Developing a heat health warning system for Thailand: An investigation into the associations between climatic variables and heat-related illnesses with stakeholder consensus exercises.

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Abstract

Title: Developing a heat health warning system for Thailand: An investigation into the associations between climatic variables and heat-related illnesses with stakeholder consensus exercises.

Introduction: The earth's climate is changing in ways that could have serious consequences for public health. For example, heat-related illnesses (HRIs) are increasing yearly. Many countries have developed heat health warning systems (HHWSs) to protect people from the adverse effects of heat and reduce the incidence of HRIs. In Thailand, a HHWS has not yet been established. As a result, the aims of this work were to explore the nature of HRIs in Thailand, examine any associations between heat index and heat-related hospitalisations within the general Thai population, and to develop a structure for a HHWS model in Thailand based on the results of statistical analyses and experts' opinion.

Methods: This study was divided into three phases using a mixed methods approach. In phase 1, a daily tally of HRI hospitalisations from the International Classification of Diseases 10 Revision (ICD10) database with diagnosis T67 (effects of heat and light) were obtained between January 2010 and December 2014 from the Bureau of Policy and Strategy, Department of Disease Control, Ministry of Public Health, Thailand. Daily temperature and humidity figures from the same period were obtained from the Meteorological Department, Ministry of Digital Economy and Society. The heat index was calculated according to the Steadman equation. Time series and Poisson regression analysis were used to explore the relationship between HRIs and the heat index controlling for day of the week and holiday indicator, with lag times of 0–7 days. Relative Risk (RR) and 95% confidence intervals were calculated based on a Poisson model from each region of Thailand. Next, a consensus exercise was conducted to establish the key components of a HHWS in Thailand. This included an e-Delphi exercise with 16 experts in climate research (phase 2) and a focus group with key stakeholders and policy makers (phase 3).

Results: The relative risks at the 75th percentile of the heat index at a lag 0 (on the same day as exposed to heat compare to non-exposed to heat) of Southern, Northern, Central and Northeast regions were 5.56 (95% CI = 1.62 – 19.04), 21.76 (95% CI =

11.33 – 41.81), 79.59 (95% CI = 33.76 – 187.64), and 39.75 (95% CI = 21.66 – 72.94), respectively. The threshold levels for a HHWS in each region were divided into three levels: pre-alert, higher alert and highest alert. Based on expert opinion, the pre-alert level is the level of the heat index below the 75th percentile (< 92 ºF (33.3°C), < 90 ºF(32.2°C), < 94 ºF (34.4°C)< 90 ºF(32.2°C) in the north-eastern, northern, central and southern regions, respectively). The higher level is the level of the heat index from the 75th percentile to the 90th percentile (92 ºF - 95 ºF (33.3 °C - 35°C), 90 ºF-94 ºF (32.2 °C-34.4°C), 94 ºF - 98ºF (34.4°C – 36.7°C), 90 ºF-92 ºF (32.2°C – 33.3°C) in the north-eastern, northern, central and southern regions, respectively). Lastly, the highest level is the level of the heat index from the 90th percentile (>95 ºF (35°C), >94 ºF (34.4°C), >98 ºF (36.7°C), >92 ºF (33.3°C) in the north-eastern, northern, central and southern regions, respectively). All thresholds were applied depending on the relationship between HRIs and the heat index in each region of Thailand. These threshold levels were in the first of four components of a HHWS for Thailand, on which consensus was sought with policy makers and stakeholders. Additional components identified in the consensus exercise related to methods of communication of health warnings and individual and community level interventions to mitigate the effects of heat on health.

Conclusion: This study found the heat index had positive associations with HRI hospitalisations. Moreover, the suitable warning threshold levels for a HHWS in Thailand varied according to region. Importantly, the results of this study support the view that Thailand should have a bespoke HHWS which is different from those operated elsewhere. The threshold of warning levels and interventions to protect from heat hazards must be explored in each country to ensure success and effectiveness.

Declaration

I declare that this thesis is my own work. The material has not been previously submitted in consideration for the award of degree at this or any university. The thesis is the candidate's own work and does not contain unacknowledged work from other sources.

Dedication

In memory of:

My beloved King Rama 9, who has inspired all the spirits of my life.

This piece of work is dedicated to:

My parents; Mr. Manoch and Mrs. Supaporn Amornpokin

My beloved husband; Assistant Professor Dr. Nattarat Tanathitikorn

My dearest son & daughter; Master Tantai and Miss Kerema Tanathitikorn

My brother; Mr. Saroj Amornthanapiboon

My sister; Miss Sireetorn Amornpokin

With my sincere thanks for your love, patience and kind support.

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List of Abbreviations

Term	Definition
AT	Apparent Temperature
BMI	Body Mass Index
CDC	Center for Disease Control and Prevention
CI	Confident Interval
EPA	Environmental Protection Agency
HHWS	Heat Health Warning System
HI	Heat Index
HRIs	Heat–Related Illnesses
IPCC	Intergovernmental Panel on Climate Change
NET	Net Effective Temperature
NOAA	National Oceanic and Atmospheric Administration
PHE	Public Health England
RR	Relative Risk
WBGT	Wet-Bulb Globe Temperature
WHO	World Health Organisation
UHI	Urban Heat Island
UNFCCC	United Nations Framework Convention On Climate Change
USA	United States of America

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Chapter 1: Introduction

1.1 Rationale for the Study

It is generally accepted that the world is experiencing a warming trend and that this is the result of human factors that contribute to "global warming" *(IPCC, 2014).* Environmental heat is increasing as a result of global warming. The IPCC defines a 'warm' day as one where the minimum or maximum temperature, respectively, exceeds the 90th percentile based on the historical distribution of the daily temperature. An extreme heat event – a "heatwave" – is an episode of several consecutive warm days thus defined *(Franklin, 2004).* When humans are exposed to environmental heat stress, it is clear that morbidity and mortality increase. The physiological mechanism is clear: when exposed to prolonged heat, the body loses the ability to maintain thermo-equilibrium, resulting in illness and possible death *(see 2.4.1).*

Heat related illnesses (HRIs) (Baccini *et al.*) are defined as a range of illnesses occurring as a result of prolonged exposure to high temperatures, including heat cramps, heat syncope, heat exhaustion and heat stroke *(Luber and McGeehin, 2008; Sankoff, 2015)*. Although there are no statistics on HRIs for the globe as a whole, a number of countries do keep records and use them as an indicator to illustrate health problems related to rising temperatures. In the USA, for example, extreme heat causes an average of 658 deaths per year *(CDC, 2013)*. However, this figure more than doubles if it includes deaths when extreme heat is deemed likely to have exacerbated a pre-existing health condition *(Haine et al., 2000)*. This highlights the challenge of defining, identifying and delimiting the term "heat related illness" – a topic explored further in Chapter 2. From 2001 to 2004, HRIs were the most common cause of environmental exposure–related injury treatment in emergency hospital departments across the USA *(Green et al., 2010; Sanchez et al., 2010)* while annual medical claims for hyperthermia treatment in emergency departments were estimated at over $36 million *(Noe et al., 2012).*

For European countries, in early August 2003 a heatwave in France was estimated to have caused 14,802 deaths over a 20 day-period *(Kovats and Kristie, 2006*), and in the same year Spain, Portugal, Italy and England recorded 17%, 36%, 19% and 16% increases in heat related deaths, respectively (Kovats *et al.*, 2006; Kovats and Hajat, 2008b; D'Ippoliti *et al.*, 2010). The challenge of accurately recording the size of the

HRIs problem is a global concern. The total number of heatwave-related deaths in selected EU countries shown in Table 1.

Table 1. Excess deaths from Europe's 2003 heatwave [1]

France	15,251
Spain	6,461
Italy	9,713
Portugal	2,196
England and Wales	1,987
Germany	7,295
Total	42,903

Turning to Asia, China, the world's largest industrial country and the country with the highest rate of carbon dioxide emissions, has witnessed a mean surface temperature increase of around 1.38°C over the past 50 years *(Gu et al., 2016a).* In Japan, the mean daily maximum temperature in 2012 was higher than that from 2000 to 2011 by around 0.5 °C *(Ito et al., 2018).* A total of 5,758 cases of HRIs were reported in the summer of 2013 in China and 58,729 cases of heat stroke were diagnosed in Japan in the same year *(Nakamura and T., 2013).*

The demand for emergency services rises with heatwave events. For every 1.0 °C increase in the daily maximum temperature in Japan in 2013, the number of extra cases requiring emergency transport for HRIs was 1,453, 1,470, 1,512 and 1,556 in Hokkaido, Tohoku, Kanto and Kyushu, respectively. With a 1.5 °C rise above the 75^{th} percentile of the mean daily maximum temperature, demand for emergency calls increases, even further, by 2.4 to 8.9 times, and it dramatically rises to 20 times at the 95^{th} percentile or higher *(Ito et al., 2018)*. The relationship between temperature and health in Delhi, India, demonstrates that every 1°C increase in maximum temperature above 29°C is associated with a 3.9% increase in mortality *(McMichael et al., 2008b)*.

[1] Source: Report on excess mortality in Europe during summer 2003 (Robine et al, 2007)

In China, most HRI patients are concentrated in urban areas around the middle and lower reaches of the Yangtze River. Similarly, the highest frequency of HRI patients in Japan are found in inland climate zones. Both areas in China and Japan are surrounded by a mountain chain, which leads to a phenomenon known as a “heat island”.

Overall, the poorest sections of society are most vulnerable to the health impacts of climate change. Poverty is associated with low-quality shelter, an increased risk of trauma from natural disasters, poor sanitation infrastructure, and an increased risk of communicable diseases *(Kovats and Ebi, 2006).*

The system designed to protect the general population from heat is known as a Heat-Health Warning System (HHWS). The operation of a HHWS includes weather forecasting, the determination of whether an “action trigger” (such as a threshold temperature or the significance of climate indices (see Chapter 2) for health effects) is likely to be exceeded in the near future, and the issuance of watch/warning messages to stakeholders in the heat–health field *(WHO, 2015).* The main aim of this system is to make the general population aware of future dangerous heat events so they can prepare themselves and take precautionary measures. By doing so, HHWSs can save lives by reducing heat-related harm. A number of studies have shown that such systems reduce incidences of heat-related mortalities. Ebi *et al.* (2004) compared expected and observed deaths from 1995-1998 in Philadelphia in a cost-benefit analysis of a HHWS. The results show that in addition to the 2.6 lives saved per day, a significant positive return on the $210,000 it costs to run the system was achieved. Foulli and colleagues (2008) study in France found that 6,452 excess deaths were expected but 2,065 deaths occurred, a full 4,387 fewer deaths after the implementation of a HHWS in 2014. However, the small number of studies in this field means it is still unclear how the systems actually reach the target population and change its behaviours. Therefore, more research is required into mechanisms of improving the utilisation of services by vulnerable populations and groups during heatwaves, in both developed and developing societies.

With a population of approximately 66 million people, Thailand is a tropical country in Southeast Asia. The bulk of the population in Thailand is employed in agriculture and some 64 percent of the people reside in rural areas. Approximately 90 percent of those, or 5.2 million farm families, earn their income through subsistence farming *(NSO, 2018).* The country has three seasons: rainy (mid-May to mid-October), winter (mid-October to mid-February), and summer (mid-February to mid-May). The highest temperatures occur in April (averaging 34.5°C) and the lowest in December (averaging 23.5°C) *(NSO, 2018).*

At present, Thailand has insufficient measurement tools to evaluate the impact of climate change on health *(Tawatsupa et al., 2012).* The first study of national data on HRIs in Thailand, covering 2010-2013, reported 3,963 HRI hospital visits and nine deaths. The highest incidence per 100,000 person per year was 3.8 per 100,000 persons per year for those aged 65 and over *(Supharerk et al., 2014).* However, as noted, few studies have explored climate change and HRIs in the general population in Thailand. A number of reasons lie behind the dearth of reliable studies and statistics. Firstly, Thailand has no standard criteria diagnosis for HRIs. Therefore, there is an underreporting of cases and staff in health centres have less experience and training to differentiate among various types of HRI, such as heat exhaustion and heat fatigue, and might miscode them as heat stroke *(Supharerk et al., 2014)*. Secondly, people often underestimate the risks associated with the heat. Lastly, the regulations and policies stipulating the authorities and departments responsible for tackling the issue are inadequate and unclear *(Tawatsupa et al., 2012)*.

Due to the considerable health burdens associated with extreme heat and the fact that heat-related morbidity is largely preventable, HHWSs have been established in developed countries to help augment protection during high-risk periods. However, there are no such preventative systems in Thailand. Therefore, this study aims to explore the nature of HRIs in Thailand, examine associations between the heat index and heat-related hospitalisations within the general Thai population, and develop a structure for a HHWS in Thailand based on the results of statistical analyses and expert opinion. The following hypotheses will be tested in this study:

1.2 Hypotheses

1. Short-term exposure to heat is associated with the number of hospitalisations for HRIs in Thailand.
2. The appropriate threshold for the heat index warning levels in Thailand is different from the heat index used by the National Oceanic and Atmospheric Administration in the United States of America.

1.3 Objectives of this Study

1. To identify the incidence of HRIs in different regions of Thailand.
2. To investigate the statistical associations between the heat index and HRIs.
3. To investigate the suitable warning threshold levels of the heat index for a HHWS in Thailand.
4. To understand and develop methods which are suitable for implementing a HHWS in Thailand by drawing on the results of this study, whilst taking note of the experiences of existing HHWSs in different countries and the World Health Organization's standard guidelines.

Using a combination of quantitative and qualitative research techniques to achieve these objectives, this study is divided into three phases. Firstly, time series analyses were used to investigate the relationship between climate and HRIs, and then a statistical model from Poisson regression generated the estimated threshold levels of the heat index in terms of surveillance indices for a HHWS. This is followed by the second phase, which applied the e-Delphi technique to elicit the opinions of a number of experts involved in climate change research and policy formulation in Thailand. Aiming to verify the feasibility of and elaborate on a HHWS model derived from the findings of the first two phases, a focus group discussion with key stakeholders and policymakers was conducted in the third phase.

Chapter 2: Scientific Background

2.1. Introduction

In this chapter, three main bodies of literature are summarised and critically examined. The first part describes the scientific background of climate and health effects, particularly HRIs and associated risk factors. In the second part, previous studies using time series analyses to identify the relationship between heat and health effects are discussed. Lastly, the general details of a HHWS and the experiences of different countries with various models are summarised.

2.2. Search strategy and selection of articles

A literature review has been conducted with the general aim of examining the methodologies used to assess the associations between climate change and health outcomes (morbidity and mortality). The relevant literature was identified using Scopus, Medline, Pubmed, Web of Knowledge Google Scholar, and other sources (see Table 2). Studies in animals, ecological and molecular areas and those not written in English were excluded. The focal area concerned public health, environmental health and occupational health from 1997 to 2018 due to the fact that climate change began to be seriously and systematically taken as an issue of concern from 1997, when the National Climate Extremes Committee (NCEC) was established in the USA and patterns in extreme climate events were perceived to be rising *(Smith, 2013).* At around this time, increasing numbers of researchers and policy makers began to focus on discovering associations between climate change and health *(Bell et al., 2018).* All the search words are given in table 3.

Table 2. Sources of the literature review

Search Methods	***Sources***
Database	Scopus, Medline, PubMed, Web of Knowledge and Google Scholar
Cross citation index	Checking other reference lists
Grey literature	WHO → IPCC reports, guidelines, EPA, NOAA, CDC → Reports
Auto Alert Service	Medline, PubMed, Web of Knowledge, Scopus
University Library	Books, eBooks

Table 3. Examples of key search words

Key words	***Number of articles from database in table 2.1***
Climate change + Heat-related illness*	231
Heat index + Heat-related illness*	102
Temperature + Heat-related illness*	255
Heatwave + Heat-related illness*	334
Climate change + heat stroke	263
Heat index + heat stroke	208
Heatwave + heat stroke	513
Climate change + Heat-related illness* + hospital admission*	27
Heat index + Heat-related illness* + hospital admission*	4
Heatwave + Heat-related illness* + hospital admission*	51
Heat + warning system	48
Heatwave + warning system	13
High temperature + warning system	10
Hot temperature + warning system	32
Hot climate + warning system	1

2.3. Climate change

Global warming *(United Nations Environment Programme, 2001)*is defined as a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants. The dominant greenhouse gas (GHG) is carbon dioxide, released by burning coal, oil and natural gas in power plants, cars, and factories, biomass burning another major sources of GHGs The second main greenhouse gas is methane, released from rice paddies, livestock, rotting garbage in landfills, mining operations, and gas pipelines. Third are chlorofluorocarbons (CFCs) and similar chemicals, which are also implicated in the separate problem of ozone depletion. Nitrous oxide (from fertilizers and other chemicals) is the fourth hazard *(IPCC, 2014).*

There is a scientific consensus that global warming is mostly caused by human activities and presents serious environmental and economic challenges. Scientists working on this issue report that the observed warming of the planet cannot be explained by natural variations such as changes in the sun's output or volcanic eruptions. The most authoritative source of information is the UN Intergovernmental Panel on Climate Change *(IPCC, 2013)*, which draws on the collective wisdom of many hundreds of scientists from around the world. The IPCC projects that the global temperature will increase by between 1.4 and 5.8°C by 2100 *(Bell et al., 2018).* Global warming will have significant impacts on people and nature. As temperatures continue to rise, precipitation is projected to come more frequently in the form of heavy downpours and violent storms. In the western US, where snowpack provides free storage for most of the water supply, a reduced snowpack will make less water available in summer *(Rosenthal and Jessup, 2009)*.

Protecting the world's climate by stabilising atmospheric concentrations of greenhouse gases will require enormous reductions in current emissions. Even if ratified, the Kyoto Protocol in its present form is only a start and would not be nearly enough to stabilise the climate. The Kyoto Protocol was established in 1992 on the back of international agreement on the need to reduce greenhouse gas emissions. It implemented the objective of the UNFCC to reduce the onset of global warming by reducing greenhouse gas concentrations in the atmosphere to a level that would prevent dangerous anthropogenic interference with the climate system *(UNFCC, 1998).*

As greenhouse gases are generated mostly by burning fossil fuel, power plantas in factories and automobiles, the need to grow the economy has made reducing greenhouse gases difficult. However, with the Kyoto Protocol, the concept of limiting emissions became a burning political issue *(J.W., 1998).* On 22 April 2016, Earth Day, 177 nations gathered to sign the Paris Agreement (COP21), and at the time of writing 187 countries have made an official commitment to take action on climate change such that each and every sector must seek to develop a low carbon path in the future *(Weimann and Patel, 2017; IPCC, 2018).* COP21 was a landmark agreement which was followed up in two subsequent COP meetings.

It is estimated greenhouse gas emissions would have to be reduced to less than one third of current levels by the end of the 2010s in order to stabilise atmospheric concentrations *(Kjellstrom and McMichael, 2013)*. This would require a major transformation of the energy sector. A mix of new and existing energy technologies will be needed to achieve this, including large increases in energy efficiency and utilisation of renewable energies. Researchers are also developing technology to capture and bury carbon dioxide thousands of feet underground. Major increases in public and private research and development are needed to make the necessary technologies available as rapidly and economically as possible, including the development of methods to measure the current impact of climate outcomes, particularly in low and middle income countries *(Rosenthal and Jessup, 2009).*

2.4. Climate change and health effects: Insights from epidemiology

2.4.1 Physiology of the human body and heat

When the human body is exposed to excessive heat, its heat-mechanisms are overwhelmed and the core temperature rises. An increase of one degree Celsius in body temperature is immediately detected by thermo-receptors on the skin, deep tissue and organs. In the next stage, the thermo-receptors send information to the hypothalamic thermoregulatory centre, which triggers two responsive pathways to increase the dissipation of heat. Firstly, cutaneous vessels are dilated by inhibiting the sympathetic centres and initiate sweating through cholinergic pathways *(Bouchama et al., 2007)*. Secondly, the cutaneous vasodilatation results in marked increases in blood flow to the skin and cardiac output, and hence cardiovascular adjustments increase the transportation rate of heat from core body to periphery. Initiation of the sweating process results in a maximum of 2–3 litres fluid excretion per hour *(Hanna, 2015)*, which results in high sodium and potassium loss *(WHO, 2015).* Thus, additional stress on the cardiovascular system automatically occurs in cases of depletion of the plasma volume. An adaptive individual body learning how to handle excessive heat is called “acclimatisation” *(Hanna, 2015).* This mechanism may take two to six weeks and includes physiological adjustment of the cardiovascular, endocrine and renal systems. This results in increased maximal stroke volumes, decreased maximal heart rate, expansion of plasma volume and a higher glomerular filtration rate and hence more work for the cardiac muscles.

2.4.2 Heat-related illnesses (HRIs)

The earth's climate is changing in ways that could have serious consequences for public health. In addition to the direct effects of higher temperatures, climate change will likely increase the number of people suffering from illnesses and injuries due to floods, storms, droughts, and fires, as well as allergies and infectious diseases *(Rosenthal and Jessup, 2009; IPCC, 2014)*. Diseases such as cholera and salmonella, which are transmitted through contaminated food or water, could become more widespread with climate change because of increased flooding. Changes in temperature and rainfall in some areas are likely to increase the range and the length of activity for ticks and mosquitoes, which can spread diseases such as Lyme disease, malaria, and West Nile virus. Climate change could also cause more severe allergy symptoms because a warmer climate is expected to promote the growth of weeds, grasses, and trees that cause allergic reactions in some people. Global food security is also threatened by climate change *(United States Environmental Protection Agency, 2016).*

Extreme heat events have long threatened public health. High heat exposure is associated with increased hospital admissions for cardiovascular, kidney (Kovats *et al.*, 2004), and respiratory disorders as well as diabetes *(Knowlton et al., 2009; Raju et al., 2014; Glaser et al., 2016; Chen et al., 2017b; Fink et al., 2017; Hajat et al., 2017; Sherbakov et al., 2018).* HRIs also significantly increase the deaths. When people are exposed to extreme heat, they can suffer from potentially deadly illnesses *(Duthie, 1998; Hanna, 2015).* HRIs range from mild heat cramps to heat exhaustion, heat syncope, and the most severe cases of heat stroke have a 50% mortality rate within 30 days *(Argaud et al., 2007; Becker, 2011; Hanna, 2015) (see Table 4).* Heat stress is a serious condition that can develop into heat stroke. It occurs when excessive sweating in a hot environment reduces the blood volume. Heat stroke is defined clinically as a condition with core body temperature that rises above 40°C, accompanied by hot, dry skin and alteration of consciousness *(Margolis, 2014).* Exertional heat stroke typically occurs in younger athletes, the military, agricultural workers and others who are exposed to high temperatures in their work or certain activities *(Widodo, 2005; Shendell et al., 2010; Becker, 2011; Nutong et al., 2018)*. Fortunately, the incidence of heat stroke is relatively low (< 10% of HRIs) and the most common form of HRI is the less serious heat exhaustion *(Becker, 2011; Fuhrmann et al., 2016).* Symptoms of HRI vary *(WHO, 2008a; Sankoff, 2015).* Babies and young children may show signs of restlessness or irritability and have fewer wet nappies. Older people may become lightheaded, confused, weak or faint. The common symptoms of heat exposure are shown in table 4 *(Hett and Brechtelsbauer, 1998; Lipman et al., 2014; Hofmeyr and D'Alton, 2017).*

Table 4. Common symptoms of HRIs

Symptoms	*Explanation*
Heat rash	Sometimes called prickly heat, this is a skin irritation caused by excessive sweating. It can occur at any age, but is most common in young children. It appears as a red cluster of pimples or small blisters. It is most likely to occur on the neck and upper chest, in the groin, under the breasts and in the elbow creases.
Heat cramp	This includes muscle pains or spasms, usually in the abdomen, arms or legs. The symptom may occur after strenuous activity in a hot environment, when the body becomes depleted of salt and water.
Dizziness and fainting	Heat-related dizziness and fainting results from reduced blood flow to the brain. Heat causes an increase in blood flow to the skin and pooling of blood in the legs, which can lead to a sudden drop in blood pressure. There can be a feeling of light-headedness, following which fainting may occur.
Heat exhaustion	More severe than heat cramps and results from a loss of water and salt in the body. It occurs in conditions of extreme heat and excessive sweating without adequate fluid and salt replacement and the body being unable to cool down properly.
Life-threatening heatstroke	Body temperature rapidly rises to greater than 40°C and is associated with central nervous system abnormalities such as stupor, confusion or coma. Hot, dry skin, nausea, hypotension, tachycardia and tachypnea are often present.

2.4.3. Factors affecting HRIs

The Center for Disease Control and Prevention (CDC) stated that not everyone is equally at risk of HRI *(CDC, 2013)*. Important determining factors include age, economic resources, and location. More vulnerable groups are elderly people, very young people, disabled people, low-income populations, people living alone, people who have existing medical conditions such as heart disease or asthma, and those performing strenuous outdoor activities *(Becker and Stewart, 2011; Na et al., 2013)*. The degree to which people will be affected also depends on the ability of a region to prepare for and respond to risks. Improvements in emergency responses, preparedness, health-care systems, and other response measures can help reduce the health impacts of climate change.

The literature has identified a number of factors which increase the risk of HRIs. Many of them are inter-related and vary depending on other factors. For instance, the impact of poverty on the heat-health relationship may be greatest among the elderly *(Wu et al., 2011).* The identification of factors associated with heat-related outcomes can be used to target interventions in high risk areas, defined as the geographical cluster of vulnerable sub-groups (e.g., elderly black men residing in the inner city) *(Reid et al., 2009; Wu et al., 2011; Harlan et al., 2014).*

Age

Age is one of the most influential factors affecting HRIs. Elderly people are significantly at higher health risk from heat exposure *(Flynn et al., 2005; Zhang et al., 2015)*, particularly those aged 65 and above *(Tan et al., 2004; Wang et al., 2009; Schaffer et al., 2012; Sun et al., 2014; Qiao et al., 2015; Schmeltz et al., 2015).* A study analysed data generated by a heatwave surveillance system operated by the Korea Centre for Disease Control and Prevention during the summer of 2012 found that Relative risk (RR) was highest in the ≥ 65 age group, equal to 1.863 (95% CI = 1.755 to 1.978) *(Na et al., 2013)*. In advanced age, the thermoregulatory response is reduced and the response rate of sweating, blood flow and cardiovascular functions are slower *(Kettaneh et al., 2010).* Additionally, renal function and water and electrolyte homeostasis decreases, increasing the risk of renal failure, particularly when the body has volume depletion *(Flynn et al., 2005; Hanna et al., 2011).* Elderly people tend to reduce water intake and lose their appetite, which leads to dehydration. Furthermore, older individuals may be more apt to suffer from social isolation or the inability to employ behavioural modifications due to immobility.

On the other hand, children under four years old are also vulnerable because they have to rely on adults to provide adequate liquid intake *(Kovats and Hajat, 2008a; Li* *et al., 2014).* Moreover, very young children may not be able to tell adults that they are feeling the effects of the heat *(Lam, 2007; Smith et al., 2016; Zivin and Shrader, 2016; Ito et al., 2018).* Children have a higher metabolic rate, lower blood volume and lower cardiac rate than adults. This means that children produce more internal heat than adults. Furthermore, the sweat gland in children produces sweat at a lower rate per gland than adults, resulting in less sweat excretion *(Falk, 1998).*

Gender

"Gender" refers to the social concepts of the functions, behaviours, activities and attributes which each society considers appropriate for men and women. It is not the same as "sex", which refers to the biological and physiological characteristics that define what men or women are *(Regitz-Zagrosek V., 2012; Diaz et al., 2018).*

Over the past decade, research has stressed that women are at a higher risk of death than men due to a higher core body and skin temperature and a lower tolerance threshold to heat than men because women excrete sweat less than men and have a thicker layer of subcutaneous fat acting as an insulating layer during vasoconstriction *(Robine, 2007; D'Ippoliti et al., 2010).* In addition to differences in body size, physical condition and state of acclimatisation to heat, there are social factors such as the gender age-distribution in the population (e.g. the greater number of elderly women) *(Hansen et al., 2008b; Stafoggia et al., 2008).* Among women of advanced age, hormone changes due to menopause have a direct impact on their thermoregulatory capability, making them more susceptible to heat *(Diaz et al., 2018).*

Regarding variations in the division of labour, in some countries the risk is greater for men as a result of undertaking strenuous tasks in outdoor or indoor heat *(Kaiser et al., 2007; Lippmann et al., 2013; Bai et al., 2014; Pillai et al., 2014; Morano et al., 2016; Sugg et al., 2016).* A time series study conducted in Florida from 2005 to 2012 by Morano and colleagues (2016) found the incidence of HRIs within males was 3.94 times higher than for females among Florida residents *(Morano et al., 2016).* In addition, in their time series analysis Sugg and colleagues identified that the rate of HRI-ED visits for males was three times greater than for females according to 122 hospital databases in North Carolina from May–September in 2007 and 2012 *(Sugg et al., 2016)*. On the other hand, traditionally viewed as resilient to adversity, the strength, stoicism and resourcefulness of male Latino farmworkers appeared to be factors which protected them against the risk of HRIs in a study using in-depth interviews and focus groups with 32 agricultural workers *(Philippe R et al., 2015).* In summary, a limited number of studies have explored the relationship between gender and HRIs, with conflicting findings – leaving the role of gender as a risk factor rather unclear.

Type of housing and home environmental surrounding

Different types of housing contribute in a variety of ways to heat exposure. For instance, one UK-based study found that top-floor flats are more likely to overheat than detached houses. Detached houses located in suburban areas had temperatures almost 0.2 °C lower than those for all housing types on average. On the other hand, terraced houses and flats had temperatures over 0.1 °C higher than the average for all housing types in the UK *(Macintyre et al., 2018).* Housing characteristics which increase the indoor temperature, such as residing in a home with a high thermal mass (e.g., brick house) or living on the top floor of an apartment building, are also factors which increase susceptibility *(Vandentorren et al.; Hajat et al., 2010).* Additionally, traditional roofs absorb solar energy and can reach between 150 to 185°F (66-85°C) during the day *(EPA, 2008).* Residents closest to the roof will be more affected by this increase in temperature than residents on lower floors. Homes with a high thermal mass are slow to absorb heat but retain the heat longer than homes with a lower thermal mass *(Reardon C.C and Milne G, 2013).* Without appropriate internal cooling (e.g., air conditioning), a home can become very warm. In fact, as the prevalence of air conditioners has increased, so has the cost of the electricity required to run them. The simple fact of owning an air conditioning unit does not mean that running the unit will be affordable *(Kovats and Hajat, 2008a).* In a study in the Netherlands, Vasaturo and colleagues evaluated the effect of passive climate change adaptation measures and building orientation (glazing on the front facade and only a single window on the back facade, compared to no windows on the lateral facades and solar shading) in current and future climate scenarios. They found that the most efficient adaptation measure consists of a combination of exterior solar shading and an increase of thermal resistance of the building, which together can reduce annual heating and cooling demands by 11% for the current climate and 15% for the future climate *(Vasaturo et al., 2018).*

To date, several studies have attempted to evaluate the impact of the Urban Heat Island (UHI), whereby ambient temperatures are often observed to be higher than those in surrounding, less-urbanised areas *(Kovats and Hajat, 2008a; Tomlinson et al., 2011; Yardley et al., 2011; Laaidi et al., 2012; Wong et al., 2016)*. The main cause of the UHI is the modification of land surfaces such as paving pathways with tarmac and asphalt or building houses with concrete instead of wood and other natural surfaces. All of these materials absorb, retain and re-radiate sunlight more than natural surfaces and thus increase urban heating *(Luber and McGeehin, 2008; Kjellstrom, 2016).* In 2015, Kammuang and colleagues studied the influence of the building and traffic densities on the UHI in Chiangmai, northern Thailand's biggest city. They applied an experimental study comparing the UHI in each season and found the results corresponded with those of the other studies cited above *(Kammuang-Lue et al., 2015)*.

Ethnicity

The effects of heat on mortality have been found to vary with race and ethnicity, which, while the results are somewhat inconsistent, seem to modify the heat-health relationship. A greater effect of heat on mortality was observed among black people compared with white people. Klinenberg (2003) found in his study of the 1995 Chicago heatwave that a disproportionate number of deaths occurred among African-Americans compared to any other group in the Chicago area *(Klinenberg, 2003b).* A case-control study of marine recruits, matched on initial training platoons, found that the odds ratio was 1.6 (95% CI = 1.2 - 2.1) when comparing black recruits with recruits of other ethnic minorities. However, this study suffered from the limitation of comparing only black and white recruits, ignoring other racial groups such as Hispanic, Asian/Pacific, Native American *(Gardner et al., 1996).*

The variation on identify association with temperature by race also happened by data source such as hospital, emergency department visits, death certificates and type of outcome (e.g. ischemic heart disease, acute renal failure, respiratory failure) *(Knowlton et al., 2009)*. In California, a study of cause-specific hospital admissions and daily temperatures during the summer months found no modification by race or ethnicity *(Green et al., 2010).* A similar mortality study saw a varying increase in non-accidental mortality by race/ethnicity for every 4.7°C (10°F) increase in mean daily apparent temperature (estimated percent increase: Whites = 2.5%, Blacks = 4.9% (95%CI = 2.0 - 7.9), Hispanics = 1.8%. The authors presented the estimated percent change associated with a 10°F increase in mean daily temperature and mortality by race/ethnic group from May through September 1999 – 2003. It indicated a non-statistical significance for the Hispanic group *(Basu and Ostro, 2008)*. Finally, a third California study, with a similar methodology, examined ED data and found that for every 5.6°C (10°F) increase in mean daily apparent temperatures, Hispanics (compared to whites) had a higher risk of ischemic heart disease (% excess risk = 7.2%; 95% CI = 2.7%, 11.9%), ischemic stroke (% excess risk = 5.2%; 95% CI = -0.1%, 10.7%) and acute renal failure (% excess risk = 21.8%; 95% CI = 14.6%, 29.5%). In the same study, Asians had a higher risk of dehydration (% excess risk = 37.4%; 95%CI = 24.9%, 51.1%) and primary diabetes (% excess risk = 7.6%; 95% CI = -0.1%, 17%) *(Basu et al., 2012),* and blacks had a lower or similar excess cause-specific ED morbidity compared to whites *(Basu et al., 2012).* O'Neill and colleagues studied the association between temperature and mortality in four U.S. cities (1986–1993) and found that the percentage change in mortality for temperatures at 29°C (84.2°F) compared to 15°C (59°F) was higher for blacks (% change = 9.0; 95%CI = 5.3, 12.8) than for whites (% change = 3.7; 95% CI = 1.9, 5.4) *(O'Neill et al., 2005).*

In conclusion, modification by race/ethnicity as demonstrated in the literature may be a proxy for other factors such as socio-economic status (including access to external cooling mechanisms), community services, and occupation. O'Neill and colleagues also noted the prevalence of central air conditioning usage in the four cites was double the usage for whites compared to blacks, accounting for approximately 64 percent of the disparity in heat-related mortality *(O'Neill et al., 2005)*.

Occupation

The impact of heat on outdoor workers was often neglected in discussions about the health effects of heat until Kjellstrom and colleagues (2011) revealed the effects of heat on worker health and productivity in the workplace, making certain professions and industries acknowledge heat effects *(Dash and Kjellstrom, 2011; Hanna et al., 2011).* Work capacity has been discussed among high heat exposure occupations because greater physical exertion generates more additional intra body heat *(Langkulsen et al., 2010; Kjellstrom et al., 2013)*. Workers and other people exposed directly to heat are at increased risk of HRIs, especially athletes, farm workers, and members of the military *(Shendell et al., 2010; Morano et al., 2015).* Unrecognised accumulation of symptoms can turn into deadly loss of life *(Schulte PA, 2016; Mutic et al., 2018; Nutong et al., 2018).* Although external heat may also impact on those with indoor occupations (including factory and office workers), literature relating to this is limited, focusing more on internal heat generated from e.g. factory machinery *(Poupart et.al. 2014; Xiang et.al. 2015).*

Socio-economic status (SES)

Socio-economic indicators include education status/attainment, income level, poverty rates, and other social deprivation indexes. People of lower income, especially those living in hot regions, are at greater risk of heat-related mortality *(Basu and Samet, 2002),* largely due to limited access to air conditioning *(Reid et al., 2009).* The heat-health relationship has been shown to vary according to individual socioeconomic indicators *(Gouveia et al., 2003; O'Neill et al., 2003; Kim and Joh, 2006; Medina-Ramon et al., 2006).* A study of four Italian cities (1997–2003) found that median population income levels did not modify the mortality-mean apparent temperature relationship (*Stafoggia et al., 2006*). However, another study of the same four Italian cities, limited to heatwaves in 2003, observed the greatest excess mortality within the cities was for sub-groups with a low SES indicator in Turin (low education attainment = 43% increase) *(Michelozzi et al., 2005).* In a study of respiratory and cardiovascular deaths in 12 U.S. cities, Braga and colleagues found no association between death on hot days (24 hour mean of 30°C) and the proportion of population in poverty for people with a college degree compared to those who were unemployed. However, Curriero and colleagues analysis of 11 Eastern U.S. cities (1973–1994) found that a 10 percent increase in the number of persons living in poverty in a city and an increase in the proportion of persons 25 years or older who had not completed high school increased the mortality risk by 4.3 and 2.8 percent respectively per 5.6°C increase in the temperature (after adjustment for latitude) *(Curriero et al., 2002).* A study in Brisbane, Australia (1996–2004) of 53,316 deaths did not observe any significant difference in temperature–mortality association across SES groups. However, with cross-classification by gender and SES, they found an estimated percent increase in mortality for every 1°C increase in average temperature in females were higher than males in both low and high SES (% change in high SES = 11.50, 95% CI = 1.24–21.76;

in low SES = 12.69, 95% CI = 3.55–21.84). It was not clear how high or low SES was defined *(Yu et al., 2010)*.

In Vandentorren and colleagues study*, s*ingle persons had a higher rate of death than married persons because less social support increases the risk of HRIs (*Vandentorren et al., 2006*). A study in four Italian cities found an association between high temperature and mortality. The pooled odds ratios (OR) of dying on a day with a temperature of 30ºC compared to a day with a temperature of 20ºC were estimated with a random-effects meta-analysis. The increased risk in single people (not married/widowed/divorced) with an odds ratio of 1.38 (95%CI 1.24 – 1.54) indicates that a lack of family support was relevant with a limited attention to personal requirements, including adequate fluid repletion and an observation of abnormal symptoms (Stafoggia *et al.*, 2006; Stafoggia *et al.*, 2008).

