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Heat index trends and climate change implications for occupational heat exposure in Da Nang, Vietnam

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ABSTRACT

Occupational extreme heat exposure can lead to a number of detrimental heat-health impacts on workers. Excessive night-time temperatures following hot days do not allow for workers to recover and can compound work heat-health impacts. A number of heat indices have been developed to estimate thermal comfort – how hot it feels – based on meteorological, physiological, and working conditions. We investigated potential changes in day and night-time ambient temperatures and heat indices for Da Nang, Vietnam over the period 2020–2049 when compared with 1970–1999 after downscaling daily minimum and maximum temperatures and humidity variables from six CMIP5 climate models. Two heat indices were employed, the U.S. National Weather Service Heat Index for day and the indoor Apparent Temperature for night. The Vietnam Ministry of Health (MOH) sets thermal comfort thresholds for particular workloads and rates. By 2050, daytime heat index values breach the average 32 °C MOH threshold for light work nearly continuously during the months of April to October. The number of nights per annum in which the heat index exceeds 28 °C is likely to range between 131 and 170 nights per year. Occupational heat exposure in Da Nang for outdoor workers or indoor workers without adequate ventilation, breaks or other cooling and heat precautionary and treatment measures will be exacerbated by climate change.

1. Practical implications

Heat waves, particularly the combination of locally above-average day and night-time temperatures with high humidity many days in a row, negatively impact human health. The human body cannot tolerate conditions exceeding 37 °C. At temperatures of 27 °C and a relative humidity of 40%, some healthy individuals may begin to experience heat stress with prolonged activity or exposure. Heat stress causes fatigue, headache and muscle cramps, while heat stroke can lead to death, even among healthy people. Certain groups of people – those with chronic health conditions like diabetes or high blood pressure, and farmers, construction workers, and other outdoor laborers – are at greater risk of suffering heat stress and heat stroke during heat waves. Consecutive days and nights of extreme heat sap workers' strength, exacerbate underlying health conditions, and can lead to heat stress and increased risk of death.

The number of heat waves is increasing worldwide due to climate change and land-use development. Cities magnify the effects of heat waves by concentrating heat emissions (and air pollution) from vehicles and air conditioning units, and by trapping and absorbing heat between buildings and the pavement. This combination of development and land-use leads to urban heat islands where urban temperatures may be up to 10 °C warmer than surrounding suburban areas or farmland. Thus, heat waves in cities can have an even worse impact on occupational heat exposure than in peri-urban or rural areas.

Heat indices are tools issued by public health departments and meteorological agencies to notify the public when dangerous temperatures and humidity have been reached. There are a number of commonly used heat indices; which one is used depends on the availability of certain meteorological observations, ease of use and historical precedence at the location.

This article discusses historical trends and future climate projections in day and night-time heat indices for the city of Da Nang,

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Vietnam. The analysis was conducted as climate services in support of an occupational heat health and safety project led by the Center for Community Health and Development (COHED) as part of the larger Asian Cities Climate Change Resilience Network (ACCCRN) initiative. COHED worked with the Labor Safety Department of the Ministry of Labor, Invalids and Social Affairs (MOLISA – national level ministry) and the Department of Labor, Invalids and Social Affairs of Da Nang (DOLISA) to evaluate heat-health safety conditions and awareness at three enterprises, develop workplace educational materials, and train the enterprises on heat safety activities.

The Vietnam Standard and Quality Institute (SQI) and the Ministry of Health (MOH) have issued general heat-humidity threshold guidelines for workplaces throughout Vietnam. The study used day and night-time temperatures and humidity projections from multiple climate models to calculate how many times per year the heat index might exceed the safety thresholds specified by the MOH by 2050. The daytime thresholds were set as: 1) 32 °C from the MOH average thermal comfort temperatures for light work; 2) 28 °C for average MOH thermal comfort temperatures for heavy labor; and 3) 37 °C as the absolute physiological threshold. The night-time temperature threshold was set at 28 °C as prolonged exposure at this value following excessively hot days can contribute to fatigue and heat cramps (NWS, 2014), and many of Da Nang's workers report a lack sufficient cooling mechanisms in their homes (Dao et al., 2013).

By 2050, Da Nang's workers and populations are at serious risk of suffering heat stress and heat stroke without additional adaptation assistance by the government and employers. The study revealed the following:

- The average heat index during the day is continually above 37 °C during April through October, with some days approaching this absolute threshold as early as March and as late as November. The hot season may be two to three months longer than it was over the period of 1970–2011.
- During the hottest months (June to August), the average night-time heat index averages around 29.4 °C.

Da Nang is a rapidly growing port city on Vietnam's central coast. Significant amounts of land are being developed for buildings and roads to accommodate a thriving tourism sector, growing industries and universities. Previous research by the Institute for Social and Environmental Transition-Vietnam (ISET-VN) and the Centre for Health Education and Development (COHED) found that the city is home to a number of low-income, migrant laborers employed in construction, self-employed workers (e.g. street vendors), and small businesses. These populations often do not have air conditioning during the day while at work and are reluctant to take rest breaks for fear of lost wages or business incomes. At night, these poorer populations already have a difficult time finding respite from the heat, as they tend to live in lower quality housing with little insulation, poor ventilation and reduced access to air conditioning. Public awareness about the risks of heat stress and heat stroke remains low, even among employees of mid to large-scale businesses.

Climate change, plus Da Nang's rapid urban development, will greatly increase the number of days and nights in which the heat index safety thresholds are exceeded. The lack of cooling at night will negatively impact recovering capacities while people sleep, exacerbating pre-existing health conditions and reducing their labor capacities during the day. Construction workers, street vendors, police and fishermen (all outdoor workers), and indoor workers engaged in manufacturing or sewing, or those in poorly ventilated and constructed buildings will be particularly hard hit. COHED, along with MOLISA and DOLISA, are working together to deliver education and outreach campaigns to businesses around occupational heat exposure, the dangers of heat stress and stroke to employees during heat waves, and what measures should be taken to reduce risks.

2. Introduction

Hot weather is recognized as detrimental to human health and labor productivity when temperatures and humidity exceed physiological thresholds (Huang et al., 2011; Smith et al., 2014). Previous research demonstrates that particular groups are more susceptible to suffering negative heat impacts – manual laborers and those working outside (Hanna et al., 2011; Kjellstrom et al., 2009; Kjellstrom, 2009); those with low incomes and/or socially isolated who may be living in poorly insulated buildings, lack air conditioning and/or living on the upper floors (Chapman et al., 2009; Curriero et al., 2002; Rey et al., 2009; Jabeen and Johnson, 2013); the elderly, young and those with pre-existing health conditions (Green et al., 2001; Zeng et al., 2012); and, some urban dwellers (Harlan and Ruddell, 2011; Mueller et al., 2014).

The combination of high ambient temperatures with humidity can lead to conditions exceeding the human physiological heat tolerance limit of 35–37 °C, at which the body can no longer cool through sweating (USGCRP, 2016). High ambient temperatures, particularly when accompanied by high humidity, can place tremendous stress on the human body. During periods of heat exposure, the body responds with thermoregulatory functions, sweating being the primary mechanism. If core body temperature exceeds 37 °C (skin surface temperature of 35 °C) for sustained periods, hyperthermia can ensue (Sherwood and Huber, 2010). At ambient temperatures of 27 °C and a relative humidity of 40%, healthy individuals may begin to experience increasing fatigue and irritability with prolonged activity or exposure (Kovats and Hajat, 2008). Individuals with underlying health conditions may have reduced heat tolerance due to impaired physiological thermoregulation and can experience heat stress and stroke at lower thresholds than healthy individuals (Semenza et al. 1999; Kenny et al., 2010). The actual thermal comfort of a particular individual is determined through a number of factors such as air temperature, humidity, radiant temperature, wind, level of physical activity and metabolism, clothing, and underlying health conditions (Segal and Pielke, 1981; Parsons, 2006).

