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Cumulative effect of indoor temperature on cardiovascular disease–related emergency department visits among older adults in Taiwan

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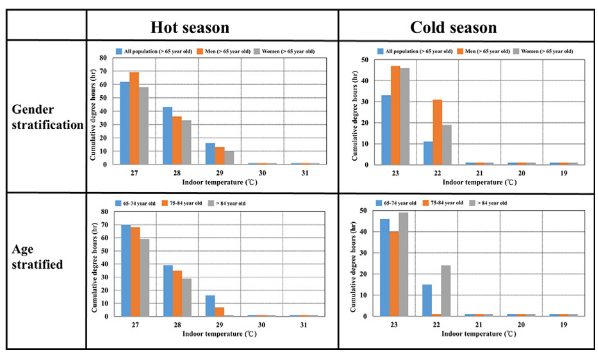
HIGHLIGHTS

- We used cumulative degree hour (CDH) to assess the threshold of temperature.
- CDH was negatively associated with the indoor temperature in hot season.
- CDH was positively associated with the indoor temperature in cold season.
- Different gender and age groups had different CDH thresholds.
- Policymaker should consider the cumulative effect of indoor temperature.

GRAPHICAL ABSTRACT



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ABSTRACT

Studies have demonstrated that exposure to extreme outdoor temperatures increases cardiovascular disease mortality and morbidity. However, people spend 80%–90% of their time indoors, and the cumulative effects of exposure to high or low temperature on the risk of cardiovascular diseases had not been considered. This study investigated the cumulative effects of high or low indoor temperature exposure on the risk of cardiovascular diseases. We estimated indoor temperatures by using a prediction model of indoor temperature from a previous study and further calculated the cumulative degree hours at different indoor temperature ranges. Samples of emergency department visits due to cardiovascular diseases were collected from the Longitudinal Health Insurance Database (LHID) from 2000 to 2014 in Taiwan. We used a distributed lag nonlinear model to analyze the data. Our data demonstrated a significant risk of emergency department visits due to cardiovascular diseases at 27, 28, 29, 30, and 31 °C when cooling cumulative degree hours exceeded 62, 43, 16, 1, and 1 during the hot season (May to October), respectively, and at 19, 20, 21, 22, and 23 °C when heating cumulative degree hours exceeded 1, 1, 1, 11, and 33 during the cold season (November to April), respectively. Cumulative degree hours were different according to gender and age groups. Policymakers should further consider the cumulative effects to prevent hot- or cold-related cardiovascular diseases for populations.

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1. Introduction

Climate change is a major global public health concern (Intergovernmental Panel on Climate Change, 2014). Studies have demonstrated that extreme outdoor temperature exposure increases mortality or hospital admission related to cardiovascular diseases by using the diurnal temperature range, temperature change between two consecutive days, or degree of acclimatization (Burkart et al., 2011; Guo et al., 2011; Kingsley et al., 2015; Lee et al., 2014; Milojevic et al., 2016; Turner et al., 2012). However, people spend 80–90% of their time indoors (Klepeis et al., 2001; Leech et al., 2002), building materials, air conditioning usage, and human activities also change the indoor temperature range (Jung et al., 2019); thus, exposure profiles are different between indoor and outdoor temperatures. Indoor temperature may be a more crucial factor influencing human health compared with outdoor temperature.

Some studies measured the change between indoor and outdoor temperature (Saeki et al., 2014a; Saeki et al., 2014b) and further investigated the association between indoor temperature exposure and biomarkers of cardiovascular diseases. There are studies investigated the effects of urban heat islands or housing energy efficiency on indoor heat-related mortality (Taylor et al., 2018a; Taylor et al., 2018b). However, these studies have not considered fully the cumulative effects of hot or cold on human health. In 1996, Frank and his coworkers developed the Cumulative Heat Strain Index (CHSI) for investigating the cumulative effect of heat on human health. They also demonstrated that the CHSI was a better indicator in investigating the cumulative effect of heat on human health compared with conventional indicators, such as the physiological strain index (Frank et al., 2001). Moreover, Sexton and Hattis indicated that exposure time, frequency, and level collection were required to adequately investigate the effects of environmental factors on human health (Sexton and Hattis, 2007). Therefore, we should not ignore the cumulative effects of high or low indoor temperature exposure.