Health conditions

Data from several sources have identified that the risk of HRIs is greater in people who suffer from cardiovascular conditions because of a resultant loss of ability to compensate for cardiac output when fluid is lost in the sweating process *(Bhaskaran et al., 2010; Giang et al., 2014; De Blois et al., 2015; Yang et al., 2015; Fuhrmann et al., 2016; Han et al., 2017; Zhao et al., 2018)*. Knowledge of vulnerable populations was clearer when cross-sectional analysis of secondary U.S. data using Nationwide Inpatient data performed by Schmeltz and colleagues found that negative outcomes were more frequent when comorbid HRI was present among respiratory and cardiovascular patients *(Wilson et al., 2013; Schmeltz et al., 2016a)*. Diabetes also affects the ability to dilate the cutaneous circulation due to atherosclerosis *(Khalaj et al., 2010; Pudpong and Hajat, 2011; Wilson et al., 2013)*. Respiratory patients are considered at greater risk as well although the precise mechanism is still unclear *(Green et al., 2010; Basu et al., 2012; Chen et al., 2017a; Zhang et al., 2018).* Heat can exacerbate the worst symptoms of asthma by inducing systematic inflammation *(Lin et al., 2009; Kim et al., 2014; Schmeltz et al., 2016a)*. In addition, it has been demonstrated that the level of dependency might be a direct risk factor for heatwave-associated mortality due to impaired cognitive functioning resulting from being bed-ridden and having a lack of self-awareness *(Belmin et al., 2007; Hansen et al., 2008a; Stafoggia et al., 2008; Tobias et al., 2012; Williams et al., 2012).* Additionally, obesity counts as a risk factor due to the fact that poor heat tolerance and excess weight are associated with elevated oxidative stress and chronic inflammation, which can contribute to pathophysiology and enhanced risk of heat stroke, especially during strenuous exercise and/or labour *(Margolis, 2014).* A prospective cohort study in Thailand among 809 conscripts found higher relative risks (RR = 2.66, 95%CI:1.01 – 7.03) in a high BMI group (> 30.0 kg/m^2) group compared to a normal BMI group (BMI 18.5 – 22.9 kg/m^2) *(Nutong et al., 2018).*

Drugs

Many drugs have a direct effect on the body's cooling mechanism as they lead to an altered central thermoregulation by changing cognitive alertness, increasing drowsiness, rapidly changing blood pressure and cardiac output, affecting cooling by vasodilation or increasing dizziness and the risk of fainting *(Martinez et al., 2002; Martin-Latry et al., 2007; Westaway et al., 2015)*. The types of drugs that affect the body's heat cooling mechanism are shown in Table 5.

Table 5. Medication and its mechanisms in relation to increasing heat risks

Medication	*Mechanism*
Sympathomimetics	Vasodilators, including nitrates and calcium channel blockers, can worsen hypotension in vulnerable patients.
Anticholinergics	Can affect central thermoregulation, reduce cognitive alertness and prevent or reduce sweating (many of the drugs listed below have anticholinergic effects).
Antihistamines	Can inhibit the sweating mechanism and reduce systolic blood pressure.
Antiadrenergics and beta-blockers	Can prevent dilation of the blood vessels in the skin, reducing the capacity to dissipate heat by convection.
Antihypertensives and diuretics	Can lead to dehydration and reduced blood pressure; hyponatremia is a common side effect and can be worsened by excess fluid intake.
Antipsychotics	Can inhibit the sweating mechanism and reduce systolic blood pressure, central

Medication	*Mechanism*
	thermoregulation, cognitive alertness and vasodilation.
Anti-Parkinson's disease agents	Can inhibit the sweating mechanism, reduce systolic blood pressure and cause dizziness and confusion.
Antidepressants	Reduce sweating; some can decrease centrally induced thermoregulation and cognitive alertness.
Antiepileptics	Can reduce cognitive alertness and increase dizziness.

Overall, most of the interesting results focused on the interplay of social and physical environments and their synergistic effects on heat and human health. As can be seen in this section, age is a major significant intrinsic risk factor. Next most important, pre-existing health conditions and SES reveal a greater risk of morbidity and mortality. However, the fact that SES was represented in so many different ways made it difficult to compare across studies although in multivariate analysis studies because the variables are widely selected and it was not easy to identify which risk factor is the most important on HRIs *(Mayrhuber et al., 2018).*

2.4.4 Burden and economic loss from HRIs

Heatwaves, rather than daily exposure to heat (e.g., high ambient temperature), appear to constitute a large part of the current global focus of response/interventions for heat-associated morbidity and mortality *(Kovats and Ebi, 2006; Kovats and Hajat, 2008a; Luber and McGeehin, 2008; Kravchenko et al., 2013).* This may be due in part to the large number of deaths (and excess morbidity) that occur within a short time period, which is actually similar to that for other natural disasters such as floods or tornadoes *(Luber and McGeehin, 2008; Knowlton et al., 2009; Anderson and Bell, 2011).* For example, during the 1995 Chicago heatwave (July 14–20) there were an estimated 739 deaths (485 recorded as HRIs by the medical examiner) and 1072 hospitalisations (731 recorded as HRIs in the medical record) *(Whitman et al., 1997; Semenza et al., 1999)*. The August 2003 heatwave in Europe caused an estimated 42,903 deaths *(see rationale for the study in 1.1).* However, heat-related outcomes do occur outside of these short intense heat episodes and understanding the relationship between ambient temperature and heat-related outcomes is essential for characterising the heat-health relationship. Understanding this relationship will also guide responses and interventions related to prevention of HRI morbidity and mortality.

The most often studied outcome when examining the heat-health relationship is all-cause morbidity or mortality. For all-cause mortality, globally, the percent change in mortality for a 1°C change in temperature ranges from 0.4-18.8 percent, with warmer climates having a potentially larger estimated affect than cooler climates *(Kunst et al., 1993; Baccini et al., 2008; Vaneckova et al., 2008; Basu, 2009; Chung et al., 2009; Yu et al., 2010; Guo et al., 2011; Gomez-Acebo et al., 2012)*. For studies comparing extreme heat days to non-extreme heat days, the percent increase for mortality ranges from 1.26-43 percent, depending on how a heatwave or extreme heat day is defined *(Kaiser et al., 2007; Bell et al., 2008; Anderson and Bell, 2011; Son et al., 2012)*. Among heatwave studies, a larger relative effect of heatwaves on mortality is seen in cooler climates than in warmer climates *(Basu and Ostro, 2008; Anderson and Bell, 2011).* In the U.S., for a 5.5°C (10°F) change in temperature, the percent change in mortality ranges from 2-14.9 percent *(Curriero et al., 2003; Basu, 2009).*

The heat-health literature on mortality is much more extensive than for morbidity. However, heatwave studies have observed an increase in all-cause morbidity ranging from 1-11 percent *(Nitschke et al., 2007; Knowlton et al., 2009; Wang et al., 2012*). Laurel and colleagues' (2016) time series study described the burden of severe HRI morbidity and mortality among Florida residents from 2005 to 2012. It conclusively showed that the burden of HRIs requiring medical attention and HRIs was largely preventable. The death toll was higher in the elderly, an unsurprising finding given that age is positively related to the incidence of HRIs. However, the burden of HRIs was higher among young adults regardless of work–related status than in the elderly *(Morano et al., 2016)*. Additionally, when individuals were not able to employ adaptation strategies such as changing their behaviour, for example, a low-income senior citizen without an air-conditioned home who felt safe leaving his home had a lower risk of HRI than someone of a similar age who did not feel safe leaving the home. This phenomenon was clearly observed during the Chicago heatwave, when seniors who left their home and/or who had access to cooling shelters reduced the risk of suffering from a HRI *(Klinenberg, 2003a).*

The economic context in terms of productivity loss caused by extreme heat has been analysed in a number of countries. For example, in India the annual loss is estimated to be up to 55 billion U.S. dollars and may even reach 450 billion dollars by 2030, while in high-income countries the loss was put at 10 billion U.S. dollars in 2010 and is estimated to reach 50 billion U.S. dollars by 2030 *(Kjellstrom, 2016).* Additionally, a number of studies has estimated costs associated with high temperature and extreme heat events. Knowlton *et.al.* (2011) estimated total costs spent on the 2006 California heatwave at $5.4 billion *(Knowlton K. et al., 2011).* Another study by Schemeltz and colleagues (2016), calculated the economic burden of hospitalisations due to HRIs in the USA from 2001 to 2010 (May-September) and found total costs of all hospitalisations was $8,826 per visit and $5,359 of HRIs per visit *(Schmeltz et al., 2016b).* Likewise, Mayrhuber *et.al.* (2018) conducted a scoping review and found that after a hot weather health-watch warning system was operationalised for 3 years in Philadelphia, Pennsylvania, the total saving of lives would have been valued at $468 million in contrast to the cost of running the system of $210,000 over the same period *(Mayrhuber et al., 2018).* Considering these figures, it is clear that developing a system to protect people from the early stages of heat conditions would also significantly decrease economic loss.

2.5 Climate and health research

2.5.1. Climatic factors in health research

The influence of climate change on health is intertwined with a multitude of factors related to climate, the environment, pollution and health exposures *(WHO, 2008b)*. Therefore, it is important to select the proper climatic factors as a proxy for heat exposure for the development of a HHWS. The perception of what constitutes a hot thermal environment, and in turn the resulting behavioural response, varies from person to person but we can approximate the exposure. A number of different measurements and metrics have been used as proxies for characterising the heat-health relationship. These proxies have also been used to alert populations to dangerous heat situations in order to prevent heat-related morbidity and mortality.

Temperature

Temperature is the most common climate factor in the field of climate research. In addition to temperature, humidity, rainfall, atmospheric pressure, UV (ultraviolet) index/solar radiation, cloud cover, wind speed and direction have also been used in climate health studies. However, air temperature alone has not been considered an appropriate indicator of heat *(WHO, 2015).* In many time-series analysis studies, the daily average, maximum, or minimum temperature is used *(Basu and Samet, 2002; Tobias et al., 2012; Ye et al., 2012)*. Short periods of intense heat assessed by using maximum temperature also increase the likelihood of HRI *(Poupart A et al., 2014; Gu et al., 2016b; Ito et al., 2018).*

Climate indices

Climate indices or bio-meteorological indices are calculated from two or more climate factors. Air temperature and relative humidity are combined to determine human perceived equivalent temperature. Human physiology cools down the body by sweating, i.e. removing heat with sweat. However, high relative humidity reduces the evaporation rate. This results in a lower rate of heat removal from the body, hence the sensation of overheating. So, relative humidity should be added to considerations to discover the association between heat and health.

The heat index is calculated from temperature and relative humidity by a regression equation based on the work of R.G. Steadman[2] *(Steadman, 1979b),* who created a table accounting for a number of parameters including the human ventilation rate, surface radiation clothing resistance to heat, and moisture transfer. The heat index is commonly used in the USA. The National Oceanic and Atmospheric Administration (NOAA) *(National Weather Service Weather Forecast Office, 2016*) developed a chart to demonstrate the hierarchy of dangers to raise the awareness of the general population and responsible organisations *(see Figure 1)*. The effects on the human body in each classification are shown in Table 6.

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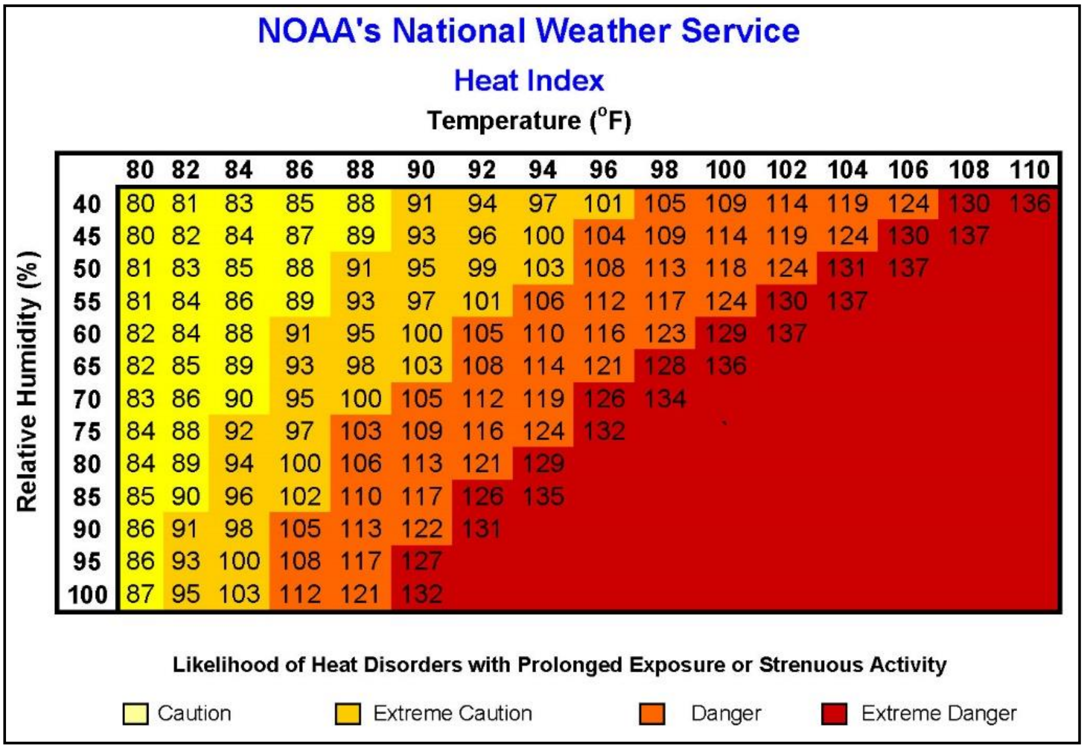
[2] Heat Index = $- 42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783 \times 10^{-3}T^2 - 5.481717 \times 10^{-2}R^2 + 1.22874 \times 10^{-3}T^2R + 8.5282 \times 10^{-4}TR^2 - 1.99 \times 10^{-6}T^2R^2$

Where T = air temperature (°F), R = relative humidity (%)

Figure 1. Heat index chart



NOAA's National Weather Service

Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution Extreme Caution Danger Extreme Danger

Source: National Weather Service (https://www.weather.gov/safety/heat-index)

Table 6. Heat index classification and effects on the body (OSHA, 2017)

Classification	Heat Index (°C)	Effect to body
Caution	80 – 90	Fatigue possible with prolonged exposure and/or physical activity
Extreme caution	91 -103	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	104 – 124	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125 or higher	Heat stroke highly likely

Apparent temperature is calculated by combining ambient temperature and *relative humidity* using saturated vapour pressure, actual vapour pressure, and dew point temperature.

The *Humidex* was created by Canadian meteorologists and first used in 1965 to explain how hot, humid weather feels to the average person (*Smoyer-Tomic et al., 2003*). The Humidex combines temperature and humidity into one number.

The *Net effective temperature (NET)* is routinely monitored by the Hong Kong Observatory, China (*Li and Chan, 2000*). It takes air temperature, wind speed and relative humidity into account. A weather warning is started when the NET is forecast to be lower (or higher) than the 2.5^{th} percentile (97.5^{th} percentile). This procedure is also used in Portugal.

The *Wet-bulb globe temperature (WBGT)* is a measurement of heat that incorporates air temperature, humidity, air velocity, and solar radiation. The WBGT requires three separate thermometers to obtain a reading: a black globe thermometer (solar radiation), a wet-globe thermometer (humidity), and a dry bulb thermometer (air temperature). As a significance of the high rates of HRIs that occur during basic training at the Marine Corps Recruit Depot, Parris Island, the WBGT was first implemented as a surveillance system by the U.S. military during the mid-1950s *(Wallace et al., 2005)*. It is also widely used by researchers in occupational medicine as an easily measured general heat-stress index *(Epstein and Moran, 2006; Kjellstrom, 2016; Park et al., 2017)*. Predetermined WBGT limits have been used in small populations (e.g., work-sites or sporting events) to effectively induce behavioural responses which prevent heat-related morbidity and mortality *(Armstrong et al., 2007)*. Heat exposure limits for work and rest schedules have also been determined based on the WBGT in combination with calculations which incorporate the other two basic parameters *(OSHA, 2017).*

The WBGT measurement system is effective in eliciting behavioural responses to prevent HRIs in real-time application for local environments, is labour intensive, requires precise setup/monitoring, and is not applicable for monitoring large geographical areas. Additionally, the incorporation of the individual parameters with the WBGT requires complicated calculations. Previously created tables specific to work-sites/situations allow for real-time applications in local work environments; however, the use of these tables is not practical when working with large populations where information about the work situation and amount/type of clothing for the individuals is not available.

2.5.2 The investigation into the threshold level of climate and health

This section looked at up-to-date studies which have critically evaluated the relationship between heat and health in order to determine a threshold level for climate indices and health outcomes (mortality/morbidity). The review focuses on the various statistical modelling and methodological approaches used in recent studies in and around the fields of health care and disease epidemiology. A variety of modelling approaches has been discovered in various climate change health settings. In general, most of the studies involve health exposure as responses (e.g., disease outcomes, morbidity, hospital admissions, mortality) and climate variables as explanatory variables. A summary of this research, which aimed to identify the threshold level of HHWS from 1995-2018, is shown in Table 7. A summary of the threshold level from those studies is shown in Table 8.

Additionally, health outcomes, either mortality or morbidity, are classified in all studies according to the International Classification of Diseases, 9th or 10th Revision. Cardiovascular diseases, respiratory diseases, gastrointestinal diseases and HRIs are classified into I00-99, J00-99, A00-99 and T67.0-67.9 respectively *(World Health Organization, 2014; Onozuka and Hagihara, 2016)*

Table 7. Summary of threshold level analysis studies between climate and health

Author	Location	Sample	Time period			Climate factors					Outcome of disease				Statistical analysis					Lag	Air pollution control		Strengths and limitations
			Heat wave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp.	HI	Air Mass	Mortality	Excess Mortality	HRI	Other Morbidities	GLM with Poisson regression	GAM with Poisson regression	GEE	Log Linear regression	DNLM		Yes	No	
Tan, 2004 (Tan *et al.*, 2004)	Shianghai China	Daily death count (10 years)	√	√						√	√	√						√				√	Pros → Airmass can explain specific climate area Cons → Unclear how to determine the threshold for a warning system
Lin, 2009 (Lin *et al.*, 2009)	New York	Hospital Admissions (13 years)			√	√	√	√						√		√				√		√	Pros Lag with day of the week, holiday control Cons → The threshold is specifically for cardiovascular and respiratory patients
McMichael, 2008 (McMichael *et al.*, 2008a)	Multiple low-middle income countries	Daily death count (up to 5 years)			√			√			√				√						√		Pros → Multi-city study shows the difference between areas more clearly Cons → The standards of registration of death different between countries

Author	Location	Sample	Time period			Climate factors					Outcome of disease				Statistical analysis					Lag	Air pollution control		Strengths and limitations
			Heat wave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess Mortality	HRI	Other Morbidity	GLM with Poisson regression	GAM with Poisson regression	GEE	Stepwise Linear regression	DNLM		Yes	No	
D'Ippoliti, 2010 (D'Ippoliti *et al.*, 2010)	9 cities in Europe	Daily mortality (14 years)		√		√	√				√						√				√		<u>Pros</u> → Gave a definition for heatwaves across European countries <u>Cons</u> → No lag day investigated
Metzger, 2010 (Metzger *et al.*, 2010)	New York	Mortality (20 years)		√					√		√				√					√		√	<u>Pros</u> → Comparison between parametric and non–parametric provided. <u>Cons</u> → Analysis limited to warm seasons
Alessandrini, 2011 (Alessandrini *et al.*, 2011)	9 cities in Italy	Ambulance Dispatches (1 year)		√				√						√					√		√		<u>Pros</u> → First relationship study between climate and ambulance dispatches <u>Cons</u> → Period of study too short, the health outcome limited to population more than 35 years old and the ambulance dispatch data not collected to assign an accurate medical diagnosis

Author	Location	Sample	Time period			Climate factors						Outcome of disease				Statistical analysis					Lag	Air pollution control		Strengths and limitations
			Heat wave	Summer	Whole year	Max. Temp	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess mortality	HRI	Other Morbidity	GLM with Poisson regression	GAM with Poisson regression	GEE	Stepwise Linear regression	DNLM		Yes	No	
Basu, 2011 (Basu and Malig, 2011)	13 counties in California	Daily mortality (7 years)		√				√			√					√				√	√		<u>Pros</u> → The results showed different associations among different counties, which means the association was area-specific
Gasparrini, 2011 (Gasparrini and Armstrong, 2011)	108 communities across the USA	Daily mortality (13 years)	√	√				√			√								√	√	√		<u>Pros</u> → Clarified the definition of heatwave <u>Cons</u> → Threshold is for warning to protect mortality, which was the late effect of heat
Tobias, 2012 (Tobias *et al.*, 2012)	52 cities in Spain	Daily mortality	√	√		√					√						√			√		√	<u>Pros</u> → Evaluate the different excess risks between heatwave days and non-heatwave days <u>Cons</u> → Threshold is for warning to protect mortality, which was the late effect of heat

Author	Location	Sample	Time period			Climate factors√					Outcome of disease				Statistical analysis						Lag	Air pollution control		Strengths and limitations
			Heat wave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess mortality	HRI	Other Morbidity	GLM Poisson regression	GAM Poisson regression	GEE	Linear regression	DNLM	Logistic regression		Yes	No	
Williams, 2013 (Williams *et al.*, 2012)	Adelaide, Australia	Daily mortality and daily hospital admission and emergency department (15 years)		√		√	√				√			√			√					√		Pros → Compared the results with various outcomes Cons → All outcomes confounded by other factors not only heat
Na, 2013 (Na *et al.*, 2013)	Korea	ED visits (3 months)		√		√			√				√					√					√	Pros → Compared the suitable index for heat surveillance system Cons → Very short time series data
Harlan, 2014 (Harlan *et al.*, 2014)	Arizona	Death certificates (8 years)		√		√			√		√				√								√	Pros → The threshold investigated each vulnerable group particularly Cons → There were many threshold levels, meaning it may be difficult for policy makers to apply

Author	Location	Sample	Time period			Climate factors√					Outcome of disease				Statistical analysis						Lag	Air pollution control		Strengths and limitations
			Heat wave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess mortality	HRI	Other Morbidity	GLM Poisson regression	GAM Poisson regression	GEE	Linear regression	DNLM	Logistic regression		Yes	No	
Li, 2014 (Li *et al.*, 2014)	4 cities in China	Daily mortality		√		√					√					√						√		Pros → The messages of multi-city analysis clearly stated and covered different climatic zones. Cons→ The threshold was specific for diseases other than HRIs
Antonio, 2015 (Gasparrini *et al.*, 2015)	Multi countries	Death counts (up to 27 years)		√				√			√								√	√				<u>Pros</u> → Long study period, multi-countries can compare the effect between countries <u>Cons</u> → The standards of registration of death differed across countries
Xiang, 2015 (Xiang *et al.*, 2015)	Australia	Work claim data (10 years)			√	√							√				√					√		<u>Pros</u> → Results illustrated directly to occupational health illness <u>Cons</u> → The threshold limited to occupational HRIs

Author	Location	Sample	Time period			Climate factors					Outcome of disease				Statistical analysis						Lag	Air pollution control		Strengths and limitations
			Heatwave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess mortality	HRI	Other Morbidity	GLM with Poisson regression	GAM with Poisson regression	GEE	Stepwise Linear regression	DNLM	Logistic regression		Yes	No	
Zhang, 2015 (Zhang *et al.*, 2015)	Nanjing, China	Daily mortality (6 years)	√					√			√								√		√	√		Pros → 15 comparisons were made between different heat wave scenarios to determine optimum threshold levels Cons → Mortality data did not reflect the direct effect by heat
Muggeo, 2009 (Muggeo and Hajat, 2009)	Santiago and Palermo	Daily mortality (3 years)			√	√	√	√			√					√				√	√			Pros → Lag investigated up to 60 days with seasonal control Cons → Mortality data did not reflect the direct effect by heat
Gu, 2016 (Gu *et al.*, 2016b)	China, Ningbo and Chongqing	Daily HRI visits (3 years)		√		√							√		√				√	√		√		Pros → The outcome as HRIs is better to give the direct effect by heat Cons → No seasonality control and short time series period

Author	Location	Sample	Time period			Climate factors					Outcome of disease				Statistical analysis						Lag	Air pollution control		Strengths and limitations
			Heatwave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess mortality	HRI	Other Morbidity	GLM with Poisson regression	GAM with Poisson regression	GEE	Stepwise Linear regression	DNLM	Logistic regression		Yes	No	
Winquist, 2016 (Winquist *et al.*, 2016)	Atlanta, Georgia	ED (20 Years)		√		√							√	√	√					√	√			Pros → Long study period, different rate ratios were analysed by 25th and 75th percentiles of max. temp Cons → The primary outcome based on primary diagnosis may not indicate a definite diagnosis
Gao, 2017 (Gao *et al.*, 2017)	China	Daily mortality (3 years)		√				√				√		√		√					√	√		Pros → Full time-series analysis applied with lag day provided along with confounders control Cons → The threshold was specifically for cardiovascular and respiratory patients
Phung, 2017 (Phung *et al.*, 2017)	Vietnam	Daily hospitali-sation	√						√					√	√				√	√		√		Pros → The results revealed many comparisons of outcomes Cons → No given period of study

Author	Location	Sample	Time period			Climate factors					Outcome of disease				Statistical analysis						Lag	Air pollution control		Strengths and limitations
			Heatwave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess mortality	HRI	Other Morbidity	GLM with Poisson regression	GAM with Poisson regression	GEE	Stepwise Linear regression	DNLM	Logistic regression		Yes	No	
Chen, 2017 (Chen *et al.*, 2017b)	Atlanta	ED visits (20 years)	√	√		√	√	√							√				√		√		√	<u>Pros</u> → This study is the longest period for a time-series analysis <u>Cons</u> → The threshold was specifically for diseases other than HRIs
Ito, 2018 (Ito *et al.*, 2018)	Japan	ER Transport (3 years)		√		√							√							√				<u>Pros</u> → The outcome as HRIs is better to give the direct effect by heat <u>Cons</u> → Meteorological data were observed value not reflected actual temperature
Zhao, 2018 (Zhao *et al.*, 2018)	China	Hospital visits (3 years)			√			√						√					√		√		√	<u>Pros</u> → Evaluate lag of 28 days <u>Cons</u> → The threshold was specifically for cardiovascular and respiratory patients

Author	Location	Sample	Time period			Climate factors					**Outcome of disease**				Statistical analysis						Lag	Air pollution control		Strengths and limitations
			Heatwave	Summer	Whole year	Max. Temp.	Min. Temp.	Mean Temp	HI	Air mass	Mortality	Excess mortality	HRI	Other Morbidity	GLM with Poisson regression	GAM with Poisson regression	GEE	Stepwise Linear regression	DNLM	Logistic regression		Yes	No	
Zhang, 2018 (Zhang *et al.*, 2018)	China	Daily mortality (4 years)			√			√						√	√				√		√		√	Pros → The outcome applied with YLL instead of mortality rates. This can be evaluated wider in the burden of diseases issue. Cons → No consideration of HRIs as death burden

Table 8. Threshold levels selected from threshold level analysis studies

Title of study	**Threshold level**
International study of temperature, heat and urban mortality: the 'ISOTHURM' project *(McMichael et al., 2008a)*	75th – 95th percentile range of mean temperature
Extreme High Temperatures and Hospital Admissions for Respiratory and Cardiovascular Diseases *(Lin et al., 2009)*	95th and 99th percentile of mean temperature
The impact of heat waves on mortality in 9 European cities: Results from the EuroHEAT project *(D'Ippoliti et al., 2010)*	90th percentile of maximum temperature
Summer heat and mortality in New York City: How hot is too hot? *(Metzger et al., 2010)*	> 95º F - 100º F
Emergency ambulance dispatches and apparent temperature: A time series analysis in Emilia-Romagna, Italy *(Alessandrini et al., 2011)*	> 30º C of mean temperature
High ambient temperature and mortality in California: Exploring the roles of age, disease, and mortality displacement *(Basu and Malig, 2011)*	> 90th percentile of mean temperature
The impact of heatwaves on mortality *(Gasparrini and Armstrong, 2011)*	> 99th percentile of mean temperature
Mortality on extreme heat days using official thresholds in Spain: A multi-city time series analysis *(Tobias et al., 2012)*	> 95th percentile of maximum temperature
Heat and health in Adelaide, South Australia: Assessment of heat thresholds and temperature relationships *(Williams et al., 2012)*	> 90th, 95th and 99th percentile of maximum temperature
Heat-Related Deaths in Hot Cities: Estimates of Human Tolerance to High Temperature Thresholds *(Harlan et al., 2014)*	> 97th percentile of heat index
Association between high temperature and mortality in metropolitan areas of four cities in various climatic zones in China: a time-series study *(Li et al., 2014)*	> 90th - 95th percentile of maximum temperature depend on area of warning

Title of study	Threshold level
Extreme heat and occupational heat illnesses in South Australia, 2001-2010 *(Xiang et al., 2015)*	> 35.5º C of maximum temperature
Temporal Variation in Heat-Mortality Associations: A Multicountry Study *(Gasparrini et al., 2015)*	> 90^{th} and 99^{th} percentile of mean temperature
Influence of heatwave definitions to the added effect of heatwaves on daily mortality in Nanjing, China *(Chen et al., 2015)*	98^{th} percentile of mean temperature
Influence of heat wave definitions to the added effect of heatwaves on daily mortality in Nanjing, China (Chen *et al.*, 2015)	98^{th} percentile of mean temperature
Heat-related illness in China, summer of 2013 *(Gu et al., 2016b)*	50^{th} and 97.5^{th} percentile of maximum temperature
Heatwave and risk of hospitalization: A multi-province study in Vietnam *(Phung et al., 2017)*	90^{th} percentile of heat index
Time-series Analysis of Heatwaves and Emergency Department Visits in Atlanta, 1993 to 2012 *(Chen et al., 2017b)*	98^{th} percentile of mean temperature
Impact of Temperature in Summer on Emergency Transportation for Heat-Related Diseases in Japan(Ito *et al.*, 2018)	50^{th}, 75^{th}, 95^{th} and more than 95^{th} percentile of maximum temperature
Impact of ambient temperature on clinical visits for cardio-respiratory diseases in rural villages in northwest China (Zhao *et al.*, 2018)	99^{th} percentile of mean temperature
Ambient temperature and added heatwave effects on hospitalizations in California from 1999 to 2009*(Sherbakov et al., 2018)*	95^{th} percentile of mean temperature

2.6 Key findings of threshold evaluation studies

2.6.1 Methodology and exposure – response curve

Various methodologies are used for defining the relationship between climate indices with mortality or morbidity to determine the threshold level for warnings. Most research in this field is usually based on time-series analyses[3] according to the nature of climate data ordered by a sequence of values of a variable at equally spaced time intervals. The biggest advantage of using time series analysis is that it can be used to understand the past as well as predict the future. The limitation of time series analysis is that the irregular pattern of any data does not form a time-series and the method should be based on the assumption that some aspects of past patterns will continue to hold in the future, a statement which is not always true (*Bhaskaran et al.*, *2013*).

As can be seen from Table 7, Poisson regression was the most common method applied in the 25 studies. However, a Generalised Additive Model *(Schmeltz et al.)* has become one of the main statistical models within the climate change and health framework because of its nature as a semi–parametric extension of GLM and its ability to deal with a non-linear and non-monotonic relationship. Poisson regression is used to model the count data. Thus, either mortality or morbidity counts can be analysed using a time series approach.

The existing literature has also explored the shape of the association between heat and morbidity and mortality as well as the relevant time windows. Specific aspects of the shape and timing of exposure are discussed here. The relationship between temperature and morbidity/mortality is nonlinear, with short lag effects. The shape of the exposure-response curve has been shown in the literature to be non-linear (above a threshold) or J-shaped *(Braga et al., 2001; Basu and Samet, 2002; Curriero et al., 2002; Baccini et al., 2008*). When the entire temperature spectrum (cold to hot) is considered, the relationship between morbidity/mortality and temperature is U-shaped. The shape of the exposure-response relationship may vary by location *(Ye et al., 2001; Basu and Samet, 2002; Curriero et al., 2002).*

[3] Time series regression models are commonly used in environmental epidemiology. The design is often used in studies attempting to quantify short–term associations of environmental exposure such as air pollution, pollen, dust and weather variables with health outcomes.

2.6.2 Threshold level

The threshold above the minimum heat–related outcomes observed is the threshold temperature. The threshold may be a single value or a range *(see Table 8).* In the literature, three general methods have been used to identify the threshold temperature: 1) visual inspection of the exposure–response curve; 2) statistically by considering the maximum likelihood applied to the exposure–response curve; 3) percentiles of the exposure data.

When the method used to estimate the cut-off point varies, the resulting effects estimate for the heat–health relation also changes. For example, Hajat and colleagues (2002) examined four threshold cut-off points in their analysis of mortality in London from 1976–1996. They found that the different cut-off points gave a different percent increase in average deaths per one degree increase in temperatures above the threshold, which were 18.9°C (90^{th} percentile), 20.6°C (95^{th} percentile), 21.5°C (97^{th} percentile) and 23.3°C (99^{th} percentile), and observed a 2.5% (95% CI = 2.35, 2.9), 3.2% (95% CI = 2.56, 3.8), 3.34% (95% CI = 2.47, 4.23) and 5.71% (95% CI = 4.3, 7.15) increase in average deaths per one degree increase from temperature above the threshold, respectively. The results also showed that a rise in heat-related deaths began at about 19°C from a plot of the mortality-temperature relation *(Hajat et al., 2002).* Additionally, the threshold cut-off point varied by location, with a warmer climate area having a higher threshold than a cooler area. Tobias and colleagues (2012) showed in a study of daily mortality in 52 cities in Spain that the low mean summer temperatures in the western area were associated with higher relative risk. They suggested that the threshold level within the western area had been set too high *(Tobias et al., 2012).*

As discussed above, the threshold level of heat varies by geographic location and individuals become acclimatised to it. In warmer climates, people are more acclimatised to heat than in cooler climates. As such, city or region specific thresholds are typically applied *(Gasparrini and Armstrong, 2011).*

2.6.3 Lag effect

The literature on lag effect has highlighted that temperature generally has an immediate effect on health outcomes (lag 0). However, the late effect could be observed up to three days after exposure (lag 1 -3) *(Lin et al., 2009; Muggeo and Hajat,* *2009; Metzger et al., 2010; Basu and Malig, 2011; Gasparrini and Armstrong, 2011; Bai et al., 2014; Winquist et al., 2016; Chen et al., 2017b; Gao et al., 2017).* To investigate the effect of heatwaves on 9,856,015 emergency department (ED) visits in Atlanta, Chen *et.al.* (2017) reported that ED visits for all internal causes were associated with heatwave days defined by a maximum temperature at lag 0 (RR = 1.02, 95%CI= 1.00 – 1.03) and lag 1 (RR = 1.02, 95%CI = 1.00 – 1.04) *(Chen et al., 2017b).* In the same vein, Bai and colleagues studied the associations between extreme heat and 3,862 HRIs in summer in 2011-2013 in Ningbo, China and found the effects of maximum temperature and heat index on total HRIs at lag 0 and lag 2 (RR = 1.3, 95%CI = 0.810 – 2.087 and RR = 1.802, 95%CI = 1.079 – 3.011) *(Bai et al., 2014).* A similar result was shown in a study by Basu and Maliq in 2011 although they used mortality as the outcome. These two scholars examined mean daily temperature and 481,757 deaths (mortality outcome) in 13 counties in California during summer from 1999 to 2006 using Poisson regression and found a 4.3% (95%CI = 3.4 – 5.2) increase in excess risk of non-accidental mortality per 5.6° C increase in apparent temperature at lag 0, with the strongest effects identified at this lag. The effect in the following days remained up to lag 3. Collectively, these studies help to support emergency response and prevention systems determine when the onset of a period of intense heat is acute.

2.6.4 Heatwaves definition

Heatwaves are considered to be periods (i.e. continuous days) of intense heat. There is currently no uniform definition of the duration or intensity of a heatwave and as a result the definition of magnitude of an effect (e.g., excess deaths) varies by study, making it difficult to draw conclusions that might inform policy *(Kinney et al., 2008; Tong et al., 2010; Kravchenko et al., 2013)*. As with other heat-health studies, the exposure metric (e.g., maximum temperature or apparent temperature) varies from study to study, with single or multiple exposure metrics (e.g., minimum and maximum temperature) used to define a heatwave (*Kovats et al., 2004; Khalaj et al., 2010; Basagana et al., 2011*). Thresholds are often used to define the intensity of a heatwave and are based on the historical summer temperature distribution. The 90th, 95th, 97th, 98th, or 99th percentiles of that distribution are used to define the threshold *(Hansen et al., 2008a; Nitschke et al., 2011; Son et al., 2012)*. For duration, a period of two, three, or four consecutive days above a particular threshold is typically used. However, Gasparrini and Armstrong observed that between 1987 and 2000, 45.4 percent of the

108 U.S. communities within their study endured a heatwave of at least 10 days and 81.5 percent of the 108 communities endured one of at least seven days *(Gasparrini and Armstrong, 2011).*

Studies that have examined the varying definitions of intensity and duration of heat have demonstrated that the health effects vary depending on the definition used. In general, greater effects on morbidity and mortality were seen during longer and more intense heatwaves, although intensity appears to have had a larger impact. Tong and colleagues*'s* (2010) case-crossover study in Brisbane, Australia (1996-2005), investigated the relationship between heatwaves and different health outcomes using ten different heatwave definitions (HWD)[4]; there was a statistically significant increase in the odds ratios ranging from 1.10–1.73 of mortality (54,318 deaths) in eight from 10 definitions and the largest effect was shown for HWD3 (RR = 1.73, 95%CI = 1.32–2.28). They also found a statistically significant increase in emergency hospital admissions for all 10 definitions with odds ratios ranging from 1.03–1.18 and the largest effect was shown for HWD5 (RR = 1.18, 95%CI = 1.11-1.25) *(Tong et al., 2010).* A study of seven Korean cities (2000–2007) by Son and colleagues *(2012)* produced similar results. When the intensity of a heatwave was defined as a temperature at or above the 97th percentile for two consecutive days or longer, there was no statistically significant relationship of the percent increase in mortality (1.8%, 95% CI = -7.2, 11.7). However, when the definition was changed to above the 98th percentile for two consecutive days or longer, a statistically significant increase of 8.4% in mortality was found (95% CI = 0.1-17.3). In conclusion, heatwave definitions vary depending on evaluation of the local/regional heat–health relationship.

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[4] HWD1, the daily maximum temperature ≥ 35ºC for 3 or more consecutive days.
HWD2, the daily maximum temperature of more than 5 consecutive days exceeds the average maximum temperature by 5ºC, the normal period being 1961-1990.
HWD3, the heat index (maximum temperature + relative humidity) is expected to reach 40.6ºC with a minimum temperature not below 26.7ºC for a period of at least 48 hours.
HWD4, the daily maximum temperature would be ≥ 35ºC for at least 2 consecutive days.
HWD5, the daily maximum temperature would be ≥ 37ºC for at least 2 consecutive days.
HWD6, the top 2.5% (≥33.59 ºC) of the daily maximum temperature for a continuous 2-day period.
HWD7, the top 2.5% (≥33.59 ºC) of the daily maximum temperature for a continuous 3-day period.
HWD8, the top 5% (≥32.65 ºC) of the daily maximum temperature for a continuous 3-day period.
HWD9, the top 5% (≥32.65 ºC) of the daily maximum temperature for a continuous 4-day period.
HWD10, the top 5% (≥32.65 ºC) of the daily maximum temperature for a continuous 5-day period.

2.7 Limitations of recent studies

2.7.1 Limitations regarding selection of outcome of interest

The use of multiple data sources to identify heat-related morbidity and mortality within the same time period can provide valuable information. The literature reveals that mortality data records are generally complete and are more readily available than morbidity data, and thus mortality has been a primary focus in assessments of the heat-health relationship for a HHWS. As shown in Table 7, 15 out of 25 studies have found a relationship between heat and mortality. However, this should not imply that the only negative outcome from heat is death.

Most of the death certificates recorded the main cause of death as respiratory failure or cardiac arrest, but this omits the actual diagnosis as a heat-related death. Harlan and colleagues (2014) characterised the relationship between temperature and mortality in central Arizona during May–October (2000-2008) and stated that limitations regarding estimating thresholds for categories of deaths that are not directly attributed to heat is subject to error because a heat effect can be masked when the majority of deaths in the category are not heat related *(Harlan et al., 2014).* They believed that the temperature threshold estimates are much higher for categories of deaths indirectly associated with heat than for deaths directly caused by heat. Similarly, Zhang and colleagues (2015) used consistent methods to model the effects of an exceptional heatwave on mortality and ED visits to examine the associations between the 2011 heatwave in Houston, Texas, and mortality and ED visits with a merged dataset from 2007 to 2011 using a time-series approach. They reported that there was no consensus on cause of death directly or indirectly affected by heat or a heatwave.