Weather conditions in conjunction with health status, workload and rate, outdoor worker exposure to sunlight and wind, indoor workers exposure to radiant heat sources or without adequate ventilation, or those workers not acclimatized can lead to heat stress and stroke in the workplace (Lucas et al., 2014; USGCRP, 2016). Consecutive days and nights of extreme heat can further exacerbate heat-related health risks, as workers without access to adequate cooling at night may have a harder time recovering from daytime exposure. Despite this scientific and medical recognition, general business awareness of extreme heat exposure and occupational health risks remains low, and regulatory standards for heat illness prevention programs for different occupations in various countries may be lacking or inconsistent (Gubernot et al., 2014; Arbury et al., 2014).

Climate change is projected to increase the number of hot days and nights, extend the length of the hot season and lead to a greater number of heat waves in many urban areas throughout Asia (Mishra et al., 2015; Ma et al., 2016; IPCC, 2012). The implications of current extreme heat exposure on occupational health and labor productivity are being investigated (Gubernot et al., 2014; Pantavou et al., 2011), and research and policy interest is growing in projecting how climate change might influence future heat exposure and occupational health risks (USGCRP, 2016; Huang et al., 2011; Hanna et al., 2011).

This article discusses historical trends and future climate projections in day and night-time heat indices for the city of Da Nang, Vietnam. The analysis was conducted as climate services in support of an occupational heat health and safety project led by the Center for Community Health and Development (COHED) as part of the larger Asian Cities Climate Change Resilience Network (ACCCRN) initiative. COHED worked with the Labor Safety Department of the Ministry of Labor, Invalids and Social Affairs (MOLISA – national level ministry) and the Department of Labor, Invalids and Social Affairs of Da Nang (DOLISA) to evaluate heat-health safety conditions and awareness at three enterprises, develop workplace educational materials, and train the enterprises on heat safety activities. The three enterprises – The Chemical Industry Company Central Mine Central, Da Nang Steel Company and VINACONEX 25 (a construction company) – represent working conditions to which workers may be exposed to sun, wind, heavy work loads and/or radiant heat. The project training materials and heat guidelines are being integrated into provincial training agendas for all Da Nang companies and enterprises after piloting at the three enterprises.

3. Da Nang's context

Da Nang is a port city, located on Vietnam's central coast, with a tropical (hot and humid) climate dominated by a dry season that lasts roughly from April to August, and a wet season from September to March (see Fig. 1). The humidity rarely drops below 60% in the city, averaging roughly 80% and the mean annual temperature is 25.9 °C. As the city has experienced rapid development in the past few decades, the large number of buildings and roads, more cars and air conditioners are trapping excess heat in the city and making it hotter than the surrounding agricultural lands. Urban heat island effects can make its dense urban development areas between 4 and 6 °C warmer than the surrounding rural areas (Nguyen and Huynh, 2015). The naturally hot and humid climate, coupled with the urban heat island, can create extreme heat conditions that have a broad range of negative health impacts on the city's residents and workers. Previous vulnerability assessment work indicates a low level of awareness of certain segments of Da Nang's population and businesses of the potential dangers of extreme heat events (Dao et al., 2013).

The same research into worker vulnerability to heat stress in Da Nang found that unregistered migrant laborers, often self-employed, were particularly vulnerable (Dao et al., 2013). Due to lack of registration, they are not able to access public services and healthcare, leaving medical conditions untreated, and often rent low-quality housing prone to overheating and allowing no relief at night. Poor women, freelance entrepreneurs and outdoor workers employed by small and medium-size businesses also face significant heat stress issues while at work, with employers having little knowledge of workplace safety regulations and minimal knowledge of heat stress. Da Nang also is rapidly urbanizing and growing as a tourist destination, spurring growth in the construction industry and related, supporting industries. Manufacturing – electronics, machinery, chemicals, etc. – also plays a predominant role in Da Nang's economy (GSO, 2009). Workers in construction and manufacturing are often exposed to high heat conditions through workload and radiant heat sources (sunlight or machinery). These sets of workers are among Da Nang's most vulnerable to suffering occupational heat stress and stroke.

4. Heat and humidity workplace guidelines for Vietnam

The Vietnam Standard and Quality Institute (SQI) and the Ministry of Health (MOH) have issued general heat-humidity threshold guidelines for workplaces throughout Vietnam. A number of heat indices (e.g. Predicted Heat Strain Model, Universal Thermal Climate Index, Effective Heat Strain Index, etc.) have been developed to account for a broad range of meteorological conditions and assumptions around physical activity, clothing, and body mass

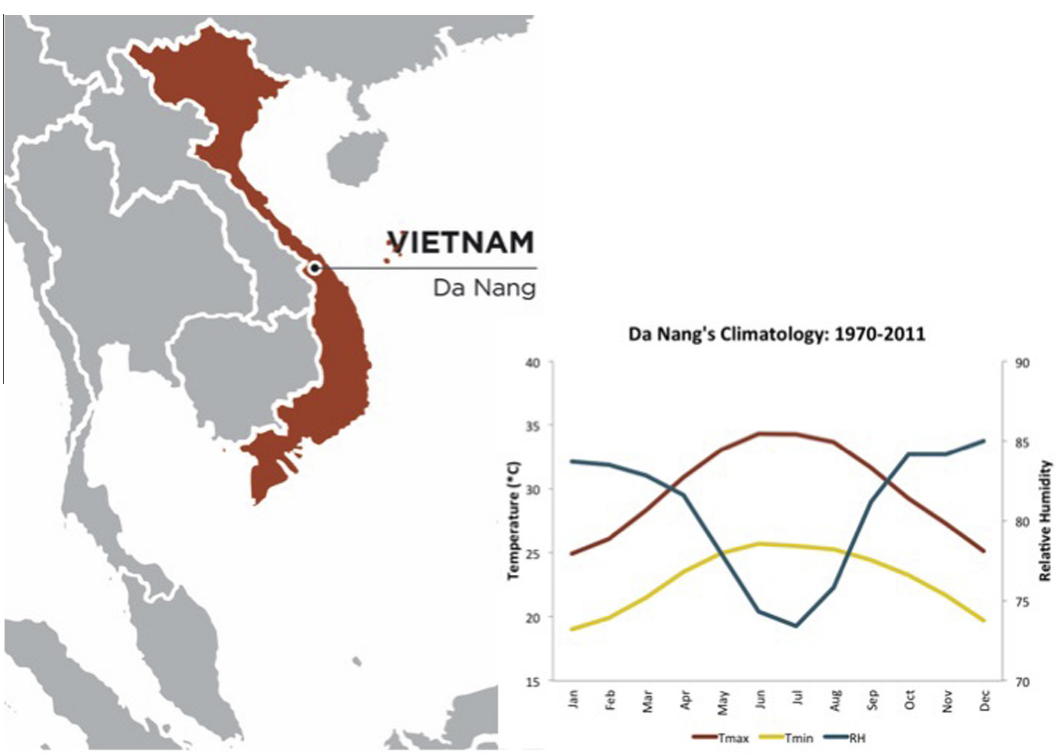

Fig. 1. Da Nang's location and climatology.

