalized linear models (N = 1616).

| Variables | LSNS-6 score[a] Absolute change (95%CI) | Social isolation[b] OR (95 % CI) |
|---|---|---|
| ***Environmental exposures*** | | |
| **Ambient temperature** [c] | | |
| Cool days (≥14.42 & < 19.52°C) | 0.00 | 1.00 |
| Warm days (≥19.52 & < 24.53°C) | −0.65 (−1.38, 0.08) | 1.10 (0.83, 1.46) |
| Hot days (≥24.53 & < 28.73°C) | **−1.54 (-2.28, -0.80)** | **1.58 (1.19, 2.10)** |
| Very hot days (≥28.73 & ≤ 29.93°C) | **−0.97 (-1.70, -0.24)** | 1.25 (0.94, 1.65) |
| Temperature per 5°C increment | **−0.48 (-0.74, -0.21)** | **1.14 (1.03, 1.26)** |
| **Sunshine** (per 1 h) [d] | 0.18 (−0.04, 0.40) | 0.96 (0.88, 1.04) |
| **Rainfall** (per 1 mm)[d] | **−0.07 (-0.10, -0.03)** | 1.01 (1.00, 1.03) |
| **Outdoor air pollution** [d] | | |
| $PM_{2.5}$ (per 10 μg/$m^3$) | **1.18 (0.75, 1.62)** | **0.72 (0.61, 0.85)** |
| $NO_2$ (per 10 μg/$m^3$) | **1.15 (0.74, 1.56)** | **0.74 (0.63, 0.87)** |
| $O_3$ (per 10 μg/$m^3$) | **0.37 (0.21, 0.52)** | **0.91 (0.85, 0.96)** |
| **Public holidays in the past month** | | |
| 0 day | 0.00 | 1.00 |
| 1–2 days | −0.41 (−1.04, 0.22) | 1.01 (0.79, 1.28) |
| 3–5 days | −0.24 (−0.88, 0.41) | 0.99 (0.77, 1.26) |
| ***Personal characteristics*** | | |
| **Age** (per 10 years) | −0.16 (−0.52, 0.20) | 1.06 (0.93, 1.22) |
| **Gender** (Female vs. Male) | **2.07 (1.53, 2.61)** | **0.49 (0.40, 0.61)** |
| **BMI** (Kg/$m^2$) | | |
| <18.5 | 0.00 | 1.00 |
| ≥18.5 & < 25.0 | **1.39 (0.49, 2.30)** | **0.61 (0.43, 0.86)** |
| ≥25.0 & < 30.0 | **1.53 (0.55, 2.52)** | **0.59 (0.40, 0.85)** |
| ≥30.0 | **2.03 (0.60, 3.46)** | **0.55 (0.32, 0.95)** |
| **Overall health status** [e] | | |
| Poor | 0.00 | 1.00 |
| Moderate | **1.29 (0.65, 1.94)** | **0.71 (0.55, 0.91)** |
| Good | **1.49 (0.84, 2.13)** | **0.64 (0.50, 0.83)** |
| **Marital status** | | |
| Married | 0.00 | 1.00 |
| Widowed | 0.05 (−0.50, 0.60) | 1.05 (0.84, 1.30) |
| Divorced/Separated/Unmarried | **−2.91 (-3.73, -2.09)** | **2.60 (1.88, 3.58)** |
| **Education level** | | |
| Not educated | 0.00 | 1.00 |
| Primary | 0.06 (−0.61, 0.73) | 1.09 (0.85, 1.41) |
| Secondary | −0.07 (−0.85, 0.72) | 0.91 (0.67, 1.23) |
| Degree or above | −0.26 (−1.45, 0.94) | 1.43 (0.91, 2.23) |
| Other | 0.08 (−1.85, 2.01) | 1.16 (0.56, 2.40) |
| **Ever smoking** (Yes vs. No) | **−1.40 (-2.03, -0.77)** | **1.78 (1.40, 2.26)** |
| **Ever drinking** (Yes vs. No) | **−1.15 (-1.91, -0.39)** | **1.55 (1.16, 2.07)** |
| **Living alone** (Yes vs. No) | **−0.90 (-1.41, -0.38)** | **1.30 (1.07, 1.59)** |
| **Religion** (Yes vs. No) | **1.53 (1.00, 2.07)** | **0.63 (0.51, 0.77)** |
| **Housing type** (Public vs. Private) | **−1.74 (-2.28, -1.20)** | **1.68 (1.35, 2.08)** |