Another issue is that the accuracy of the record of death certification was noted as a problem in the recording process. In Korea, Na and colleagues (2013) studied the effects of temperature and HRIs instead of mortality because death is required to be reported within a month and it takes approximately one year to establish official mortality statistics nationwide *(Na et al., 2013).* Death certification data also has limitations in the assessment of personal characteristics, as Basu and Malig (2011) discussed in their time series analysis that examined mean daily apparent temperature and mortality in 13 counties in California during the warm season from 1999 to 2006. They found that they could not assess personal characteristics such as individual-level income or individual-level air conditioning use and air conditioning use may be less of a marker of socioeconomic status in California *(Basu and Malig, 2011).*

As opposed to preventing death, an effective prevention system may be better set up to prevent disease. In this case, morbidity is considered the outcome of study. Health proxies for heat exposure, such as emergency ambulance dispatch data, 911 calls or even ED visits, have been considered by numerous studies *(see Table 7).* However, the limitations of morbidity data can also be seen in those studies, largely due to the limited data registration of heat-related data, a lack of standard criteria for physicians to identify HRIs, or weak surveillance systems, leading to a smaller number of patients being definitively diagnosed with a HRI *(Wang et al., 2009; Na et al., 2013; Onozuka and Hagihara, 2016).* Na and colleagues (2013) found a limitation after they set out to select HRIs as the outcome of interest in a time series study in Korea during June to September 2012, namely that there was a possibility of underestimation due to the fact that the patient reporting system is not mandatory. It was possible that there was no reporting during times of heavy workloads in hospitals *(Na et al., 2013).* In China, the number of HRIs was also underestimated, although a HHWS is currently operated. Gu and colleagues (2016) analysed data from the entire country, collected from the Heat-related Illness Surveillance System at the Chinese Centre for Disease Control and Prevention (China CDC). A total of 5758 cases were reported in the summer of 2013 and the researchers found that HRI figures were underestimated because Henan province has a population of nearly 100 million, and the maximum temperatures of many places were above 35 °C, but no cases of HRIs at all were reported from 2011 to 2013 *(Gu et al., 2016b)*. Thus, reporting HRIs is another challenge that needs to be overcome when designing or improving HHWSs. All areas of the country require the same system to accurately report HRIs.

Moreover, all health proxies are not directly to heat-specific diseases because they are diagnosed by symptoms at the first visit and may have changed by the end of a definite diagnosis. By drawing on this limitation, Lin and colleagues found in their study of extremely high temperatures and hospital admissions for respiratory and cardiovascular disease in New York City that the data for cardiovascular and respiratory diseases showed a higher degree of validity than HRIs themselves *(Lin et al., 2009)*. As a result, a poorly defined diagnosis is likely to occur. In summary, to select the outcome of interest depends on the quality of data sources, the recording process, and the surveillance system in operation in the country or region *(Pattenden et al., 2003; Kaiser et al., 2007; Hartz et al., 2012; Li et al., 2014; Gasparrini et al., 2015; Fuhrmann et al., 2016).*

2.7.2 Limitations regarding climate variables

Air pollutant levels have been found to be related to temperature during extreme climate events. Many studies control pollution variables as confounders due to their unavoidable link with health *(see table 7).* Ozone levels and particulate matter (PM) are two dominant measures *(Li et al., 2012; Qiao et al., 2015)*. Ozone levels have been used particularly in studies on chronic bronchitis, pneumonia and heart disease as outcomes *(Green et al., 2010).* Bhaskaran and colleagues controlled both factors (ozone and PM_{10}) in a time series regression study on the short-term effects of temperature on the risk of myocardial infarction, influenza and respiratory syncytial virus infection in England and Wales (2003–2006) *(Bhaskaran, 2010).* Most recent studies control air pollution as a confounder and had the limitation of missing air pollution data *(Williams et al., 2012; Turner et al., 2013; Onozuka and Hagihara, 2016; Gao et al., 2017)*. Mainly because there was incomplete air pollution data due to fact that pollution monitoring did not cover all areas of study (*Pauli and Rizzi, 2006; Ito et al., 2018*).

There is a debate on whether pollutants should be included in climate research because the results from many studies found that there was no statistical significant association in the model that controlled air pollution. Winquist and colleagues performed a time series analysis with Poisson regression for estimating the association between extreme heat and ED visits in Atlanta, Georgia, with controls for many air pollutions such as carbon monoxide, nitrogen dioxide, sulphur dioxide, ozone and PM_{10} in the model. The inclusion of air pollutions in the model did not substantially affect the rate ratios for the relationship between temperature and the health outcomes they were considering *(Winquist et al., 2016).* In their study of Nanjing, China, Chen and colleagues (2015) supported Winquist and colleagues' view that the association between heatwaves and daily mortality with and without adjusting for air pollutants (PM_{10}, NO_2 and SO_2).

2.7.3 Limitation of period of study and lag selection

Many studies from Table 7 were conducted in the summer, limiting observations to a particular season. The effects of heat may occur throughout the entire year, especially in the hot countries, so the focus on the summer may be considered a selection bias for analysis.

Consequently, the lag period of climate variables seems to vary in studies and it is necessary to optimise the length of a suitable lag period for particular diseases, seasons and countries. Any climate change study should take into account regional differences since areas within certain boundaries may have a more homogenous environment and demographic. Thus, research which is not population based could be restricted in terms of the extrapolation of results to other regions *(Yang et al., 2015).*

2.8 Heat–Health Warning Systems (HHWSs)

As climate change has resulted in rising global temperatures, there has been an increase in the frequency and severity of heatwaves in many parts of the world. The particular issue of heat effects on health was identified after a heatwave had a devastating impact on the European continent in 2003 causing approximately 40,000 deaths because of inadequate social and health systems *(see 1.1)* (*Centre for Disease Control and Prevention, 2013; Bell et al., 2018)*.

Systems to warn of excessive heat conditions during a heatwave are known as Heat Health Warning Systems (HHWSs). HHWSs have been established in many countries to protect health from heat exposure. For example, a French national heatwave plan was created in 2004 *(Pascal et al., 2011; Hanna, 2015)*. HHWSs serve as alerts to the general population and policy makers to remain vigilant during dangerously hot weather *(WHO, 2008a; WHO, 2008b)*. Additionally, they serve as a source of advice on how to avoid the debilitating health outcomes that can follow hot weather periods and to ensure that health, social care and other voluntary and community organisations are prepared and able to deal with a heatwave when it occurs *(Patz and Hatch, 2013).* Once a heatwave starts, the window of opportunity for effective action is very short. Therefore, advanced planning and preparedness are essential. Effective action taken early can reduce the health impacts of exposure to excessive heat. Most of these are simple preventive measures which, to be effective, need to be planned in advance

(Kravchenko et al., 2013). A HHWS can also activate individuals and communities to help their neighbours, friends, and relatives to be ready for action in the event of health problems during spells of very hot weather.

Multiple agencies have a critical role in preparing and responding to a heatwave at the local level, working closely with health and environmental organisations on long-term strategic planning, which is essential to support the co-ordinated planning between agencies to protect people and infrastructure from the effects of severe hot weather, thus reducing excess summer illnesses and deaths *(Yardley et al., 2011).* Long-term multi-agency planning for adaptation and mitigation to reduce the impact of climate change has been developed in the UK and Australia, including 'greening the built environment' in such ways as specific building designs, increasing shading around and insulation of buildings, and increasing energy efficiency by reducing carbon emissions and improving transport policies.

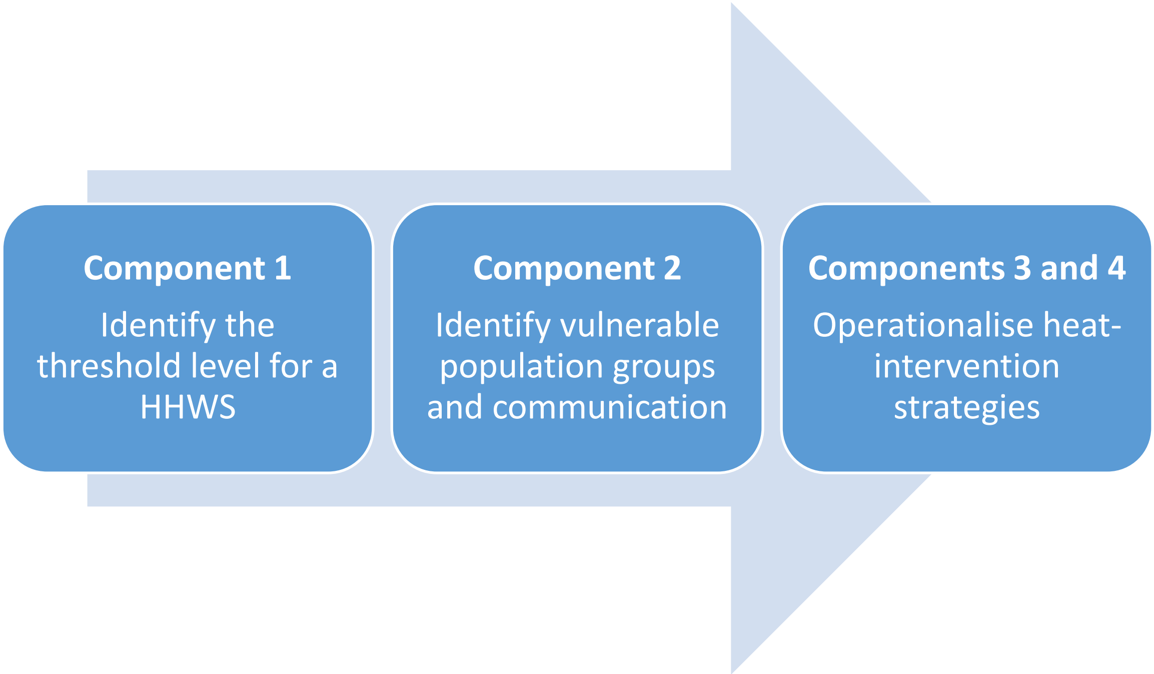
HHWSs save lives and reduce heat-related harm and the results of numerous studies show that a HHWS can have a significant reduction in heat-related mortalities *(Toloo et al., 2013a; Toloo et al., 2013b)*. Chau and colleagues compared excess deaths from Ischemic Heart Diseases (IHDs) and strokes on days with and without a warning system in operation in Hong Kong and found that incidences were reduced by 727 cases and 574 cases, respectively *(Chau et al., 2009)*. Ebi and colleagues compared expected and observed deaths from 1995 to 1998 in Philadelphia, combined with a cost-benefit analysis of the use of a HHWS. They found that 2.6 lives were saved per day, which was, in financial terms, a sizeable return on the $210,000 it costs to run the system *(Ebi et al., 2004).*The advantages of a HHWS were also seen by Foulliet and colleagues (2008), who performed a Poisson regression model relating the daily fluctuations in summer temperature and mortality in France from 1975 to 2003 to estimate the daily expected number of deaths over the period 2004–2006 as a function of the observed temperatures. They found that 6,452 excess deaths were expected but only 2,065 deaths actually occurred (i.e. some 4,387 fewer deaths) after the implementation of a HHWS. Palecki and colleagues studied the temporal association of meteorological conditions and mortality in the US Midwest, showing contrasting results for Chicago and St. Louis. In St. Louis, excess deaths increased from 27 in 1995 to 36 in 1999 after a HHWS was implemented. They explained this as the result of a more intensive heatwave in 1999 *(Palecki MA, 2001)*. To support the position that the implementation of a HHWS in the USA after a heatwave in 1995 would reduce risk for vulnerable groups, Wang and colleagues conducted a large-scale national study of 23.5 million participants aged 65 years or older and used the matched data set between heat wave day and non-heat wave day by county and by week. They found that the risk of heat stroke in older people residing in 1,1916 counties declined over time from 71.0 (95%CI = 21.3–236.2) in 1999 to 3.5 (95%CI = 1.9–6.5) in 2010 *(Wang et al., 2016*).

However, the small number of studies in this field leaves it unclear how a system reaches the target populations or how it changes behaviours *(Toloo et al., 2013b)*. More research is thus urgently required into mechanisms of improving the utilisation of services by vulnerable populations and groups during heatwaves, in both developed and developing societies *(Takahashi et al., 2015; Telesca et al., 2018).* For a convenient and correct communication, HHWS nomenclature should be clearly understood by the public, local stakeholders and decision-makers, and the differences between levels should be clearly stated *(Kathryn Lane et al., 2013; Khare et al., 2015).* For example, the USA has four threshold levels of HHWSs: excessive heat warning, heat advisory, heat watch and excessive heat outlook. As few members of the public understand this terminology, it is imperative that the public are informed about the details of a HHWS *(NOAA, 2018a).*

2.9. Components of a HHWS

A total of four components of a HHWS for this study were gathered mainly from three sources: the *WHO's Heatwaves and Health: Guidance on Warning-System Development (WHO, 2015)*; the heat-health plan for Victoria, Australia, as known *Protecting health and reducing harm from extreme heat and heatwave (Victorian Government, 2015)*; and *the Heatwave Plan for England (PHE, 2018)*. A summary of the four components is shown in Figure 2

Figure 2. Summary of the 4 components of a HHWS



2.9.1 Weather forecasting and threshold levels for a HHWS

A HHWS must be a tailor-made system, not a one–size fits all project, especially in large countries where there are different cultural and climatic zones *(WHO, 2015).* Moreover, all systems should be based on thresholds that are related to actual heat–health outcomes. Thus, the determination of whether an action trigger, such as a threshold temperature or bio-meteorological index of significance for health effects, is the first step to creating an appropriate warning level.

At least 12 countries *(see Table 9: Belarus, Belgium, France, Greece, Hungary, Latvia, the Netherlands, Poland, Portugal, Romania, Spain, the UK)* have utilised only temperature or a modified form of apparent temperature to set the threshold levels for a HHWS. Switzerland, Canada and the USA add a heat index to employ the threshold levels. These indices could be beneficial in areas with variable levels of atmospheric moisture, making the temperature alone perhaps less representative of the humidity of the weather than in locations where humidity is relatively consistent from day to day.

All HHWS threshold values in each country are set specifically to identify associations with negative human responses such as increased morbidity (HRI admissions, emergency calls or visits) or mortality data *(see section 2.5.2),* which are more widely used because mortality data are regularly reported with the same standard in all areas. On the other hand, hospital admission data reporting, based as it is on the judgement of a health professional, may vary by severity and depends on the health service system. Nevertheless, heat-related deaths have been known to underestimate the true impact of heat. The type of threshold used for triggering warnings in each country is shown in Table 9.

Table 9. Summary of threshold selection in different countries

Country	**Parameter**	**Human outcome**	**Triggering threshold**
Australia[1]	Apparent temperature	-	Exceed 35°C in Brisbane and 37°C in Amberly on 2 consecutive days
Belarus[2]	T	-	Exceed 30°C on one day
Belgium[2]	T_{max}	-	95th percentile of summer maximum temperature
Canada[3]	Humidex/Synoptic Based system	Excess mortality	Exceed 40 on 2 consecutive days
China[4]	Airmass	Excess mortality	Exceed 35°C on 2 consecutive days
France[5]	T_{max}/T_{min}	50% increase in predicted mortality	-
German[2]	T	Excess heat load	-
Greece[2]	T_{max}	-	Exceed 38°C on 1 day
Hungary[2]	T_{mean}	-	-
Italy[2]	Airmass	Non–accidental mortality	-
Korea[6]	T_{max}		Exceed 35°C on 2 consecutive days
Latvia[2]	T_{max}	-	Exceed 33°C on 1 day

Country	Parameter	Human outcome	Triggering threshold
Netherland[2]	T_{max}	-	Exceed 30°C on 1 day
Portugal[2]	T_{max}	Announcement if 31% increase in predicted mortality. Alert if 93% increase predicted mortality.	Exceed 32°C on 2 consecutive days
Spain[7]	T_{max}/T_{min}	-	Exceed 41°C on 1 day
Switzerland[2]	Heat index	-	Exceed 41°C on 2 consecutive days
UK[8]	T_{max}/T_{min}	-	Exceed 28°C on 2 consecutive days
A[9]	Heat index	Excess mortality	Exceed 41°C on 2 consecutive days

[1]Heat-health plan for Victoria, Protecting health and reducing harm from extreme heat and heatwave *(Victorian Government, 2015).* [2]Heatwaves and Health: Guidance on Warning-System Development *(WHO, 2015).*[3]A general and flexible methodology to define thresholds for heat health watch and warning systems, applied to the province of Québec (Canada) *(Chebana et al., 2013).* [4]An operational HHWS in Shanghai *(Tan et al., 2004).* [5]Methods to analyse the health impact of heat waves: real-time monitoring, ex-post facto assessment *(Pascal et al., 2011).* [6]Trend of Outbreak of Thermal Illness Patients Based on Temperature 2002-2013 in Korea *(Kim et al., 2017).* [7]Mortality on extreme heat days using official thresholds in Spain: A multi-city time series analysis *(Tobias et al., 2012).* [8] Heatwave Plan for England *(PHE, 2018).* [9] Heat watch/warning systems save lives: Estimated costs and benefits for Philadelphia 1995-98 *(Ebi et al., 2004).*

2.9.2 Identifying vulnerable population groups

The word 'vulnerability' is often seen in public health policies to tailor the appropriate intervention or provide proportionate resources. As such, the identification of vulnerable sub–groups is a necessary concern of HHWS interventions *(Tarik B. et al., 2018).* The literature on vulnerable group identification has highlighted several groups of at-risk people, mostly in the UK, the USA, Australia, Canada and European countries *(see Table 10).* Most are people over 65 years of age. The UK has grouped >75 years old as a vulnerable group *(PHE, 2018)* and children younger than four, followed by people who have underlying diseases such as heart disease, diabetes, asthma, and obesity. The physiology of how these groups are susceptible to heat sicknesses was covered in Section 2.4.3 Outdoor workers are also directly exposed to heat. The evaluation of the effect of heat on outdoor workers is done through analysis of heat-related work capacity or productivity losses *(Kravchenko et al., 2013; Sahu et al., 2013; Kjellstrom, 2016).* It is particularly important that a HHWS for outdoor workers be established and implemented.

Table 10. Vulnerable populations for HHWSs in each country

Country	Vulnerable population for HHWS							
	Age	Age	Underlying disease people					Outdoor worker
	> 65	< 5	heart	mental	diabetes	medication	obesity	
UK[1]	√	√	v	√	√	√	√	-
USA[2]	√	√	√	√	√	√	√	√
Australia[3]	√	√	√	√	√	√	√	√
Europe[4]	√	√	√	-	-	-	-	-
Canada[5]	√	v	√	√	√	√	√	√
Korea[6]	√	√	-	-	--	-	-	-
China[7]	√	√						

[1]Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance (Smith et.al., 2016),[2]Identifying Individual Risk Factors and Documenting the Pattern of Heat-Related Illness through Analyses of Hospitalization and Patterns of Household Cooling (Schmeltz et.al., 2015); Impact of Extreme Heat Events on Emergency Department Visits in North Carolina 2007-2011 (Fuhrmann et.al.,2016),[3]The impact of heat on mortality and morbidity in the Greater Metropolitan Sydney Region: a case crossover analysis (Wilson et.al.,2013); Heat health plan for Victoria, Protecting health and reducing harm from extreme heat and heatwave (Victorian Government, 2015),[4]Factors affecting in-hospital heat-related mortality: a multi-city case-crossover analysis (Stafoggia et.al., 2008); Short-term effect of heat waves on hospital admissions in Madrid: Analysis by gender and comparison with previous findings (Diaz et.al.,2018),[5]The Montreal heat response plan: evaluation of its implementation towards healthcare professionals and vulnerable populations (Price et.al.,2018),[6]The impact of heat, cold, and heat waves on hospital admissions in eight cities in Korea (Son et.al.,2014); Trend of Outbreak of Thermal Illness Patients Based on Temperature 2002-2013 in Korea (Kim et.al.,2017),[7]The burden of ambient temperature on years of life lost: A multi-community analysis in Hubei, China (Zhang et.al.,2018).

2.9.3 The operationalisation of heat-intervention strategies

It is necessary that consideration of intervention measures can be developed to protect the population as a whole, along with specific targeting of vulnerable populations. This section reviews practical intervention methods in different countries, divided into intervention at the level of the individual level *(see Table 11)* and intervention at the level of the community *(see Table 12).* Many countries provide similar general interventions *(PHE, 2018).* However, differences exist, for example Australia has a specific instruction to apply sufficient sunscreen due to the government's concerns about the depletion of the ozone *(Victorian Government, 2015).*

Table 11. Intervention at the individual level in each country

Country / ***Intervention***	***UK[1,2]***	***USA[3]***	***Australia [4] (Victorian Government)***	***Europe[5]***	***Canada[3],[6] (Toronto/Montreal)***
Using air conditioning to reduce the individual risk of disease	√	√	√	√	√
Using a fan to reduce the individual risk of disease	√ (<35 °C)	√ (<35 °C)	√	√ (<37 °C)	-*
Increasing self-awareness to reduce the risk of disease	√	√	√	√	√
Encouraging self-detection of symptoms and signs of HRIs to reduce the risk of disease	√	√	√	√	√
Keeping out of the sun between 11.00 a.m. and 3.00 p.m	√	√	√	-*	-*
Avoiding extreme physical exertion	√	√	√	-*	-*
Applying sunscreen	√	√	√	-*	-*
Wearing a hat	√	√	√	-*	-*
Having plenty of cold drinks (two to four glasses per hour)	√	√	√	-*	-*

Intervention \ Country	***UK[1,2]***	***USA[3]***	***Australia [4] (Victorian Government)***	***Europe[5]***	***Canada[3],[6] (Toronto/Montreal)***
Avoiding excess alcohol consumption	√	√	-*	-*	-*
Avoiding excess caffeine consumption	√	√	-*	-*	-*
Avoiding excessive hot drinks can reduce the risk of disease	√	-*	-*	-*	-*
Keeping windows that are exposed to the sun closed during the day and open at night when the temperature has dropped	√	-*	√	-*	-*
Keeping indoor plants and bowls of water in the house as evaporation helps cool the air	√	-*	√	-*	-*
Considering installing external shading outside windows; growing trees and leafy plants near windows to act as natural air-conditioners	√	√	√	-*	-*
Placing a thermometer in the house to keep a check on the temperature	√	-*	√	-*	-*

-* Limited information

[1]Heat protection behaviour in the UK: results of an online survey after the 2013 heatwave *(Khare et al., 2015).* [2]Heat Wave Plan for England *(PHE, 2018).* [3]Heatwaves and Health: Guidance on Warning-System Development *(WHO, 2015).* [4]Heat health plan for Victoria *(Victorian Government, 2015).* [5]The impact of heat waves on mortality in 9 European cities: Results from the EuroHEAT project (D'Ippoliti *et al.*, 2010). [6] Temporal and spatial variation of heat-related illness using 911 medical dispatch data *(Bassil et al., 2009).*

Table 12. Intervention at the community level in each country

Country / Intervention	UK[1, 2]	USA[3]	Australia[4]	Europe[5]	Canada[3,6]
Establishing a cooling centre or a temporary cooling shelter is good practice for prevention of heat exposure	√	√	√	√	√
Increasing facilitation and capability of rapid surveillance team	-*	-*	√	-*	√
During heat events, a buddy system[5] should be implemented to keep monitor isolated, elderly, ill or very young people and make sure they are able to keep cool.	√	√	√	√	√
Increasing medical service during warnings in anticipation of higher demand	√	√	√	√	√
Implementing alternative working hours to avoid daytime heat	-*	√	-*	-*	√

-* Limited information

[5] Anyone can be a Buddy. A Buddy can be a friend, relative, neighbour, or landlord. A Buddy should be someone an elderly person who lives alone can trust in his or her home. A Buddy makes a daily personal visit to his or her elderly Buddy during a heatwave. A Buddy encourages the elderly person to rest, stay cool, and drink plenty of fluids. If there are any errands that must be done, the Buddy does them, or makes sure they get done.

2.9.4 Communicating HHWS information and heat-related information to stakeholders and the public

Advanced warnings and messages need to be integrated across health and weather services to allow adequate service preparation. Therefore, careful consideration of the features of a warning is critical *(Kovats and Ebi, 2006).* The first aspect to consider is the actual need for a warning. The public expect to be warned in advance of impending life-endangering events and situations. Proper determinations of warning levels are linked to appropriate warning times. Secondly, to warn the general public and specific target populations, the warning messages need to be aired in unambiguous terms. Use of clear, plain language and prioritisation of the order of the importance of the information being given are crucial for successful communication. A recent study by Tarik and colleagues (2018) conducted two focus groups on 19 participants from vulnerable target populations for a HHWS in Montreal, Canada. They concluded that the vulnerable target groups perceived and understood the information and message warnings or interventions differently.The two groups also had distinct perspectives regarding the appropriateness of specific measures in the heat action plan, for example, the first group concurred with the idea that policies should prioritize specific populations while the second group suggested that the vulnerability should focus on underlying conditions, such as material deprivation and social exclusion, *(Tarik B. et al., 2018).*

No consensus has been reached regarding the best type of media for dissemination of warning messages *(Nitschke et al., 2017)*. Kathryn and colleagues (2013) conducted a mixed methods study using telephone surveys and focus groups to elicit qualitative information about heat–health knowledge and awareness among 719 adults aged 18+ in New York. They found that local TV, health medical correspondents, doctors and meteorologists were considered trustworthy sources of heat health information *(Kathryn Lane et al., 2013)* . Each of these media has positive and negative aspects. Television and radio have the capacity to reach a mass population. TV also presents warning messages in graphic format. However, the costs of TV broadcasting are high. Moreover, as social media such as Facebook, Whatsapp and Twitter have become more popular, there is a concern that at least certain populations are watching less TV than before. Short Messaging System (SMS/texting) is also a popular modern way of receiving weather information. In Australia, the government provides an application called “the better health channel app” for health staff and the general population to receive heat health alerts and to be made aware of when extreme heat is forecast *(Victorian Government, 2015).* Whatever media is used, coordination between government and media and across the various media platforms is essential for the accuracy of warnings because different communication methods reach different target populations at different speeds.

2.9.5 Evaluation of HHWS effectiveness

It is fundamentally important to evaluate the effectiveness of a HHWS in terms of reducing heat-related mortality and morbidity, analyse its cost-effectiveness, and identify the factors that may influence its effectiveness in alerting the public. Several reports have shown that substantially fewer people have died after the implementation of a HHWS than what would have been expected had such a system not been implemented *(see section 2.8)*. The Government of Victoria in Australia claimed that the reduction in excess deaths may be attributed to the establishment of heat health plans and increased prevention activities by different agencies *(Victorian Government, 2015)*. However, because the number of studies in this area is limited, no causal relationship between the implementation of a HHWS and reduced mortality or morbidity has, as yet, been established. However, the WHO emphasised that evaluation of the effectiveness of a HHWS should consider the following criteria *(WHO, 2015)*:

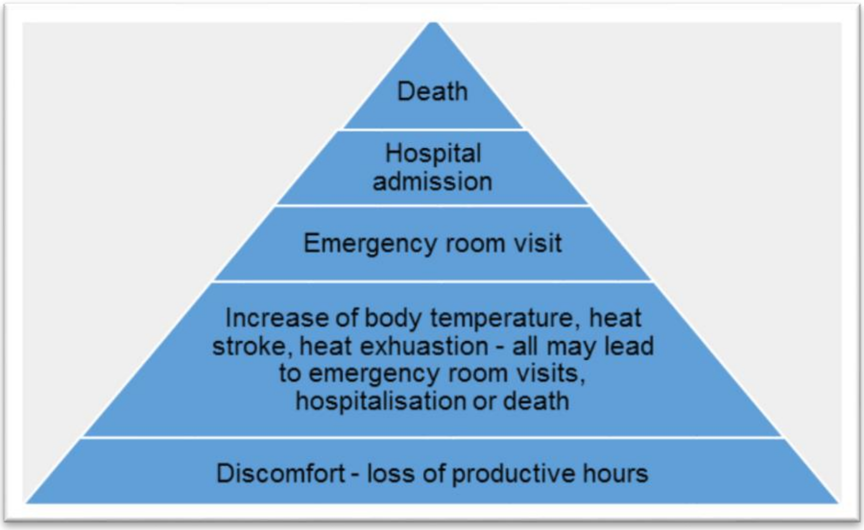
- Simplicity: the system should be as simple as possible in fulfilling all objectives.
- Acceptability: working simultaneously as a whole organisation is the key to success. Therefore, interaction between agencies, participation of agencies other than the one issuing the warning, and completeness of response in participating agencies should be considered.
- Timeliness: the warnings should be timely with respect to the different response activities and any delays in a HHWS should be noted and corrected.

  Sensitivity and Specificity: in order to avoid false positive forecasts it is necessary to monitor how often a warning was not issued even though adverse climate conditions actually occurred, and how accurate the meteorological forecasts are.

2.10. Development of a HHWS in Thailand: The knowledge gap

Many studies have performed a threshold analysis study by using mortality data as the outcome *(see Section 2.5.2).*However, the health impacts of heat can be arranged from mild to severe in a pyramid figure *(see figure 3).* As can be seen in the figure, the number of deaths is the tip of the pyramid, meaning mortality is the most severe but least widespread. Overall, heat and human health research lacks analysis involving morbidity, a glaring gap in existing studies. Thailand, specifically, also has a limited heat-related death record due to the final diagnosis being heart or respiratory failure, rather than being recorded as a heat-related death. Moreover, discomfort and increasing body temperature are symptoms, not definite diagnosis. Additionally, morbidity proxies as respiratory or cardiovascular diseases are not directly linked to heat-specific diseases. Thus, a first step to consider HRIs from hospital admissions would be a good start for identifying the threshold level of a HHWS in Thailand.

Figure 3. Health outcomes of heat exposure



There are robust statistical techniques to test weather–health predictive models *(see Section 2.6).* However, to consider only quantitative studies leaves us unable to support the creation of all the necessary components of a HHWS. All strategies within a HHWS need a top–down and a bottom-up approach involving government and non–government organisations and diverse stakeholders. Therefore, a combination of quantitative and qualitative methods would be the optimum technique to explore the gaps which currently exists in the research to date. Combining quantitative and qualitative methods will enable us to broaden the scope of research to include different facets, possibly leading to new perspectives and knowledge.

Thailand does not have a HHWS. Nevertheless, a group of researchers from the Meteorological Development Bureau at the Thai Meteorological Department conducted a study looking into a Simulation of a Heat Index for developing a Heat Alert System. The stimulation of this study are used to support military operations in general missions, including war practice and training *(Kirtsaeng and Kirtsaeng, 2015)*. However, the military system differs in numerous ways from that which will be implemented for the civil population and the study was limited in that the relationship between actual health effects and heat was not investigated. Furthermore, in 2015, a project by the Department of Health at the Ministry of Public Health was funded by the WHO to develop a HHWS for Thailand. The aim of this project was to provide a threshold level to prepare warnings in each region of Thailand. Unfortunately, a threshold level for the southern region was not given. The Department of Health's project suffered from a number of limitations. Firstly, the outcome of the project was mortality, which reflected all cause of death not heat related deaths. Secondly, the selection of meteorological factors that use temperature can obscure the real effects of heat as Thailand has high humidity. Lastly, the statistical analysis of the project did not control such confounders as the day of week and seasonality.

As noted above, a threshold level for the southern part of Thailand was not given from the investigation. The key difference between this PhD research project and the project undertaken by the Department of Health is the selection of variables. Using a heat index is deemed more suitable and appropriate because it considers relative humidity as well as temperature. Consequently, the southern region, although it has lower average temperatures than other regions, has high relative humidity, so if only temperature is analysed the result may thus not be totally reflective of actually existing conditions.

2.11. Summary

This chapter has provided a critical literature review of how heat affects health, especially HRIs and a range of factors that may influence heat vulnerability through determining the heat sensitivity of individuals. These include a mix of socioeconomic, personal, behavioural and medical risk factors.

Climatic indices are composed of one, two or multiple meteorological variables that this chapter has attempted to describe. The choice of method for assessing heat stress will depend on the resources available to the developers of a HHWS.

This chapter has also identified a number of significant gaps in the existing scholarship, including investigations into threshold levels, a necessary steps in the development of a HHWS. This gap informed the choice of methods used in this study, which are outlined in Chapter 3.

Chapter 3: Methodology

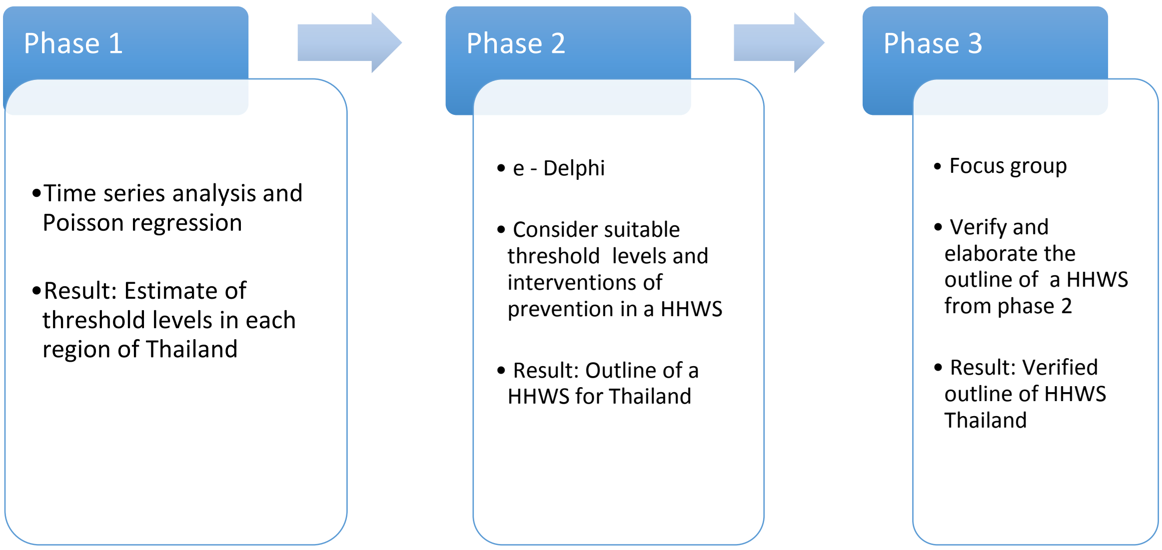
3.1 Introduction

General information about the materials and the methods used in this study are provided in this chapter, including the details of each phase and ethical considerations.

3.2. Study design

To achieve the objectives outlined in Section 1.2, this study is divided into three phases and uses a combination of quantitative and qualitative research techniques. In phase one, a Time series analysis was used to investigate the relationship between the heat index and HRIs and a Poisson regression was applied to estimate the threshold levels of the heat index in terms of surveillance indices for a HHWS. Following this, phase two applies an e-Delphi technique to elicit the opinions of 16 experts involved in climate change research and policy formulation. In the third phase, to verify the feasibility of a HHWS model derived from the findings, a focus group discussion with key stakeholders and policy makers was conducted. A summary of the phases is shown in Figure 4.

Figure 4. Summary of the three phases of the study



3.3 Study area

The study was carried out in Thailand, a tropical country in Southeast Asia. Thailand has 77 provinces in four regions: northern, north-eastern, southern, and central *(see Figure 5).* The general climatic conditions in Thailand are influenced by southwest and northeast monsoon winds of seasonal character. The southwest monsoon usually starts in mid-May and ends in mid-October while the northeast monsoon normally starts in mid-October and ends in mid-February. The southwest monsoon brings a stream of warm, moist air from the Indian Ocean, causing abundant rainfall over the country, especially on the windward side of the mountains. The northeast monsoon brings cold and dry air from the anticyclone in the Chinese mainland over major parts of Thailand, especially the northern and north-eastern areas, where the altitudes are higher *(NSO, 2018) .* The climate of Thailand is divided into three seasons, as follows (the seasonal mean of temperature is shown in table 13.

The rainy, or southwest, monsoon season (mid-May to mid-October) prevails over Thailand and abundant rain falls across the country. The wettest period of the year is August to September. The exception to this is along the south-eastern coast, where abundant rain remains until the end of the year, which marks the beginning period of the northeast monsoon. November is the wettest month.

- Winter, or the northeast monsoon season (mid-October to mid-February), is the mildest period of the year, cooler in December and January in upper Thailand. There is a large amount of rainfall along the south-eastern coast, especially during October to November.
- Summer, or pre-monsoon season (mid-February to mid-May), is the transitional period from the northeast to the southwest monsoons. The weather becomes warmer, especially in upper Thailand. April is the hottest month

Figure 5. The four regions of Thailand

Table 13. Seasonal mean maximum temperature (°C) in each part of Thailand, 1981–2010 (https://www.tmd.go.th)

Temperature	Region	Winter	Summer	Rainy
Mean maximum	North	31.1	36.1	32.4
	North east	30.6	35.2	32.6
	Central	32.3	36.2	33.4
	South			
	- East Coast	30.4	33.0	32.7
	- West coast	32.0	34.0	31.6

3.4 Study Population

The population for the study is all citizens living in Thailand in the period between January 2010 and December 2014. The population data were taken from the National Statistical Office of Thailand (*see Table 14*).

Table 14. Thailand's population (from the National Statistics Office Survey, average 5-year estimate from 2010–2014, excluding Bangkok)

	Population	Percent
Total Thailand Population	58,899,534	
Male	29,008,588	49.25%
Female	29,770,070	50.54%
Central region	16,220,804	27.54%
Male	7,905,217	13.42%
Female	8,315,587	14.12%
Northern region	11,809,379	20.05%
Male	5,816,021	9.87%
Female	5,993,358	10.18%
North-eastern region	21,695,470	36.83%
Male	10,820,218	18.37%
Female	10,875,252	18.46%
Southern region	9,053,005	15.37%
Male	4,467,132	7.58%
Female	4,585,872	7.79%
Age		
Under 5 years	3,803,959	6.46%
5 to 9 years	3,971,579	7.10%
10 to 14 years	4,221,746	7.17%
15 to 19 years	4,795,384	8.18%
20 to 24 years	4,665,478	7.92%
25 to 29 years	4,743,286	8.05%

	Population	Percent
30 to 34 years	5,164,807	8.76%
35 to 39 years	5,278,091	8.96%
40 to 44 years	5,343,528	9.07%
45 to 49 years	5,096,278	8.65%
50 to 54 years	4,419,792	7.50%
55 to 59 years	3,526,700	5.99%
60 to 64 years	2,715,476	4.61%
65 to 69 years	1,888,288	3.21%
70 to 74 years	1,459,788	2.48%
75 to 79 years	1,081,128	1.84%
80 to 84 years	657,164	1.17%
85 years and over	462,245	0.78%

3.5 Study Phases and Methods

3.5.1 Phase one

The main objectives of this phase were to identify incidences of disease related to heat in different regions of Thailand and to investigate the statistical associations between climatic variables and HRIs and illness trends over time. The HRI admission data were collected by the Bureau of Policy and Strategy from January 2010 to December 2014. Statistical analysis was performed using version 21.0 of SPSS software. Descriptive analysis of the meteorological data was performed using the open-air toolset (*Carslaw, 2015*) developed for R software.

Data collection on HRI hospitalisations

Daily HRI hospital admissions were collected from the Bureau of Policy and Strategy, Department of Disease Control, at the Ministry of Public Health, from January 2010 to December 2014. The ICD10 database, with diagnosis T67 (Effects of heat and light), was used to guide the collection. The data were sent with a provincial format covering 76 provinces, excluding Bangkok.