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(Epstein and Moran, 2006; Blazecjzyk et al., 2012). The most common heat indices are the Apparent Temperature (AT) and the Wet Bulb Globe Temperature (WBGT). The AT is an empirical human body – heat balance relationship and can be calculated directly from standard meteorological variables (Steadman, 1979a,b, 1984). This makes it a particularly useful index for estimating possible climate change impacts on heat stress. The WBGT is a heat index developed by U.S. Army and Marine Corps to protect soldiers working outdoors (heavy physical activity), with heavy clothing in high heat, humidity and sunny conditions in the 1950s (Yaglou and Minard, 1957).

The MOH and SQI guidelines are based on Yaglou and Minard's WBGT for the following temperature, humidity, wind and solar radiation conditions in Table 2 (MOH, 2002; SQI, 2009). The government guidelines do not specify whether the weather conditions must occur over a particular time period, for example an hour or a few hours. Workload rates are demarcated according to heart rate as measured over a three-minute period, see Table 1.

5. Methodology

The analysis of Da Nang's historical day and night-time heat index trends and potential climate change impacts on ambient temperatures and heat indices involved multiple steps, which are described here. The first portion of the analysis involved determining which heat index to use, based on ease of use in the workplace and available data. Historical climate data for Da Nang were surveyed for availability, quality and completeness, and then compiled into an area-averaged dataset for the period 1970–2011. The historical dataset was used to analyze trends in day and night-time ambient and heat index temperatures, and to evaluate the bias of a set of climate models. Statistical downscaling and bias correction of the climate model variables was then conducted. These bias corrected, projected variables were then used to calculate potential shifts in daytime and night-time heat indices over the period of 2020–2049. Each step is described below.

5.1. Selection of heat indices for analysis

The WBGT heat index workplace thresholds specified in Vietnamese policy require non-standard meteorological instruments for measurements. Many workplaces do not have or maintain WBGT thermometers. While WBGT components can be approximated from standard meteorological variables, the relationships for approximation are not standardized and it has been known to lead to over- or under-estimation (which could potentially be dangerous) of actual heat conditions (Budd, 2008; Srinavin and Mohamed, 2003). Non-meteorologists – e.g. public health officials and workplace safety officers – wishing to estimate heat stress risk and issue warnings may find the WBGT non-intuitive to calculate in situations where climate services must be done in house. Furthermore, of the Da Nang businesses surveyed in previous work, few had regular thermometers onsite and none had globe thermometers (Dao et al., 2013). For these reasons, it may be preferable to use AT or a derivative of it in estimating heat stress conditions where only standard meteorological variables are available.

There are three simplified AT formulas – one for indoor, one for outdoors in the shade, and one for outdoors in the sun (the equations for outdoors are not presented here, see Steadman, 1984):

$$\text{Indoor}: \ AT_{in} = -1.3 + 0.92T + 2.2p$$

where AT and T (ambient temperature) are in °C and p is vapor pressure in kPa. Vapor pressure is empirically derived; we used Bolton's (1980) formula for this investigation. The simplified AT indoor formula was used to evaluate trends and project future shifts in *night-time* thermal comfort.

As COHED began working with the three enterprises in Da Nang, it was found that both the MOH weather condition thresholds and the AT were too complicated for workplace safety officers. A simplified, visual heat index – NOAA's National Weather Service (NWS) Heat Index – was found to be far more understandable and easier to implement for monitoring workplace heat exposure conditions and prompting protective actions at different thresholds.

The NWS Heat Index (HI) was developed through multiple regression analysis of Steadman's equations for radiation and wind exposure, as a way of using only two conventional independent variables – ambient temperature and relative humidity. Solar radiation, windiness, clothing resistance and human physiology and workload are implicitly assumed in the NWS index (Rothfusz, 1990). Even though this index was designed for outdoor working conditions, in practice it is being used in indoor and outdoor work environments (MSU, 1999; NIOSH, 2016). Thus, the NWS HI was used for daytime calculations in this study. There are two equations for calculating the daytime HI pertinent to Da Nang's climatological conditions, where T is in °F and Rh in percent:

General HI for ambient temperatures above 80 °F and relative humidity above 40%:

$$\begin{aligned} HI = & -42.379 + 2.04901523T \\ & + 10.14333127Rh - 0.22475541TRh - 6.83783 \times 10^{-3}T^2 \\ & - 5.481717 \times 10^{-2}Rh^2 + 1.22874 \times 10^{-3}T^2Rh \\ & + 8.5282 \times 10^{-4}TRh^2 - 1.99 \times 10^{-6}T^2Rh^2 \end{aligned}$$

For conditions where RH is greater than 85% and the ambient temperature between 80 and 87 °F, the following adjustment is subtracted from the HI:

$$Adjs = [(Rh - 85)/10] * [(87 - T)/5]$$

The HI readily lent itself to a visual table for approximate thermal comfort beginning with ambient temperatures of 27 °C or higher and a relative humidity of 40% or higher. Corresponding health impacts for different heat index values are then demarcated on the table (See Fig. 2). The test three enterprises found the NWS HI table the easiest to use given current capacity and access to either weather forecasts and/or onsite measurements.

5.2. Dataset compilation

Daily data were collected for the following variables in order to calculate AT: 2-m minimum and maximum temperature, relative humidity, and 10-m wind speed. Data over the historical period

Table 1
Workload class according to labor heart rate (MOH, 2002).

Workload classification	Heart rate (beat/min)
Light	<90
Medium	90–100
Heavy	100–120
Very heavy	120–140
Extremely heavy	140–160
Maximum	>160

Table 2
Yaglou thermal comfort index thresholds (°C) per workload class and rate (MOH, 2002; SQI, 2009).

Kind of work	Light	Medium	Heavy
Continuous work	30.0	26.7	25.0
50% working, 50% at rest	31.4	29.4	27.9
25% working, 75% at rest	33.2	31.4	30.0

- Caution
- Extreme Caution
- Danger
- Extreme Danger

Relative Humidity (%)	temperature (°C) 27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
40	27	28	29	30	31	32	34	35	37	39	41	43	46	48	51	54	57
45	27	28	29	30	32	33	35	37	39	41	43	46	49	51	54	57	
50	27	28	30	31	33	34	36	38	41	43	46	49	52	55	58		
55	28	29	30	32	34	36	38	40	43	46	48	52	55	59			
60	28	29	31	33	35	37	40	42	45	48	51	55	59				
65	28	30	32	34	36	39	41	44	48	51	55	59					
70	29	31	33	35	38	40	43	47	50	54	58						
75	29	31	34	36	39	42	46	49	53	58							
80	30	32	35	38	41	44	48	52	57								
85	30	33	36	39	43	47	51	55									
90	31	34	37	41	45	49	54										
95	31	35	38	42	47	51	57										
100	32	36	40	44	49	54											

Heat stress Index (°C)	Category	Dangers
27–32	Caution	Fatigue possible with prolonged exposure and/or physical activity
32–41	Extreme caution	Sunstroke, heat cramps and heat exhaustion possible with prolonged exposure and/or physical activity
41–54	Danger	Sun stroke, heat cramps or heat exhaustions likely, and heatstroke possible with prolonged exposure and/or physical activity
Above 54	Extreme danger	Heat/sunstroke highly likely with continued exposure

Fig. 2. NWS heat index table and broadly corresponding health impacts (NWS, 2014).

1970–2011 were collected from meteorological records compiled from a number of sources (Table 3) to create an area-averaged dataset. The projected values of these variables over the periods 1970–2005 and 2006–2055 were downloaded from six general climate models (GCM), two scenarios each (RCP 4.5 and 8.5), from the CMIP5 data portal. The six GCMs were selected through the evaluation of literature on the performance of the models in replicating key climatological characteristics over the Southeast Asia region (Lee and Wang, 2012; Song and Zhou, 2014). Due to time constraints, it was not possible to independently verify GCM model performance or to evaluate additional GCMs beyond those selected for this study (see Table 3).