Cooling degree hours and heating degree hours are universal indexes for assessing the relationship between thermal comfort and energy consumption indoors (Papakostas and Kyriakis, 2005; Satman and Yalcinkaya, 1999). The equations for cooling and heating degree hours are as follows:

$$\text{Cooling degree hours} = \sum_{i=1}^{n_{cd}} (T_o - T_{bal}) \tag{1}$$

$$\text{Heating degree hours} = \sum_{i=1}^{n_{hd}} (T_{bal} - T_o), \tag{2}$$

where T_{bal} is the balance-point temperature, T_o is the outside temperature, and n_{cd} and n_{hd} are the number of cooling and heating degree hours in one day, respectively.

In this study, we followed Eqs. (1) and (2) and modified them to investigate the cumulative effects of indoor temperature.

$$\text{Cooling degree hours} = \sum_{i=1}^{N} (T_i - T_b) \tag{3}$$

$$\text{Heating degree hours} = \sum_{i=1}^{N} (T_b - T_i), \tag{4}$$

where T_i is the indoor temperature, T_b is the threshold, and N is the hours in a day. The degree hour for indoor cooling were estimated using the Eq. (3) in hot season; the degree hour for indoor heating were estimated using the Eq. (4) in cold season.

Many studies have demonstrated that older adults have a higher risk of disease and lower ability to respond to temperature change compared with younger people (Gasparrini et al., 2012; Khajavi et al., 2019; Wallmüller et al., 2018). According to a United Nations report, the global population of people over 60 years old is 962 million in 2017 and will reach almost 2.1 billion in 2050 (United Nations, 2017). In Taiwan, the population over 65 years old was 7% in 1993 and will reach 20% in 2026 (Ministry of the Interior, 2018). Taiwan's rate of population aging is ranked number one in the world. Moreover, thermoregulation ability differs by gender (Xiong et al., 2015), and one study has shown gender-related differences in sweat loss (Mehnert et al., 2002). Although the effects of higher or lower temperature exposure differ by gender or age groups, the previous studies didn't consider the cumulative effects.

This study aimed to focus on the association between cumulative degree hours of indoor temperatures and emergency department visits due to cardiovascular diseases in Taiwan and established the cumulative degree hour thresholds for different indoor temperature ranges; moreover, we further examined the differences between gender and age groups.

2. Materials and methods

2.1. Cumulative degree hours

Before calculating the cumulative degree hours of indoor temperatures, we estimated indoor temperatures. The estimation of hourly indoor temperature was based on a prediction model of indoor temperature. Detailed information about the estimation of prediction model of hourly indoor temperature is shown in the supplemental materials (Fig. S1 and Table S1). In brief, we collected hourly levels of indoor and outdoor temperature and relative humidity, land surface temperature, normalized difference vegetation index (NDVI), building characteristics, occupants' behavior, and electricity consumption for 30 households in 11 cities in Taiwan from 2012 to 2015. Then, we combined all data and used a mixed effect model to estimate the prediction model of hourly indoor temperature for each month (Table S2).