International Classification of Diseases 10th edition of T67 (Effects of heat and light) are:

- T67.0 Heatstroke and Sunstroke
- T67.1 Heat syncope
- T67.2 Heat cramp
- T67.3 Heat exhaustion, anhydrotic
- T67.4 Heat exhaustion due to salt depletion
- T67.5 Heat exhaustion, unspecified
- T67.6 Heat fatigue, transient
- T67.7 Heat edema
- T67.8 Other effects of heat and light
- T67.9 Effect of heat and light, unspecified

HRI data included the unit code, which illustrated the hospital and primary care unit name and location, area of admission in each province, age of patient at admission time, sex of patient, occupational record, educational level, discharge status (full recovery/referral (refer from primary care unit to the hospital)/dead), diagnosis of disease and date of admission. A total number of 6,895 HRIs hospitalisations were obtained during the study period.

Meteorological data

Daily maximum temperatures (in °C) and relative humidity at the same time with a maximum temperature (%) from January 2010–December 2014 were obtained from the Meteorological Department, Ministry of Digital Economy and Society. There were a total of 126 stations covering the whole of the country *(figure 6*). The coverage of data was 81.58 percent (62 from a total of Thailand's 76 provinces).

Figure 6. Location of weather stations in Thailand

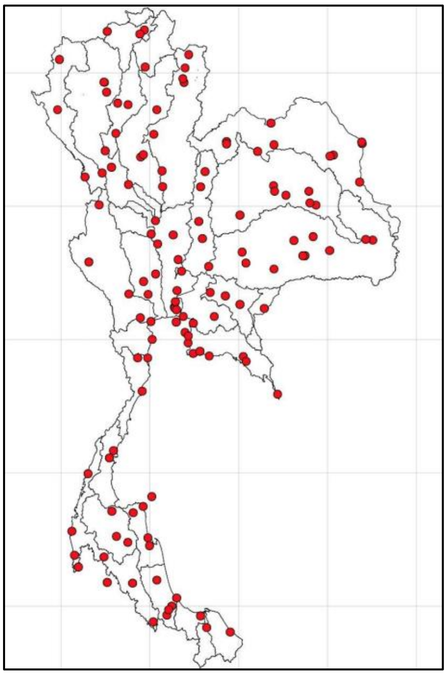


Table 15. Variables related to meteorological factors and pollutants

Climatic variables	
Daily maximum temperature (°C)	Heat index
Daily relative humidity at the same time with maximum temperature (%)	

Table 15 shows the climatic variables used in this study. The maximum temperature was used to calculate the heat index before the time-series and a GLM with Poisson regression was conducted. It is encouraging to compare this set-up with that of Na *et al.* (2013), who conducted an investigation into the relationship between HRIs developed in the summer of 2012 and explored whether maximum temperature or average temperature was the most suitable proxy index to operate a heatwave surveillance system in Korea. They concluded that daily maximum temperature led to the model with the best goodness of fit*.* Turning to Europe, the EuroHeat project (2010) aimed to standardise the definition of heatwave for nine selected countries. Eventually, the identification of heatwaves across Europe was determined as a period of at least two days on which the maximum temperature exceeded the 90th percentile of the maximum temperature value *(D'Ippoliti et al., 2010).*

Data management and cleaning

Data cleaning was performed to evaluate the quality of the primary data. The data were then re-formatted for analysis at each step. The data were obtained from each province and re-formatting and evaluating for the missing days of monitoring found that there were no missing data from both data sources within the 1826 days of the collection period. The meteorological data were divided into four regions, aligning with Thailand's geographic differences. Northern Thailand is mountainous, meaning that average temperatures are cooler than other areas, especially during winter. Central Thailand is a fertile, densely populated area. The North-eastern region has the longest dry season of the regions. Lastly, the Southern region is totally distinct from the others, with less diurnal and seasonal variation in temperature due to strong maritime influences. Most of Thailand's North, Northeast, and Central regions are characterised by dry weather during the northeast monsoon and abundant rainfall during the southwest monsoon. In the southern parts of Thailand, abundant rainfall occurs in both the northeast and southwest monsoon seasons. Before the analysis stage, the daily counts of HRI hospitalisations were matched using the same date and provincial codes as the heat index data.

The heat index was calculated using an equation consisting of temperature and relative humidity, as shown below *(Steadman, 1979a).*

Heat Index = $-42.379 + 2.04901523\mathrm{T} + 10.14333127\mathrm{R} - 0.22475541\mathrm{TR} - 6.83783 \times 10 - 3\mathrm{T2} - 5.481717 \times 10 - 2\mathrm{R2} + 1.22874 \times 10 - 3\mathrm{T2R} + 8.5282 \times 10 - 4\mathrm{TR2} - 1.99 \times 10 - 6\mathrm{T2R2}$

T = air temperature (°F)

R = relative humidity (%)

As outlined in Chapter 2, the heat index was selected to investigate the relationship between climate and health in various studies due to the fact that air temperature alone is not considered an appropriate indicator of human health. At least two parameters have been developed to describe the complex conditions of heat exchange between the human body and its thermal environment. The first and most important reason to select a heat index in this study was the fact that it combines indicators of temperature and humidity and is widely used in the USA. Notably, it is useful for determining apparent temperature – how hot it actually feels when the relative humidity is high and when the evaporation rate of water decreases. Another reason relates to the diverse geographic circumstances across each region, in particular the high humidity which the Southern region experiences.

Data analysis

To investigate the relationship between meteorological factors and HRIs in Thailand, a time-series analysis was used, the main reason being that the dependent and independent variables are measured over time. This is especially suitable for evaluating the short–term effects of time varying exposure. Additionally, covariates varying between subjects but not influenced by time (such as, for example, gender) are unable to confound the associations. The potential confounding factors in a time-series analysis are seasonality and trends, which should be accounted for *(Tadano et al., 2012; Bhaskaran et al., 2013).*

A Poisson regression model was applied in the time-series analyses to evaluate the impact on human health due to the non-linearity of the response variables and HRIs were collected as non-negative counts. The following four steps needed to be followed in order to fit the GLMs with a Poisson regression model *(McCullagh and Nelder, 1989).*

Step one: data formation

The raw data from the original sources were re–formatted and prepared before analysis. The outcome for the purposes of this study was the morbidity of HRIs. A number of admissions for HRIs at each hospital in Thailand were used as the dependent variable. The independent variables were the maximum heat index[6] and mean heat index[7]. All data were collected over a five-year period to capture seasonal trends. The long-term confounder in this case was seasonality and the short-term confounders were day of the week and holiday indicator.

[6] The maximum heat index is the highest value of the daily heat index in each region.
[7] The mean heat index is the mean value of the daily heat index in each region.

Step two: temporal trends adjustment

The unmeasured confounding factors are those that may influence the outcome counts. They vary in time, similarly with meteorological factors. Temporal confounders relate to a defined time-specific duration and its effect on an exposure and outcome. In the raw data, the temporal confounder is seasonality because it varies on a timescale in the same way that meteorological factors and HRIs do *(Tadano et al., 2012; Bhaskaran et al., 2013)* and it is likely to dominate the data. The aim of controlling seasonality was to eliminate long-term patterns and determine whether the heat index could explain some of the remaining short-term variation. Hence, parametric splines (natural cubic spline) were used to adjust this trend. The other potential confounding factors, varying on short timescales, were day of the week and holiday indicator. The number of admissions could be lower on weekends than on weekdays and also during holidays.

To adjust the weekday trend a new variable was added for each day of the week from one to seven starting on Sunday. For holiday indicators, one meant holiday and zero meant workdays. The final expression for the GLM with a Poisson regression was:

$$\boxed{log(y) = \beta_0+\beta_1 HI+\beta_2 H+\beta_3 dow+\beta_4 ns,}$$

Where, y = daily HRI hospitalisations; β_0 = model interception; $\beta_{(1\text{-}4)}$ = regression coefficient associated with each covariate; HI = Heat index; H = time trend variable for holidays; dow = time trend variable for day of the week; ns = natural cubic spline to adjust for seasonality.

A GLM with a Poisson regression was then applied in R software *(R.Core.Team, 2014)* with the following equation:

model.name < − glm (HRIs ~ ns(dos. df) + as.factor (dow.) + as.factor (H) + (x), database. name, family = poisson, na. action = . na.omit)

Where model.name is the name given to the analysis; ns is natural cubic spline; df refers to degrees of freedom; dow = time trend variable for day of the week; X is heat index; database.name is the name given to the database file. To compare between models, Akaine Information Criteria (*McIver et al.,2016*) were considered. The smaller the AIC, the better the model. The comparison of the AIC with different degrees of freedom for seasonality adjustment is shown in Table 16.

$$AIC = D + 2df$$

Where D denotes the deviance, and df are the degrees of freedom for the model.

Table 16. Comparison of AIC with different degrees of freedom for seasonality adjustment for whole country data

Degree of freedom	Mean heat index	Maximum heat index
4	7656.1	7632.6
5	7650.5	7626.1
6	7633.5	7607.6
7#	7620.1	7596.4
8	7624.3	7602.9

#Best fit model was the model with degree of freedom = 7

A partial autocorrelation function was used to analyse time trends after adjustment. The short-term trends (days of the week (dow) and holiday indicator (H)) can lead to autocorrelation between data from one day and the previous days. To analyse this time trend, the partial autocorrelation function were plotted against lag days *(Pengelly et al., 2007)*.

In the plot, the residuals should be as small as possible, ranging from $-2n^{-1/2} – 2n^{-1/2}$. In this study, the number of observations was 1826 (from 1 January 2010–31 December 2014) and the range was -0.047 to 0.047 *(see Figure 7 and Figure 8).* The lines in the partial ACF plot out of the range (-0.047 to 0.047), indicating a strong autocorrelation between data from one day and previous days. In this case, it means the database has autocorrelations. Thus, the residuals should be included in the model.

Figure 7. Partial ACF plot for the mean of the heat index against lag days without residuals (nationwide)

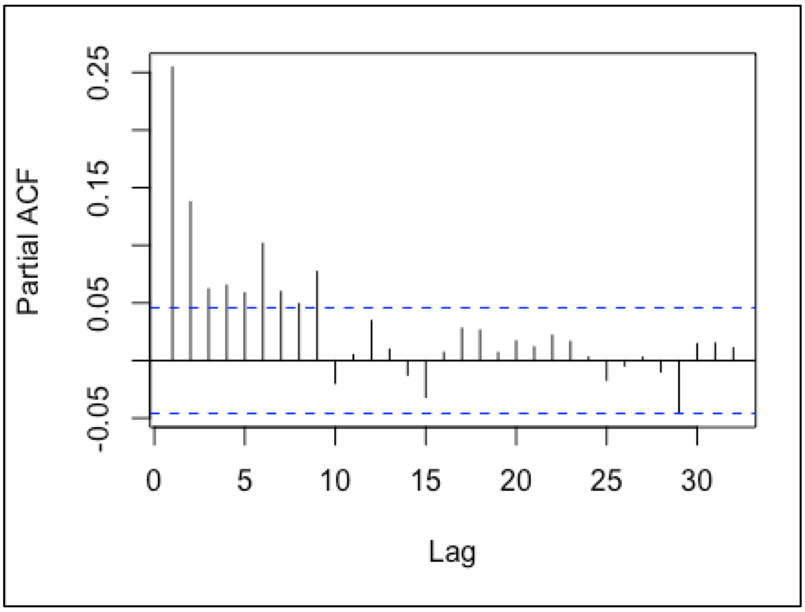
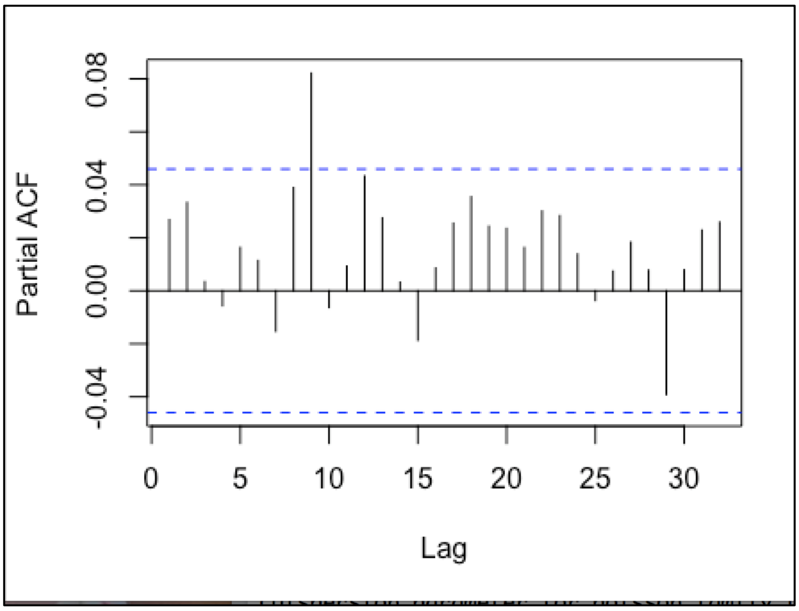


Figure 8. Partial ACF plot for mean of heat index against lag days with residuals (nationwide)



<u>Step three</u>: goodness of fit

Pseudo R 2 was used to assess goodness-of-fit for the Poisson regression model. It is defined as:

$$Pseudo\ R^2 = \frac{l\ (b_{min}) - l(b)}{l(b_{min})}$$

Where l = log – likelihood function; $l(b_{min})$ = maximum value of the log likelihood function for minimal model with the same parameter for all y and no explanatory variables (null model) and $l(b)$ = maximum value of log – likelihood function for the model with p parameters (complete model) *(Dobson and Barnett, 2008)*

Additionally, Chi–square and Pearson were used to calculate the goodness of fit. The Chi–squared statistic is the sum of the Pearson residual of each observation. According to this statistic, a model that fits well to the data and has a Chi–squared statistic close to the degree of freedom (X^2/df~1) is considered a good fit in this study, where *df* = n – p (n= number of observations and p = number of parameters).

<u>Step four</u>: Relative risk calculation

The usefulness of a Poisson regression in epidemiology is that it provides an estimate of relative risk (RR) *(Tobias and Saez, 2004)*:

$$RR_i = \exp^{(\beta i)X}$$

Where β_i is the regression coefficient associated with a unit of heat index, "X" is the data point (heat index) and exp is the exponential function

The 95% confidence interval (95% CI) of the RR is computed as the antilogarithm (exponential function) of the two confidence limits, as computed below:

$$95\%\ CI = \exp(\ln(RR) - 1.96 \times SE\{\ln(RR)) \text{ to } \exp(\ln(RR) + 1.96 \times SE\{\ln(RR)\})$$

3.5.2 Phase two: Delphi (HHWS consensus development part 1)

The Delphi technique has been defined as a multi–stage survey which attempts ultimately to achieve consensus on an important issue. Dalkey and Helmer (1963) defined the Delphi technique as a method to obtain the most reliable consensus of opinion among a group of experts by a series of intensive questionnaires *(Dalkey, 1963*). Additionally, Lynn *et al.* (1998) defined the Delphi technique as an iterative process designed to combine expert opinion into a group consensus, the purpose being to achieve a consensus among a group of experts on a certain issue where no agreement previously existed.

There are various differing forms of Delphi. A summary of the types of Delphi techniques and their main characteristics is provided in Table 17.

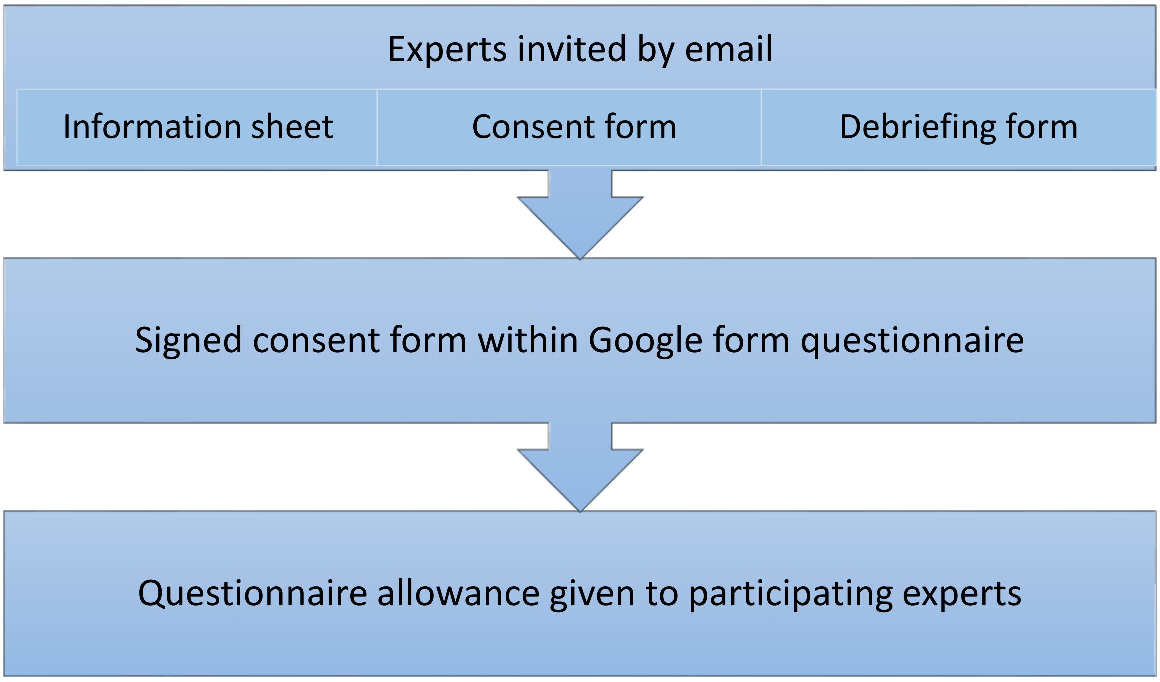
Table 17. Types of Delphi technique and main characteristics (Sinead, 2011).

Type of Delphi technique	**Main characteristics**
Classical Delphi	Uses an open first round to facilitate generation of ideas to elicit opinion and gain consensus. Uses three or more postal rounds.
Modified Delphi	Usually takes the form of replacing the first postal round with face-to-face interviews or focus groups and may use fewer than three postal or email rounds.
Decision Delphi	Same process usually adopted in the classical Delphi but focuses on making decisions rather than reaching a consensus.
Policy Delphi	Uses the opinion of experts to reach agreement on the future policy of a given topic.
Real time Delphi	Similar process to the classical Delphi except that the expert may be in the same room. Consensus reached in real time rather than by post. Sometimes this type calls for a consensus conference.
e-Delphi	Similar process to the classical Delphi but administered by email or online web surveys.
Technological Delphi	Similar process to the classical Delphi but using technology such as hand-held keypads to allow experts to respond to questions immediately while the technology works out the mean/median and feedback, giving experts the chance to revote and thus move towards consensus in the light of group opinion.

To achieve the objective of developing an outline for a HHWS in Thailand, a Delphi technique was applied based on the lack of information following the fact that a HHWS was not in place at that moment. The e-Delphi technique, with three rounds of online questionnaires, was selected to complete the component consensus on a HHWS model for Thailand before moving on to the next phase of the study, a focus group. An e-Delphi was selected for use in this study because the questionnaire was administered by email with an online questionnaire (Google form). Anonymity provided an equal opportunity for each expert to give an opinion and react to ideas unaffected by the identities of other participants. Thus, the respondents are not known to one another, eliminating subject bias.

Sixteen experts were carefully selected by purposive sampling based on their expertise and experience regarding climate studies and their ability to provide helpful inputs and publications on climate and health issues. The diversity of each expert’s field was also a deciding factor *(Hsu, 2007; Skulmoski et al., 2007).* The experts hold a range of senior positions in university and government departments in Thailand, covering epidemiology, environmental concerns and occupational health related to the climate sector. All of them were contacted by phone before they were sent the consent form and questionnaire. The flow chart of expert recruitment is shown in figure 9.

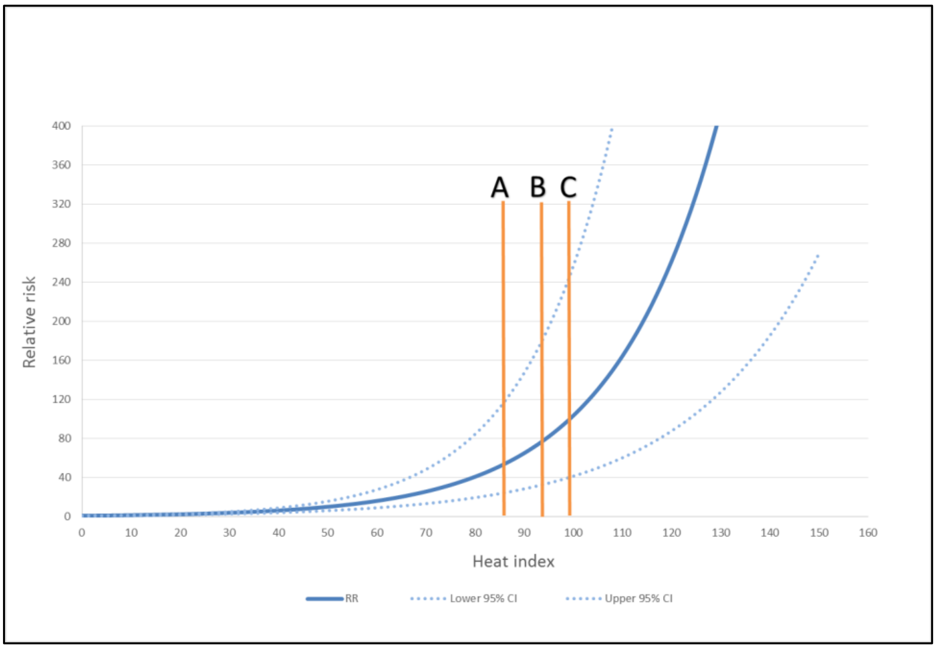
Figure 9. Experts recruitment



Delphi round

There were three rounds of e-Delphi in this study *(Junger et al., 2017).* Different approaches are used to generate questions for inclusion in Delphi questionnaires, with some studies using open-ended questions in round one, which then form the basis for questions in subsequent rounds *(Iqbal and Young, 2009).* In this study, the questions for round one were generated using information obtained from a review of the literature and the results from the first phase of the research, which mainly involved component 1 of the HHWS. The estimated relative risks were plotted along with the heat index level as a dose-response relationship graph *(see figure 10).* The graph was sent in the questionnaire for the Delphi Round 1 and Round 2, allowing the experts to select the suitable threshold cut-off point for the system in each region of Thailand. The additional information of days of the year beyond each cut-off line (orange colour lines A = 25th percentile, B = 75th percentile and C = 90th percentile) was provided to support the feasibility of operating a warning system (see Appendix A-1).

Figure 10. An example of estimated relative risk of HRIs by the heat index produced in the questionnaire in Delphi rounds 1 and 2

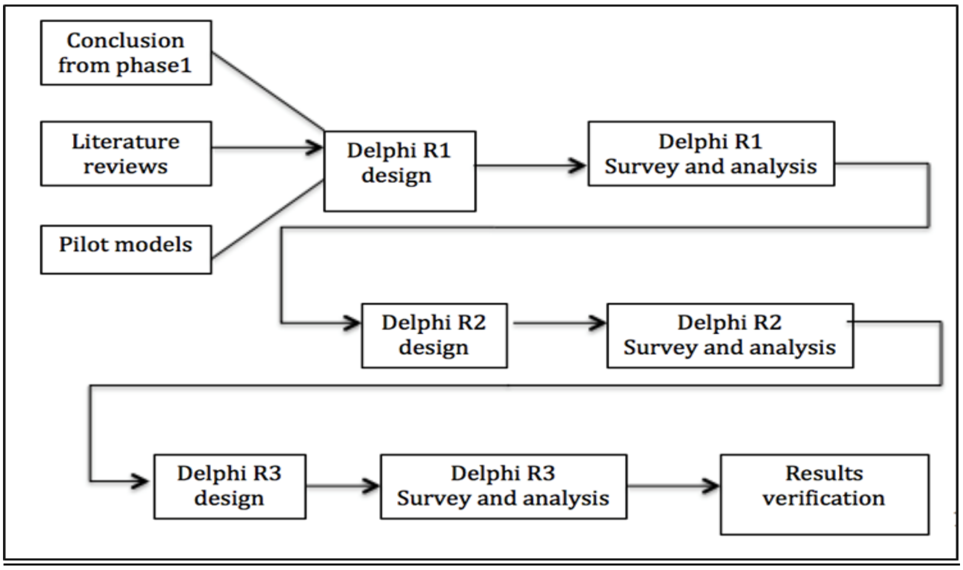


Finally, 31 questions were written in English with a five-point Likert rating scale (strongly disagree to strongly agree) and devised to elicit the opinions of the selected experts. Free text boxes enabled the participants to comment on individual questions and again after each set of questions. Regarding the fact that this round contained open-ended questions, the elaborate information in each component from the questionnaire was expected to generate new or add-on questions in the second round. The round one questionnaire is shown in Appendix A-1.

In round two, the analysis of the first round of comments led to two additional statements about the individual intervention in HHWS component 3 being added. Although some Delphi surveys remove from subsequent rounds items that have achieved consensus, in this study the 21 items were retained so that the strength of consensus in round two could be assessed in comparison with other items, an important decision given that the findings were to be presented to the consensus group in phase three. Hence, 33 statements were sent to the same 16 experts aiming to confirm the consideration. The second round questionnaire is shown in Appendix A-2.

In the third round, each expert again received a questionnaire that included the items and ratings summarised from the previous round. This round provided the final opportunity for the experts to revise their judgements, following Skulmoski's recommendation *(Skulmoski et al., 2007*). The third round questionnaire is shown in Appendix A-3. The questionnaires in each round were emailed to the experts with a specific return date of four weeks after the initial email was sent. A follow-up and reminder process was important between each round *(Edwards et al., 2007*), the details of which were stated in the survey email. One week before the return date, the reminder email was sent and a telephone call was made to those members of the expert panel who had not yet returned the questionnaire *(Starr et al., 2015*).

Figure 11. Diagram of e-Delphi process



Questionnaire framing

The questionnaires in the Delphi survey were created follow the component of HHWS, as stated in Section 2.9. Components of a HHWS

Component 1. Threshold levels for Thailand's HHWS

The operation of a HHWS includes weather forecasting, an action trigger such as a threshold temperature or bio-meteorological index having a significant effect on health. In this case, the verification and application of the heat index will be set based on the statistical analysis results gleaned from phase one. There are three separate warning categories: a pre-alert level for the implementation plan for the coming heat event or stressful weather; a higher-level issuance that informs people if the weather might be dangerous to their health; and the highest-level warning, at which time a variety of intervention measures are put in place by the community. In component 1, the experts were requested to provide their opinions for agreement on the cut-off points between the three warning categories.

Component 2. Issuance of warning and communication

The standard terminology was defined at the national level and local level together with understandable criteria and messages. The identification of agreement on the target population and people at risk were included within this component. A mitigation and adaptation plan were paired with an effective notification and response programme, which included lines of action as defined by multiple stakeholders or agencies and interaction with the media and messages to the public as they should react to extreme weather.

Components 3 and 4. Interventions at the individual and community levels

The effective interventions for individual and community level were screened from existing experiences in various countries. A HHWS should involve general interventions that alert the entire population to the threat of heat so that people are aware of the danger *(see 2.9.3).* Similar to some health promotion programmes, the development of a HHWS that targets the population as a whole requires multiple, flexible and community-driven strategies. This needs to be done within a multidisciplinary context, bearing in mind that the programme is intended to give individuals and communities a means to improve their wellbeing.

Data analysis for phase two

All rounds consisted of both agreement level and an open ended-questionnaire. The round one questionnaire was specifically designed to allow the experts to comment on and give ideas for each question. Content analysis was applied for the data given in the first round to form additional statements in the round two questionnaire. When all questionnaires were returned, the response from each expert was input into SPSS. Frequency and percentage were calculated with the consensus level of opinion set at more than 70 percent *(Keeney, 2011).*

3.5.3 Phase three: Focus group (HHWS consensus development part 2)

To evaluate and elaborate the HHWS model from the previous phase, focus groups were selected. Focus groups were conducted to give an external validation of the outline of the HHWS from the Delphi round. Focus groups were justified in this study for the following reasons. Firstly, it is common to use focus groups to gain insights into fulfil and to clarify an issue, particularly when there is limited available information (*Krueger, 2015*). Secondly, the flexible pattern encourages discussion and allows researchers to explore related areas of interest. The open-ended style of discussion also allows participants to comment and share experiences with their peers *(Beyea and Nicoll, 2000).* Sometimes a single comment can initiate and trigger a chain of new responses. Once the respondents become comfortable and relaxed within the group, they will often express feelings and ideas at a deeper level. Lastly, focus groups are relatively inexpensive and more easily managed in terms of time.

The policy makers and stakeholders from the National Committee on Climate Change Policy (NCCCP) of Thailand *(see Figure 12)* were invited, a group consisting of different participants from those involved in the Delphi round.

Figure 12. National Committee on Climate Change of Thailand

National Committee on Climate Change (NCCC)

Prime Minister: Chairman

Ministry of Natural Resources: Vice chairman

Environment and Ministry of Foreign Affairs: Vice Chairman

NCCC members

- Prime Minister's Office
- Ministry of Finance
- Ministry of Agriculure and Cooperatives
- Ministry of Transport
- Ministry of Information and Communication Technology
- MInistry of Energy
- Ministry of Commerce
- Ministry of Interior
- Ministry of Science and Technology
- MInistry of Education
- Ministry of Public Health
- Ministry of Industry
- Bangkok Metropolitan Administration
- Office of National Economics and Social Development Board (NESDB)
- Bureau of Budget

Role of Moderators

Moderators play an important role in stimulating discussion and ensuring the participants remain on track *(Barbour, 2007).* Additionally, they prevent any one individual or group of individuals from dominating the discussion *(Puchta, 2004).* For the purpose of this study, I acted as the moderator. The justification for this decision is intimate knowledge and understanding of every step of the research. As Morgan (1998: 48) recommended, “An outside professional might actually detract from what your own research team is able to do best” *(Morgan et al., 1998).*

Topic guide development

A topic or discussion guide is a method to elicit relevant and precise information from a group of participants to meet the research aims *(Hannick, 2007).* It contains a prepared list of discussion topics or actual questions used by the moderator to facilitate the flow of discussion. The function of the topic guide is to act as a memory aid for the moderator.

The topic guide in this study consisted of open-ended questions on three components of a HHWS from phase two, designed to elaborate the ideas, experiences and opinions on each of those components. The participants were invited to respond to the results of the Delphi, including comments made in open-ended questions, and to highlight any aspects that they felt were missing from the HHWS. The guide provided the moderator with an outline to direct the flow of discussion. A copy of the topic guide can be seen in Appendix B.

Conducting the focus group

A one-day focus group was conducted with eight policy makers and stakeholders at a meeting room of the Bureau of Occupational and Environmental Diseases, Department of Disease Control, Ministry of Public Health of Thailand. The location is known by all participants and is also free from distraction. Although a number of participants (three from eight) in this focus group were known to one another (in contrast to a classical focus group participants), the specification of responsibility from each participant (who is a policy maker from different ministries) will not interfere with and/or dominate the others. None of participants knew the researcher in person. In this way, an atmosphere conducive to discussion was ensured.

The invitation letters were sent to members of the NCCCP and eight were accepted, a number deemed optimum for a focus group (*Morgan et al., 1998*). The session lasted two hours and included an introduction and discussion of the results from the first and second phase presentations before a new focus group was started. Details regarding the focus group, such as where it would be held, what areas would be discussed, and the role of the topic guide, were included in the participant information sheet and consent form, which was emailed to the participants. Reminder telephone calls were made a week before the focus group was due to convene.

Permission for video and voice recording of the conversation was sought and given beforehand. By recording the focus group discussion, the moderator was able to concentrate and control the process rather than focus on taking notes. The meeting was conducted in the Thai language. To ensure that the data collected were reliable and valid, the moderator summarised the discussion and asked participants whether the summary was correct. A full verbatim transcript was made in Thai and then translated into English for analysis.

Focus group data analysis

The directed content analysis processes were planned as multiple steps, beginning with categorising the data by each component of the HHWS from the second phase of the study. The goal of using the directed content analysis approach is to validate and extend conceptually the pre-existing literature and outline of the HHWS from phase 2 *(Hsieh and Shannon, 2005)*. Thus, the outline of the HHWS was addressed as a framework for focus group data analysis.

To analyse the data in focus group phase, all the data were transcribed then the second step was to find the linkages by sifting the data to compare the relationships between each component of the HHWS. Thirdly, coding the keywords from each participant's response made a search of the linkages to identify what patterns emerged. The last step of the analysis was to develop an explanation and structure the report. To present the results under each component of HHWS (theme for this study) with conclusions the results are supported by quotes from transcript.

Both consensus and non-consensus statements in each round from the Delphi phase were re-evaluated for the public and policy feasibility in the focus group meeting. Additionally, the final findings of the present study were drawn from the focus group above the Delphi findings and the final findings can be modified from the Delphi round based on the aim that the focus group was conducted to evaluate and elaborate the HHWS guideline for Thailand.

3.6 Ethical approval and risk assessment

Ethical approval was obtained from Newcastle University (No. 01075/2016), covering the study period from 5th January 2015 until 5th January 2019. A copy of the ethical approval letter is attached as Appendix C.

3.7 The Role of the author

This section explains how to achieve the e-Delphi stage and focus groups, which invited an expert panel, including experts from academia, policy makers from the NCCC Thailand, and various stakeholders.

I, the author of this thesis, am an occupational physician employed by the Bureau of Occupational and Environmental Diseases, Department of Disease Control, Ministry of Public Health, Thailand. The main authority is to produce guidelines and information support to policy makers regarding national health policy involving occupational health and environmental health.

I have worked at the Ministry of Public Health for 12 years, a period of time during which I noticed there was a dearth of knowledge about climate change and health topics to support policy development. Fortunately, I was offered an excellent opportunity to apply for a scholarship to study the field of climate change.

Chapter 4: Results of the Analysis of Heat and Health Data for Thailand 2010-2014

4.1. Introduction

In this chapter, the results of the descriptive analysis of HRI hospitalisations and the meteorological variables are presented. This is followed by the detailed results of the Poisson regression model and estimated relative risk analysis in every region of Thailand.

4.2. Descriptive analysis results for HRIs

Table 4.1 shows the characteristics of HRI visits and the incidence rate per 100,000 persons per year, as recorded by the Ministry of Public Health, Thailand, for the period of January 2010 to December 2014. There are 77 provinces in Thailand across four regions, namely, Central, North-eastern, Northern and Southern. In this study, Bangkok[8] was excluded due to the inadequate data collection system. During January 2010-December 2014, there were 6,895 HRI admissions. The total number of incidents was 2.14 visits per 100,000 persons per year.

The majority of patients were female, with 4,246 admissions (61.6%). The mean age of the patients was 43.7 years. The highest incidence was in the 80–84-year group, at 7.21 per 100,000 persons per year, and the lowest was in the 0-4 age group, at 0.58 admissions per 100 000 persons per year *(see Table 18)*

Table 18. Characteristics of HRI admissions and incidence rate per 100,000 persons per year from January 2010 to December 2014

	Admissions (%)	Incidence rate per 100,000 persons per year
Gender		
Male	2649 (38.4)	1.67
Female	4246 (61.6)	2.59
Age (Year)		

[8] The Bangkok population is 12.8% of the total population of Thailand

	Admissions (%)	Incidence rate per 100,000 persons per year
0 - 4	111 (1.6)	0.58[9]
5 - 9	275 (4.0)	1.38
10 - 14	610 (8.8)	2.89
15 - 19	503 (7.2)	2.10
20 - 24	361 (5.2)	1.55
25 - 29	277 (4.0)	1.17
30 - 34	313 (4.6)	1.21
35 - 39	414 (6.0)	1.57
40 - 44	517 (7.5)	1.94
45 - 49	498 (7.2)	1.95
50 - 54	565 (8.2)	2.56
55 - 59	513 (7.5)	2.91
60 - 64	506 (7.3)	3.77
65 - 69	397 (5.7)	4.20
70 - 74	356 (5.1)	4.88
75 – 79	298 (4.3)	5.51
80 - 84	235 (3.4)	7.21
85 - 89	107 (1.6)	7.10
➢ 90	39 (0.6)	4.86

[9] Incidence by age group was weighted for population in each age group

The highest frequency of heat-related visits was in the North-eastern region, at 2,167 admissions over five years. The incidence per 100,000 persons per year was 3.41 visits in the Southern region and 3.17 visits in the Northern region *(see Table 19).* By province, Pichit ranked highest, with a rate of 10.26 per 100,000 persons per year *(see figure 13).*

Table 19. Incidence rate per 100,000 persons per year of HRIs by region

	Admissions (%)	Incidence rate per 100,000 persons per year
Regions		
Central (Exclude Bangkok)	1311 (19.0)	1.67
North-eastern	2167 (31.4)	2.00
Northern	1873 (27.2)	3.17
Southern	1544 (22.4)	3.41

Figure 13**. **The highest incidence rate per 100,000 persons per year by province in each region of Thailand

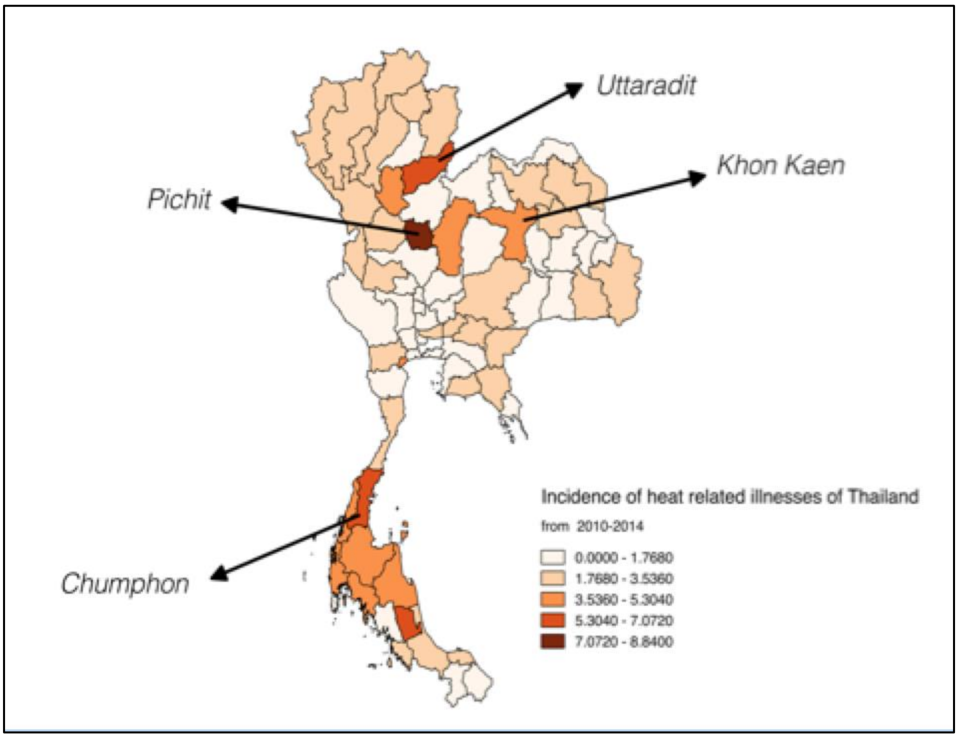
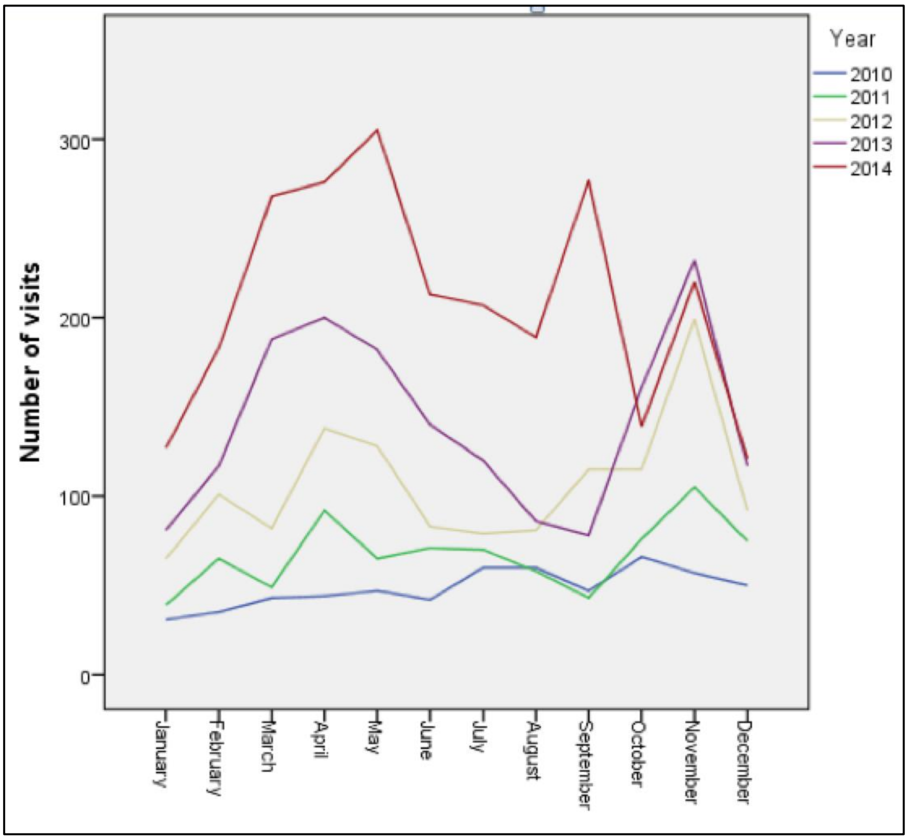


Figure 14 shows the number of HRI admissions in Thai hospitals from 2010 to 2014. The trend of visits increased significantly throughout this period. There were two annual peaks: in April–May and in November. These results correspond with Thailand's seasons, where summer lasts from mid-February to mid-May (when we have the highest temperatures) and November is the wettest month of the year. However, there was a clear peak in 2014, representing different climatic events in the period between August and September of that year.