Da Nang has a highly heterogeneous topography, from sea level to mountains over a distance of less than 20 km; this complex geography greatly influences localized wind patterns and heat pockets. Additionally, the city has undergone rapid land use change and development, also altering localized heat patterns (Nguyen and Huynh, 2015). The current (and historical) placement of meteorological stations cannot capture the diversity of conditions in the city. Additionally, significant portions of data were missing over the period of 1973–1993 as a legacy of the American/Vietnam War. Based on these caveats, area-averaged datasets of select variables were compiled from multiple sources for the period of 1970–2011, as described in Moore et al. (2012). The datasets incorporated from NCEP Reanalysis data (1973–1978) and ERA-Interim data (1978–1993), introducing some errors difficult to correct in the historical dataset. The potential implications of these errors are discussed in the results section.

Table 3
Climate datasets used in analysis.

Dataset/model	Data provider	Description
ERA-Interim	European Centre for Medium-Range Weather Forecasting	High-resolution daily datasets 1979–2011 (Dee et al., 2011)
NCEP Reanalysis	NOAA/OAR/ESRL PSD, Boulder Colorado	Coarse resolution daily datasets from 1970 to 1980 (Kalnay et al., 1996)
Station-level: Da Nang & nearby stations	Hydro-Meteorological Region Southern Centre (Vietnam) Global Summary of the Day & Global Historical Climatology Network – National Climatic Data Centers (NCDC USA)	Daily observation data from 1970 to 2011
CMIP5:		Simulated daily variables:
• BCC-CSM1.1(m)	Beijing Climate Center, China Met Administration	• Historical (1960–2005)
• CanESM2	Canadian Centre for Climate Modelling & Analysis	• RCP 4.5 (2006–2055)
• CSIRO-MK3.6.0	Commonwealth Scientific & Industrial Research Organization (CSIRO)/ Queensland Climate Change Centre of Excellence	• RCP 8.5 (2006–2055)All downloaded from CMIP5 Multi-Model Ensemble Dataset: http://pcmdi9.llnl.gov/esgf-web-fe/
• MIROC-ESM	Japan Agency for Marine-Earth Science &Technology, Atmosphere & Ocean Research Institute (University of Tokyo), and National Institute for Environmental Studies	
• MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M)	
• NCAR-CCSM4	National Center for Atmospheric Research	

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5.3. GCM skill testing

A number of standard skill tests were run to assess the models' ability to hindcast (replicate) seasonality and reasonably (quasi-subjective) replicate observational moments (mean, standard deviation and skew) for all of the variables over the period of 1970–1999. Tests also included a correlation of the hindcast variables with the observational datasets. As described previously, the poor quality and spatial representation of historical datasets means that some subjective interpretation of skill scores is necessary. Some of these skill score results are summarized in Taylor Diagrams, presented in the results section.

5.4. Downscaling and bias correction

General circulation models (GCMs) simulate the interactions between the land, ocean and atmospheric processes that influence climate, but they do so on a large-scale, typically between ~100 and ~300 km. They cannot fully capture local climate processes, such as the city-scale (~5–50 km) and generally have large biases in simulating local fields like precipitation (Kripalani et al., 2007; Jourdain et al., 2013). As a result, it is necessary to downscale and/or bias correct GCM output when deriving estimates of potential future climate impacts at the local scale. The GCM skill testing mentioned in Section 5.3 is used to analyze models' biases and ability to capture a location's climatology.

We employed a quantile mapping technique to statistically downscale the four variables and correct for model bias without losing the important climate change signals embedded in the model projections. There are many methods for downscaling and bias correcting GCM output; these methods fall into either a dynamical or statistical downscaling category (Opitz-Stapleton and Gangopadhyay, 2011; von Storch et al., 2000; Wilby et al., 2004). It is beyond the scope of this article to discuss the trade-offs between different downscaling techniques.

The quantile mapping method has been used in other climate change studies, typically to downscale temperature and precipitation (Quintana-Seguí et al., 2011; Hashimo et al., 2007; Gudmundsson et al., 2012). The method involves developing a transfer function from the cumulative distribution function (CDF) of the model simulations to match the CDF of the observation data. In order to account for the possibility that climate change will alter the variability and the skew of the distribution over time, in addition to the mean, we used the equidistant mapping method proposed by Li et al. (2010). We used a linear transfer function after testing other transfer functions to find out the best possible fit over the historical period and used this to shift the projections:

$$x_{m,adj} = x_{m,fut} + F_{obs}^{-1}(F_{m,future}(x_{m,fut})) - F_{m,past}^{-1}(F_{m,fut}(x_{m,fut}))$$

where x_m = the model variable, *adj* is the downscaled value and *fut* is the uncorrected model variable. F = a transfer function derived either from the observation data or from the model data. We downscaled each variable separately according to Li et al. (2010) coded in R (v.3.1.1 'Sock it to Me') and drawing from the 'qmap' package (Gudmundsson et al., 2012).

5.5. Calculation of historical and climate change-conditioned day and night heat indices

We calculated both the historical day and night heat indices from the observational data and potential future indices using the downscaled, bias corrected GCM variables. We then analyzed how the range of projected (2020–2049) minimum and maximum ambient temperatures, and daytime and night-time heat indices, changed when compared with the observed values over the period 1970–1999. The number of days (nights) in which the heat index exceeded particular temperature thresholds was also calculated. The daytime thresholds were set as: 1) 32 °C from the MOH average thermal comfort temperatures for light work; 2) 28 °C for average MOH thermal comfort temperatures for heavy labor; and 3) 37 °C as the absolute physiological threshold (see Table 2 and article introduction). The night-time temperature threshold was set at 28 °C as prolonged exposure at this value following excessively hot days can contribute to fatigue and heat cramps (NWS, 2014), and many of Da Nang's workers report a lack sufficient cooling mechanisms in their homes (Dao et al., 2013).

6. Results

6.1. Model skill scores

The selected GCMs were able to reasonably replicate seasonality in minimum and maximum temperatures and tended to capture minimum temperature variability better than that of maximum temperatures. All models exhibited a cold bias in replicating maximum temperatures except for Miroc-ESM, which had a hot bias. The models did a poor job of replicating 2-m relative humidity. The models failed to capture the area's high humidity patterns, with four out of the six displaying an inverse relationship with the observational relative humidity, even though all of the models showed average high humidity. These results underscore the need for downscaling and bias correction of large-scale GCM output when projecting climate change impacts for highly localized studies (see Fig. 3).

6.2. Historical trends in ambient temperatures and heat indices

Between 1970 and 2011, there were an average of 246 (264) days per year in which the heat index was equal to or greater than the MOH's recommendations of 32 °C (28 °C) for light (heavy) labor. Depending on the season, the daytime heat index is ~1–6 °C warmer than the ambient temperature. There is no trend over the historical period in the number of days in which the heat index exceeds the MOH thresholds, however the number of days exceeding 37 °C has been increasing at a rate of 0.3 days/per decade. Seasonal maximum ambient temperatures are increasing at an average rate of ~0.2 °C per decade during the months of June–August of for Da Nang, which is consistent with trends seen in other studies (Nguyen et al., 2014).

The number of nights in which the heat index exceeds 28 °C remained constant at a median of 51 per year over 1970–1999, but appears to have decreased post-2000 to a median of 26 nights per year. Overall, average night-time ambient temperatures declined by about 0.3 °C between 1970 and 2011, with most of the downward trend happening after 1993. While a small decrease, it is statistically significant at the 97.5th percentile according to a non-parametric Mann Kendall trend test.