We calculated the hourly indoor temperature of each day from 2000 to 2014 in Taiwan based on the monthly prediction model of hourly indoor temperature. The weather, land surface temperature, NDVI, electricity consumption, and building characteristics of prediction model were collected from Taiwan's Central Weather Bureau, National Aeronautics and Space Administration (NASA, US), NASA, Taiwan power company, and statistical report of Ministry of the Interior in Taiwan, respectively. Indoor temperature was then used to estimate daily cooling and heating cumulative degree hours of both the hot (May to October) and cold (November to April) seasons by using Eqs. (3) and (4) (Fig. S2), and the threshold values were 27 °C and 23 °C (indoor temperature), respectively. We only calculated the cumulative degree hours only at 27 °C–31 °C during the hot season and at 19 °C–23 °C during the cold season to analyze the association with emergency department visits due to cardiovascular diseases because our previous study (Lo, 2017) indicated a significant risk of cardiovascular diseases at indoor temperatures of 27 °C–31 °C during the hot season and 19 °C–23 °C during the cold season. We assumed that the study population remained indoors all day because older people spend most of their time indoors (Hussein et al., 2012; Matz et al., 2014).

2.2. Source of data for health

In 1995, Taiwan's government launched the single-payer National Health Insurance program. According to its statistical report (National Health Insurance, 2015), 99.6% of Taiwan's population (Taiwan's population was estimated to be 23,800,000 in 2019) was enrolled in this program in 2014. We collected emergency department visit data for cardiovascular diseases from 2 million participants from the Longitudinal Health Insurance Database (LHID) of the National Health Insurance program to analyze the associated cumulative effects of indoor temperature. The LHID data were collected from 1 January 2001 to 31 December 2014. The diagnoses of emergency department visits were based on the International Classification of Diseases, Ninth Revision (ICD-9-CM390-459). Participants from 317 townships on the island of Taiwan, a total of 2,000,118 participants, were randomly sampled from the LHID. We excluded those younger than 65 years. Thus, a total of 260,465 people were included in this study. These participants were divided into three age groups: 65–74 years old, 75–84 years old, and >85 years old.

Many studies (Khajavi et al., 2019; Kingsley et al., 2015) have indicated that air pollution is also a factor influencing the risk of cardiovascular diseases. Therefore, in this study, we also collected the air pollutant concentration (NOx, $PM_{2.5}$, and O_3) from Taiwan's Environmental Protection Administration from 2000 to 2014 to control for the association between cumulative degree hours and emergency department visits for cardiovascular diseases. Table S3 presents the average concentrations of $PM_{2.5}$, O_3, and NO_x from 2000 to 2014. The data showed that air quality was poorer during the cold season (November to April) than during the hot season (May to October).

2.3. Data analysis

The delayed effects of environmental factor exposure on human health showing non-linear relationship (Gasparrini, 2011), so a distributed lag nonlinear model (DLNM) was used to analyze the association between cumulative degree hours and emergency department visits for cardiovascular diseases. Because the number of emergency department visit were different in different study day, we adjusted the day of the week (DOW); moreover, the number of emergency department visits could increase due to the outpatient was closed during holiday, we also adjusted the holiday. The equation of DLNM is as follow:

$$\log(E(Y)) = \beta_0 + \sum_{t=0}^{7} NS(CDH_t, DF, 5; lag, 7) + \sum_{t=0}^{1} Lin(PM_{2.5\ t}) + \sum_{t=0}^{1} Lin(O_{3\ t}) + \sum_{t=0}^{1} Lin(NO_{x\ t}) + \text{NS}\left(\text{Time}, \frac{7}{year}\right) + DOW + Holiday \quad (5)$$

where Y is the emergency department visits for cardiovascular diseases, NS is the nature cubic spline, CDH is the cumulative degree hour, DF is the degree of freedom (DF is 5), lag is the lag day (7 days), time is the node (7), and DOW is the day of the week.

For example, a DLNM was applied to analyze the relationship between the daily emergency visits (dependent variable) and the daily cumulative degree hours when indoor temperature exceeding 27 °C (independent variable). The significance level found would indicate the relative risk (RR) and the corresponding cumulative degree hours when indoor temperature exceeding 27 °C.

According to the Lo's study (Lo, 2017), the risk of emergency department visits due to cardiovascular diseases was significant at indoor temperatures of 27 °C–31 °C during the hot season (May to October) and 19 °C–23 °C during the cold season (November to April). Therefore, we analyzed the association between cumulative degree hours and emergency department visits for cardiovascular diseases at indoor temperatures of 27 °C–31 °C during the hot season and 19 °C–23 °C during the cold season. We used SAS (v9.4, SAS Institute Inc., Cary, NC, USA) software to analyze data. Statistical significance was defined as $p < 0.05$.