Figure 14. Total number of monthly admissions from January 2010 to December 2014



4.3 Descriptive analysis of meteorological data

A summary of meteorological information by province is given in Table 20. There are 25, 17, 20 and 14 provinces in the central, northern, north-eastern and southern regions respectively. Meteorological data was obtained from 62 provinces, representing 81.58 percent coverage of the country (the dash in the table shows provinces that do not have a weather station). Bangkok station was excluded in this study due to Bangkok has separate health system and not compatible with the rest of the country.

Table 20. Summary of meteorological data by province

Province	Maximum temperature (ºC)		Relative humidity (%)		Heat index	
	Max	Min	Max	Min	Max	Min
Southern						
Chumphon	31.0	20.7	97	60	102.6	63.7
Krabi	30.4	23.3	99	61	100.3	70.2
Nakhonsrithummarat	31.25	23.4	98	63	102.9	70.8
Narathivas	30.6	22.4	97	67	100.9	67.6
Pangnga	30.3	22.2	99	50	101.5	65.8
Pattani	30.9	23.4	98	64	99.8	71.1
Phuket	32.1	24.2	96	56	106.	74.7
Ranong	31.5	21.7	95	57	100.4	68.5
Satun	30.7	23.8	96	55	99.3	72.6
Songkla	31.5	24	96	62	102.2	74.0
Suratthani	31.5	22.6	98	63	102.2	70.1
Trang	31.1	23.5	98	60	101.3	70.9
Yala	30.7	23.1	99	60	97.8	69.9
Pattalung	-	-	-	-	-	-
Northern						
Chaingmai	34.5	16.4	95	40	100.6	66.1
Chaingrai	31.6	13.7	95	49	97.7	64.7
Lumpang	34.6	15.7	96	43	105.3	60.9
Maehongson	36.7	16.2	94	40	106.7	62.6
Nan	35.5	14.5	99	49	105.3	61.8
Phayao	33.6	14.3	95	41	100.5	61.1
Prae	35.5	15.5	97	45	105.2	59.2
Lumphun	35.2	16.0	98	41	103.4	60.4

Province	Maximum temperature (ºC)		Relative humidity (%)		Heat index	
Uttaradit	34.9	16.2	95	50	107.2	62.4
Nakhon Sawan	35.7	17.1	97	49	112.4	58.5
Tak	36.2	16.2	94	28	104.00	63.0
Sukhothai	35.4	16.3	96	46	113.4	59.6
Phitsanulok	34.3	16.5	95	52	109.5	62.2
Phetchabun	34.6	15.8	97	46	108.6	62.7
Kamphaeng Phet	34.0	16.5	99	50	111.1	56.6
Uthai Thani	-	-	-	-	-	-
Phichit	-	-	-	-	-	-
Central						
Phra Nakhon Si Ayutthaya	33.6	18.6	94	50	111.3	72.2
Chai Nat	34.5	17.1	92	50	108.1	64.8
Kamphaeng Phet	34.0	16.5	99	50	111.1	56.6
Lop Buri	34.3	18.3	97	41	111.0	69.0
Nakhon Pathom	33.3	17.9	98	58	111.4	64.9
Samut Prakan	32.6	19.4	92	47	110.7	69.9
Suphan Buri	34.0	17.6	98	50	116.1	86.8
Kanchanaburi	34.5	18.5	94	41	108.7	65.3
Phetchaburi	32.6	19	95	49	110.6	67.9
Prachuap Khiri Khan	32.3	20.1	96	47	109.9	69.3
Ratchaburi	32.5	18.2	100	56	109.6	65.4
Chachoengsao	31.6	18.7	97	50	104.9	71.6
Chanthaburi	31.4	20.5	97	48	104.8	67.4
Chon Buri	33.5	21.0	93	47	110.7	72.2
Prachin Buri	33.3	21.5	95	45	111.6	74.2
Rayong	32	21.3	95	49	110.1	71.6

Province	Maximum temperature (ºC)		Relative humidity (%)		Heat index	
Sa Kaeo	33.1	19.1	98	51	107.8	68.4
Trat	31.1	22.8	97	48	104.4	75.0
Pathum Thani	34.1	18.9	96	54	118.8	68.9
Nonthaburi	-	-	-	-	-	-
Ang Thong	-	-	-	-	-	-
Sing Buri	-	-	-	-	-	-
Saraburi	-	-	-	-	-	-
Samut Sakhon	-	-	-	-	-	-
Samut Songkhram	-	-	-	-	-	-
Nakhon Nayok	-	-	-	-	-	-
Northeastern						
Buri Ram	34.5	16.6	97	48	108.7	66.0
Chaiyaphum	34.3	17.5	97	42	104.5	63.8
Kalasin	36.6	16.2	97	47	115.2	64.1
Khon Kaen	34.3	15.7	96	40	105.0	61.2
Nakhon Ratchasima	34.2	17.4	99	45	107.4	67.0
Loei	33.3	14.5	94	41	100.7	64.2
Maha Sarakham	34.7	16.4	98	46	112.3	63.1
Mukdahan	34.0	15.6	95	41	107.0	66.0
Nakhon Phanom	33.5	15.7	98	48	113.0	62.9
Nong Khai	34.2	15.2	98	44	108.3	61.1
Roi Et	34.3	16.7	97	42	108.2	63.8
Sakon Nakhon	34.4	15.3	97	42	106.2	62.6
Si Sa Ket	33.3	16.8	95	55	106.3	63.9
Surin	33.6	17.2	97	49	104.3	65.4
Ubon Ratchathani	33.7	16.5	98	49	105.4	61.6

Province	Maximum temperature (ºC)		Relative humidity (%)		Heat index	
Udon Thani	34.1	15.7	95	39	105.4	64.1
Yasothon	-	-	-	-	-	-
Amnat Charoen	-	-	-	-	-	-
Bueng Kan	-	-	-	-	-	-
Nong Bua Lam Phu	-	-	-	-	-	-

Figure 15 shows the mean maximum temperature and figure 16 shows the mean maximum relative humidity by province. The ranges of maximum temperature in the Central, North-eastern and Northern regions were higher than in the Southern region, namely, 31.1°C-34.5°C, 33.3°C-36.6°C, 31.6°C-36.7°C and 30.3°C-32.1°C respectively. In contrast, the ranges of relative humidity were high in the Southern region (95%-99%) and North-eastern region (94%-99%). Lastly, figure 17 shows that the range of the maximum heat index was high in the Central region (104.4°F-118.75 °F) and the North-eastern region (100.7°F-115.2°F).

Figure 15. Map of average maximum temperature by province (C°)

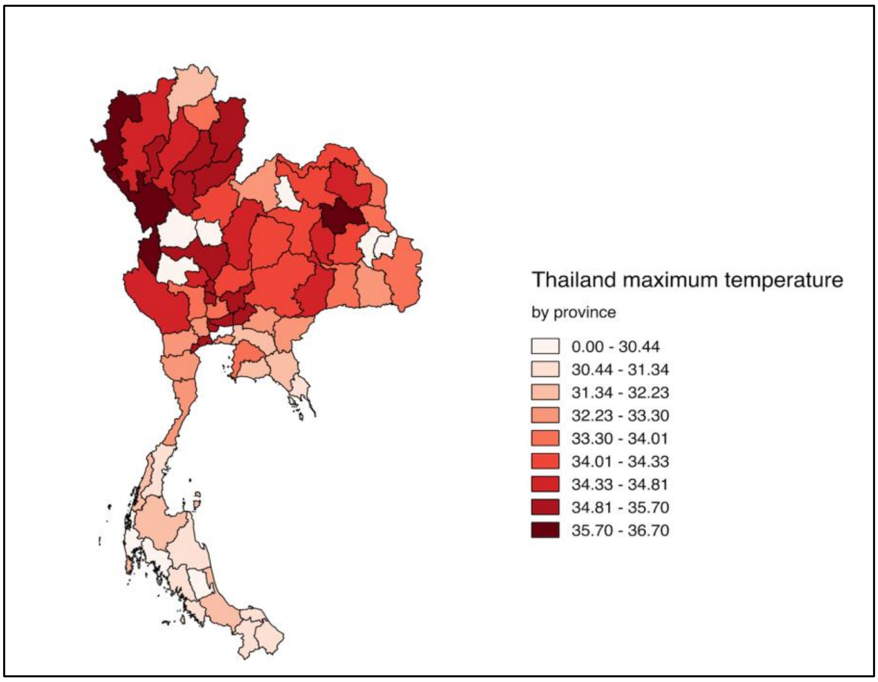


Figure 16. Map of average relative humidity by province

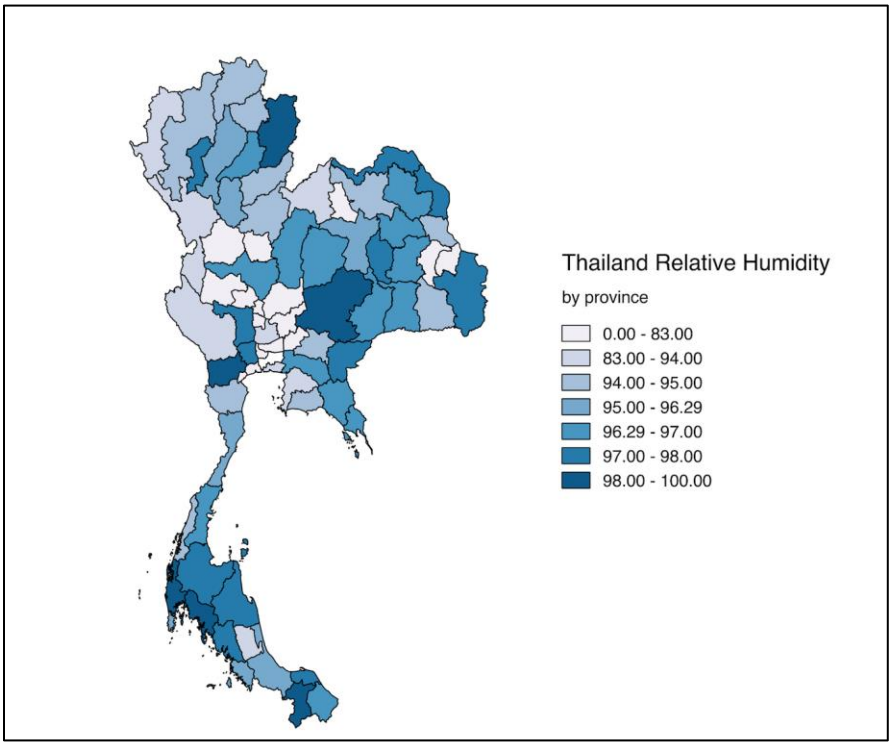


Figure 17. Map of maximum heat index by province (°F)

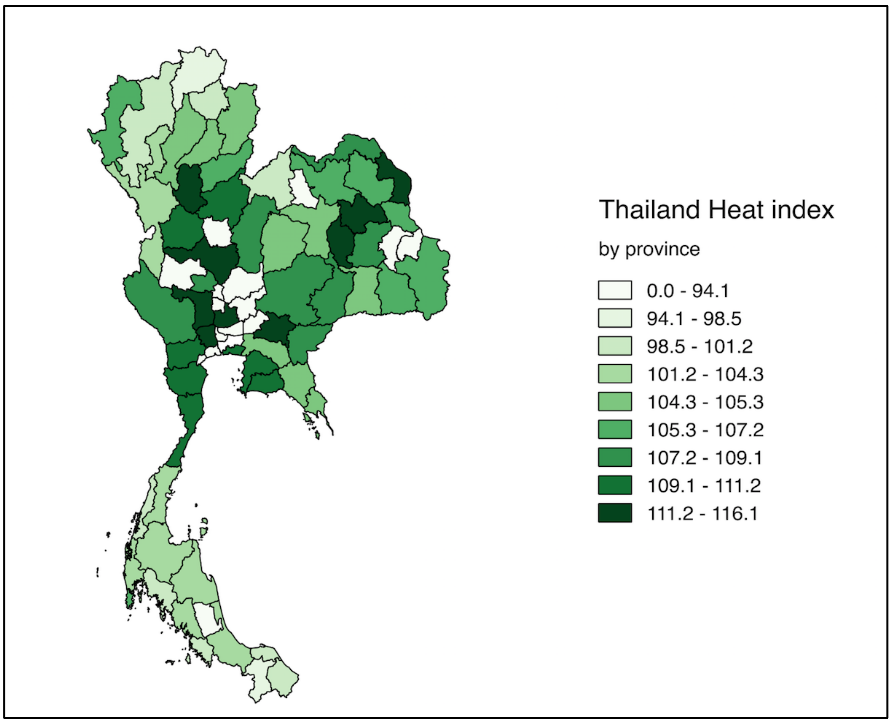
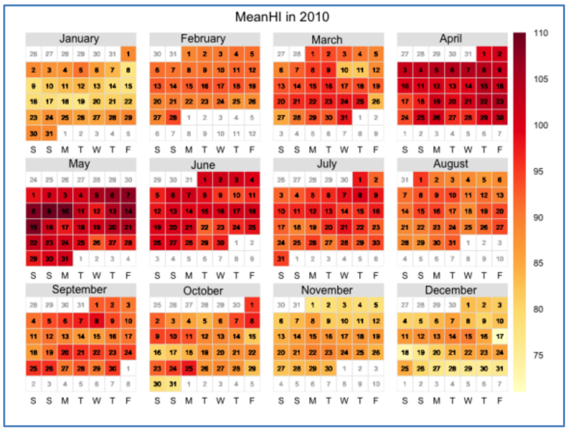
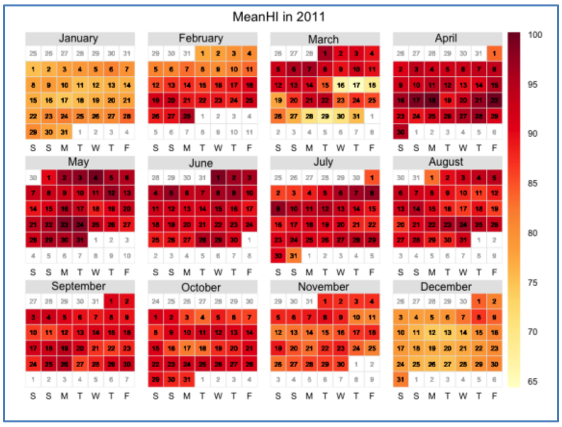


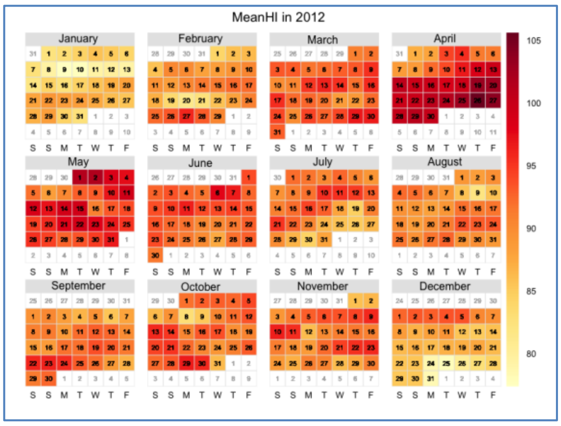
Figure 18. Calendar plot of the heat index by month from 2010 to 2014 in the Central region



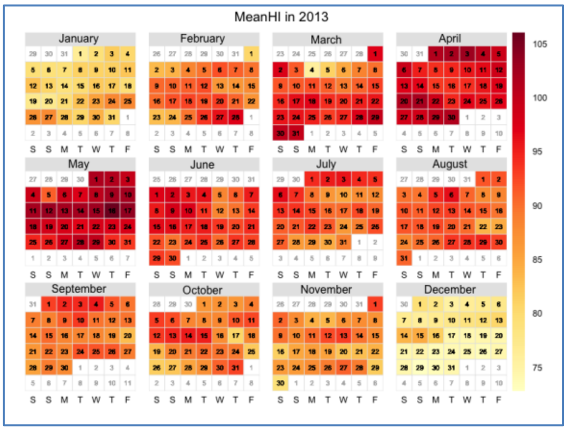
2010



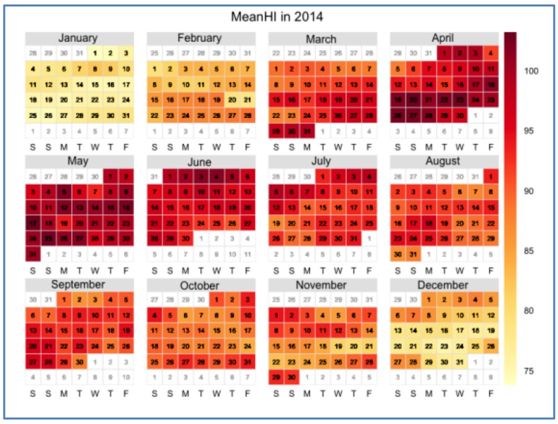
2011



2012



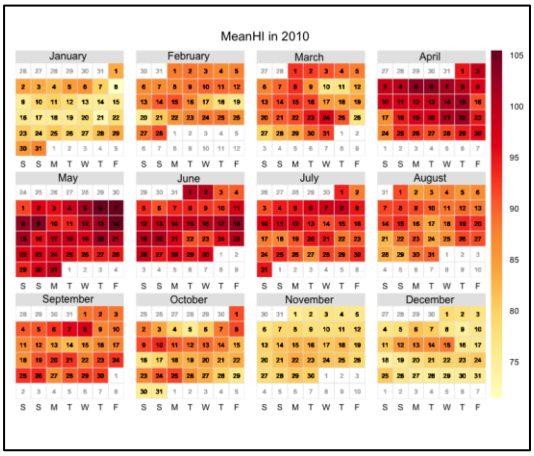
2013



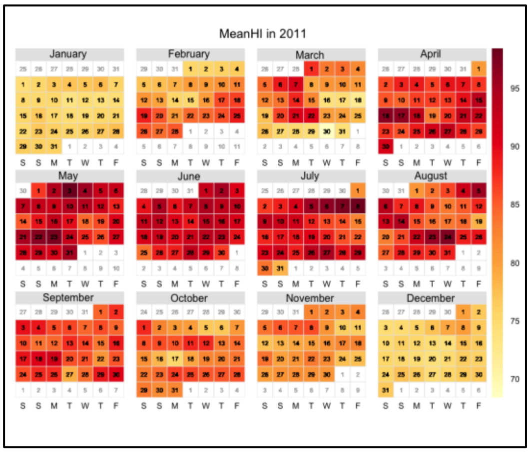
2014

Figure 18 is a calendar plot revealing the heat index in the Central region. The heat index was high in April to June each year, mostly confined to the summer to the middle of the rainy season. The trend was the same for 2010–2014. As can be seen from the calendar plot, the highest heat index was in 2011, and it continued longer than for the other years.

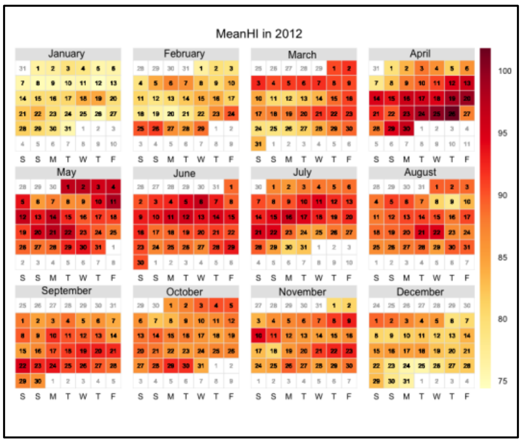
Figure 19. Calendar plot of the heat index by month from 2010 to 2014 in the Northeastern region



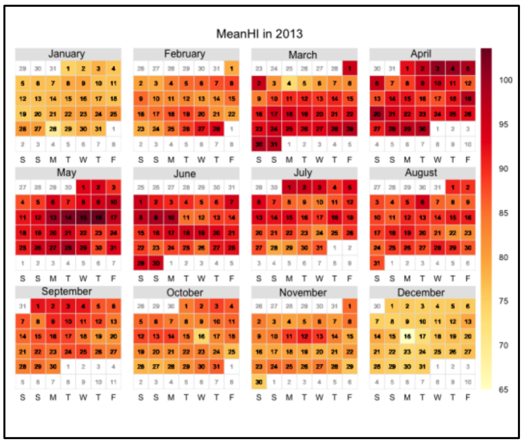
2010



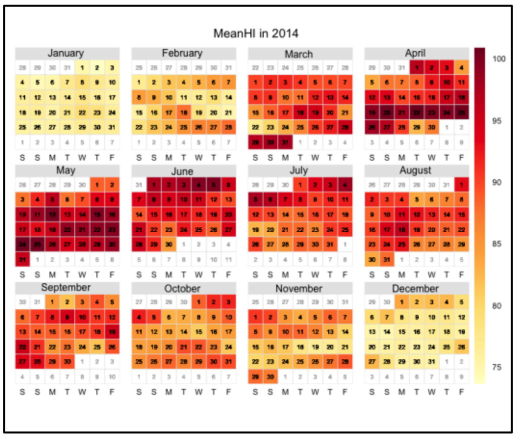
2011



2012



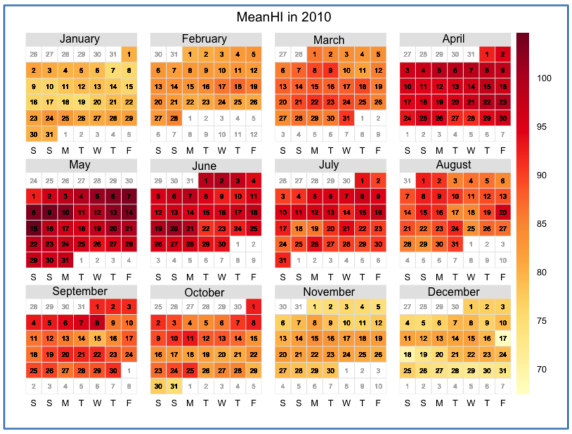
2013



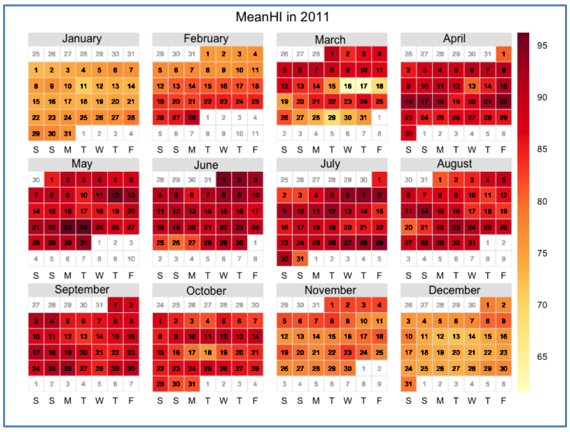
2014

Figure 19 is the calendar plot revealing the heat index in the Northeastern region. The index was high in the longer period compared to the Central region. The heat index is high in April to August each year and had the same trend for 2010–2014. The highest heat index was in 2011 and 2014, different years compared to the highest figures for the Central region.

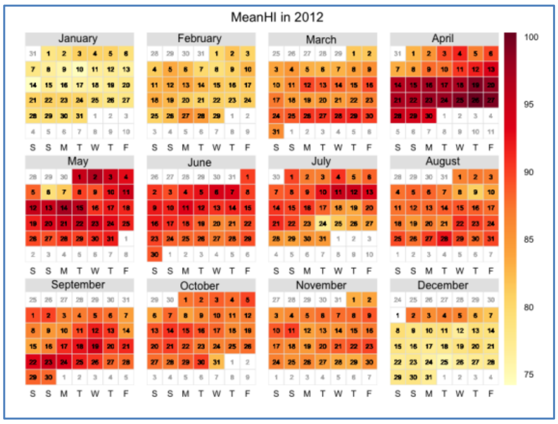
Figure 20. Calendar plot of the heat index by month from 2010 to 2014 in the Northern region



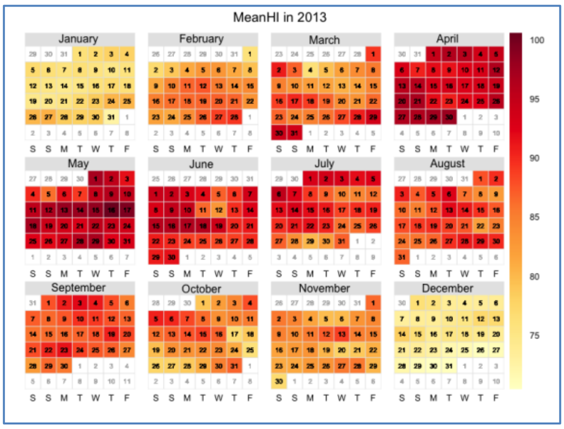
2010



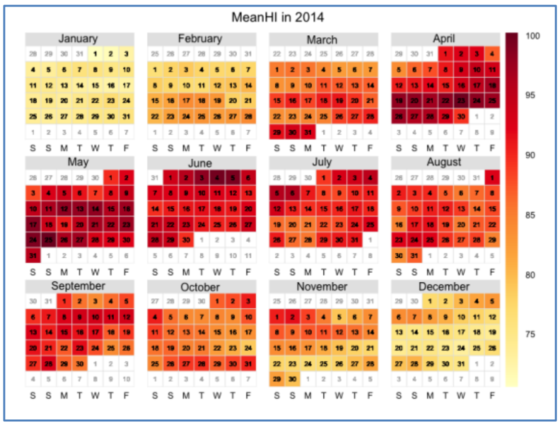
2011



2012



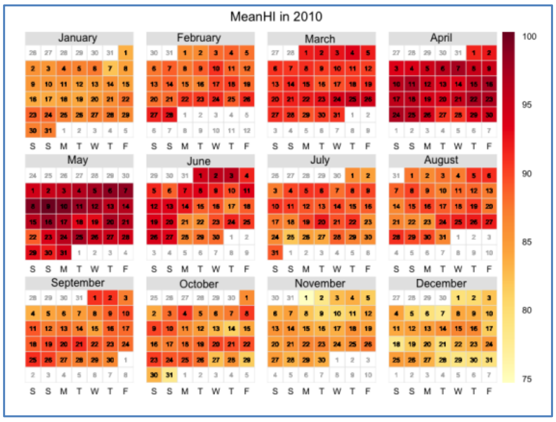
2013



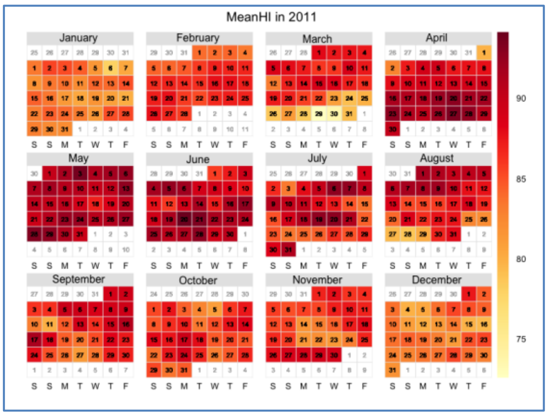
2014

Figure 20 is the calendar plot revealing the heat index in the Northern region. The index was also high in April to September each year and had the same trend from 2010 to 2014 year. This includes the periods of summer and the entire rainy season. Again, the calendar plot shows that the highest heat index was in 2011 and it continued longer than the other years, as was the case in the Central region.

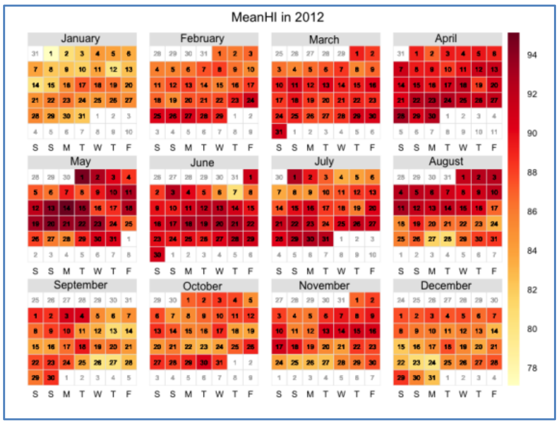
Figure 21. Calendar plot of the heat index by month from 2010 to 2014 in the southern region



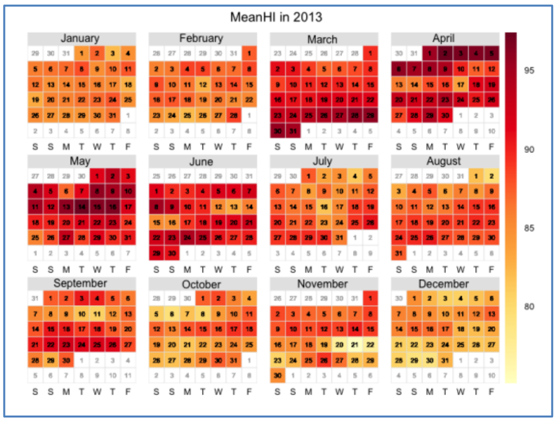
2010



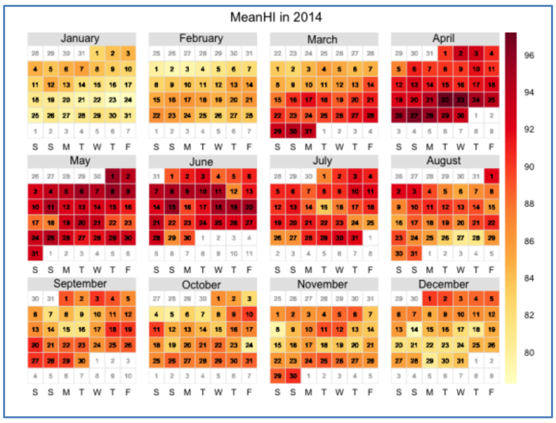
2011



2012



2013



2014

Figure 21 is the calendar plot revealing the heat index in the Southern region. The index was also high in April to November each year and had the same trend from 2010 to 2014. This includes the periods of summer and the entire rainy season. Again, from the Calendar plot, the highest heat index was in 2011 and it continued for longer than the other years, as was the case in the Central region.

4.4 Descriptive analysis of daily HRIs and meteorological data

Table 21 shows the descriptive exploration of the daily HRI admissions, the maximum temperature, relative humidity and the heat index for the chosen study period. Both data sets of health and climate contained 1826 days covering the five years of the study. The median of HRIs was three admissions per day and the maximum admission was 37 admissions per day. Some 75% of the maximum temperature was less than 28.58°C and 75% of the heat index was less than 91.47°F.

Table 21. Descriptive results of daily HRIs and meteorological data

		HRIs (Counts/day)	**Temperature (°C)**	**Humidity (%)**	**Heat index (°F)**
Daily number		1826	1826	1826	1826
Mean		3.78	27.48	75.93	87.67
Median		3	27.68	76.40	88.14
SD		3.43	1.99	6.07	5.68
Minimum		0	19.70	57.43	70.91
Maximum		37	32.73	89.05	104.56
Quartiles	25th	1	26.61	71.49	84.10
	75th	5	28.58	80.74	91.47

4.5 Time variation between HRIs and climate factors

The time variation between the HRIs and the meteorological factors are shown in figure 22–25. It is clear that the number of patients reached a peak in summer, according with the highest temperature level and the heat index at that time. The curious second peak in November each year may be explained by relative humidity, as it is the period directly following the rainy season. Furthermore, the end of October through to November is a harvesting period for Thai farmers, and hence there is increased outdoor exposure at this time of the year compared to other months. More information on the day of admission to hospital each week is shown in the time variation plot. The patients tended to visit hospital more on weekdays than at the weekend.

Figure 22. Time-variation plot of HRI visits and weather variables for the Central region

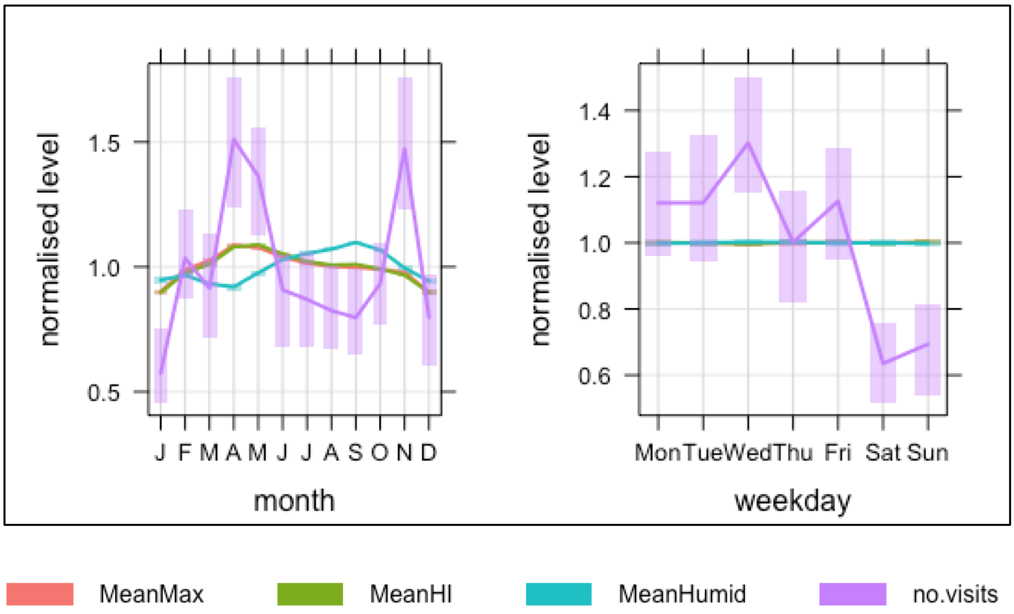
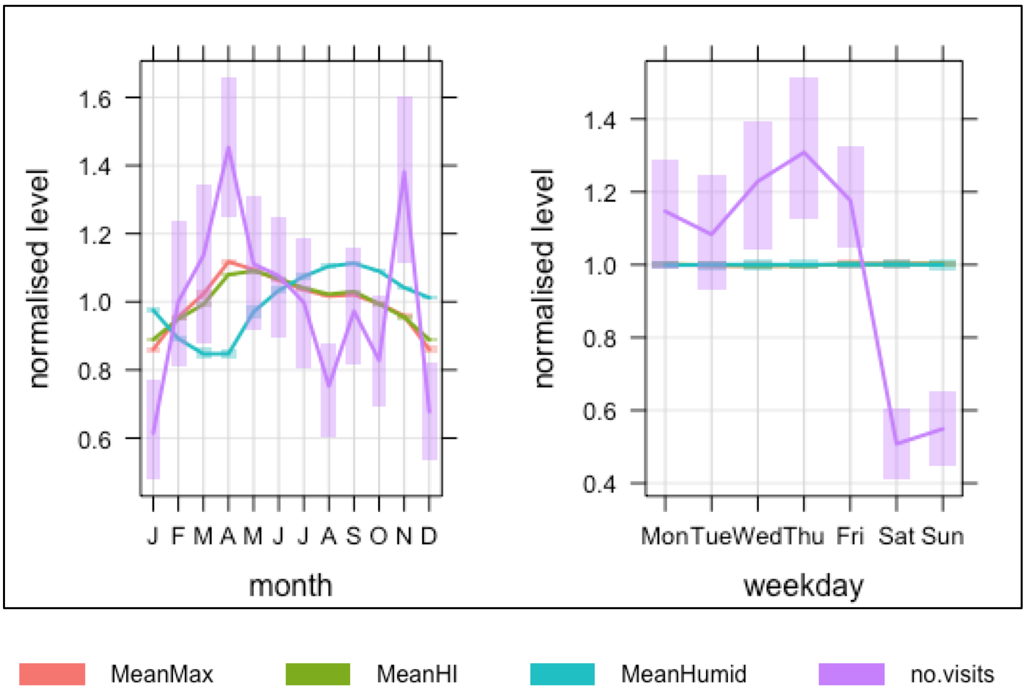


Figure 23. Time-variation plot of HRI visits and weather variables for the Northern region



* The red line shows the variation of the mean maximum temperature from 2010 to 2014. The green line shows the variation of the heat index mean from 2010 to 2014. The blue line shows the variation of mean humidity from 2010 to 2014. The purple line shows the variation of daily hospitalisations for HRIs from 2010 to 2014. The purple shade is the confidence interval of the normalising concentrations of all variables.