We speculate that the downward trend seen since 1993 is partially due to the amount of data missing prior to this year, and low station density coupled with lack of metadata for adjusting station deficiencies. There was considerable missing daily data from the station datasets between 1973 and 1993 that was interpolated with ERA-Interim datasets and some NCEP Reanalysis data. While the ERA datasets were highly correlated with the daily minimum temperatures, they did exhibit a hot bias that could have artificially inflated the number of hot nights prior to 1993. The ERA data more closely captured daily maximum temperatures than minimums, and no similar downward trends were seen in day temperatures. The NCEP Reanalysis data is of very coarse resolution (~278.3 km spacing) and was also used to interpolate missing days prior to

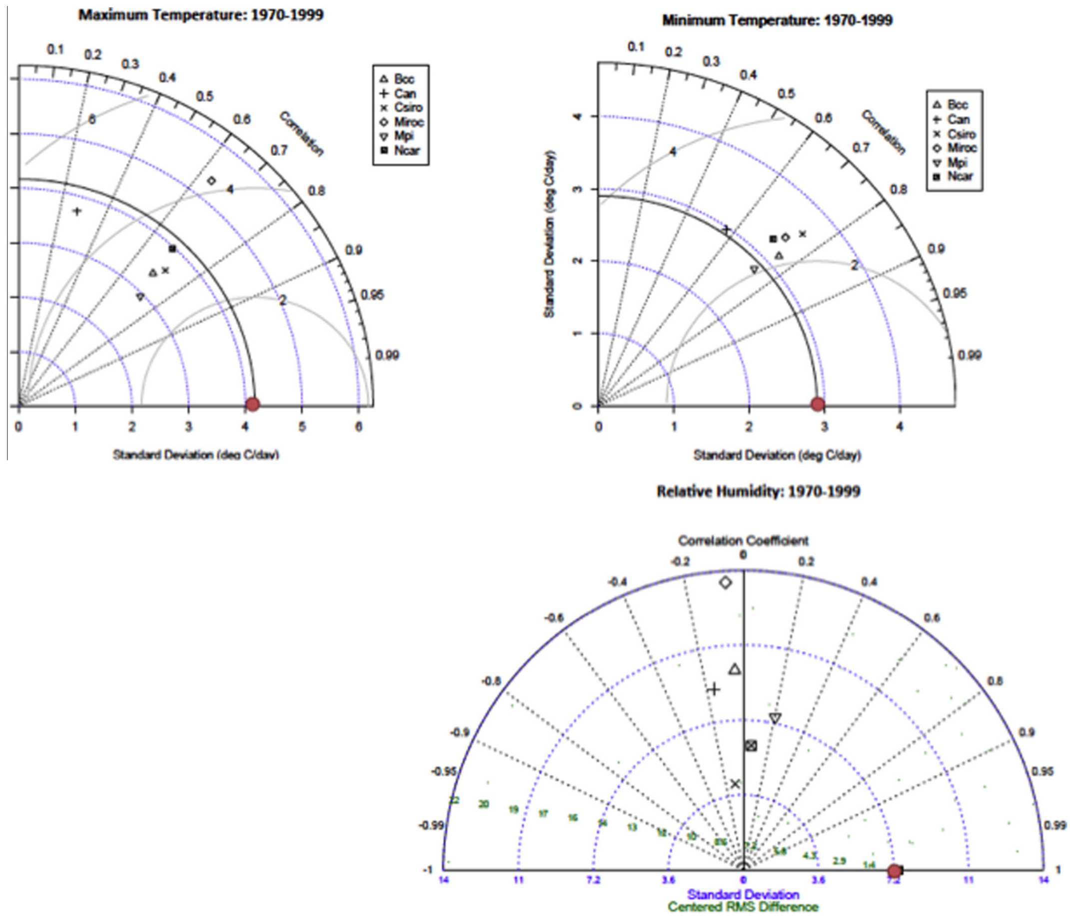

Fig. 3. Taylor diagrams of the GCMs' skill.

the years covered by the ERA datasets, also introducing a bias. We do not expect it to continue in the future however, as climate change is likely to warm nights according to the multi-model projections used in this study.

6.3. Climate change projections 2020–2049

Multi-model median projections of future day and night ambient temperatures and heat index values under nearly all climate change scenarios show continued warming through 2050 (see Fig. 4 and Table 4). Warming is most pronounced in the months leading up to (April and May) and just after (September through November) the hot season, though the very hot season (June to August) will also get warmer. Because of these increases in ambient temperature, the NWS HI during the day continually averages above 52.3 °C during May through September, creating dangerous heat exposure conditions for both outdoor and indoor workers. The median heat index during the day is not likely to fall below 43.9 °C during any season by 2050, putting both outdoor and indoor workers at risk of heat stress and stroke unless a variety of coping mechanisms are adopted. It is only during the early spring that the multi-model interquartile spread does not project significant increases in ambient day and night temperatures or the respective heat indices.

The total length of the hot season in which the daytime heat index does not fall below 32 °C or 37 °C may extend by 2–3 months when compared with the historical period (Fig. 5). *If the daytime heat index threshold of 28 °C for heavy labor is used, it is exceeded almost year-round by 2050.* The types of change in ambient temperature are consistent with previous projections (MONRE, 2011). Because of climate change, the daytime heat index may be between 0 and 11 °C hotter than historical ambient day temperatures (Table 4).

Ambient temperatures are also expected to increase at night. Night-time heat index temperatures during the hottest months (June to August) are not likely to drop below an average of 29.4 °C, reducing recovery capacity at night while sleeping. The number of nights per annum in which the heat index exceeds 28 °C is likely to range between 131 and 170 nights per year according to the interquartile spread, with a mean of 149 nights per year by 2050. This is nearly three times the number of hot nights over the early historic period (1970–1999) and five times the number averaged after 1999.

7. Discussion

According to the multi-model projections employed in this study, climate change is likely to increase ambient day and night-time temperatures and heat index values by 2050 for Da Nang. This study used the Apparent Temperature heat index as an estimate of night-time thermal comfort, which is more widely used by meteorological agencies than the Wet Bulb Globe Temperature index, which is currently employed more by industrial and labor organizations. After testing with three pilot enterprises, the NWS heat index (an approximation of the Apparent Temperature) was used to develop occupational heat stress guidelines and training materials. There are pros and cons to each that we only briefly discussed. While the potential impacts of climate change on