3. Results

3.1. Cumulative degree hours of indoor temperature

Table 1 shows the cumulative degree hours for different seasons. The average cumulative degree hours during the hot season were 32.6 ± 24.6, 16.5 ± 16.9, 6.0 ± 9.1, 1.2 ± 3.3, and 0.1 ± 0.6 at 27, 28, 29, 30, and 31 °C, respectively. During the cold season, the average cumulative degree hours were 1.4 ± 6.1, 4.1 ± 11.7, 9.3 ± 19.0, 17.4 ± 27.4, and 28.8 ± 36.1 at 19, 20, 21, 22, and 23 °C, respectively.

Table 1
Descriptive statistics for cooling and heating cumulative degree hours in hot and cold seasons, respectively.

Temperature (°C)	Cumulative degree hours	
	Mean ± SD.	Min to max
Hot season (May to October)		
27	32.6 ± 24.6	0 to 109.5
28	16.5 ± 16.9	0 to 85.5
29	6.0 ± 9.1	0 to 61.5
30	1.2 ± 3.3	0 to 37.5
31	0.1 ± 0.6	0 to 16.5
Cold season (November to April)		
19	1.4 ± 6.1	0 to 83.1
20	4.1 ± 11.7	0 to 107.1
21	9.3 ± 19.0	0 to 131.1
22	17.4 ± 27.4	0 to 155.1
23	28.8 ± 36.1	0 to 179.1

SD: standard deviation.

3.2. Emergency department visits for cardiovascular diseases

Table 2 presents a summary of emergency department visits due to cardiovascular diseases in each group. More emergency department visits occurred during the cold season (138,227) than during the hot season (122,238). Table 2 also shows that more emergency department visits occurred among participants who were 75–84 years old during both hot and cold seasons, and more emergency department visits occurred among men.

3.3. Association between indoor temperature and cardiovascular diseases

Cumulative degree hours at different indoor temperatures during both the hot and cold seasons are presented in Table 3. During the hot season, the risks of emergency department visits due to cardiovascular diseases were significant when cumulative degree hours exceeded 62, 43, 16, 1, and 1 at indoor temperatures of 27 °C, 28 °C, 29 °C, 30 °C, and 31 °C, respectively. During the cold season, the risks of emergency department visits due to cardiovascular diseases were significant when cumulative degree hours exceeded 1, 1, 1, 11, and 33 at indoor temperatures of 19 °C, 20 °C, 21 °C, 22 °C, and 23 °C, respectively.

Table 4 presents the cumulative degree hours for each gender during the hot and cold seasons. During the hot season, the risks of emergency department visits due to cardiovascular diseases were significant among men when cumulative degree hours exceeded 69, 36, 13, 1, and 1 at indoor temperatures of 27 °C, 28 °C, 29 °C, 30 °C, and 31 °C, respectively; among women, the risks were significant at these temperatures when cumulative degree hours exceeded 58, 33, 10, 1, and 1, respectively. During the cold season, the risks of emergency department visits due to cardiovascular diseases occurred among men were

Table 2
Summary of cardiovascular disease–related emergency department visits from 2000 to 2014 in hot and cold seasons based on different subgroups.

	Hot season (May to October)	Cold season (November to April)
Older adults (≧65 years old)	122,238	138,227
Age		
65 to 74 years old	50,713	57,452
75 to 84 years old	53,971	60,485
>85 years old	17,554	20,290
Gender		
Man	62,064	69,233
Woman	60,174	68,994

Table 3
Cooling and heating cumulative degree hours for cardiovascular disease–related emergency department visits for older adults in hot and cold seasons from 2000 to 2014, respectively.