[a] LSNS-6 score as a continuous outcome variable and.
[b] Social isolation as a binary outcome variable (0: LSNS-6 ≥ 12, means no social isolation; 1: LSNS-6 < 12, means social isolation) was fit by the generalized linear model (GLM), respectively.
[c] The ambient temperature moving average in the past month was categorized into 4 groups using quartiles as the cut-off points, and the 1st group as the reference to estimate its potential nonlinear effect; temperature as a categorical or continuous variable was included in the model separately.
[d] The sunshine hours, rainfall, and ambient air pollution concentrations moving average in the past month were included in the model.
[e] Overall health status score ranged from 0 to 100 was categorized into three groups, using tertiles as the cut-off points. Statistically significant effect estimates are in bold.

comparable to other well-established risk factors such as physical inactivity, obesity, and smoking [27]. However, the association of ambient temperature with social isolation has not been well studied up to date. We added to the literature the independent association between hot ambient temperature at ≥24.5°C and increased odds of social isolation among older adults in the current study. Social deprivation or isolation has been found to modify the association between cold or hot temperatures and mortality in previous studies [12–14]. Individuals living in conditions of isolation have also been characterized by higher risks with an increasing vulnerability to extreme temperatures [13]. The higher social isolation level may amplify the vulnerability to heatwave-related mortality among the elderly population [15]. The social connection and support for the community-dwelling elderly population is a big public health issue that the government should pay attention to and initiate interventional strategies, especially under the hot weather.

Besides ambient temperature exposure, we also observed statistically significant associations of gender, health status, marital

**Table 3**
Association of ambient temperature with LSNS-6 score or social isolation, adjusting other environmental exposures and individual socio-demographic characteristics in the multivariate generalized linear models (N = 1616).

| Variables | LSNS-6 score[a] Absolute change (95%CI) | Social isolation[b] OR (95 % CI) |
|---|---|---|
| Ambient temperature [c] | | |
| Cool days (≥14.42 & < 19.52°C) | 0.00 | 1.00 |
| Warm days (≥19.52 & < 24.53°C) | **−1.84 (-2.58, -1.10)** | **1.47 (1.07, 2.03)** |
| Hot days (≥24.53 & < 28.73°C) | **−2.38 (-3.13, -1.63)** | **1.90 (1.40, 2.60)** |
| Very hot days (≥28.73 & ≤ 29.93°C) | **−1.94 (-2.70, -1.17)** | **1.49 (1.10, 2.02)** |
| Temperature per 5°C increment | **−1.11 (-1.56, -0.67)** | **1.49 (1.22, 1.82)** |
| **Sunshine** (per 1 h) [d] | **0.28 (0.06, 0.50)** | – |
| $NO_2$ (per 10 μg/m$^3$)[d] | −0.21 (−0.45, 0.03) | – |
| **Gender** (Female vs. Male) | **1.89 (1.34, 2.43)** | **0.48 (0.37, 0.63)** |
| **Overall health status** [e] | | |
| Low | 0.00 | 1.00 |
| Moderate | **1.41 (0.80, 2.02)** | **0.66 (0.51, 0.87)** |
| High | **1.83 (1.21, 2.45)** | **0.55 (0.42, 0.72)** |
| **Marital status** | | |
| Married | 0.00 | 1.00 |
| Widowed | 0.15 (−0.56, 0.86) | 1.24 (0.97, 1.59) |
| Divorced/Separated/Unmarried | **−2.22 (-3.14, -1.30)** | **2.84 (2.01, 4.00)** |
| **Living alone** (Yes vs. No) | **−0.73 (-1.38, -0.08)** | – |
| **Religion** (Yes vs. No) | **1.06 (0.55, 1.56)** | **0.69 (0.55, 0.86)** |
| **Housing type** (Public vs. Private) | **−1.97 (-2.54, -1.40)** | **1.72 (1.35, 2.19)** |