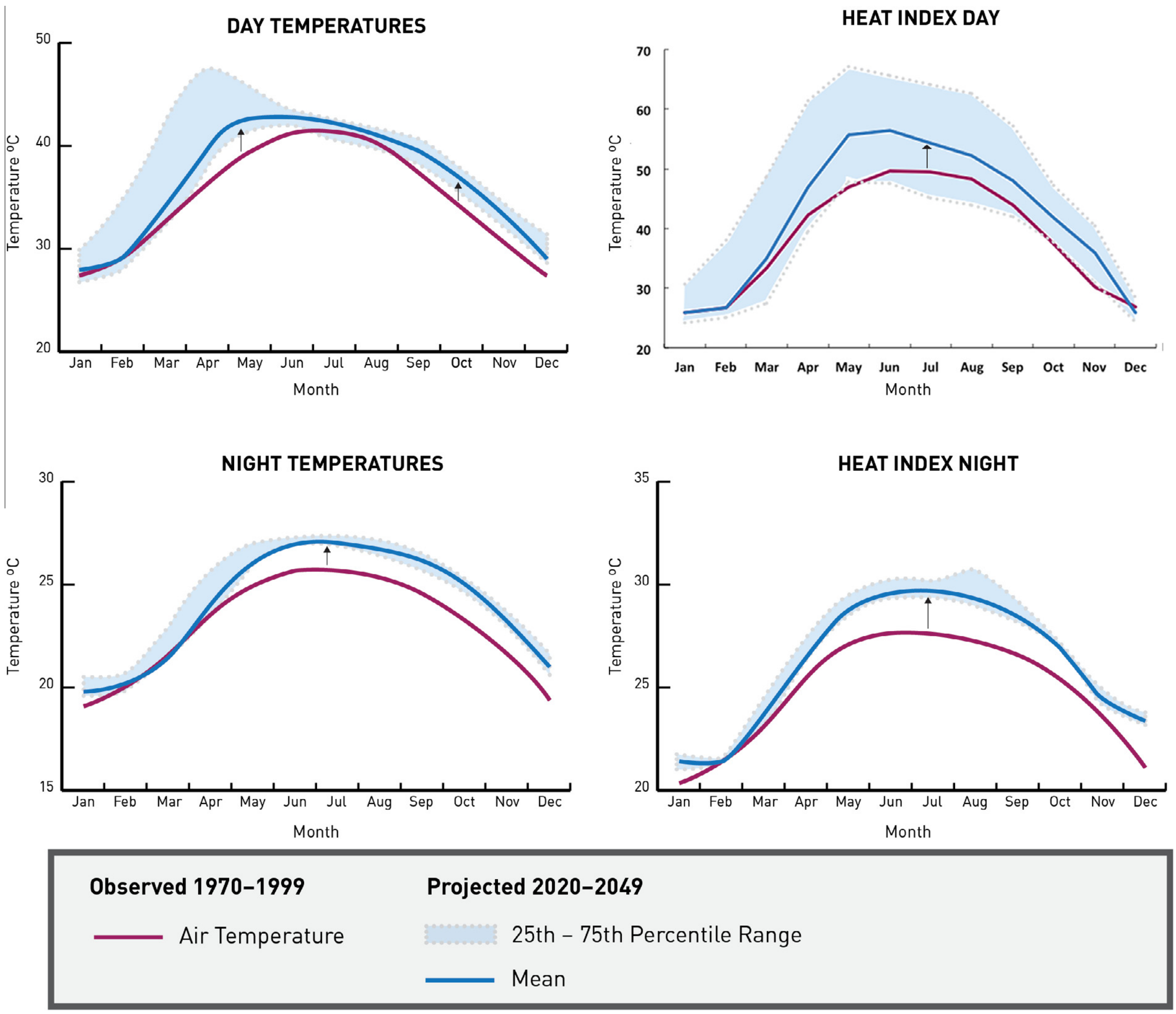

Fig. 4. Day and night shifts in ambient temperatures and heat indices values over 2020–2049 when compared with 1970–1999.

Table 4
Median seasonal heat indices at day (NWS HI) and night (AT indoor) over the historical period (1970–1999) and the future (2020–2049). The future heat index value is the multi-model median projected value. Average number of days (nights) per season exceeding a particular threshold is also indicated.

	1970–1999					2020–2049				
	Ambient Temp (°C)	NWS Heat Index (°C)	Days Median HI Exceeds 28 °C	Days Median HI Exceeds 32 °C	Days Median HI Exceeds 37 °C	Ambient Temp (°C)	NWS Heat Index (°C)	Days Median HI Exceeds 28 °C	Days Median HI Exceeds 32 °C	Days Median HI Exceeds 37 °C
Day										
DJF	25.3	26.5	24	16	4	28.1	26.2	18	4	0
MAM	30.7	40.8	79	75	64	34.9	45.9	90	84	71
JJA	33.9	49.2	92	91	90	38.7	54.3	92	92	92
SON	29.2	37.2	70	64	48	33.1	41.9	90	87	71

	1970–1999			2020–2049		
	Ambient Temp (°C)	AT Indoor Heat Index (°C)	Nights Median AT Exceeds 28 °C	Ambient Temp (°C)	AT Indoor Heat Index (°C)	Nights Median AT Exceeds 28 °C
Night						
DJF	19.6	20.3	0	21.0	22.1	0
MAM	23.4	23.8	9	25.3	26.4	31
JJA	25.6	26.7	32	27.5	29.4	80
SON	23.2	24.9	5	25.2	26.5	25

occupational heat-health risk are not yet within general occupational safety officer awareness, DOLISA and other policy makers within Da Nang are increasingly concerned with climate change shifts in heat-health risk.

We do run into a challenge that the NWS HI index is most appropriate for outdoor use. As far as we can tell from the literature, it has not necessarily been tested for indoor settings – including those with radiant heat sources from machinery, etc.

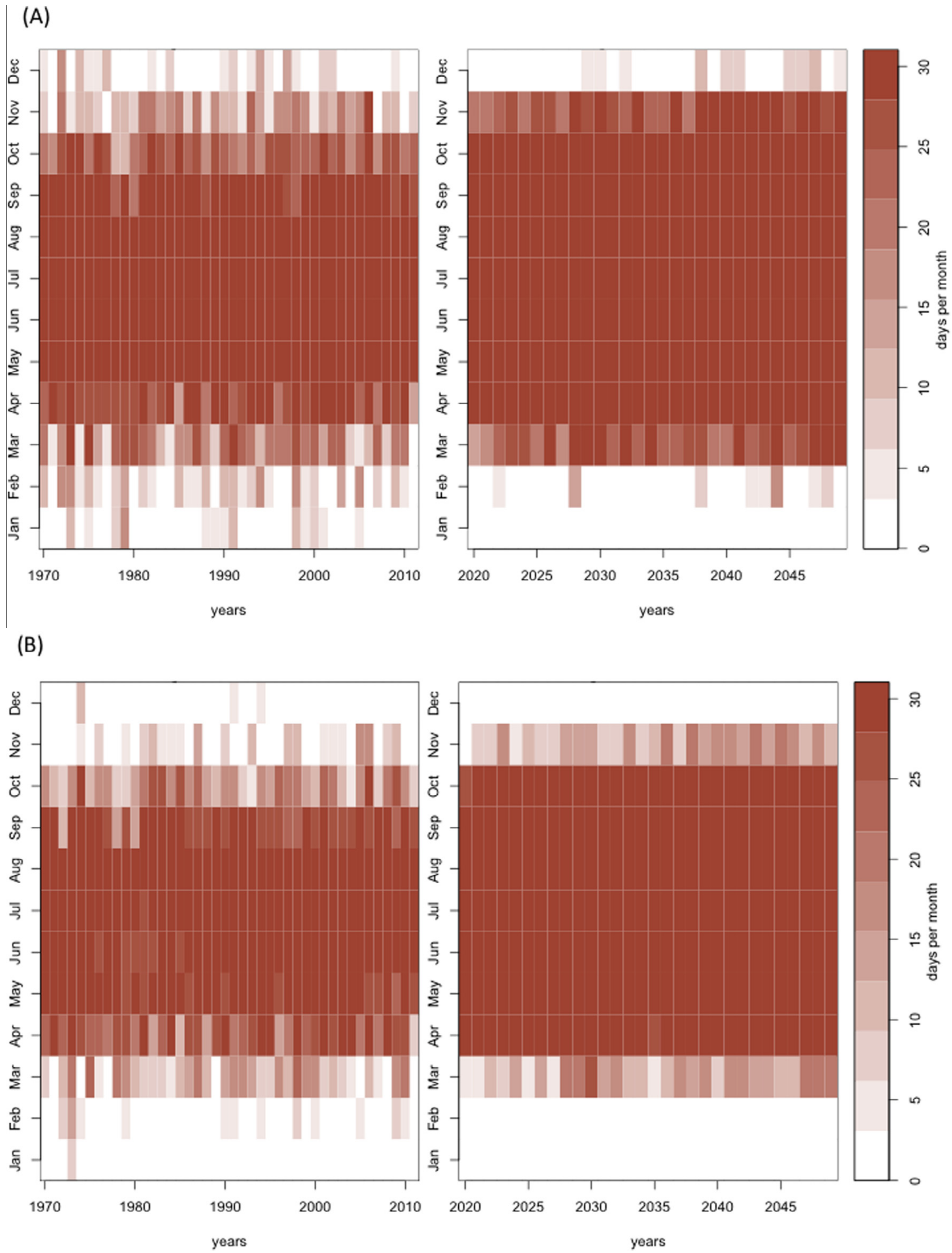

Fig. 5. Number of days per month in which the heat index exceeds 32 °C (A) and 37 °C (B).