Setpoint temperature (indoor)	CDH	Relative risk (95% CI)
Hot season (May to October)		
27 °C	62	1.145 (1.003, 1.307)
28 °C	43	1.078 (1.001, 1.161)
29 °C	16	1.035 (1.001, 1.071)
30 °C	1	1.013 (1.007, 1.020)
31 °C	1	1.082 (1.056, 1.109)
Cold season (November to April)		
23 °C	33	1.086 (1.001, 1.180)
22 °C	11	1.039 (1.000, 1.079)
21 °C	1	1.011 (1.008, 1.016)
20 °C	1	1.014 (1.008, 1.020)
19 °C	1	1.015 (1.006, 1.024)

CDH: cumulative degree hours; CI: confidence interval.

significant when cumulative degree hours exceeded 1, 1, 1, 31, and 47 at indoor temperatures of 19 °C, 20 °C, 21 °C, 22 °C, and 23 °C, respectively; among women, the risks were significant at these temperatures when the cumulative degree hours exceeded 1, 1, 1, 19, and 46, respectively.

Table 5 presents the cumulative degree hours in each age group during the hot and cold seasons. During the hot season, a significant risk of emergency department visits due to cardiovascular diseases occurred in participants aged 65 to 74 years when cumulative degree hours exceeded 70, 39, 16, 1, and 1 at indoor temperatures of 27 °C, 28 °C, 29 °C, 30 °C, and 31 °C, respectively; participants aged 75 to 84 years had a significant risk after 68, 35, 7, 1, and 1 cumulative degree hours, and those older than 85 years had a significant risk after 59, 29, 1, 1, and 1 cumulative degree hours, respectively. During the cold season, a significant risk of emergency department visits due to cardiovascular diseases occurred in participants aged 65 to 74 years when cumulative degree hours exceeded 1, 1, 1, 15, and 46 at indoor temperatures of 19 °C, 20 °C, 21 °C, 22 °C, and 23 °C, respectively; participants aged 75 to 84 years had a significant risk after 1, 1, 1, 1, and 40 cumulative degree hours, and those older than 85 years had a significant risk after 1, 1, 1, 24, and 49 cumulative degree hours, respectively.

4. Discussion

To the date, this is the first study to investigate the cumulative effects of high or low indoor temperature exposure and assess cumulative degree hours at different temperature ranges on the basis of the risk of emergency department visits due to cardiovascular diseases. Our data revealed a significant risk of emergency department visits due to cardiovascular diseases when higher temperatures during the hot season and lower temperatures in the cold season reduced the cumulative degree hours. Moreover, the cumulative degree hours differed by gender and age groups. These results can be used in adaptation plans for reducing the risk of adverse health effects under climate change.

Our study demonstrated that high or low temperature exposure increased the risk of cardiovascular diseases, which was consistent with a number of relevant studies (Basu et al., 2012; Breitner et al., 2014; Bunker et al., 2016; Kingsley et al., 2015; Knowlton et al., 2008; Phung et al., 2016). Studies have also explained the biological mechanisms

Table 4
Cooling and heating cumulative degree hours for cardiovascular disease–related emergency department visits for older adults in hot and cold seasons from 2000 to 2014 (gender stratified), respectively.

Setpoint temperature (indoor)	Man		Woman	
	CDH	Relative risk (95% CI)	CDH	Relative risk (95% CI)
Hot season (May to October)				
27 °C	69	1.183 (1.006, 1.392)	58	1.159 (1.004, 1.337)
28 °C	36	1.133 (1.004, 1.279)	33	1.130 (1.007, 1.269)
29 °C	13	1.082 (1.004, 1.166)	10	1.081 (1.003, 1.165)
30 °C	1	1.032 (1.018, 1.047)	1	1.035 (1.021, 1.050)
31 °C	1	1.197 (1.132, 1.266)	1	1.197 (1.137, 1.260)
Cold season (November to April)				
23 °C	47	1.111 (1.001, 1.232)	46	1.092 (1.004, 1.189)
22 °C	31	1.097 (1.001, 1.203)	19	1.069 (1.0002, 1.1410)
21 °C	1	1.012 (1.007, 1.016)	1	1.011 (1.007, 1.016)
20 °C	1	1.014 (1.008, 1.021)	1	1.014 (1.007, 1.020)
19 °C	1	1.016 (1.006, 1.026)	1	1.014 (1.004, 1.024)

CDH: cumulative degree hours; CI: confidence interval.