[a] LSNS-6 score as a continuous outcome variable and.
[b] Social isolation as a binary outcome variable (0: LSNS-6 ≥ 12, means no social isolation; 1: LSNS-6 < 12, means social isolation) was fit by the generalized linear model (GLM), respectively, using backwards stepwise approach with all the covariates listed in Table 2 at the beginning.
[c] The ambient temperature moving average in the past month was categorized into 4 groups using quartiles as the cut-off points, and the 1st group as the reference to estimate its potential nonlinear effect; temperature as a categorical or continuous variable was included in the model separately.
[d] The sunshine hours and ambient air pollution concentrations moving average in the past week were included in the model.
[e] Overall health status score ranged from 0 to 100 was categorized into three groups, using tertiles as the cut-off points with 113 missing values denoted as a special category. Statistically significant effect estimates are in bold.

**Table 4**
Sensitivity analysis on the association of ambient temperature with LSNS-6 score or social isolation by excluding participants without an exact value in health status (N = 1503).

| Variables | LSNS-6 score[a] Absolute change (95%CI) | Social isolation[b] OR (95 % CI) |
|---|---|---|
| Ambient temperature [c] | | |
| Cool days (≥14.42 & < 19.52°C) | 0.00 | 1.00 |
| Warm days (≥19.52 & < 24.53°C) | **−1.80 (-2.55, -1.04)** | **1.46 (1.04, 2.05)** |
| Hot days (≥24.53 & < 28.73°C) | **−2.39 (-3.15, -1.62)** | **2.14 (1.49, 3.07)** |
| Very hot days (≥28.73 & ≤ 29.93°C) | **−1.93 (-2.72, -1.15)** | **1.44 (1.03, 2.01)** |
| Temperature per 5°C increment | **−1.00 (-1.37, -0.62)** | **1.45 (1.18, 1.78)** |
| **Sunshine** (per 1 h) [d] | **0.25 (0.02, 0.48)** | – |
| $NO_2$ (per 10 μg/m$^3$)[d] | −0.19 (−0.44, 0.06) | – |
| **Gender** (Female vs. Male) | **2.00 (1.36, 2.63)** | **0.48 (0.36, 0.63)** |
| **Overall health status** (per 5 score) [e] | **0.26 (0.19, 0.32)** | **0.92 (0.89, 0.95)** |
| **Marital status** | | |
| Married | 0.00 | 1.00 |
| Widowed | 0.34 (−0.40, 1.08) | 1.23 (0.95, 1.59) |
| Divorced/Separated/Unmarried | **−2.26 (-3.23, -1.30)** | **3.21 (2.23, 4.62)** |
| **Living alone** (Yes vs. No) | **−0.94 (-1.62, -0.26)** | – |
| **Religion** (Yes vs. No) | **1.06 (0.54, 1.58)** | **0.68 (0.54, 0.85)** |
| **Housing type** (Public vs. Private) | **−1.82 (-2.41, -1.24)** | **1.78 (1.36, 2.32)** |

[a] LSNS-6 score as a continuous outcome variable and.
[b] Social isolation as a binary outcome variable (0: LSNS-6 ≥ 12, means no social isolation; 1: LSNS-6 < 12, means social isolation) was fit by the generalized linear model (GLM), respectively, using backwards stepwise approach with all the covariates listed in Table 2 at the beginning.
[c] The ambient temperature moving average in the past month was categorized into 4 groups using quartiles as the cut-off points, and the 1st group as the reference to estimate its potential nonlinear effect; temperature as a categorical or continuous variable was included in the model separately.
[d] The sunshine hours and ambient air pollution concentrations moving average in the past week were included in the model.
[e] Overall health status score ranged from 0 to 100 as a continuous variable, excluding 113 participants with missing values. Statistically significant effect estimates are in bold.

status, living alone, religion, and housing type with LSNS-6 score. That is female and married participants with better health status, holding religions, and living in private houses tended to have a higher LSNS-6 score and lower odds of social isolation. To some extent, these findings were consistent with the evidence reported from a systematic review and meta-analysis which identified the risk factors associated with social isolation in older adults [1]. Generally, women exhibit a greater propensity to expand their social networks and cultivate numerous intimate friendships. Enhanced physical well-being with better health status facilitates their engagement in outdoor pursuits, while religious adherence motivates regular participation in religious activities. Residing in privately owned residences signifies improved socio-economic status. Consequently, individuals possessing these attributes tend to manifest higher scores on the LSNS-6 scale, indicative of heightened social connectedness. The study population was highly elderly, with an average age of 80.9, and relied on social services provided by the NGOs. Therefore, we cannot observe a significant association between advancing age and heightened social isolation, which needs further study.