Additionally, it and the Steadman AT (outdoor – sun and wind) index formula on which it is based has not been verified for conditions beyond the range of those listed in Steadman's original work (Steadman, 1984). Despite of these caveats however, from a practical standpoint, the businesses in Da Nang are finding this index to be the most intuitive and easiest to use. Given simple thermometer and humidity readings onsite, if such equipment is available, or from daily weather forecast data, the pilot enterprise safety officers were able to estimate heat exposure conditions for their workplace using the NWS HI look-up table. The importance of differences in indoor and outdoor thermal comfort in Da Nang may require additional investigation. From a practical standpoint around developing training programs and awareness, it is not that important, particularly as not all businesses (actual percentage unknown) are still not aware of occupational heat stress and stroke and taking precautionary measures.

Low-income workers, migrant laborers and outdoor workers are already struggling to cope with the city's hot and humid climate. Interviews with employees and employers in a previous study found that workplace heat exposure is prevalent, exacerbating existing illness and triggering heat stress symptoms, while increasing financial stress due to decreased labor productivity (Dao et al., 2013). Despite reporting being negatively impacted by heat, few of the workers or business owners knew of measures they could take to reduce heat stress. The lack of knowledge and capacity translated to largely ineffective coping strategies employed at home during the night, and further perpetuates heat-health complications during the day due to the physical inability to recover at night.

This study, and the related temperature and heat index analysis presented in this article, arose out of the identified lack of awareness of occupational heat exposure and workplace heat-health risk reduction strategies. COHED, MOLISA, and DOLISA are expanding training programs and introducing occupational heat exposure guidelines to enterprises throughout Da Nang (COHED, 2016a,b). The programs and guidelines contain activities for monitoring daily weather forecasts and site temperature and humidity, then using the NWS Heat Index Table to warn supervisors and workers if dangerous heat conditions are occurring. The materials also educate workers about the signs and symptoms of heat stress and stroke, and actions to take to assist a stricken worker. The companies were provided with recommendations for rest periods, ventilation and protective clothing measures, and providing adequate water to employees.

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References

Arbury, S., Jacklitsch, B., Farquah, O., et al., 2014. Heat Illness and Death Among Workers – United States, 2012–2013. Morbidity and Mortality Weakly Report 63(31), 661–665. U.S. Department of Health and Human Services: Centers for Disease Control and Prevention.

Blazecjzyk, K., Epstein, Y., Jendritzky, G., et al., 2012. Comparison of UTCI to selected thermal indices. Int. J. Biometeorol. 56, 515–535.

Bolton, D., 1980. The computation of equivalent potential temperature. Mon. Weather Rev. 108, 1046–1053.

Budd, G.M., 2008. Wet-bulb globe temperature (WBGT) – its history and its limitations. J. Sci. Med. Sport 11, 20–32.

Chapman, R., Howden-Chapman, P., Viggers, H., et al., 2009. Retrofitting houses with insulation: a cost-benefit analysis of a randomised community trial. J. Epidemiol. Community Health 63 (4), 271–277.

COHED, 2016a. Standard Process of Heat Stress Prevention at Work for Workers. COHED Center, Hanoi.

COHED, 2016b. Heat Stress Prevention for Workers Working in High Temperature Environments, Educational Flipchart. COHED Center, Hanoi.

Curriero, F., Heiner, K., Samet, J., et al., 2002. Temperature and mortality in 11 Cities of the Eastern United States. Am. J. Epidemiol. 155 (1), 80–87.

Dao, T.M.H., Nguyet, D.A., Nguyen, H.P., et al., 2013. Heat Stress and Adaptive Capacity of Low-income Outdoor Workers and their Families in the City of Da Nang, Vietnam. Asian Cities Climate Resilience Working Paper Series 3:2013. COHED and IIED, Vietnam.

Dee, D.P., Uppala, S.M., Simmons, A.J., et al., 2011. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Q. J. R. Meteorol. Soc. 137, 553–597.

Epstein, Y., Moran, D.S., 2006. Thermal comfort and the heat stress indices. Ind. Health 44, 388–398.

Green, H., Gilbert, J., James, R., Byard, R.W., 2001. An analysis of factors contributing to a series of deaths caused by exposure to high environmental temperatures. Am. J. Forensic Med. Pathol. 22 (2), 196–199.

General Statistics Office (GSO), 2009. Socio-Economic Statistical Data of 63 Provinces and Cities, Vietnam. Statistical Publishing House, Hanoi.

Gubernot, D.M., Anderson, G.B., Hunting, K.L., 2014. The epidemiology of occupational heat exposure in the United States: a review of the literature and assessment of research needs in a changing climate. Int. J. Biometeorol. 58 (8), 1779–1788.

Gudmundsson, L., Bremnes, J.B., Haugen, J.E., et al., 2012. Technical note: downscaling RCM precipitation to the station scale using quantile mapping – a comparison of methods. Hydrol. Earth Syst. Sci. Discuss. 9, 6185–6201.

Hanna, E.G., Kjellstrom, T., Bennet, C., et al., 2011. Climate change and rising heat: population health implications for working people in Australia. Asia Pac. J. Public Health 23 (2 Suppl), 14S–26S. http://dx.doi.org/10.1177/1010539510391457.

Harlan, S.L., Ruddell, D.M., 2011. Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. Curr. Opin. Environ. Sustainability 3 (9). http://dx.doi.org/10.1016/j.cosust.2011.01.001.

Hashimo, T., Bradley, A.A., Schwartz, S.S., 2007. Evaluation of bias-correction methods for ensemble streamflow volume forecasts. Hydrol. Earth Syst. Sci. 11, 939–950.

Huang, C.R., Barnett, A.G., Wang, X., et al., 2011. Projecting future heat-related mortality under climate change scenarios: a systematic review. Environ. Health Perspect. 119 (12). http://dx.doi.org/10.1289/ehp.1103456.

IPCC, 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. In: Field, C.B., Barros, V., Stocker, T.F., et al. (Eds.), A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY.

Jabeen, H., Johnson, C., 2013. Perceptions of climate variability and coping strategies in informal settlements in Dhaka, Bangladesh. In: Joffe, H., Rossetto, T., Adams, J. (Eds.), Cities at Risk 33. Springer, Netherlands, pp. 149–170.

Jourdain, N.C., Gupta, A.S., Taschetto, A.S., et al., 2013. The Indo-Australian monsoon and its relationship to ENSO and IOD in reanalysis data and the CMIP3/CMIP5 simulations. Clim. Dyn. 41, 3073–3102.

Kalnay, E., Kanamitsu, M., Kistler, R., et al., 1996. The NCEP/NCAR 40-Year Reanalysis Project. BAMS 77, 437–470.