Table 5
Cooling and heating cumulative degree hours for cardiovascular disease–related emergency department visits for older adults in hot and cold seasons from 2000 to 2014 (age stratified), respectively.

Setpoint temperature (indoor)	65 to 74 years old		75 to 84 years old		>85 years old	
	CDH	Relative risk (95% CI)	CDH	Relative risk (95% CI)	CDH	Relative risk (95% CI)
Hot season (May to October)						
27 °C	70	1.148 (1.00004, 1.318)	68	1.178 (1.,0004 1.387)	59	1.222 (1.011, 1.477)
28 °C	39	1.144 (1.006, 1.300)	35	1.135 (1.005, 1.282)	29	1.193 (1.002, 1.421)
29 °C	16	1.098 (1.002, 1.203)	7	1.063 (1.001, 1.129)	1	1.018 (1.004, 1.033)
30 °C	1	1.027 (1.015, 1.039)	1	1.035 (1.019, 1.051)	1	1.042 (1.019, 1.065)
31 °C	1	1.141 (1.080, 1.205)	1	1.221 (1.157, 1.289)	1	1.264 (1.172, 1.363)
Cold season (November to April)						
23 °C	46	1.095 (1.005, 1.193)	40	1.039 (1.001, 1.220)	49	1.140 (1.006, 1.292)
22 °C	15	1.058 (1.0003, 1.119)	1	1.004 (1.0004, 1.008)	24	1.108 (1.001, 1.225)
21 °C	1	1.006 (1.001, 1.011)	1	1.012 (1.008, 1.017)	1	1.015 (1.008, 1.021)
20 °C	1	1.011 (1.004, 1.017)	1	1.016 (1.010, 1.023)	1	1.015 (1.007, 1.024)
19 °C	1	1.013 (1.005, 1.018)	1	1.014 (1.003, 1.024)	1	1.026 (1.012, 1.040)

CDH: cumulative degree hours; CI: confidence interval.

between high or low temperature exposure and cardiovascular diseases. Some studies indicated that blood is more concentrated due to water and salt loss when humans exposed to high temperatures (Keatinge, 2002; Medina-Ramon, 2007), which further induces the development of cardiovascular diseases. Moreover, studies have indicated that heat influences the human circulatory system, and heat exposure causes organ damage (González-Alonso, 2012; González-Alonso et al., 2008; Taylor and Groeller, 2008). Low temperature exposure causes blood to become more concentrated because of a higher heart rate and blood pressure, which further induces the development of cardiovascular diseases (Anderson and Bell, 2009; Hajat et al., 2007; Nguyen et al., 2014).

Although studies have demonstrated that high or low temperature exposure increases the risk of cardiovascular diseases, they didn't consider cumulative adequately effects. Studies have indicated that high or low temperature exposure increased the risk of cardiovascular diseases with sustained exposure to specific temperature ranges (Byrne et al., 2006; Chan et al., 2008; Périard et al., 2015). In this study, we predicted indoor temperature and calculated the cumulative degree hours at different indoor temperature ranges on the basis of the risk of cardiovascular diseases, which provides important information about the cumulative effects of high or low indoor temperature exposure. Policymakers can formulate elastic temperature adaptation policies to reduce the risk of adverse health effects. For example, during the hot season, a significant risk of emergency department visits due to cardiovascular diseases occurred after fewer cumulative degree hours at 30 °C than at 27 °C (Table 3), which indicated that an adaptation policy should be implemented to warn people to immediately act to reduce adverse health effects when temperatures reach 30 °C and provide buffer a time to act when temperatures reach 27 °C.