Although significant associations were found between air pollutants/rainfall and LSNS-6 score in the univariate model, their independent associations were attenuated to null in the multivariate model with ambient temperature included, which may probably be due to the high correlation between pollution concentrations/rainfall and ambient temperature. Furthermore, we found a statistically significant association of sunshine hours with the increased LSNS-6 score. More sunshine exposure would encourage old people to pursue outdoor activities and thus have more social connections. Previous studies have demonstrated that sunlight exposure was beneficial to the mental health of operating room nurses [28], while seasonal increases in sun time were associated with decreased mental health distress [29].

### *4.3. Strengths and limitations*

To the best of our knowledge, this is the first study up to date to examine the association between ambient temperature and social isolation, with comprehensive individual characteristics being collected through a questionnaire survey and adjusted in the analytical model. The diagnoses of the residuals of the final multivariate model showed that we had excluded the residual confounding to the greatest extent. Meanwhile, some limitations should be noted. First, this is a cross-sectional study, only the association but not the causal effect of ambient temperature can be examined. Future studies with prospective longitudinal study design may help to detangle the causal association. The physiological, psychological, and behavioral mechanisms that link ambient temperature with social isolation should also be explored further. Second, we used the ambient temperature and environmental data regularly measured from the outdoor general monitoring stations to represent the population exposures which did not consider the indoor-outdoor difference. Although such an approach is commonly used in environmental epidemiological studies [7,8,11,15] and the potential exposure assessment bias should be non-differential [30,31] to the social isolation status, future studies incorporating personal temperature measurements would offer a more precise assessment of individual exposure to ambient temperature. Third, Hong Kong lies at the northern fringe of the tropical zone with subtropical climate. The temperature exposure in monthly average ranged from 14 to 30$^{o}$C, in which we were not able to assess the potential association of extremely cold and hot temperatures with social isolation. Fourth, the study population is highly elderly who received social services in Hong Kong's urban area. The association between hot temperatures and increased odds of social isolation observed in the current study may not be generalized to the other populations with different healthcare services and in other geographic regions with different climates, weather conditions, and cultural contexts. Further studies with diverse populations in other regions are warranted. However, the findings identified adverse association of ambient temperature with social isolation at the tropical zone with limited temperature variation. Moreover, air conditioning is extensively employed during the summer months in Hong Kong, not just within households but also in entertainment venues, activity spaces, shopping malls, and similar locations. This prevailing circumstance poses a hindrance for us to accurately assess the true relationship between very hot temperatures and social connection as air conditioning is a modifier in the heat-related risk assessment [32,33].

## 5. Conclusion

Our study revealed a clear association between ambient cool temperatures and reduced social isolation, as well as association between hot temperatures and increased odds of social isolation among Chinese older adults residing in the urban community of Hong Kong. The findings offer valuable insights for the government in terms of providing social services to the aging population during hot weather conditions.

## CRediT authorship contribution statement

**Eliza Lai-Yi Wong:** Writing – original draft, Supervision, Methodology, Conceptualization. **Hong Qiu:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Kin-Fai Ho:** Writing – review & editing, Conceptualization. **Annie Wai-Ling Cheung:** Writing – review & editing, Project administration. **Hera Leung:** Writing – review & editing, Supervision, Data curation. **Frank Youhua Chen:** Writing – review & editing, Funding acquisition, Conceptualization. **Eng-Kiong Yeoh:** Writing – review & editing, Conceptualization.

## Ethical approval and consent to participate

The Human Subjects Ethics Sub-Committee at the City University of Hong Kong approved the study in which written informed consent was applied in the study "Transformation of community-based elderly care: Improving the care continuum of elderly services

across two clusters through operations optimization and analytics" (Reference No.: 2-4-201701_01). Consent was obtained from each respondent before taking the interviews. We explained the purpose of the study, that their participation was voluntary, and that their responses would remain confidential. All methods were performed following the relevant guidelines and regulations.

## Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2025.e41721.

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