Kenny, G.P., Yardley, J., Brown, C., et al., 2010. Heat stress in older individuals and patients with common chronic diseases. CMAJ 182 (10), 1053–1060.

Kjellstrom, T., 2009. Climate change, direct heat exposure, health and well-being in low and middle-income countries. Glob. Health Action 2, 920–928.

Kjellstrom, T., Kovats, R.S., Lloyd, S.J., et al., 2009. The direct impact of climate change on regional labor productivity. Arch. Environ. Occup. Health 64 (4), 217–227.

Kovats, R.S., Hajat, S., 2008. Heat stress and public health: a critical review. Annu. Rev. Public Health 29, 41–55.

Kripalani, R.H., Oh, J.H., Kulkarni, A., et al., 2007. South Asian summer monsoon precipitation variability: Coupled climate model simulations and projections under IPCC AR4. Theor. Appl. Climatol. 90, 133–159.

Lee, J.Y., Wang, B., 2012. Future change of global monsoon in the CMIP5. Clim. Dyn. http://dx.doi.org/10.1007/s00382-012-1564-0.

Li, H., Sheffield, J., Wood, E.F., 2010. Bias correction of monthly precipitation and temperature fields from Intergovernmental Panel on Climate Change AR4 models using equidistant quantile matching. J. Geophys. Res. 115. http://dx.doi.org/10.1029/2009JD012882.

Lucas, R.A., Epstein, Y., Kjellstrom, T., 2014. Excessive occupational heat exposure: a significant ergonomic challenge and health risk for current and future workers. Extrem. Physiol. Med. 3, 14.

Ma, W., Lin, H., Liu, T., et al., 2016. Human health, well-being and climate change in China. In: Nadin, R., Opitz-Stapleton, S., Xu, L. (Eds.), Climate Risk and Resilience in China. Routledge, Oxon, U.K.

Ministry of Health, 2002. Promulgating 21 Labor Hygiene Standards, 05 Principles and 07 Labor Hygiene Measurements. No. 3733/2002/QD-BYT. The Socialist Republic of Vietnam, Hanoi.

Ministry of Natural Resources and Environment, 2011. National Climate Change Strategy. Vietnam Ministry of Natural Resources and Environment (MONRE).

Mishra, V., Ganguly, A.R., Nijssen, B., et al., 2015. Changes in observed climate extremes in global urban areas. Environ. Res. Lett. 10, 024005.

Moore, S.M., Monaghan, A., Griffith, K.S., et al., 2012. Improvement of disease prediction and modeling through the use of meteorological ensembles: human plague in Uganda. PLoS One 7 (9), e44431.

MSU, 1999. MSU Employee Guidelines for Working in Hot Environments. The Office of Radiation, Chemical and Biological Safety, Michigan State University.

Mueller, N., Kuttler, W., Barlag, A.B., 2014. Counteracting urban climate change: adaptation measures and their effect on thermal comfort. Theor. Appl. Climatol. http://dx.doi.org/10.1007/s00704-013-0890-4.

National Weather Services (NWS), 2014. Beat the Heat Weather Ready Nation Campaign. National Oceanic and Atmospheric Administration.

Nguyen, D.Q., Renwick, J., McGregor, J., 2014. Variations of surface temperature and rainfall in Vietnam from 1971 to 2010. Int. J. Climatol. 34, 249–274.

Nguyen, H.K.L., Huynh, V.C., 2015. Assessing the impact of urbanization on urban climate by remote sensing perspective: a case study in Danang City, Vietnam. Int. Arch. Photogrammetry Remote Sens. Spatial Inf. Sci. XL-71W3.

NIOSH, 2016. NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments. U.S. Dept. of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS (NIOSH) Publication 2016-106.

Opitz-Stapleton, S., Gangopadhyay, S., 2011. A non-parametric, statistical downscaling algorithm applied to the Rohini River Basin,Nepal. Theor. Appl. Climatol. 103, 375–386.
Parsons, K., 2006. Heat stress standard ISO 7342 and its global application. Ind. Health 44, 368–379.
Pantavou, K., Theoharatos, G., Mavrakis, A., et al., 2011. Evaluating thermal comfort conditions and health response during an extremely hot summer in Athens. Build. Environ. 46, 339–344.
Quintana-Seguí, P., Habets, F., Martin, E., 2011. Comparison of past and future Mediterranean high and low extremes of precipitation and river flow projected using different statistical downscaling methods. Nat. Hazards Earth Syst. Sci. 11, 1411–1432.
Rey, G., Fouillet, A., Bessemoulin, P., et al., 2009. Heat exposure and socio-economic vulnerability as synergistic factors in heat-wave-related mortality. Eur. J. Epidemiol. 24 (9), 495–502.
Rothfusz, L.P., 1990. The Heat Index ‘‘Equation" (or, More Than You Ever Wanted to Know About Heat Index). U.S. National Weather Service, Technical Attachment SR 90-23.
Segal, M., Pielke, R.A., 1981. Numerical model simulation of human biometeorological heat load conditions-summer day case study for the Chesapeake Bay Area. J. Appl. Meteorol. 20 (7), 735–749.
Semenza, J., McCullough, J., Flanders, D., McGeehin, M., Lumpkin, J., 1999. Excess hospital admissions during the July 1995 heat wave in Chicago. Am. J. Prev. Med. 16 (4), 269–277.
Sherwood, S.C., Huber, M., 2010. An adaptability limit to climate change due to heat stress. PNAS 107 (21), 9552–9555.
Smith, K.R., Woodward, A., Campbell-Lendrum, D., et al., 2014. Chapter 11. Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Cambridge University Press, Cambridge.
Song, F., Zhou, T., 2014. Interannual variability of East Asian summer monsoon simulated by CMIP3 and CMIP5 AGCMs: skill dependence on Indian-Ocean Western Pacific anticyclonic teleconnection. J. Clim., 10:1175/JCLI-D-13-002481.
SQI, 2009. Workplace Air – Microclimate Requirements and Method for Measurement. TCVN 5508-2009. Vietnam Standard and Quality Institute.
Srinavin, K., Mohamed, S., 2003. Thermal environment and construction workers' productivity: some evidence from Thailand. Build. Environ. 38, 339–345.
Steadman, R.G., 1979a. The assessment of sultriness. Part I: a temperature-humidity index based on human physiology and clothing science. J. Appl. Meteorol. 18, 861–873.
Steadman, R.G., 1979b. The assessment of sultriness. Part II: effects of wind, extra radiation and barometric pressure on apparent temperature. J. Appl. Meteorol. 18, 874–885.
Steadman, R.G., 1984. A universal scale of apparent temperature. J. Clim. Appl. Meteorol. 23, 1674–1687.
USGCRP, 2016. In: Crimmins, A., Balbus, J., Gamble, J.L., et al. (Eds.), The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC.
von Storch, H., Hewitson, B., Mearns, L., 2000. Review of empirical downscaling techniques. In: Regional Climate Development under Global Warming, General Technical Report No. 4, Conference Proceedings, Torbjornrud, Norway.
Wilby, R.L., Charles, S.P., Zorita, E., et al., 2004. Guidelines for Use of Climate Scenarios Developed from Statistical Downscaling Methods. Supporting Material for the Task Group on Data and Scenario Support for Impacts and Climate Analysis (TGICA).
Yaglou, C.P., Minard, D., 1957. Control of heat casualties at military training centers. Am. Med. Assoc. Arch. Ind. Health 16, 302–316.
Zeng, W.L., Ma, W.J., Zhang, Y.H., et al., 2012. Modification effect of latitude on relationship between high temperature and mortality risk among elderly: a Meta-analysis. J. Environ. Health 29 (7), 639–642.

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