Figure 24. Time-variation plot of HRI visits and weather variables for the Northeastern region

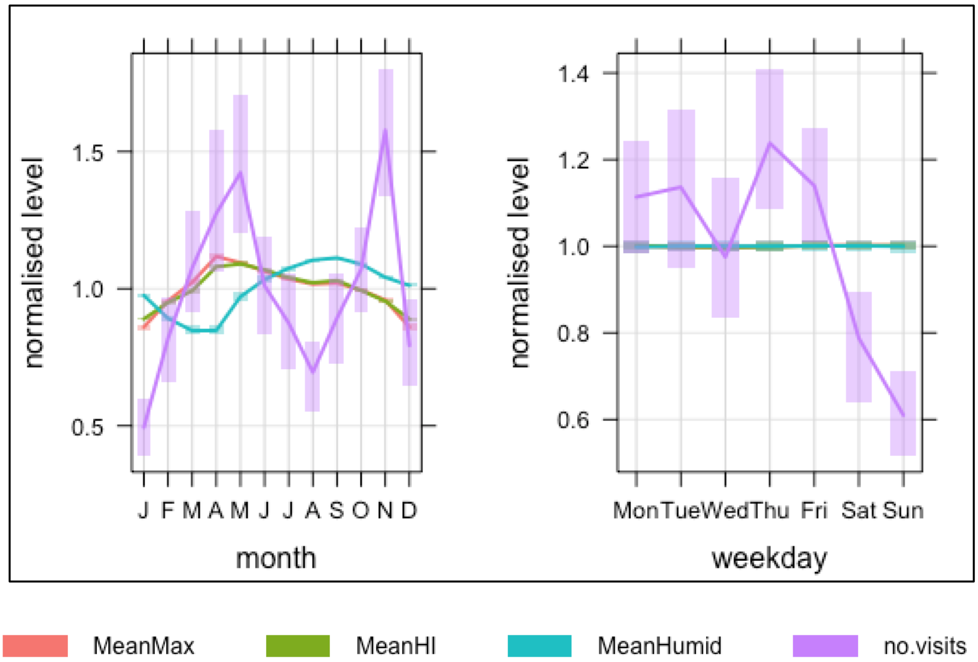
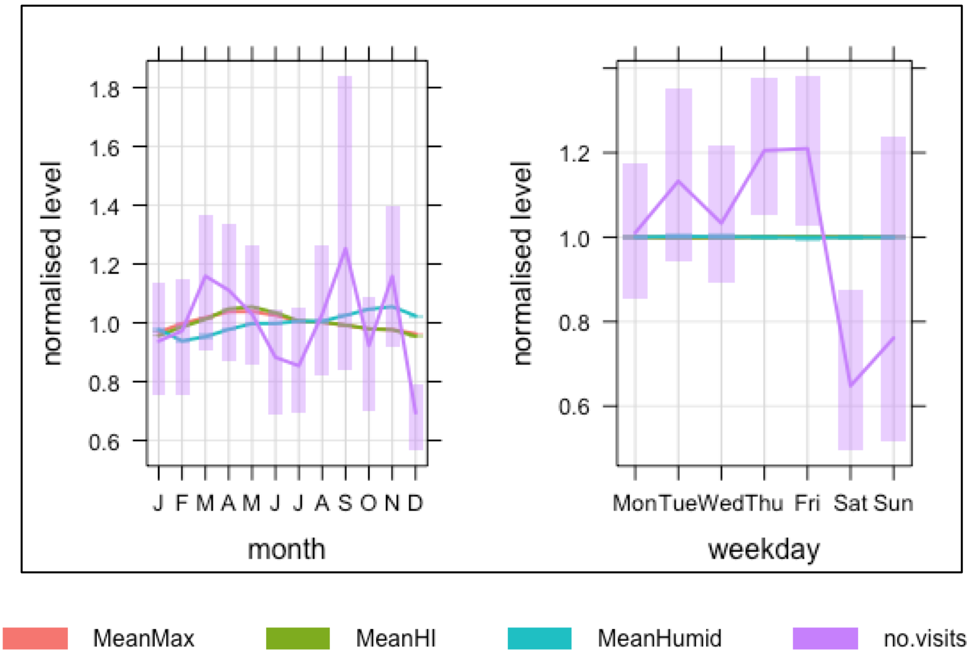


Figure 25. Time-variation plot of HRI visits and weather variables for the Southern region



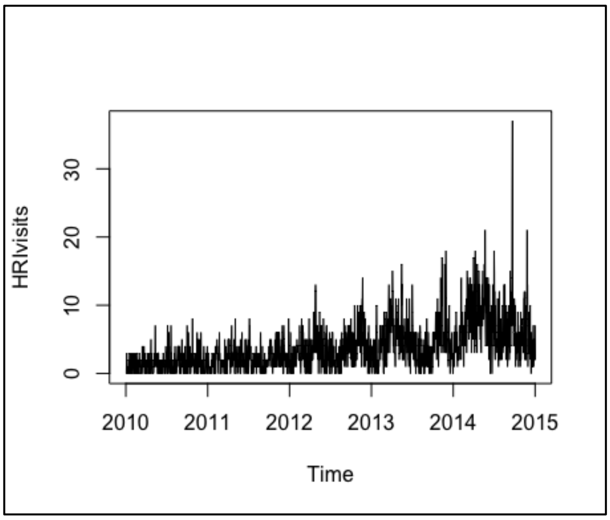
* The red line shows the variation of the mean maximum temperature from 2010 to 2014. The green line shows the variation of the heat index mean from 2010 to 2014. The blue line shows the variation of mean humidity from 2010 to 2014. The purple line shows the variation of daily hospitalisations for HRIs from 2010 to 2014. The purple shade is the confidence interval of the normalising concentrations of all variables.

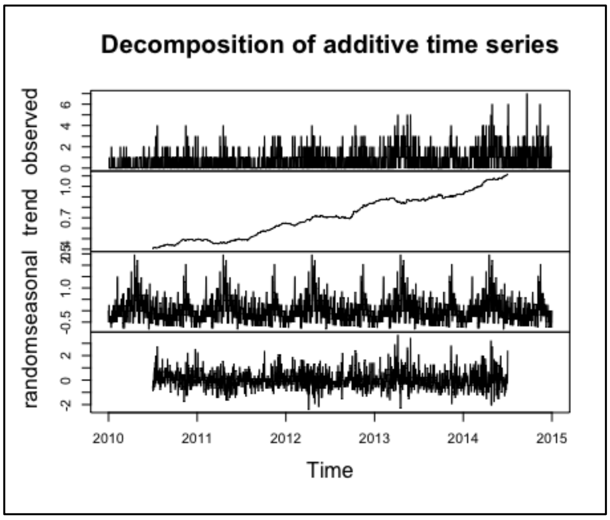
As can be seen in Figures 22-25, the number of hospitalisations reached a peak in September, followed by November and March respectively. However, this pattern was different in the Southern region compared to the rest of the country.

4.6 Time-Series Plot of HRIs and meteorological data

Figure 26–29 illustrate the time series and decomposition[10] plot of HRI hospitalisations, the temperature and the relative humidity across the entire country over the five-year period. The figures show that all variables were affected by season, as depicted by the pattern of the seasonal cycle in the decomposition plot.

Figure 26. Time series and decomposition plot of daily HRI visits for the period 2010 to 2014 in the whole country

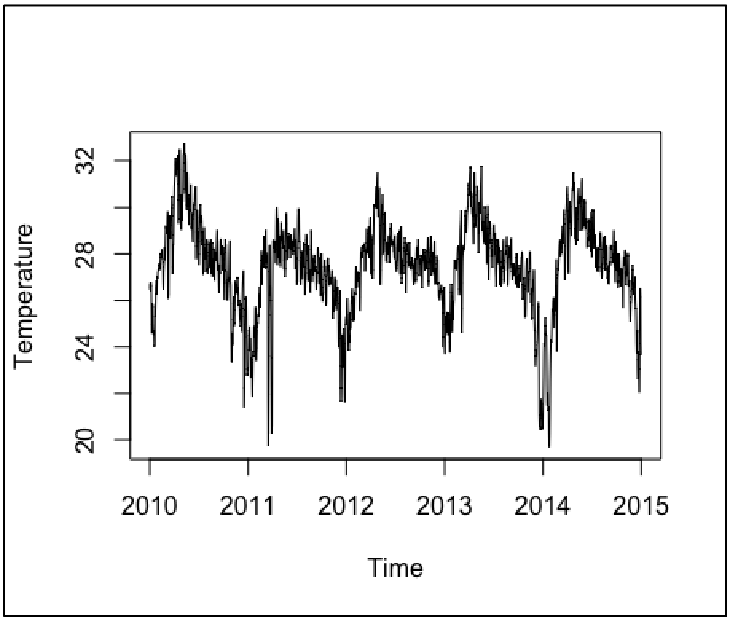


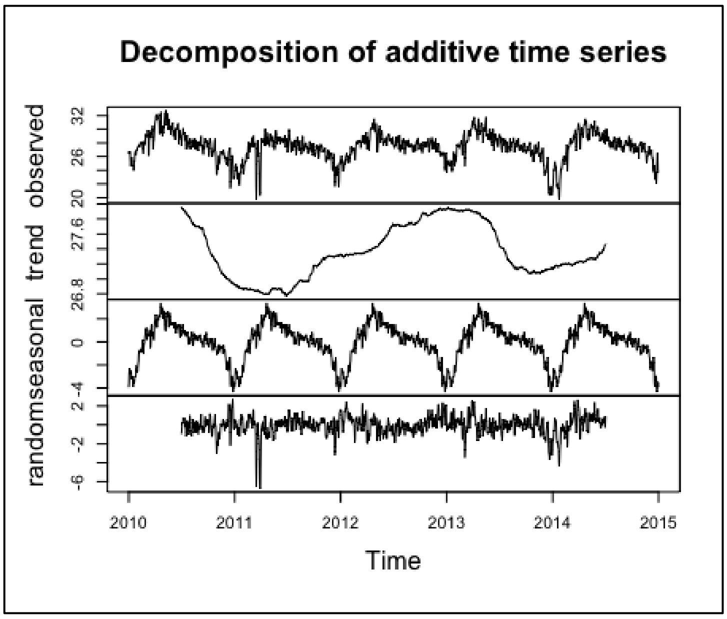


The trend of daily HRI hospitalisations continued increasing from 2010 to 2014. As can be seen in the decomposition plot, the trend of HRI hospitalisations mainly increases after the seasonal effect is removed. Many peaks correlate between the seasonal graph and observed values. This information supports the fact that the peak for hospitalisation and season correlate.

[10] Decomposing a time series means separating it into its constituent components, which are usually a trend component and an irregular component and, if it is a seasonal time series, a seasonal component.

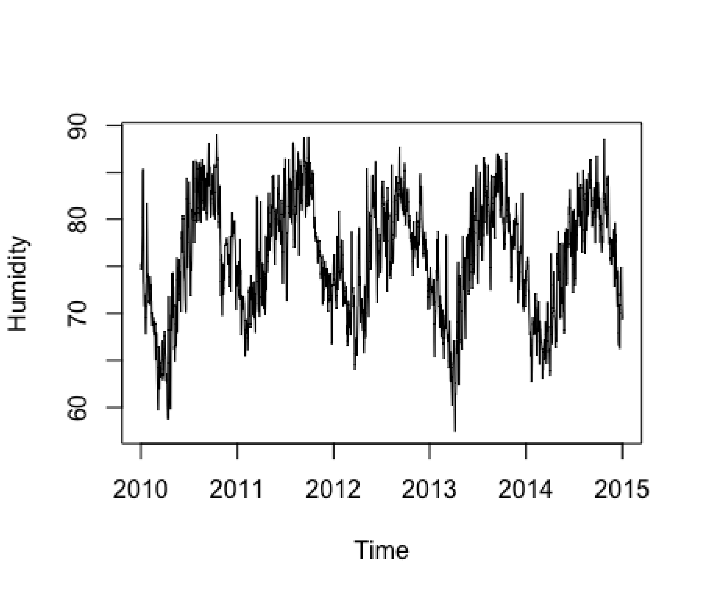
Figure 27. Time series and decomposition plot of mean maximum temperature for the period 2010 to 2014 in the whole country

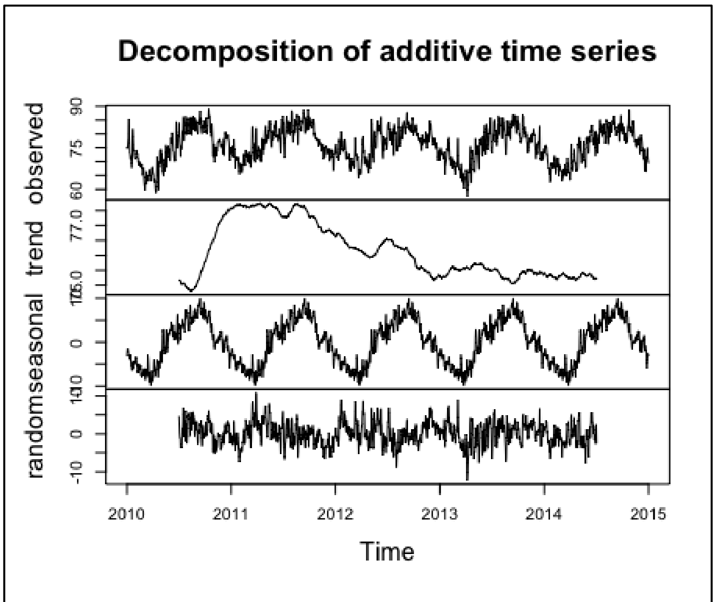




The trend of the daily mean of maximum temperature fluctuated from 2010 to 2014. The highest temperature was in summer each year, and the peaks correlate between the seasonal graph and observed values.

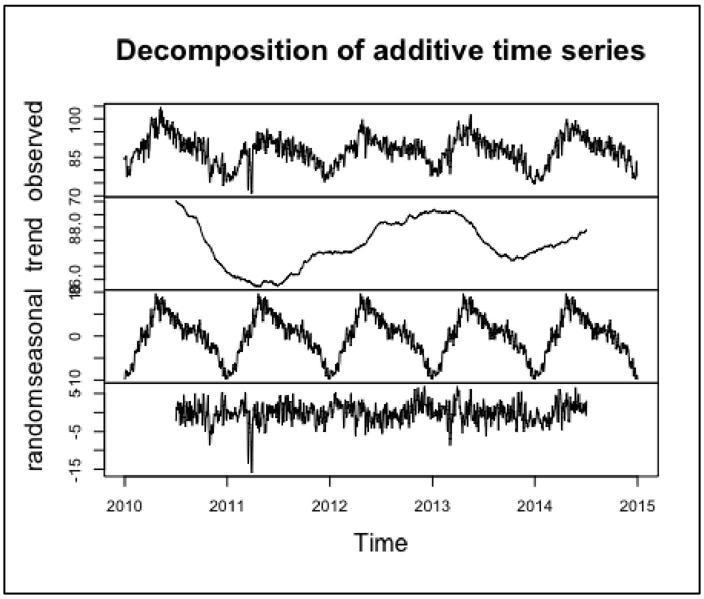
Figure 28. Time series and decomposition plot of relative humidity for the period 2010-2014 in the whole country

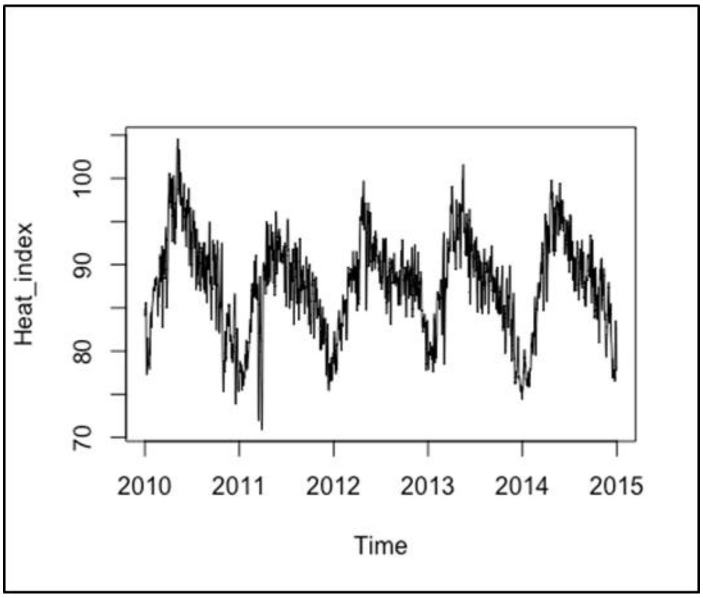




The trend of the daily mean for humidity fluctuated during over the period from 2010 to 2014. The highest peak humidity level was in the rainy season each year, and the peaks correlate between the seasonal graph and observed values.

Figure 29. Time series and decomposition plot of heat index for the period 2010-2014 in the whole country





The trend of the daily mean for the heat index fluctuated from 2010 to 2014. Surprisingly, the variation of the heat index correlates with the temperature (which reaches a peak in summer each year) more than with humidity, and the peaks correlate between the seasonal graph and observed values.

4.7 Poisson regression analysis

4.7.1 Central region model

Seasonality, day of the week and holidays were taken into account as long-term and short-term trends confounding. To decide which degrees of freedom (Df) should be applied for the natural cubic spline of the day of study, 4-8 degrees of freedom were applied in the model to compare which one was selected in each region before considering the Akaike Information Criteria *(McIver et al.,2016).* A smaller AIC indicates a better fit of model. The AIC is automatically calculated from R software *(see results in Table 22).* For the Central region the best fitting model had df of 7. However, the model with df of 4,5,6 and 8 had AIC were only slightly different. Thus, these models provided a similar good fit to the data.

Table 22. Comparison of models by AIC for seasonal adjustment for the Central region

Number of degrees of freedom/year	**Maximum heat index**	**Mean heat index**
4	3936.9	3938.6
5	3936.7	3938.3
6	3935.4	3937.3
7#	3932.6	3934.8
8	3933.5	3935.2

Best fit degrees of freedom for the model

In a Partial ACF plot, the residuals should be as small as possible, ranging from $-2n^{-1/2}$ – $2n^{-1/2}$. In this study, the range was equal at -0.047 to 0.047 due to the observations equal to 1826. The lines in the Partial ACF plot were out of range, indicating a strong autocorrelation between data from one day and previous days. Consequently, residuals were included in both the maximum and the mean heat index model (*Figure 30 and figure 32).*

Figure 30. Partial ACF plot of the maximum heat index against lag[11] days without residuals included for the Central region

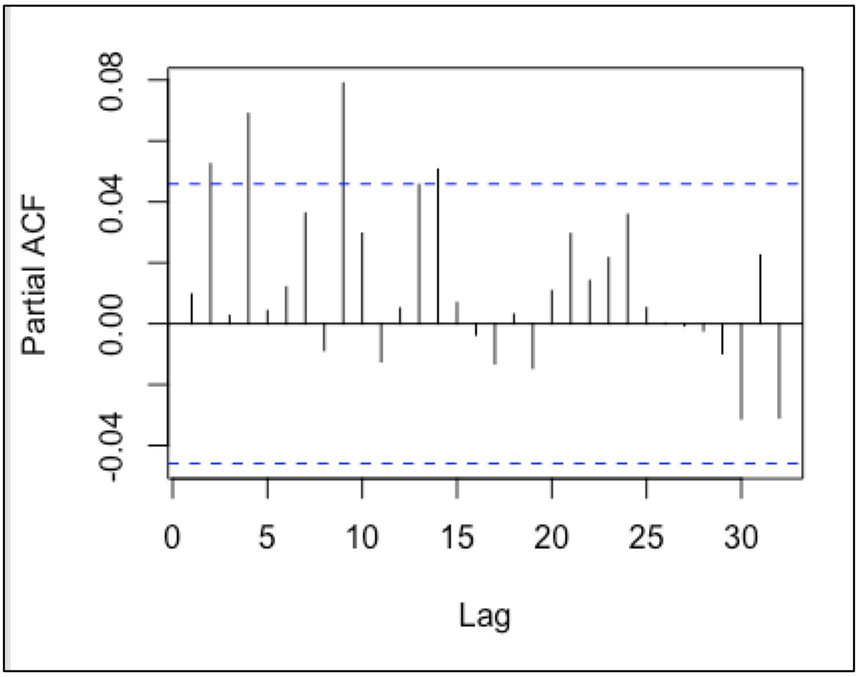
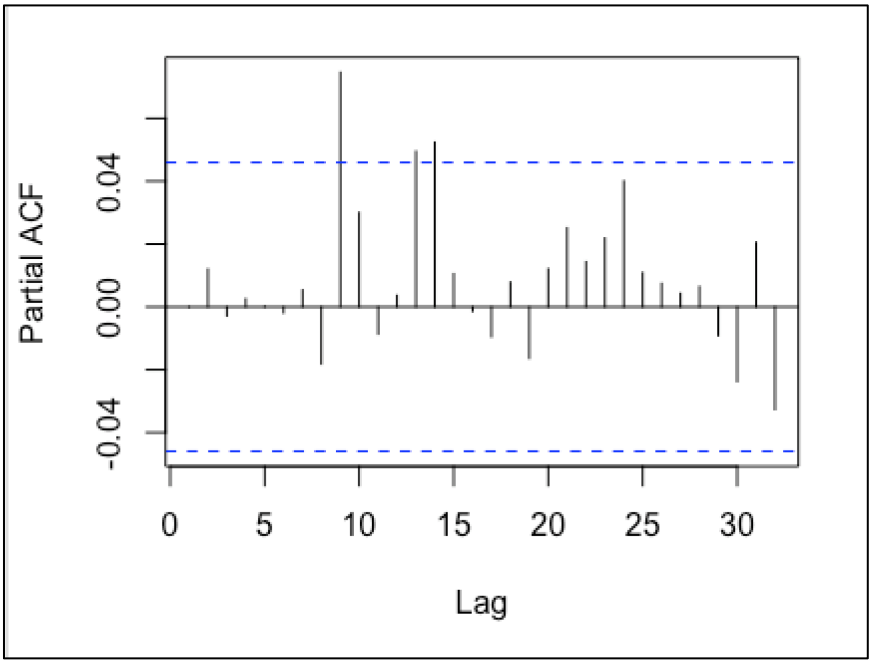


Figure 31. Partial ACF plot of the maximum heat index against lag days with residuals included for the Central region



[11] Lag model is a model for time series data in which a regression equation is used to predict current values of a dependent variable based on both the current values of an explanatory variable and the lagged (past period) values of this explanatory variable. Lag 0 model means the model predicts current values of a dependent variable based on the value of explanatory variables on the same day.

Figure 32. Partial ACF plot of the mean heat index against lag days without residuals included for the Central region

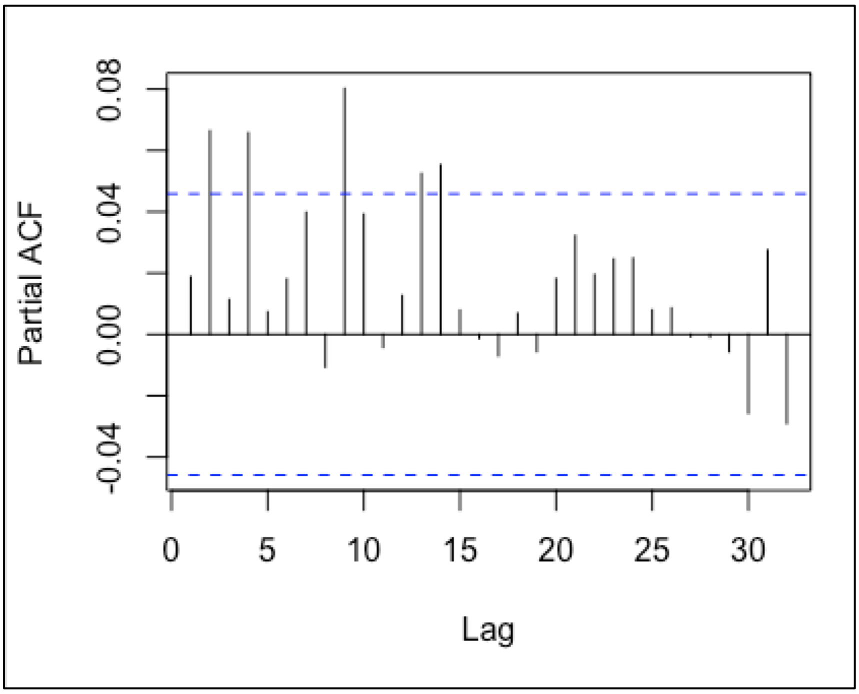
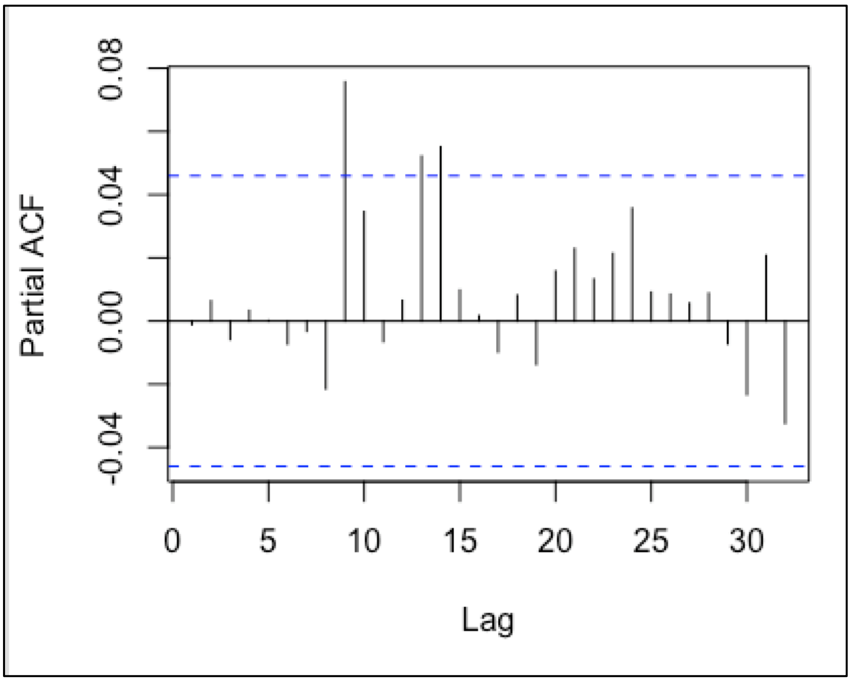


Figure 33. Partial ACF plot of the mean heat index against lag days with residuals included for the Central region



The goodness of fit for the Central region model

Pseudo R^2 (R^2) and chi-square (X^2) were applied for goodness of fit testing in the GLM with the Poisson regression. An R^2 value lower than 0.6 was considered a good fit. The fitting of the models for each region was considered by using AIC values; the lowest AIC value gave the best fitting model. Table 23 and Table 24 show the goodness of fit for the Central region model and lag 0 was the best fitting model for both the maximum and the mean heat index.

Table 23. Goodness of fit results for the analyses of the maximum heat index for a no lag day to seven lag days for models without residual and including residuals in the model for Central region

Max HI	Without residual					Max HI	With residual				
Lag days	R^2	X^2	df	X^2/df	AIC	Lag days	R^2	X^2	df	X^2/df	AIC
0	0.176	1913.17	1825	1.048	3932.6	0 #	0.186	1918.36	1818	1.055	3925.3
1	0.161	1966.84	1809	1.087	3965.8	1	0.169	1952.41	1818	1.073	3960.6
2	0.156	1970.88	1808	1.090	3976.2	2	0.164	1958.04	1818	1.077	3971.8
3	0.151	1981.90	1807	1.098	3986.8	3	0.159	1972.46	1818	1.084	3982.5
4	0.150	1988.18	1806	1.100	3990.2	4	0.157	1981.01	1818	1.089	3987.2
5	0.151	1996.16	1805	1.105	3987.6	5	0.156	1987.87	1818	1.093	3988
6	0.152	1983.12	1804	1.099	3985.6	6	0.157	1974.68	1818	1.086	3987.1
7	0.148	1991.58	1803	1.105	3993.8	7	0.153	1984.02	1818	1.091	3995.3

Best fitting model

Table 24. Goodness of fit results for the analyses of the mean heat index for a no lag day to seven lag days for models without residual and including residuals in the model for Central region

Mean HI	Without residual					Mean HI	With residual				
Lag days	R^2	X^2	df	X^2/df	AIC	Lag days	R^2	X^2	df	X^2/df	AIC
0	0.175	1945.22	1825	1.066	3934.8	0 #	0.186	1922.62	1818	1.058	3924.5
1	0.161	1967.34	1809	1.088	3965.4	1	0.169	1950.31	1818	1.073	3958.6
2	0.152	1980.04	1808	1.095	3984	2	0.164	1964.53	1818	1.081	3977.7
3	0.148	1986.61	1807	1.099	3993.8	3	0.159	1974.79	1818	1.086	3988.5
4	0.147	1995.42	1806	1.104	3994.7	4	0.157	1985.74	1818	1.092	3989.9
5	0.149	1997.72	1805	1.106	3991.4	5	0.156	1986.91	1818	1.093	3990.2
6	0.150	1985.40	1804	1.101	3989.2	6	0.157	1974.19	1818	1.086	3988.4
7	0.147	1994.53	1803	1.106	3996.7	7	0.153	1984.67	1818	1.101	3996.2

Best fitting model

The relative risks of HRIs against the heat index for the Central region

Both the maximum and the mean heat index were associated with an increase in daily HRIs. However, the mean heat index model gave a better model than the maximum heat index considering the AIC was smaller *(Tadano et al., 2012) (see table 25).*

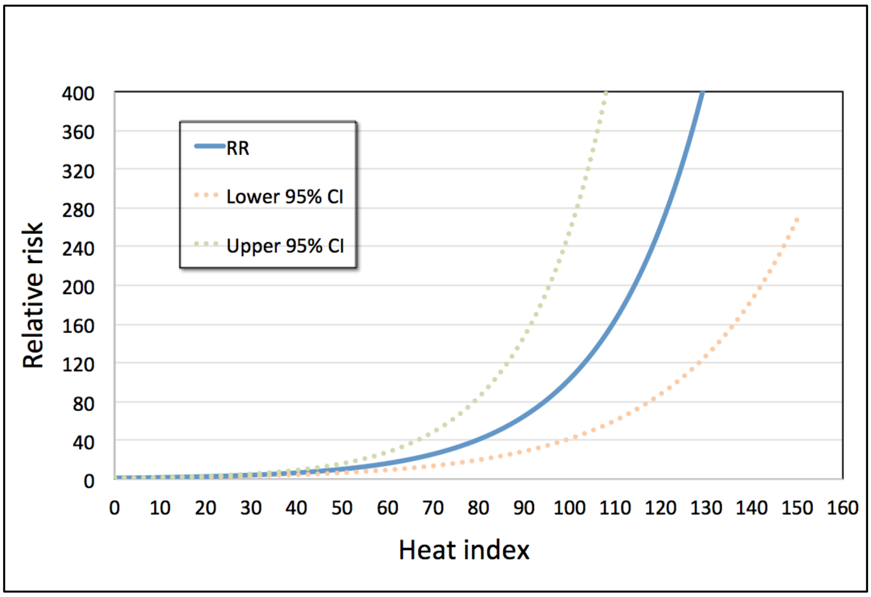
Table 25. Analysis of the regression coefficients (β) for the heat index for Central region

Variable	Lag	β	ε	T-value	AIC
MeanHI	0	0.046376	0.004636	10.003*	3924.5
MaxHI	0	0.044593	0.004397	10.141*	3925.3

* Statistical Significance level – α (0.001)

Therefore, the relative risk of HRI hospitalisation against the heat index for the central region was calculated from the mean heat index model. The plots of the relative risk of HRI hospitalisations against the heat index for the central region are shown in figure 34. An increase in the daily mean heat index in the central region was associated with an increase in daily HRIs on the same day (lag 0). The relative risk of HRI hospitalisations in the central region at the 25th, the 75th and the 90th percentile of the mean of the heat index were 55.37 (95%CI = 25.21–121.55), 79.59 (95%CI = 33.76–187.64) and 96.13 (95%CI = 39.31–235.29), respectively

Figure 34. Estimates of relative risk of HRIs by heat index for the central region



4.7.2 Northern region model

Table 26 shows that degrees of freedom 7 gave the lowest AIC value; thus, Df = 7 gave the best fit for the Poisson regression model of the northern region.

Table 26. Comparison of models by AIC for seasonal adjustment for the Northern region

Number of degrees of freedom/year	Maximum heat index	Mean heat index
4	4524	4536.2
5	4523.3	4535.2
6	4517.5	4528.9
7#	4503.5	4512.5
8	4506.9	4515

Best fit degrees of freedom

The lines in the Partial ACF plot were not out of range *(figure 35),* indicating there was no strong autocorrelation between data from one day and previous days. Hence, the residuals were not included in the maximum heat index model. On the other hand, the lines in the Partial ACF plot of the mean heat index were out of range *(figure 36),* indicating there was an autocorrelation between data from the same day and previous days. Consequently, residuals were included in the mean heat index model.

Figure 35. Partial ACF plot for the maximum heat index against lag days without residuals included for the Northern region

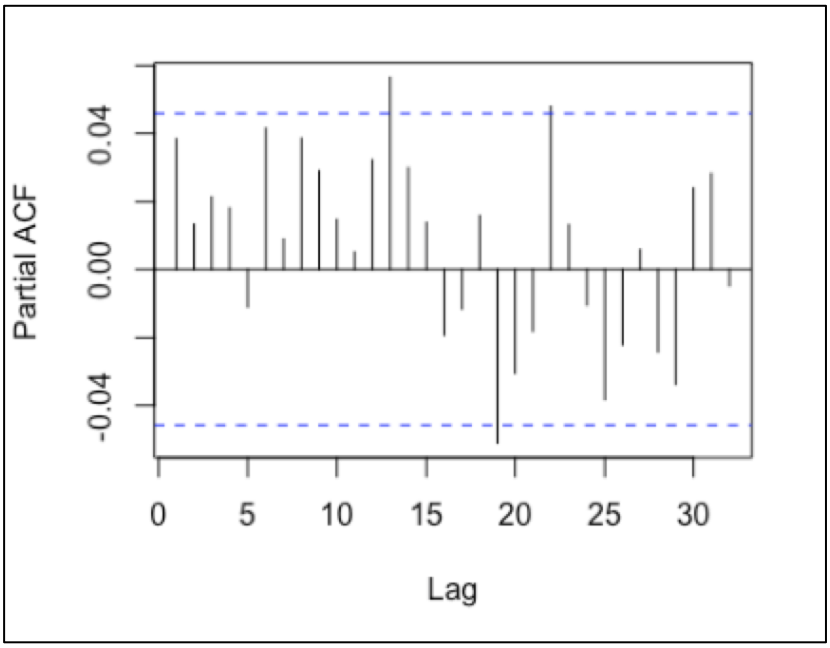


Figure 36. Partial ACF plot of the mean heat index against lag days without residuals included for the Northern region

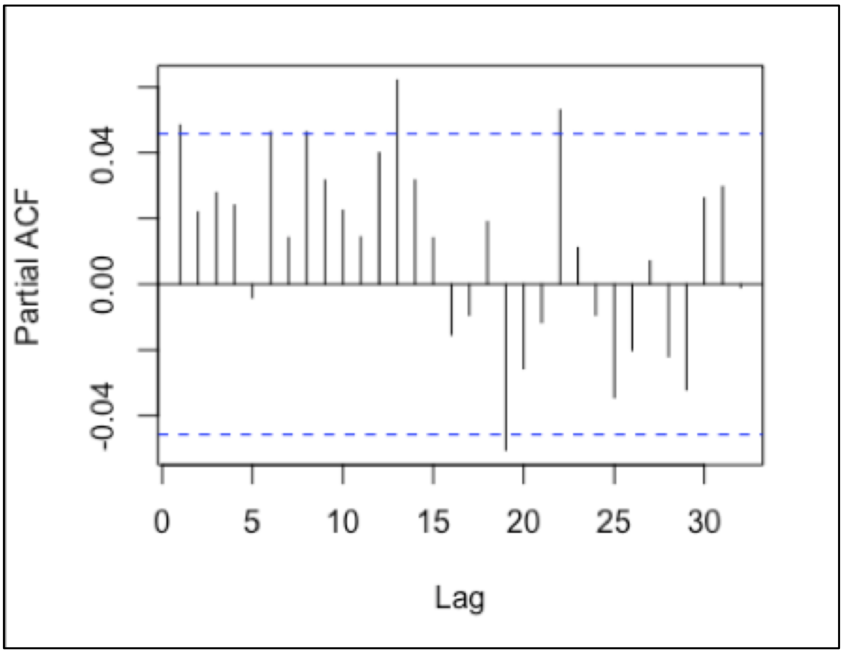
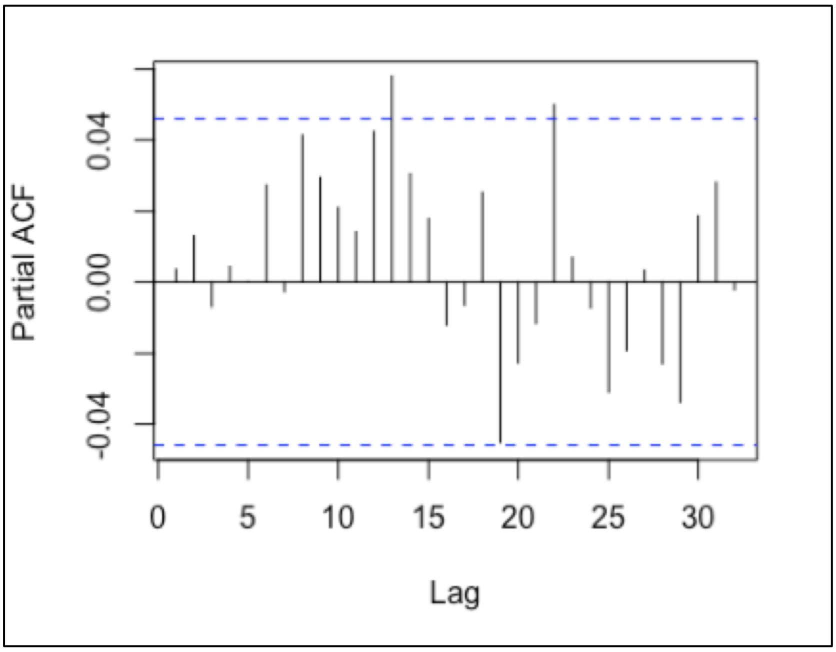


Figure 37. Partial ACF plot of the mean heat index against lag days with residuals included for the Northern region



The goodness of fit for the Northern region model

Table 27 and Table 28 show the goodness of fit for the Northern region model. Considering the AIC values, lag 0 was the best fitting model for both the maximum and the mean heat index.