During hot and cold seasons, men had more cumulative degree hours than women (Table 4). One study indicated that the change in root mean square of successive differences in men was larger than that in women when exposed to high or low temperatures (Zhang, 2007), which indicates that men have better thermoregulatory abilities to overcome temperature changes. Studies have also indicated that women had poorer thermoregulatory abilities during menstruation (Pivarnik et al., 1992), and the thermoregulatory null zone was reduced in postmenopausal women (Freedman and Krell, 1999). These findings suggest that physiological differences contributed to the fewer cumulative degree hours observed in women than in men.

Table 5 displays fewer cumulative degree hours in the group of participants older than 85 years, which indicates that the oldest people had the poorest thermoregulatory ability compared with the other groups during the hot season. This result was consistent with the study of Gasparrini and his co-workers (Gasparrini et al., 2012). However, our data showed that the participants aged 75 to 84 years had the fewest cumulative degree hours during the cold season. We speculated that the group aged over 85 years has a higher proportion of comorbidities (Liu et al., 2012), such as diabetes, cancer, or high blood pressure; thus, cardiovascular diseases were not logged in the LHID database. Moreover, Gasparrini and his colleagues demonstrated that the relative risk of heat-related mortality for all causes increased with age (Gasparrini et al., 2012). However, they also indicated that the relative risk of heat-related mortality was different for different cardiovascular diseases. We analyzed the association between cumulative degree hours and emergency department visits due to cardiovascular diseases for all heart-related causes. The phenomenon may justify why the fewest cumulative degree hours did not occur in the group of participants older than 85 years during the cold season.

Our study had several limitations. First, we used a prediction model to estimate indoor temperature rather than skin temperature, so our data may not reflect the real exposure situation. Nevertheless, a study demonstrated a significant relationship between indoor temperature and skin temperature (Liu et al., 2011). However, our study aimed to investigate the cumulative effect of exposure to high or low indoor temperatures on emergency department visits due to cardiovascular diseases. Second, this study used the LHID, which limited risk factors for cardiovascular diseases for adjusting, such as alcohol consumption or smoking. However, in Taiwan, alcohol consumption and smoking are more common among men than women (Gender Equality Committee of the Executive Yuan, 2018; Health Promotion Administration, 2019). In this study, we analyzed the association between indoor temperature exposure and emergency department visits due to cardiovascular diseases for different genders to control the confounder. Third, occupant's behavior was highly linked to the variation of indoor temperature, yet, was not included in the corresponding predictive model due to the lack of detailed records of respective frequencies and exact time of event. Applying feasible technology to collect occupant's behavioral frequency and time on a long-term basis is imperative in future study. Finally, this study used only the prediction model of indoor temperature to calculate the indoor temperature distribution in Taiwan, which may not reflect the real exposure situation. However, in this study, the average building age, building structure proportions, floor, category, area, and population density of the 30 selected households were similar to the distributions in Taiwan (Department of Statistics, 2017). We concluded that the data from study households can reflect the situation of most households in Taiwan.

5. Conclusion

We observed that cumulative degree hours decreased as indoor temperature increased during the hot season and decreased during the cold season. Different gender and age groups had different cumulative degree hours. We recommend that public health intervention strategies for hot- or cold-related cardiovascular diseases should further consider the cumulative effect for different populations. Moreover, we also suggested that the researchers should analyze the cumulative effects of temperature exposure in cold or temperature zone for reducing the health risks.

CRediT authorship contribution statement

Chien-Cheng Jung: Data curation, Formal analysis, Writing - original draft. **Ying-Fang Hsia:** Data curation, Formal analysis, Writing - original draft. **Nai-Yun Hsu:** Investigation. **Yu-Chun Wang:** Data curation, Writing - review & editing. **Huey-Jen Su:** Conceptualization, Writing - review & editing.

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.scitotenv.2020.138958.

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