Table 27. Goodness of fit results for the analyses of the maximum heat index for a no lag day to seven lag days for models without residual inclusion in the model for Northern region

Max HI	Without residual				
Lag days	R^2	X^2	df	X^2/df	AIC
0#	0.369	1973.12	1825	1.081	4503.3
1	0.362	1988.86	1809	1.099	4523.1
2	0.356	2002.09	1808	1.107	4537.4
3	0.353	2015.83	1807	1.116	4549.2
4	0.354	2019.06	1806	1.118	4548.4
5	0.352	2026.83	1805	1.123	4553
6	0.357	2018.96	1804	1.119	4540.6
7	0.354	2018.42	1803	1.119	4548.7

Best fitting model

Table 28. Goodness of fit results for the analyses of the mean heat index for a no lag day to seven lag days for models without residual inclusion and including residuals in the model for Northern region

Mean HI	Without residual					Mean HI	With residual				
Lag days	R^2	X^2	df	X^2/df	AIC	Lag days	R^2	X^2	df	X^2/df	AIC
0	0.366	1977.21	1825	1.083	4512.5	0 #	0.377	1957.78	1818	1.077	4499.4
1	0.357	2001.48	1809	1.106	4537	1	0.367	1983.42	1818	1.090	4524
2	0.353	2010.39	1808	1.112	4548.2	2	0.364	1992.52	1818	1.096	4533.5
3	0.352	2014.94	1807	1.115	4553.6	3	0.361	1997.56	1818	1.105	4540.5
4	0.355	2011.01	1806	1.114	4557.2	4	0.358	2008.10	1818	1.105	4549.3
5	0.351	2023.11	1805	1.121	4556.1	5	0.357	2008.82	1818	1.105	4553.5
6	0.353	2018.95	1804	1.119	4550.5	6	0.358	2003.89	1818	1.102	4550.4
7	0.352	2016.27	1803	1.118	4553.8	7	0.356	2002.46	1818	1.101	4554.4

Best fitting model

The relative risks of HRIs against the heat index for the Northern region

Both the maximum and the mean heat index were associated with an increase in daily HRIs. However, the mean heat index model offered a better fitting model than the maximum heat index considering the AIC was smaller *(see Table 29).*

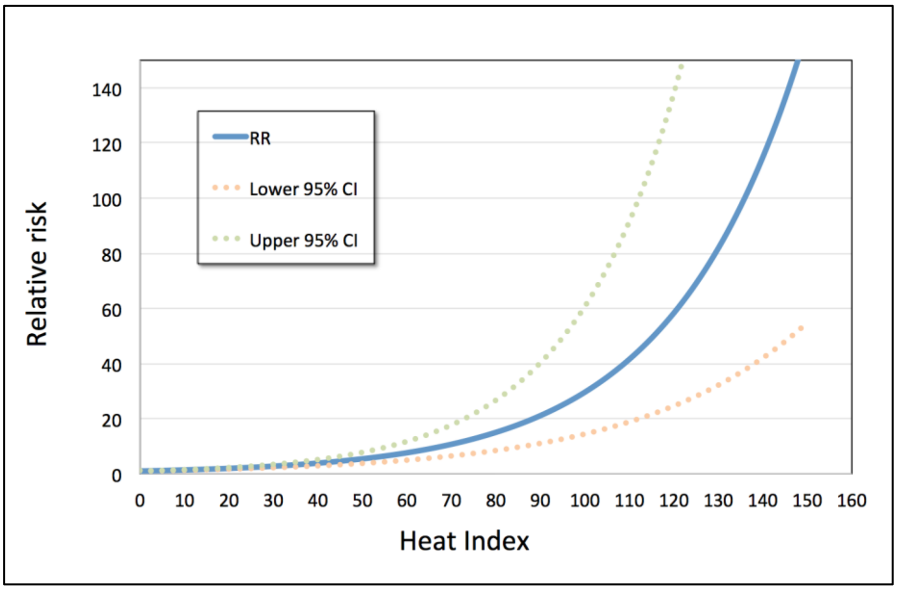
Table 29. Analysis of the regression coefficients (β) for the heat index for Northern region

Variable	Lag	β	ε	T-value	AIC
MeanHI	0	0.033885	0.003665	9.246*	4499.4
MaxHI	0	0.032340	0.003407	9.493*	4503.3

* Statistical Significance level – α (0.001)

As with the Central region, the relative risk of HRI hospitalisations against the heat index for the Northern region was also calculated from the mean heat index model. The plots of the relative risk of HRI hospitalisation against the heat index for the Northern region are shown in figure 38. An increase in the daily mean heat index in the Northern region was associated with an increase in daily HRIs on the same day (lag 0). The relative risk of HRI hospitalisations in the Northern region at the 25th, the 75th and 90th percentile of the mean of heat index were 15.79 (95%CI = 15.38–45.23) and 21.76 (95% CI = 21.66–72.94) and 24.84 (95%CI = 24.54–86.79), respectively.

Figure 38. Estimates of relative risk of HRIs by the heat index for the Northern region



4.7.3. Northeastern region model

Table 30 shows that degrees of freedom 7 gave the lowest AIC value; thus, Df = 7 gave the best fit for the Poisson regression model of the North-eastern region.

Table 30. Comparison of models by AIC for seasonal adjustment for the Northeastern region

Number of degrees of freedom/year	Maximum heat index	Mean heat index
4	4923	4906.4
5	4917	4901.1
6	4907.7	4893.2
7#	4906.1	4892.6
8	4912	4899

Best fit degrees of freedom

The lines in the Partial ACF plot were out of range in figure 39 and figure 41 indicating a strong autocorrelation between data from one day and previous days. As a result, residuals were included in both the maximum and the mean heat index model.

Figure 39. Partial ACF plot for the maximum heat index against lag days without residuals included for the Northeastern region

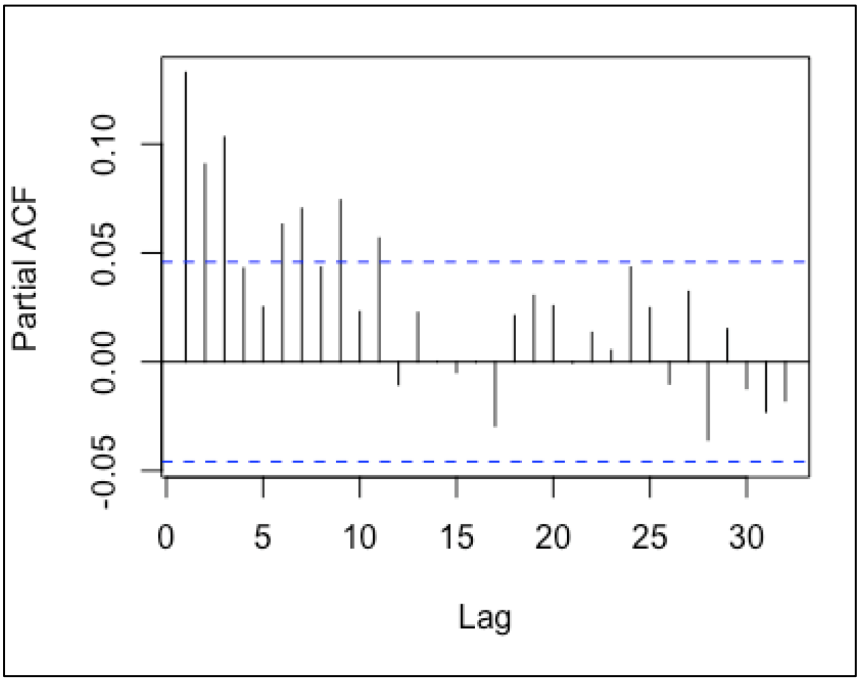


Figure 40. Partial ACF plot for the maximum heat index against lag days with residuals included for the Northeastern region

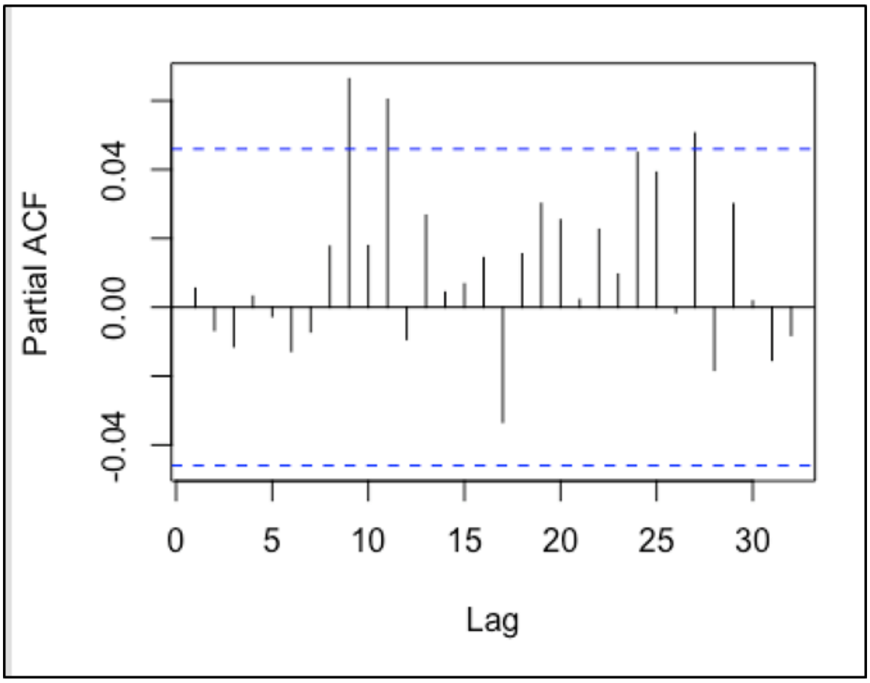


Figure 41. Partial ACF plot for the mean heat index against lag days without residuals included for the Northeastern region.

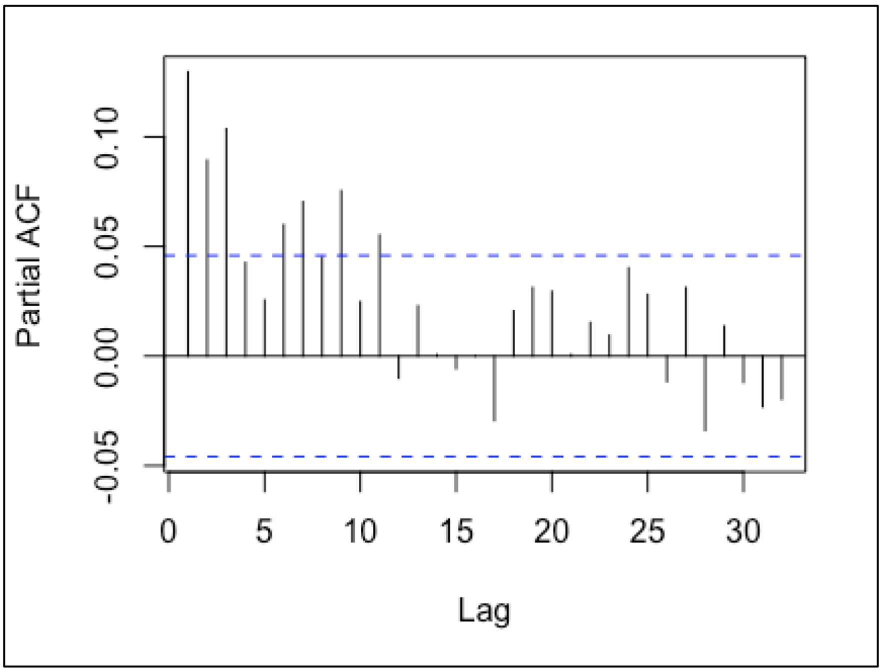
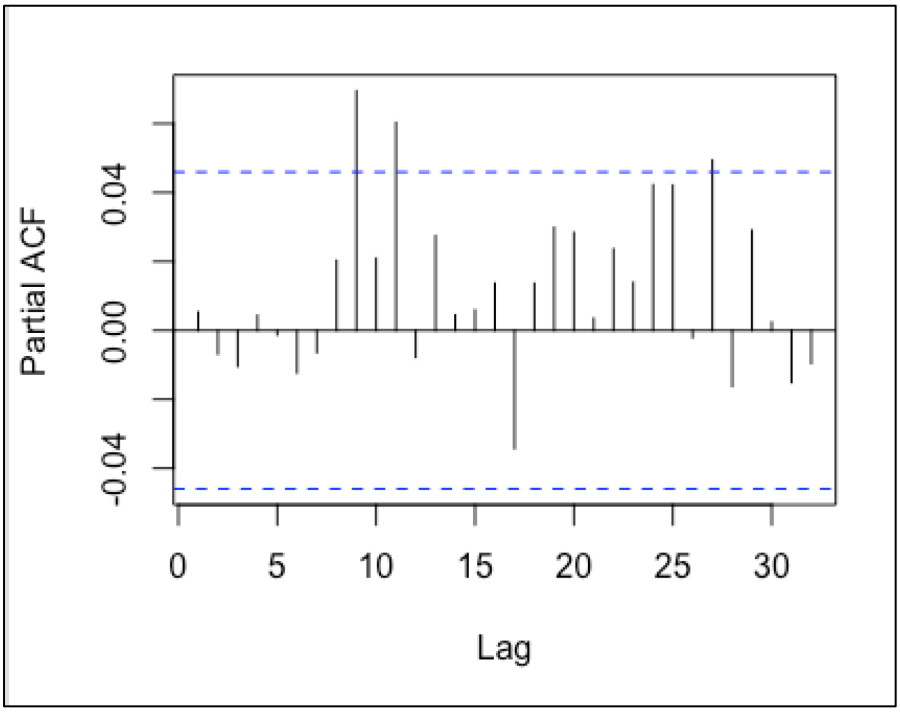


Figure 42. Partial ACF plot for the mean heat index against lag days with residuals included for the Northeastern region



The goodness of fit for the North-eastern region model

Table 31 and Table 32 show the goodness of fit for the north-eastern region model. Considering the AIC value, lag 0 was the best fitting model for both the maximum and the mean heat index.

Table 31. Goodness of fit results for the analyses of the maximum heat index for a no lag day to seven lag days for models without residual and including residuals in the model for north-eastern region.

Max HI	Without residual					Max HI	With residual				
Lag days	R^2	X^2	df	X^2/df	AIC	Lag days	R^2	X^2	df	X^2/df	AIC
0#	0.390	2120.38	1825	1.162	4906.1	0	0.424	2043.62	1818	1.124	4816.5
1	0.381	2159.94	1809	1.194	4932.9	1	0.412	2084.63	1818	1.147	4852.3
2	0.372	2189.17	1808	1.211	4959.8	2	0.403	2120.30	1818	1.166	4881
3	0.366	2219.15	1807	1.228	4977.1	3	0.397	2149.45	1818	1.182	4900.7
4	0.361	2245.00	1806	1.243	4992.9	4	0.391	2174.09	1818	1.196	4918.4
5	0.367	2234.41	1805	1.238	4988.3	5	0.392	2164.05	1818	1.190	4913.3
6	0.362	2226.89	1804	1.234	4989.9	6	0.392	2157.74	1818	1.186	4915.6
7	0.362	2234.81	1803	1.239	4991.0	7	0.391	2162.74	1818	1.189	4917.3

Best fitting model

Table 32. Goodness of fit results for the analyses of the mean heat index for a no lag day to seven lag days for models without residual and including residual in the model north-eastern region

Mean HI	Without residual					Mean HI	With residual				
Lag days	R^2	X^2	df	X^2/df	AIC	Lag days	R^2	X^2	df	X^2/df	AIC
0#	0.395	2103.65	1825	1.153	4892.6	0	0.428	2031.85	1818	1.118	4806.6
1	0.385	2135.91	1809	1.181	4922.9	1	0.415	2070.75	1818	1.139	4845.7
2	0.375	2175.82	1808	1.203	4952.4	2	0.405	2112.04	1818	1.161	4871.1
3	0.367	2215.95	1807	1.226	4974.6	3	0.396	2151.09	1818	1.183	4902
4	0.362	2245.49	1806	1.243	4991.1	4	0.391	2180.18	1818	1.199	4980
5	0.362	2237.11	1805	1.239	4989.9	5	0.391	2172.83	1818	1.195	4918.75
6	0.364	2223.94	1804	1.233	4986.2	6	0.392	2159.86	1818	1.186	4915.6
7	0.362	2233.32	1803	1.239	4991.2	7	0.389	2167.21	1818	1.192	4922.3

Best fitting model

The relative risks of HRI against the heat index for the North-eastern region

Both the maximum and the mean heat index were associated with an increase in daily HRIs. However, the mean heat index model offers a better fitting model than the maximum heat index considering the AIC was smaller *(Table 33.)*

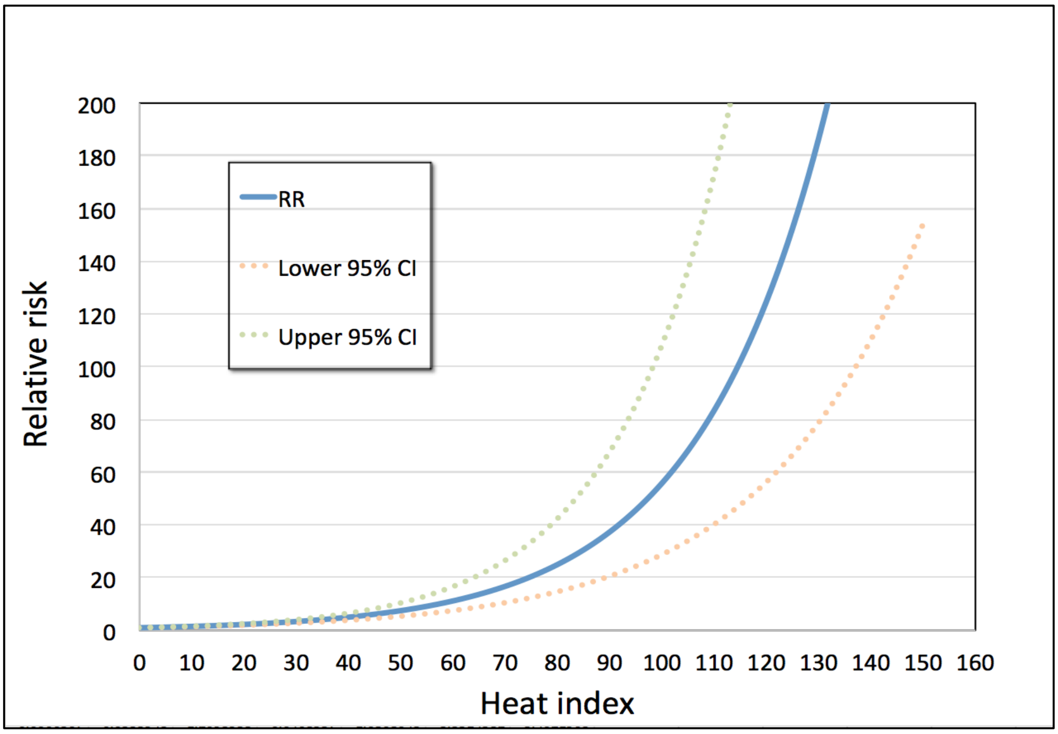
Table 33. Analysis of the regression coefficients (β) for the heat index for North-eastern region

Variable	Lag	β	ε	T-value	AIC
MeanHI	0	0.040225	0.003383	11.891*	4806.6
MaxHI	0	0.033753	0.002996	11.264*	4816.5

* Statistical Significance level – α (0.001)

The relative risk of HRI hospitalisation against the heat index for the north-eastern region was calculated from the mean heat index model. The plots of the relative risk of HRI hospitalisation against the heat index for the north-eastern region are shown in figure 43. An increase in the daily mean heat index in the north-eastern region was associated with an increase in daily HRIs on the same day (lag 0). The relative risk of HRI hospitalisations in the north-eastern region at the 25th, the 75th and 90th percentile of the mean of the heat index were 26.258 (95%CI = 18.79–28.31), 39.75 (95%CI = 11.33–41.81) and 46.14 (12.57–49.07), respectively.

Figure 43. Estimates of relative risk of HRI by the heat index for the Northeastern region



4.7.4. Southern region model

Table 34 shows that degrees of freedom 8 gave the lowest AIC value; thus, Df = 8 gave the best fit for the Poisson regression model of the Southern region (Table 34).

Table 34. Comparison of models by AIC for seasonal adjustment for the Southern region

Number of degrees of freedom/year	Maximum heat index	Mean heat index
4	4394.2	4392.2
5	4394.7	4392.8
6	4394.9	4393.2
7	4385.8	4383.4
8#	4377.1	4374.9

Best fit degrees of freedom

The lines in the Partial ACF plot were not out of range (figure 44 and figure 45), indicating no strong autocorrelation between data from one day and the previous days. As a result, residuals were not included in the maximum and the mean heat index model for the Southern region.

Figure 44. Partial ACF plot for the maximum heat index against lag days without residuals included for Southern region

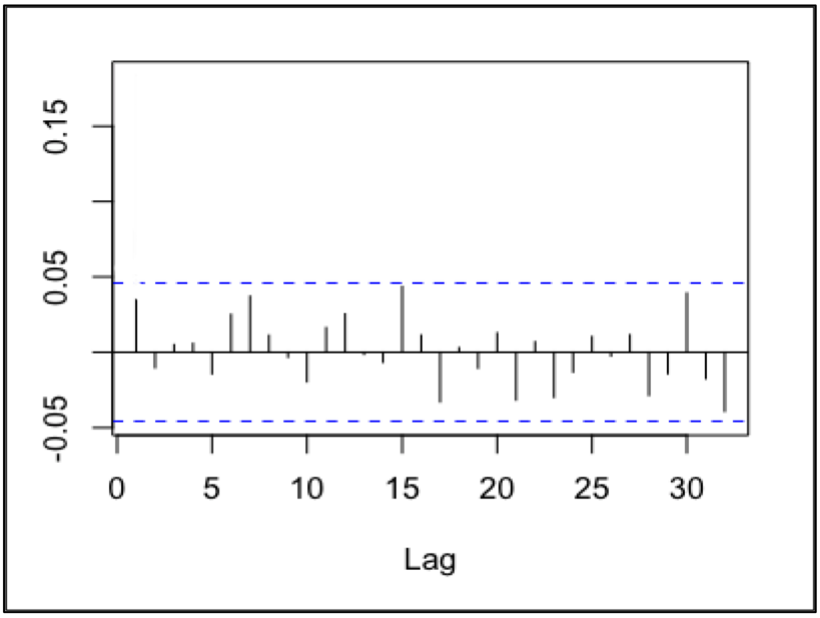
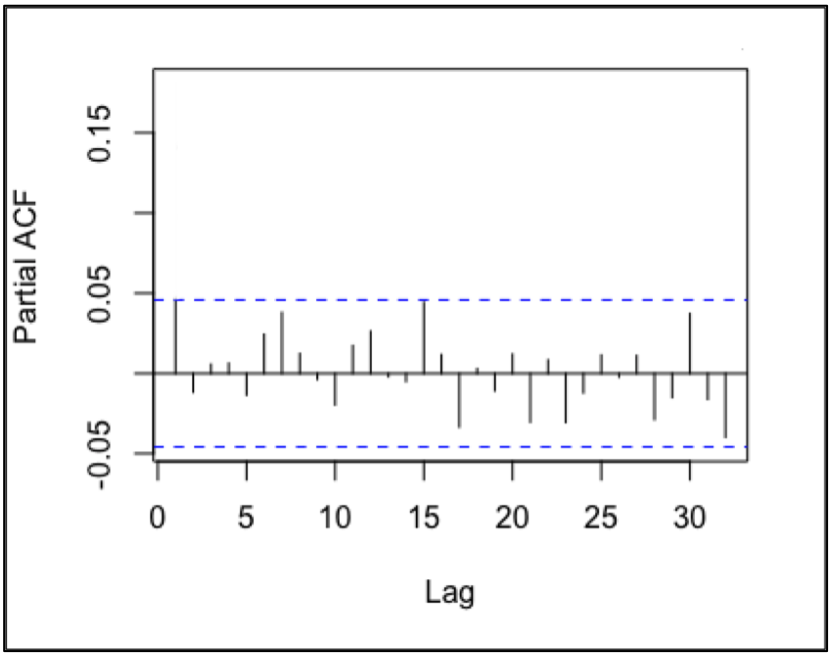


Figure 45. Partial ACF plot for the mean heat index against lag days without residuals included for the Southern region



The goodness of fit for the Southern region model

Table 35 and Table 36 show the goodness of fit for the Southern region model. Considering the AIC value, lag 0 was the best fitting model for both the maximum and the mean heat index.

Table 35. Goodness of fit results for the analyses of the maximum heat index from a no lag day to seven lag days for models without residual inclusion in the model for Southern region

Max HI	Without residual				
Lag days	R^2	X^2	df	X^2/df	AIC
0	0.297	3045.53	1825	1.669	4377.1*
1	0.296	3035.06	1809	1.668	4380.5
2	0.296	3032.08	1808	1.677	4380.3
3	0.296	3036.26	1807	1.680	4379.5
4	0.296	3038.55	1806	1.682	4381.1
5	0.297	2961.48	1805	1.641	4377.6
6#	0.298	2942.06	1804	1.631	4375.8*
7	0.298	3024.85	1803	1.677	4376.4

Best fitting model, * significant at $p < 0.05$

Table 36. Goodness of fit results for the analyses of the mean heat index for a no lag day to seven lag days for models without residual inclusion in the model for Southern region

Mean HI	Without residual				
Lag days	R^2	X^2	df	X^2/df	AIC
0#	0.299	3029.89	1825	1.660	4374.9**
1	0.298	3024.85	1809	1.672	4375.4**
2	0.297	3006.25	1808	1.663	4377.2
3	0.296	3029.74	1807	1.677	4379.7
4	0.296	3023.59	1806	1.674	4380.4
5	0.298	2949.80	1805	1.634	4375.7*
6	0.299	2957.66	1804	1.639	4375.5*
7	0.298	3018.75	1803	1.674	4375.6

Best fitting model, ** significant at $p < 0.01$, * significant at $p < 0.05$

The relative risks of HRI against the heat index for the Southern region

The mean heat index was associated with an increase in daily HRIs. In contrast, the maximum heat index model showed a negative association with daily HRIs. However, the mean heat index model gave a better fitting model than the maximum heat index considering the AIC was smaller *(Table 37).*

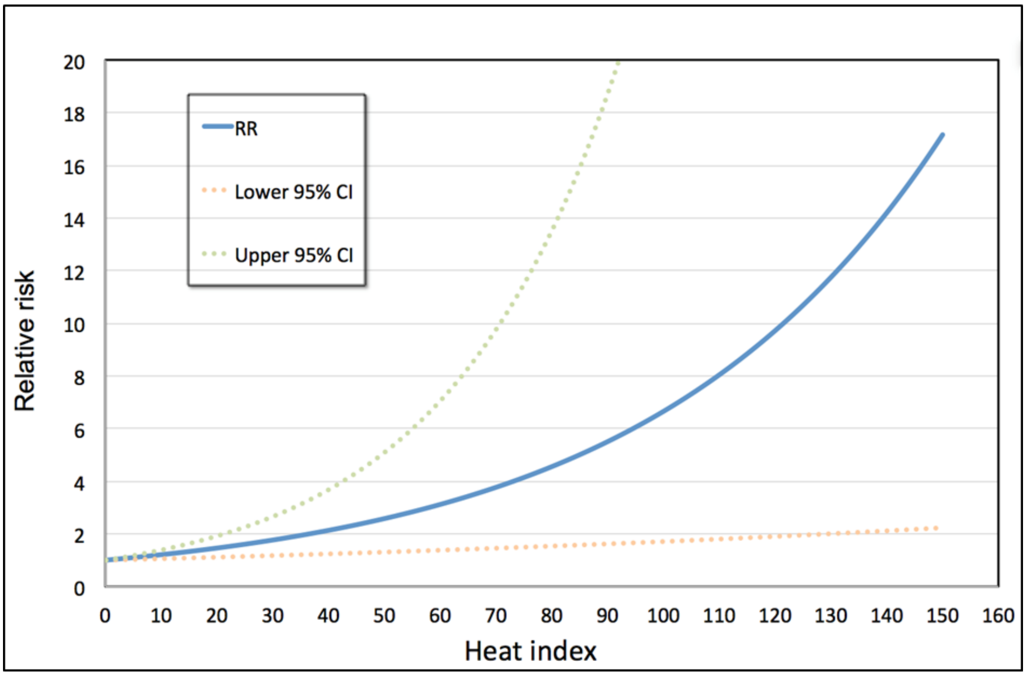
Table 37. Analysis of the regression coefficients (β) for the heat index for Southern region

Variable	Lag	β	ε	T-value	AIC
MeanHI	0	0.018950	0.006939	2.731*	4374.9
MaxHI	6	-0.015836	0.007382	-2.145*	4375.8

* Statistical Significance level – α (0.001)

The relative risk of HRI hospitalisations against the heat index for the Southern region was calculated from the mean heat index model. The plots of the relative risk of HRI hospitalisations against the heat index for the Southern region are shown in figure 46. An increase in the daily mean heat index in the Southern region was associated with an increase in daily HRIs on the same day (lag 0). The relative risks of HRI hospitalisation in the Southern region at the 25th, the 75th and the 90th percentile of the mean of the heat index were 5.01 (95%CI = 1.58–15.95), 5.56 (95%CI = 1.62–19.04) and 5.80 (95%CI = 1.64–20.46), respectively.

Figure 46. Estimates of relative risk of HRIs by the heat index for the Southern region



4.8 Summary

There were 6,895 HRI hospitalisations over the chosen study period. The overall incidence was 2.14 visits per 100,000 persons per year. The highest incidence per 100,000 persons per year was 3.41 visits in the Southern region, followed by 3.17 visits in the Northern region. The majority of patients were female. The highest incidence was in the 80–84 year old age group, with an age–specific incidence rate of 7.21 per 100,000 persons per year. An increase in the daily mean heat index in every region of Thailand was associated with an increase in daily HRIs on the same day (lag 0). There was a marked increase in daily HRI after the 90th percentile and for this reason this was chosen as a cut-off point for phase 2. The choice of the 25th and the 75th percentiles was made taking into account the likely impact in terms of warning days *(Table 38).*

Table 38. Relative risks of HRIs at the 25th, 75th and 90th percentiles of the heat index in each region

	Relative risks at (percentile) with 95% CI interval		
Regions	25th	75th	90th
Central	55.36 (25.21 – 121.55)	79.59 (33.76 – 187 – 64)	96.13 (39.31 – 235.29)
Northeastern	15.79 (15.38 – 45.23)	21.76 (21.66 – 72.94)	24.84 (24.54 – 86.79)
Northern	26.258 (18.79 – 28.31)	39.75 (11.33 – 41.81)	46.14 (12.57 – 49.07)
Southern	5.01 (1.58 – 15.95)	5.56 (1.62 – 19.04)	5.80 (1.64 – 20.46)

At the end of this phase, the most significant finding was that the relative risk of HRI hospitalisations increased positively with an increase in the heat index in every region of Thailand. In the Central region, a statistically significant association was shown that relative risk increased by 20.8% when the heat index increased from the 75th to the 90th percentile in the lag 0 model. In the Northern region, a statistically significant association was shown that relative risk increased by 16.1% when the heat index increased from the 75th to the 90th percentile in the lag 0 model. In the North-eastern region, a statistically significant association was shown that relative risk increased by 14.2% when the heat index increased from 75th to 90th percentile in the lag 0 model. In the Southern region, a statistically significant association was shown that relative risk increased by 4.3% when the heat index increased from 75th to 90th percentile in the lag 0 model.

Chapter 5: Results of Consensus Methods to Develop a HHWS for Thailand

5.1. Introduction

The issue that straddles phases one and two of the study concerns the decision about what a warning threshold cut-off point should be at each level of the HHWS. Section 1 of the questionnaire required the expert panel to determine the threshold level for the HHWS. Sections 2–4 required that all components of the HHWS were completed by the experts (see Appendixes A-1, A-2, A-3). The results of the Delphi and focus group results are detailed in this chapter.

5.2. e-Delphi (HHWS consensus development part 1)

5.2.1. Demographics of the expert panel

For this study, individuals were considered experts if they were from Thailand and had published one or more publications on the climate or climate and health. Sixteen experts agreed to join the panel and none subsequently dropped out. The panel was composed of 10 men (62.5%) and six women (37.5%). Most of the experts had a doctorate degree as their highest education level (93.75%). The primary academic interests of the expert panel were diverse *(see Table 39).*

Table 39. Characteristics of the participants in the e-Delphi phase

Demographics	**N (16)**
Job title	
Academic experts	4
Government experts	4
Military experts	1
Gender	
Male	10
Female	6
Highest degree level	
Master	1
Doctorate	15

Demographics	N (16)
Age	
30 - 40	1
40 - 50	9
50 - 60	6
Primary career focus	
Epidemiologist	3
Occupational medicine physician	2
Environmental medicine physician	2
Occupational and Environmental Health	2
Geography	1
Climatology	2
Public Health	1
Oceanography and climatology	1
Meteorologist	1

5.2.2. Delphi Round 1

Round 1 started on December 25, 2017 and ended on January 24, 2017. Two weeks after the questionnaire was sent by email, seven experts were reminded by phone to check whether they had received the email. The Round 1 questionnaire was created in Google form platform (online questionnaire) and the link to access the questionnaire was attached in the email.

A 100 percent response rate was achieved after three weeks. The consensus level of opinion was set at more than 70%. Consensus was achieved (>70% agreed or strongly agreed with the statement) for 22 of 31 statements in this round. In addition, the responses to the open-ended questions were summarised and the results informed the creation of the Round 2 questionnaire.

5.2.3 Delphi Round 2

Round 2 started on February 14, 2018 and ended four weeks later. A 100 percent response rate was achieved within the deadline. The reminder process remained the same as for Round 1. In Round 2, the analysis from the first round formed two statements added on within this round. Although some Delphi surveys remove from subsequent rounds items that have achieved consensus, in this study the 31 items were retained so that the strength of consensus in Round 2 could be assessed in comparison with the other items. Hence, 33 statements were sent to the same sixteen experts.

5.2.4 Delphi Round 3

Round 3 started on April 1, 2018 and ended on April 15, 2018. A shorter period for responses was granted since a focus group meeting would be held in late April. This was explained in a cover letter attached to the email sent to all the experts. A 100 percent response rate was again achieved. No reminder was made for this final round. However, it did prove necessary to phone one expert who had not sent a response by the deadline.

In the analysis from Round 2, Component 1, the threshold level for Thailand's HHWS, was removed round due to the fact that a strong agreement was made with more than 70 per cent consensus in each region of the country. Hence, 32 statements were retained to compare the strength of consensus between Round 2 and Round 3. Moreover, one expert commented on item 17 (about applying sunscreen and wearing a hat and light scarf being good practice for prevention of heat exposure). He felt the item was not clear. His exact comment was: “The question asks about more than one point, so it is confusing. If I think sunscreen is not but a big hat is, what choice should I choose?” Therefore, item 17 was divided into two new statements (17.1 and 17.2). Eventually, 33 statements were sent to the experts for consideration in Round 3.

5.3 Delphi results from Round 1 to Round 3

5.3.1 Round 1 and Round 2, Component 1: Threshold levels for Thailand's HHWS

This section addresses the selection of threshold levels for a HHWS. The WHO identifies three levels of heat warning: pre-alert, higher alert and highest alert. Thus, to apply the threshold level for a HHWS in Thailand, the experts had to consider and select cut–off points in each chart for different threshold levels. The results between Round 1 and Round 2 are shown in Table 40. A consensus on the cut–off point for heat health warning threshold levels was reached for all regions in Round 2.

Table 40. Percentage of responses on threshold levels for Thailand's HHWS

Selection on threshold levels by region	Round 1			Round 2			Consensus
	25^{th} - 75^{th}	25^{th} - 90^{th}	75^{th} - 90^{th}	25^{th} - 75^{th}	25^{th} - 90^{th}	75^{th} - 90^{th}	
Central	12.5	25.0	62.5	12.5	12.5	75.0	Yes
Northern	18.75	6.25	75.0	6.25	6.25	87.5	Yes
Northeastern	18.75	6.25	75.0	12.5	0	87.5	Yes
Southern	18.75	18.75	62.5	6.25	12.5	81.25	Yes

5.3.2 Component 2; Issuance of warning and communication

In Round 1, there were ten statements in Component 2 about the issuance of warnings and communications. Seven from the ten statements reached a consensus. Statements 4, 5 and 6 achieved consensus, with more than 70% strongly in agreement.

In Round 2, there were ten statements in Component 2, the same as in Round 1. The movement of agreement was made between Round 1 and Round 2 (see Table 41). However, only five from ten statements reached consensus: statements 4, 5, 6 and 7 achieved consensus, with more than 70% strongly in agreement.

In Round 3, I decided to retain every statement although consensus was achieved from the previous round, aiming to identify any movement change in agreements until the end of the final round. Thus, ten statements were conserved in this round. A significant movement changed was clearly seen in the final round from agree to strongly agree. Item 1 achieved consensus added on from the previous round, meaning six from ten statements eventually reached consensus *(see Table 41).*

Table 41. Percentage of responses to the statements of issuances of warnings and communications

Statements	Round 1					Round 2					Round 3					
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Consensus
1. The HHWS for Thailand should be combined with the air-quality warning system.	0	12.5	12.5	25.0	50.0	6.25	12.5	12.5	12.5	56.25	0	12.5	6.25	12.5	68.75	Yes
2. The heat information centre should be established as a standalone organisation to improve the quality of information.	0	12.5	6.25	43.75	37.5	6.25	25.0	0	37.5	31.25	6.25	31.25	0	37.5	25.0	No
3. The heat information centre can join with the national public health system by adding heat information, capacity of surveillance and rapid response on HRIs.	6.25	6.25	6.25	37.5	43.75	12.5	0	0	18.75	68.75	6.25	0	0	12.5	81.25	Yes
4. The population older than 60 is an important target group for surveillance.	6..25	0	0	6.25	87.5	25.0	0	0	0	75	6.25	0	0	6.25	87.5	Yes
5. The population aged under 5 is an important target group for surveillance.	0	6.25	6.25	12.5	75.0	12.5	6.25	0	0	81.25	6.25	6.25	0	0	87.5	Yes

Statements	Round 1					Round 2					Round 3					Consensus
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
6. The population working outdoors is an important target group for surveillance	0	0	6.25	18.75	75	18.75	0	0	12.5	68.75	0	0	0	0	100	Yes
7. The population who have an underlying disease is an important target group for surveillance.	0	0	0	31.25	62.75	6.25	0	0	18.75	75.0	0	0	0	12.5	87.5	Yes
8. The warning system should issue a warning once a day (any morning, afternoon or evening).	6.25	37.5	18.75	31.25	6.25	12.5	50.0	6.25	25.0	6.25	6.25	62.5	6.25	18.75	6.25	No
9. The warning system should issue warnings three times a day (morning, afternoon and evening).	0	31.25	37.5	18.75	12.5	0	31.25	50.0	12.5	6.25	0	37.5	50.0	6.25	6.25	No

Statements	Round 1					Round 2					Round 3					
	Television	Radio	Social Media	SMS	Other	Television	Radio	Social Media	SMS	Other	Television	Radio	Social Media	SMS	Other	Consensus
10. In a critical period, what is the best media to spread the warning message?	0	12.5	12.5	25.0	50.0	6.25	12.5	12.5	12.5	56.25	0	12.5	6.25	12.5	68.75	Not applicable

5.3.3. Component 3: Intervention at the individual level

Component 3 relates to the interventions recorded in the literature review and the experiences of HHWSs in other countries. The experts agreed on the suitable interventions that need to be established for individual populations in a HHWS for Thailand. This component comprised 14 interventions, nine of which reached a consensus in Round 1. Then, all fourteen interventions were retained to evaluate the strong commitment for Round 2 and Round 3. One more statement was added in Round 2 after the analysis performed in Round 1. However, no significant movement was recorded between Round 1 and Round 2 and again nine from fifteen reached a consensus after Round 2. As mentioned above, item 17 was split into 17.1 and 17.2 in Round 3 following a comment from an expert in Round 2.

Finally, sixteen statements were retained in this round because of the one statement that was divided into two. A significant movement change in the final round from agree to strongly agree was clearly shown. Item 1 achieved consensus, added on from the previous round, meaning six from sixteen statements reached a consensus *(see Table 42).*

5.3.4. Component 4: Intervention at the community level

There were five interventions for Component 4 on interventions at the community level. As in Component 3, the experts decided whether each intervention would be appropriate for a HHWS in Thailand. Table 43 shows the percentage of responses for interventions at the community level. Four from five interventions achieved consensus in Round 1. Regarding the comments from Round 1, two interventions were added to the Round 2 questionnaire. Four from seven interventions achieved consensus, the same as in Round 1.

In the final round, seven interventions were retained for this component. A consensus was reached on item 30 in this round. Thus, five from seven statements achieved consensus.

Table 42. Comparing responses to intervention at the individual level for a HHWS

Statements	Round 1					Round 2					Round 3					Consensus
	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**	
11. Using air conditioning can reduce the individual risk of disease.	0	0	0	62.5	37.5	0	0	0	75.0	25.0	0	0	0	75.0	25.0	Yes
12. A fan can reduce the individual risk of disease.	0	25.0	31.25	31.25	12.5	0	12.5	25.0	56.25	6.25	0	6.25	31.25	62.5	0	No
13. Increasing self-awareness of how to maintain core body temperature can reduce the risk of disease.	0	0	0	50.0	50.0	6.25	0	0	31.25	62.5	6.25	0	0	25.0	68.75	Yes
14. Encouraging self-detected symptoms and signs of HRIs can reduce the risk of disease.	0	0	0	50.0	43.75	6.25	0	0	56.25	37.5	0	0	0	50	50	Yes
15. Keeping out of the sun between 11.00 a.m. and 3.00 p.m. is good practice for prevention of heat exposure.	0	0	6.25	56.25	37.5	0	0	6.25	68.75	25.0	0	0	0	81.25	18.75	Yes

Statements	Round 1					Round 2					Round 3					Consensus
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
16. Avoiding extreme physical exertion and wearing light, loose-fitting cotton clothes is good practice for prevention of heat exposure.	0	0	6.25	50.0	43.75	6.25	0	0	56.25	37.5	0	0	0	56.25	43.75	Yes
17.1 Applying sunscreen is good practice for prevention of heat exposure.	0	12.5	6.25	68.75	12.5	0	6.25	18.75	62.5	12.5	0	25	25	43.75	6.25	No
17.2 Wearing a hat and light scarf are good practice for prevention of heat exposure	0	12.5	6.25	68.75	12.5	0	6.25	18.75	62.5	12.5	0	6.25	25	56.25	12.5	No
18. Having plenty of cold drinks (two to four glasses) can reduce the risk of disease.	0	0	12.5	62.5	25.0	0	0	0	81.25	18.75	0	0	0	93.75	6.25	Yes
19. Avoiding excess alcohol can reduce the risk of disease.	0	0	0	31.25	68.75	12.5	0	0	31.25	56.25	6.25	0	0	25.0	68.75	Yes

Statements	Round 1					Round 2					Round 3					Consensus
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
20. Avoiding excess caffeine can reduce the risk of disease	0	12.5	37.5	43.75	6.25	0	0	37.5	56.25	6.25	0	0	31.25	56.25	12.5	No
21. Avoiding excess hot drinks can reduce the risk of disease	0	18.75	50.0	18.75	6.25	0	0	75.0	25.0	0	0	0	68.75	31.25	0	No
22. Keeping windows that are exposed to the sun closed during the day and open at night when the temperature has dropped are good practices for prevention of heat exposure.	0	18.75	31.25	37.5	12.5	6.25	12.5	12.5	68.75	0	6.25	0	31.25	62.5	0	No
23. Keeping indoor plants and bowls of water in the house as evaporation helps cool the air is good practice for prevention of heat exposure.	6.25	0	50.0	31.25	12.5	6.25	0	37.5	56.25	0	0	12.5	18.75	62.5	6.25	No

Statements	Round 1					Round 2					Round 3					
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Consensus
24. Considering putting up external shading outside windows and growing trees and leafy plants near windows to act as natural air-conditioners are good practices for prevention of heat exposure.	0	0	0	56.25	43.75	6.25	0	0	62.5	31.25	0	0	0	62.5	37.5	Yes

Table 43. Comparing responses to intervention at the community level for a HHWS

Statements	Round 1					Round 2					Round 3					
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Consensus
25. Using artificial rain to reduce the surface temperature in order to reduce risk at the level of the population is useful for preventing HRIs.	0	6.25	31.25	43.75	18.75	0	6.25	25.0	50.0	18.75	0	6.25	25.0	56.25	12.5	No
26. Establishing a cooling centre or a temporary cooling shelter are good practices for prevention of heat exposure.	0	0	6.25	75.0	18.75	0	0	0	87.5	2	0	0	0	81.25	18.75	Yes
27. Increasing facilitation and capability of rapid surveillance teams are good practices for prevention of heat exposure.	0	0	12.5	62.5	25.0	0	0	0	68.75	31.25	0	0	0	56.25	43.75	Yes
28. During heat events, a buddy system should be provided to monitor isolated, elderly, ill or very young people and ensure they are able to keep cool.	0	0	0	56.25	43.75	6.25	0	0	62.5	31.25	0	0	0	81.25	18.75	Yes
29. The medical service should increase staffing	0	0	12.5	62.5	25.0	0	0	6.25	75.0	18.75	0	0	0	81.25	18.75	Yes

Statements	Round 1					Round 2					Round 3					
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Consensus
during warnings in anticipation of higher demand.																
30. Monitoring in-house temperatures by using a thermometer is good practice for awareness of heat exposure.	-	-	-	-	-	0	0	31.25	37.5	31.25	0	0	18.75	50.0	31.25	Yes
31. Monitoring urine colour in critical periods is good practice to detect the risk of disease.	-	-	-	-	-	0	0	31.25	50.0	6.25	0	0	25.0	62.5	6.25	No

5.4. Focus group (HHWS consensus development part 2)

The data gained from the focus groups were analysed to evaluate the HHWS model from the previous phase. The twenty consensus statements in the Delphi Round 3 were summarised along with non-consensus statements. Both were contained in the topic guide before the focus group meeting started, aiming to provide more information on content and agreement in each component of the HHWS. The analysis of the focus group was based on open coding and categorisation by the components of a HHWS.

5.4.1 Participants

Ten participants were invited, of whom two declined because of unavailability. Seven participants were from the government sector and were involved with policy development. One was from academia and was a senior expert in the climate change adaptation sector. Another was from The Royal Thai Army. The demographic data of the participants is shown in Table 44.

Table 44. The demographic data of the focus group participants

Demographics	
Job title	N (8)
National Committee on Climate Change (NCCC)	6
Academic expert (different person from Delphi)	1
Military (different person from Delphi)	1
Gender	N (8)
Male	4
Female	4

5.4.2. Qualitative findings

In general, the focus group clarified and elaborated on the Delphi results and revealed additional issues. The findings are illustrated in a combined feature that reflects both the Delphi and the focus group results.

Component 1: Threshold levels for Thailand's HHWS

From the Delphi Round 2, the experts agreed on the cut–off point for the threshold levels of a HHWS, at the 75th and the 90th percentiles of the heat index in each region *(see Table 45).*

Table 45. Warning threshold levels of the heat index in each region (the numbers in the table are based on the heat index of 2009-2014, which may vary by percentile of the heat index in any year)

Region	Pre – alert	Higher - alert	Highest alert
North-eastern	< 92	92 - 95	> 95
Northern	< 90	90 - 94	> 94
Central	< 94	94 - 98	> 98
Southern	< 90	90 - 92	> 92

Most specialists accepted the values of the proposed heat index. However, the suggested colours of each level should be changed to reflect follow the international standard. The extreme value in Thailand is different from western countries. Moreover, one expert in the focus group provided a suggestion on outcome of interest for the next project, namely that he was curious to know if any point of the heat index had affected excess mortality so a threshold point could be set from that result.

Component 2: Issuance of warnings and communications

Table 46 shows that a consensus was reached on the following statements in the Delphi Round 3.

Table 46. Consensus statements for Component 2

	Consensus Level
The HHWS of Thailand should be combined with the air-quality warning system.	81.3%
The heat information centre can join with the national public health system by adding heat information, capacity of surveillance and rapid response to HRIs.	93.8%
The population aged over 60 is an important target group for surveillance.	93.8%
The population aged below five is an important target group for surveillance.	87.5%
The population that works outdoors is an important target group for surveillance.	100%
The population that has an underlying disease is an important target group for surveillance.	100%

As the experts reviewed the consensus from the Delphi round on pollution and the heat index, it was clear that periods of high pollution occur in hot and dry seasons, highlighting the central role of temperature. In some areas in Thailand, varied seasons affect the index, as one expert noted:

> *The different seasons affect the INDEX. In the south of Thailand, most pollutions are from a burning on Sumatra Island. Additionally, personal health and heat are still concerned.*

In addition, some occupations were categorised as high-risk groups, such as jobs exposed to direct sun, especially soldiers, construction workers, and athletes. According to one expert:

> *Those who are working outdoors such as construction workers and athletes should be concerned.*

This statement reflects the fact that significant groups of people are at enhanced risk of HRIs such as dehydration and stroke. Therefore, there ought to be measures put in place to help protect them.

In the aspect of a warning system and communications, the most prominent consensual idea was to educate local people. Generally, two groups deemed relevant for informing about how to protect people from HRIs were local people and health service volunteers. For local people, they should be informed about how to keep themselves safe from extreme exposure to the sun and be provided with accurate knowledge and appropriate methods to help them avoid such illnesses. In the case of health service volunteers, they should be primed for any emergency situation. Moreover, they must develop their communication skills.

From the Delphi round, no consensus was reached on the following statements:

> ‘The heat information centre should be established as a standalone organisation to improve the quality of information.’
>
> ‘The warning system should issue a warning once a day (any of morning, afternoon or evening)’
>
> ‘The warning system should issue warnings three times a day (morning, afternoon and evening)’
>
> ‘At critical periods, what is the best media to spread the warning message?’

Regarding the methods used for communication, media and digital applications were introduced into the discussion. Television and radio were the general channels that most local people could access easily. Two further channels proposed were Facebook and Line[12], which have become popular ways to obtain and share knowledge and information. As one expert said:

[12] Line is a popular social application in Thailand, and 63% of the population (43,000,000 people) use it.

Generally, if we see something important, we communicate by Line of Public Health in the province. Then, it is sent to the hospitals around and health service volunteers immediately. Also, it is sent to local people.

Component 3: Intervention at the individual level

Table 47 shows that consensus was reached on the following interventions.

Table 47. Consensus interventions for individual level

	Consensus level
Using air conditioning can reduce the individual risk of disease.	100%
Increasing self-awareness of how to maintain core body temperature can reduce the risk of disease.	93.8%
Encouraging self-detected symptoms and signs of HRIs can reduce the risk of disease.	100%
Keeping out of the sun between 11.00 a.m. and 3.00 p.m. is good practice for prevention of heat exposure.	100%
Avoiding extreme physical exertion and wearing light, loose-fitting cotton clothes is good practice for prevention of heat exposure.	100%
Having plenty of cold drinks (two to four glasses) can reduce the risk of disease.	100%
Avoiding excess alcohol can reduce the risk of disease.	93.8%
Considering putting up external shading outside windows and growing trees and leafy plants near windows to act as natural air-conditioners are good practices for prevention of heat exposure.	100%

In discussing this component, three areas of preventive measures emerged: improving physical aspects, developing self-awareness, and taking the appropriate action in a certain job.

Beginning with improving physical aspects, some experts argued against installing domestic air-conditioners since they expected that this solution would not become a significant measure even it were universally used. Due to financial inequalities, this method seemed impractical for all groups. However, most experts agreed that planting trees around domestic areas could help decrease the temperature, with one expert stating:

I believe planting trees helps a lot.

This coincided with what another expert said:

Trees planted outdoors is O.K. But inside it is not.

Another measure at the individual level is to develop the self-awareness of local people. To clarify, they must be educated and provided with the correct knowledge and information to extend their awareness of how to protect themselves against HRIs. They should comprehend, for example, that it is important to avoid drinking alcohol and coffee as both lead to dehydration. According to one expert:

We must extend the knowledge that caffeine causes more urinating, which is related to dehydration.

Moreover, people should be aware of going outside on hot days or understand the importance of putting on a hat when exposed directly to the sun. It is also important to extend avoidance of the sun from 11.00 a.m. until 4.00 p.m. One traditional method of reducing exposure to the heat is to turn on an electric fan. However, people, especially the elderly, must be informed that this is actually counterproductive as using electric fans on hot days only heightens the ambient room temperature. Other pieces of information to be shared with local people include drinking sufficient amounts of water, keeping the body temperature with the proper stage and special precautions for overweight persons.

The last domain the experts included in this component was taking the correct action in certain jobs. There was a consensus of expert opinion on categorising patients' diseases and symptoms. This procedure could lead to specific warning and curing methods. Three jobs were discussed as extreme cases: construction workers, soldiers and athletes. The experts firstly suggested that people in these occupations must be informed of the right temperature to stay safe. In addition, the frequency of evaluating the temperature each day must be taken into account, with one expert stating:

> *We evaluate the weather every day at 8:00 a.m., 10:00 a.m., 1 p.m., 3 p.m. and 5:00 p.m. In the past, we evaluated it four times a day, but the statistics show an increase in HRIs in practice, so we have added one more weather evaluation. Moreover, we examine the colour of patients' urine and their body temperature in order to check the risk to dehydration.*

Other significant issues are materials used to make outfits and installing ventilation or cooling systems.

No consensus was reached on the following interventions in Component 3 of the Delphi phase:

'Using a fan can reduce the individual risk of disease.'

'Applying sunscreen is good practice for prevention of heat exposure.'

'Wearing a hat and light scarf is good practice for prevention of heat exposure'

'Avoiding excess caffeine can reduce the risk of disease'

'Keeping windows that are exposed to the sun closed during the day and open at night when the temperature has dropped are good practices for prevention of heat exposure.'

'Keeping indoor plants and bowls of water in the house as evaporation helps cool the air is good practice for prevention of heat exposure.'

The member of the focus group from the military added a number of interesting suggestions used to help protect soldiers from HRIs, such as ice bathing, soaking the forearms, and rubbing the body with a wet towel.

In summary, the experts brainstormed and offered suggestions such as drinking much more water, having a cool bath, planting trees, installing insulators on the roof, and rubbing the back of the neck with a wet towel. In terms of weather forecasts and consuming adequate water, a smart watch and smart phone will be able to facilitate these actions more effectively in the future.

Component 4: Interventions at the community level

Table 48 shows that consensus was reached on the following interventions.

Table 48. Consensus interventions for intervention at the community level

	Consensus level
Establishing a cooling centre or a temporary cooling shelter are good practices for prevention of heat exposure.	100%
Increasing the facilitation and the capabilities of a rapid surveillance team are good practices for prevention of heat exposure.	100%
During heat events, a buddy system should be provided to monitor isolated, elderly, ill or very young people and ensure they are able to keep cool.	100%
The medical services should increase staffing during warnings in anticipation of higher demand.	100%
Monitoring in-house temperatures by use of a thermometer is good practice for awareness of heat exposure	81.3%

To achieve the goal of promoting this issue in the community, the experts stressed the need for collaboration among medical specialists such as doctors, nurses, clinicians, and health service volunteers. Importantly, communities should increase the capacity of their Rapid Surveillance Teams (SRRTs) by increasing the number of medical specialists and volunteers in the community. They should organise home visits to educate local people about how to avoid HRIs. According to one expert:

> *We must emphasise the BUDDY system for Rapid Surveillance team that can adapt altogether. In terms of medical services, doctors, nurses, and hospitals should prepare themselves to handle unexpected situations.*

This reflects the cooperation within medical service teams. Moreover, a Line Application should be used as one channel to maintain contact with medical specialists and volunteers. One of the most significant points is to inform the Public Health Service in local areas to categorise heat-related symptoms.

To provide the community with a Cooling Centre or Chamber was one recommendation offered by the experts. Furthermore, illegal drugs must continue to be strictly regulated. As one expert said:

> *To manage this issue, leaflet about how to prepare themselves is distributed to all new soldiers. The strict rules are not to drink liquor and use illegal drug.*

No consensus was reached on the following interventions in Component 4 of the Delphi phase:

> ‘Using artificial rain to reduce the surface temperature in order to reduce the risk for the population is useful in preventing HRIs.’
>
> ‘Monitoring urine colour in the critical period is a good practice to detect the risk of disease.’

Although consensus was not reached on the above statements in the Delphi phase. The participants from the focus group agreed that informing people to observe their urine colour should be implemented, and it was noted that this practice is currently performed during military training in Thailand. The participant from the Royal Thai Army suggested that this intervention is useful and non-invasive because it is easy to understand and requires only a thermometer at the soldiers’ barracks. Moreover, both of these interventions come at the earliest stages of recognising a health issue for soldiers. For example, on the hot days, the soldiers can realise and prepare the equipment and methods to protect themselves from heat by monitoring the barrack’s temperature if it feels high, indicating that the temperature outside should be higher. They will prepare to drink more water or prepare the equipment needed to protect themselves while training, such as an ice bath tub, towels, and plenty of drinking water. These interventions can be applied by the general population as the government can provide financial support for a thermometers for vulnerable groups. Also, providing a thermometer is useful and these methods are easy and inexpensive.

5.5. Summary

This chapter has explored the qualitative results from both the Delphi Round and the focus group with all components as followed

Component 1. Warning Threshold Level

There are 3 warning threshold levels for a HHWS in Thailand:

- The pre-alert level is when the heat index is below the 75th percentile.
- The higher–alert level is when the heat index is between the 75th and the 90th percentiles.
- The highest–alert level is when the heat index rises above the 90th percentile.

Component 2. Issuance of warnings and communications

In future, a HHWS should be developed in combination with an air pollution warning system. The main operational office or information centre can join with the national public health system by adding heat information, thereby enhancing surveillance capacity response speeds to incidents of HRIs. Populations at risk are those older than 65 and younger than five, outdoor workers (especially athletes, construction workers and soldiers), and people who have underlying diseases.

Component 3. Interventions at the individual level

The following individual interventions will be provided for the general population when the higher or highest alert is reached:

- Using air-conditioners, particularly for the target population
- Keeping out of the sun between 11.00 a.m. and 4.00 p.m.
- Avoiding extreme physical exertion
- Wearing light, loose-fitting cotton clothes and a hat when outdoors
- Having plenty of water (two to four glasses per hour), especially on hot days
- Avoiding excess alcohol consumption

Providing the right knowledge and information to extend local people's awareness of how to protect themselves from HRIs and planting trees for shade are pre–alert level actions.

Component 4. Interventions at the community level

The following interventions at the community level will be provided when the higher or highest alert is reached:

- Establishing a cooling centre or a temporary cooling shelter
- Increasing facilitation and the capability of Rapid Surveillance Teams
- Providing a buddy system to monitor isolated, elderly, ill or very young people to ensure they are able to keep cool
- Increasing medical staffing during warnings in anticipation of higher demand
- Monitoring in-house temperatures by use of a thermometer

Chapter 6: Discussion, Conclusions and Recommendations

6.1. Introduction

In this chapter, the findings are discussed under three main headings according to the objectives of the study. First, the findings are discussed in relation to the incidence of HRIs in Thailand with the trend of their occurrence over the five years of the study (objective one). Second, the statistical associations between climatic variables and HRIs and the suitable warning threshold levels of the heat index for a HHWS for Thailand are investigated (objectives two and three). Lastly, the outline of a HHWS for Thailand is discussed in the context of the experiences of existing HHWSs in different countries and the standard guidelines provided by the WHO (objective four). This is the novel study to applied both quantitative and qualitative research techniques to fill existing knowledge gaps in the field by exploring the potential for the development of a HHWS in Thailand.

6.2. Incidence of HRIs in Thailand

This study found that HRIs were most common in older people *(see section 4.2).* The highest incidence was in the 80-84 year old group, followed by those aged 85–89, and then people aged 75–79. This is due to the fact that the elderly have a decreased ability to thermoregulate *(Tan et al., 2004; Wang et al., 2009; Schaffer et al., 2012; Sun et al., 2014; Qiao et al., 2015; Schmeltz et al., 2015)* and/or inability to employ behavioural modifications *(Olde Rikkert et al., 2009).* This study is one of two that have explored the burden of HRIs in Thailand. Thawillarp and colleagues (2015) did a descriptive study on the HRIs in Thailand (1 Jan 2010 to 30 Sep 2013). We used the same health data source from the Bureau of Policy and Strategy, Ministry of Public Health Thailand, but Thawillarp and colleagues' study period was two years shorter than this study and found 3,963 HRI visits in the period of his study, with the highest incidence in the age group of 65 years and over *(Thawillarp et al., 2015).* However, by using more finely grained age categories I was able to identify that age-related risk continues to increase beyond 65 years with the risk for those aged 80 and over greater than for the 65-79 age groups.

On the other hand, very young people (younger than four years old) have also been mentioned as a vulnerable group because they may not realise the effects of heat or the abnormal symptoms of HRIs *(Kovats and Hajat, 2008a; Zivin and Shrader, 2016).* However, this study found that those aged 0–4 years showed the lowest incidence rate

(0.58 per 100,000 persons per year). Similarly, Thawillarp and colleagues' study found the lowest incidence rate in the 0-6 years (0.6 per 100,000 persons per year). This could be explained by under diagnosis by Thai paediatricians regarding the complications that differentiate from the other symptoms and also by the fact that parents may bring their children to private clinics or private hospitals to avoid the lengthy waiting times which prevail in government hospitals. A survey by the National Statistic Office of Thailand showed that the proportion of Thai people who use private hospitals and private clinics compared to public facilities was 1:4 in 2017 *(NSO, 2017).* Thus, the number of young patients may actually be lower than the real number because the private health care sectors is not mandated to report to the government's health database system in Thailand. Another feasible explanation that may cause the lower incidence in young children could be that they are unable to explain the symptoms or causes of the symptom accurately.

My findings also showed that females had a higher incidence rate than males, at 2.59 per 100,000 persons per year for females compared to 1.67 per 100,000 persons per year for males *(see section 4.2).* In general, women have less tolerance to heat exposure than men due to the fact that they have a lower physiological tolerance threshold to heat than men *(Robine, 2007; D'Ippoliti et al., 2010; Na et al., 2013; Phung et al., 2017)*.

I observed that the HRI burden varied geographically. The highest incidence rates of HRI hospitalisations[13] were in the Southern region. Considering only the number of daily hospitalisations, the highest number of cases was in the north-eastern region, the region with the highest temperature and heat index. This finding concurs with previous observations in revealing differences in heat hospitalisations across areas *(Kovats et al., 2004; Hansen et al., 2008a; Semenza et al., 2011).* Phung and colleagues *(2017*) found that province–level effects varied across provinces in Vietnam. The risk of hospitalisation due to high temperatures was higher in the north than in the south of that country *(Phung et al., 2017).* This study did not investigate the differences between urban and rural areas because the main district in each province of Thailand may count as urban area but the rest are rural areas. For example, Nakhonrachasima is the biggest province in Thailand. It comprises 34 districts but only one - Muang district - is

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[13] Incidence rate of HRI hospitalisation is calculated by $\frac{\text{No. of new cases of HRIs hospitalisation}}{\text{Total population at risk from 2010−2014}} \times 100{,}000$

an urban area, a fact which affects the low number of hospitalisations there compared to the total number of hospitalisations from all rural districts. However, the literature review included a number of studies which have explored the association between HRIs and people living in rural and urban areas *(Schmeltz et al., 2015; Morano et al., 2016).* Rural-urban differences in HRIs may be explained by differences in the distribution of factors such as socio-economic status or access to health care or greater occupational risk factors (e.g., agricultural work in rural areas).

In contrast to most other studies, which focused on limited periods of extreme temperatures or heatwaves (*Tan et al., 2004; Gasparrini and Armstrong, 2011; Tobias et al., 2012; Chen et al., 2015; Phung et al., 2017*), my study was based on analysis of a five-year period with data from entire years and different seasons included so that seasonal effects could be analysed. However, HRIs can occur outside heatwaves and periods of extreme temperatures, especially in Thailand, where the temperature often fluctuate greatly throughout the year. The results in section 4.2 show that, in every year considered (2010-2014), HRIs in Thailand occurred in every month of the year, albeit with a peak in April. Between 2010 and 2014, both the overall number of HRIs and the extent of variation within the year increased (with greater fluctuation and more pronounced peaks in 2014 than in 2010). Thus, using entire year data to include every season of the year provides a fuller understanding of the HRI burden, as well as providing a more useful baseline for assessing changes in the HRI distribution within the population *(McMichael et al., 2008a; Muggeo and Hajat, 2009; Xiang et al., 2015; Zhang et al., 2018).* Additionally, limiting the analysis to warm periods might reduce the impact of seasonal mortality trends and increase the potential for model misspecification to conflate the seasonal impact of short-term temperature changes *(Metzger et al., 2010).*

One unanticipated finding of this study was that there were two HRI peaks over the five-year period, one in summer but the second not in summer. The second peak occurred at the beginning of the winter period. This could be explained by the fact that the harvesting season for rice begins in October and lasts until the end of November, meaning that farmers are exposed to heat while harvesting. However, understanding the precise factors involved here requires further, focused investigation.

6.3. Statistical associations between the heat index and HRIs in different regions of Thailand

I was able to suggested that the relative risks of HRI hospitalisation increase positively with an increase in the heat index *(see Section 4.6).* In the central region, a statistically significant association showed that relative risk increased by 20.8% when the heat index increased from the 75th to the 90th percentile in the lag 0 model. In the northern region, a statistically significant association showed that relative risk increased by 16.1% when the heat index increased from the 75th to the 90th percentile in the lag 0 model. In the north-eastern region, a statistically significant association showed that relative risk increased by 14.2% when the heat index increased from the 75th to the 90th percentile in the lag 0 model. In the southern region, a statistically significant association showed that relative risk increased by 4.3% when the heat index increased from the 75th to the 90th percentile in the lag 0 model.

I was able to efficiently summarise the heat-health relationship over countrywide geographical area, notably that there is regional diversity in HRI rates and the average heat index. However, the incidence rate of disease was highest in the Southern region and lowest in the Central region. This finding was unexpected and suggests that factors involving sensitivity to heat among the population in the Southern region should be explored in greater detail in the future, such as the acclimation mechanism of local people, variation in occupation and adaptation methods people use to protect themselves against heat exposure and the risk assessment of exposure to heat. In order to create an effective HHWS in Thailand, it is important to conduct region-specific research to characterise the different heat-health relationships.

I was able to provide guidelines on a HHWS framework for tropical and humid subtropical areas. This positive association corroborates with the findings of many previous studies on the relationship between the heat index and health outcomes. Morano and colleagues (2016) studied the relationship between the heat index and HRIs in Florida, a humid sub-tropical area with similar conditions to areas of Thailand. This study confirmed a 16% increase in non-work-related HRIs per 1°C increase in the same-day maximum daily heat-index *(Morano et al., 2016).* The variety of outcomes for different studies makes it difficult to compare the magnitude of relative risks. For example, Metzger and Ito (2010) assessed the public health risk of heatwaves to set the criteria for alerts for excessive heat with a Poisson time–series generalised linear model by using mortality data as the outcome of the model. They found that the heat index provided a moderately better model fit compared with a model that uses average or minimum or maximum temperatures. It is interesting to note that Metzger and Ito's study (2010) showed that the heat–mortality relationship used both parametric and non-parametric modelling approaches in their study, which had a remarkably similar magnitude of effects. This also corresponded with an earlier observation made by Phung and colleagues (2017), who performed a Poisson regression time-series analysis in Vietnam using the heat index and all causes of hospitalisation. The result of their study showed a significant association with a 2.5% (95%CI: 0.8–4.3) increase in all causes and infectious admissions at lag 0.

The main reason for the selection of HRIs as the outcome instead of mortality in this study is that HRIs are both treatable and preventable diseases if identified in the early stages *(Morano et al., 2016; Mutic et al., 2018)* and HRIs also have the highest sensitivity outcome to heat in order to identify the initial heat-health outcome relationship. Li and colleagues (2014) performed a time series analysis aimed at examining the association between high temperatures and mortality outcomes in four cities with different climatic characteristics in China. The scholars noted in their limitations of the study that morbidities such as hospitalisations were more sensitive to heat than mortality *(Li et al., 2014).*

Additionally, a report by the Center of Disease Control and Prevention (CDC) which projected 3,442 deaths in the United States *(CDC, 2006)* found that the figure was most likely an underestimation. Although nearly all the studies that have assessed the heat–health relationship for the development of a HHWS have utilised mortality data, this certainly should not be taken to imply that the only negative health outcome from excessive heat is death. However, datasets for mortality are nevertheless the most popular as they record a clear dichotomy (dead or alive), unlike hospital admissions, which assess levels of severity.

Turning to Thailand, the mortality database is not valid for heat-related death as most death certificates recorded cardiovascular failure and respiratory failure. There were nine cases from 2010–2014 that were diagnosed as heat stroke. With those mortality figures, it was impossible to find any relationship between heat-related death and heat. Compared to the quality of HRI hospitalisation database from the Bureau of Policy and Strategy, Ministry of Public Health, which is validated and controlled by disciplined of researchers and it covers the entire country. Another issue on the selection of health outcomes was elaborated on at the end of focus group, namely that excess HRIs or excess of all causes of mortality (not only heat-related deaths) could be useful to define the threshold level to make forecasting more precise. This suggestion should be acted on in further studies based on data coverage.

The main reason for selecting the heat index as a proxy for heat exposure in this study was that considering only temperature as a proxy may not be suitable for Thailand, a tropical country with high humidity. Section 2.5.1 indicated that humidity plays an important role in heat perception. The heat index is widely used in many countries (WHO, 2015; OSHA, 2017), mostly where relative humidity was seen to obscure the real effects of the direct temperature or in countries where there is a high degree of geographic diversity. A study by Phung and colleagues (2017) in Vietnam, a neighbouring country of Thailand with similar geographic and climatic features, supported the claim that a heatwave (defined by the heat index value being more than the 90th percentile for three consecutive days) is associated with an increased risk of 1,194,152 daily admissions in every province in Vietnam *(Phung et al., 2017).* Concerning geographical differences in Thailand using temperature alone is thus not an appropriate strategy for developing an effective HHWS for Thailand. I found that the mean heat index model gives a better fit than maximum heat index in every region of Thailand, demonstrated by the lower AIC *(see Section 4.7)*. Some studies have provided advantages of using a heat index for a HHWS beyond the reason that it gives the actual perception of heat. For instance, a study by Morano and colleagues (2016) conducted a time series analysis to determine the association between climate indices and HRI hospitalisations in Florida. The result revealed that the goodness of fit statistic indicated that a model using the heat index provided a better fit model compared with one that used ambient temperature (the AIC was used to compare models with different heat metrics *(Morano et al., 2016)*. Similarly, Metzger and colleagues (2010) used Poisson time-series and GAM to estimate weather–mortality relationships using various metrics, lag and compared model fit in New York city from 1990-2006. The result showed that a model including cubic functions of maximum heat index on the same and three previous days provided the best fit, a better than models using maximum, minimum, or average temperature. Moreover, they also found that goodness of fit of maximum heat index–mortality functions were similar using parametric and nonparametric models *(Metzger et al., 2010)*.

Some limitations to calculating the heat index by Steadman's original equation occur when relative humidity is less than 40 percent exist. The U.S. National Weather Service has created an algorithm to account for this limitation of the heat index calculation and has provided an alternative algorithm on their website *(NWS, 2014).* Comparing to the findings from Thailand, Kirtseang and Kirtseang (2015) suggested that to apply the heat index value as a prevention level for heat strokes during training and the results showed that the heat index proved to be satisfactory and effective in reducing the risk of heat strokes among Thai soldiers. *(Kirtsaeng and Kirtsaeng, 2015)*. The very clear advantage of using a heat index in Thailand is based on the existence of a system called the "Heat Alert System", which was devised in a collaboration between Phramongkutklao Hospital and the Meteorological Department of Thailand and has been applied as a prevention measure for heat strokes during military training. Thus, it is feasible to develop a HHWS for Thailand based on heat index thresholds.

Another important finding of this study was that the best model was lag 0 model (same day of heat exposure) in every region. From this, it can be inferred that the severe effect of heat on the Thai population will occur on the day of exposure. This finding broadly supports the work of other studies in this area linking health outcomes with climate indices. Basu and Malig (2011) demonstrated associations between elevated temperatures and mortality and considered a number of apparent temperature measures for a time series analysis with Poisson regression in 13 counties of California, including lag days of 0–20. The observation of a significant effect for non-accidental mortality was strongest in lag 0 and the effect was less strong as the number of days of lag increased in northern and coastal areas *(Basu and Malig, 2011)*. In Canada, Poupart and colleagues (2014) quantified the association between occupational HRIs and summer temperature and found the highest estimated incidence rate ratio in the lag 0 model *(Poupart A et al., 2014).* In New York, Lin and colleagues (2008) further supported the idea that the potential impact of temperature on respiratory diseases was highest on the same day as exposure. However, cardiovascular disease risk was the highest after three days of exposure *(Lin et al., 2009).* A time-series study in 108 communities of the USA was performed by Gasparrini and Armstrong in 2011, covering a 13-year period over which they sought to arrive at a definition of heatwave. They provided an analysis of the impact of heatwaves on mortality and suggested that the excess risk during a heatwave period was most pronounced on the immediate day and lasts for four days *(Gasparrini and Armstrong, 2011).* The longest lag effect evaluation was performed in 2016 in Santiago, Chile, when Muggeo and Hajat (2016) allowed a multi-lag segmented approximation to account for a non-linear effect of temperature for up to 60 days. The results showed that the effect at peak lag is at lag 0 for cardiovascular and respiratory admissions and all causes of mortality within all age groups *(Muggeo and Hajat, 2009).* Gao and colleagues (2017) used a time–series analysis with GEE focusing on the relationship between ambient temperature and cardio–cerebrovascular disease mortality in Harbin, China, and found the heat effects were immediate and lasted up to four days after exposure *(Gao et al., 2017).*

6.4. The suitable warning threshold levels of the heat-index for a HHWS for Thailand (Component 1)

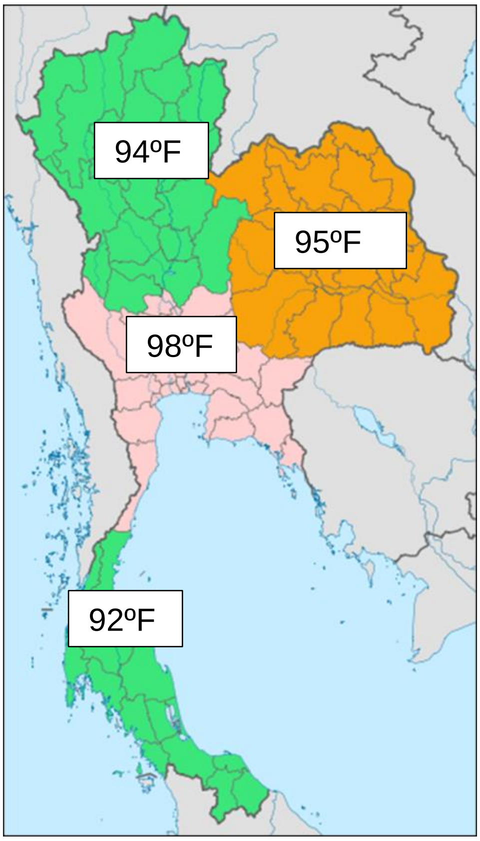
The most important significant finding from this study is that the threshold levels are specific to Thailand. This means that the threshold levels of the USA, for example, are not suitable for Thailand *(WHO, 2008a)*. The guidelines for HHWS thresholds for Thailand are shown in Table 49, which comprises three warning levels.

Table 49. HHWS threshold guidelines for Thailand

Heat Health Warning Threshold Levels for Thailand	
Pre–alert level	Less than 75th percentile of heat index
Higher–alert level	75th – 90th percentile of heat index
Highest alert level	More than 90th percentile of heat index

Figure 47 shows the starting point of the heat index (°F) for the highest alert level in each region of Thailand. These are: >94°F in the Northern region, >95°F in the Northeastern region, >98°F in the Central region, and >92°F in the Southern region, respectively.

Figure 47. The starting point for the heat index (°F) for the highest alert level in each region of Thailand based on data from 2009 to 2014



The USA has four levels of a HHWS *(NOAA, 2018b)*:

- Excessive Heat Warning is the highest precaution level, mandating that action be taken within 12 hours of the onset of extremely dangerous heat conditions. The general rule is when the maximum heat index temperature is expected to be 105°F or higher for at least 2 days.
- Excessive Heat Watches are issued when favourable conditions are predicted for an excessive heat event in the next 24 to 72 hours. A Watch is used when the risk of a heatwave has increased but its occurrence and timing is still uncertain.
- A Heat Advisory is issued within 12 hours of the onset of extremely

dangerous heat conditions. The general rule of thumb for an Advisory is when the maximum heat index temperature is expected to be 100°F or higher for at least 2 days.

- Excessive Heat Outlooks are issued when the potential exists for an excessive heat event in the next 3-7 days. An Outlook provides information to those who need considerable lead-time to prepare for the event.

As can be seen from the threshold levels of the USA compared to Thailand, the latter's warning threshold levels start from a lower heat index level for the highest level precaution compared to the USA. A Heat Advisory seems to be compatible with the outcome of interest in Thailand in this study because this warning criterion is based on studies that look for a relationship between the heat index and morbidity, such as emergency room visits. Nevertheless, these levels of warning are practically applied throughout the country. For instance, if the heat index is expected to reach 100°F in the city of Elmira, a heat advisory would be issued for that county. This is different from the guidelines for a HHWS for Thailand, in which the criteria would apply specifically for the regional level and not the country level. It is clear that in different areas the threshold level given from the statistical model has a different value of heat index to warnings across the region *(NOAA, 2018a)*.

In this study, the warning threshold levels for a HHWS for Thailand were determined by statistical models and the opinions of experts, policy makers and stakeholders. To the best of my knowledge, this is the first research involving threshold selection for a HHWS that used a mixed-methods study and verified the threshold levels with experts regarding the aspects beyond statistical results. The main purpose of the decision to fill the existing gap in the research was that no other studies exist on the selection of threshold levels based on policy establishment. Moreover, the definition of each threshold level for a HHWS in each country was not clearly stated from literature review *(see section 2.5.2).* In this case, to select which point should be the suitable cut-off point was not easy to determine using statistical results alone.

The threshold level in this study was divided into three levels and the highest level was higher than the 90th percentile of the heat index because the curve from estimates of relative risk sharply increase beyond this point. Threshold levels in the literature vary from the 50th percentile to the 99th percentile for any proxy indices *(McMichael et al., 2008a; D'Ippoliti et al., 2010; Metzger et al., 2010; Gasparrini and Armstrong, 2011; Williams et al., 2012; Harlan et al., 2014; Chen et al., 2015; Gu et al., 2016b; Phung et al., 2017; Ito et al., 2018).* Some studies have defined an exact figure for the cut–off point and not the percentile. For example, the first one to do so was a study conducted in South Australia and defined the threshold level at more than 35.5 ºC of the maximum temperature *(Xiang et al., 2015)*. The second one was a study by Metzger *et.al.* (2010) in New York city, which determined the threshold level at more than 95ºF–100ºF of the heat index by Poisson time-series generalised linear models to estimate weather–mortality relationships using various metrics such as minimum temperature, average temperature, maximum temperature and the heat index *(Metzger et al., 2010)*. Another recent study was conducted by Alessandrini and colleagues (2011) in Emilia-Romagna, Italy, (2002–2006) to identify the threshold temperature using time series techniques. These scholars found that an average temperature more than 30ºC was suitable for a threshold level (Alessandrini *et al.*, 2011).

In contrast to earlier findings, Thai HHWS threshold levels are identified by percentile instead of the exact number of the heat index. Hence, it could conceivably be hypothesised that the heat index will differ in different areas of the country. This hypothesis is supported by Basu and Malig (2011), who found that a percentile threshold rather than a given value temperature was more useful to set the threshold level of the heat index *(Basu and Malig, 2011).*

As discussed above, the threshold warning levels for Thailand in this study were verified and agreement was reached among the participating experts and stake holders from both the meteorological field and the public health sector. In the UK, to identify heat–heath thresholds would need consideration on precision and cost operations by authoritative organisation, alongside, the local plan are adapted as appropriate to local context *(PHE, 2018)*. In many cases, the decision on whether or not to call a warning is made at the meteorological end *(Sheridan C.S., 2004; Tobias et al., 2012; PHE, 2018).* It is then up to local health authorities to decide whether and if so how to act on this warning.

The advantages of multi-agency cooperation have been shown in many countries. A heat-health watch system in England (2018) comprises main keys success on warning system based on NHS and local authority commissioners, together with multi – agency take appropriate actions according to the heat health watch alert level in place with their professional judgements *(PHE, 2018)*. Sheridan *et.al.* (2004) reviewed the progress of heat watch warning system technology in the USA and Canada and emphasised that the system was run by a webpage which was password protected so that only the local weather forecast office and authorised agencies (such as health departments) could access the output. All agencies have access to the website, as the forecast issued by the system is a recommendation and not a final decision. The ultimate decision as to whether to issue a warning was based on brainstorming among the stakeholders, the local National Weather Service office and the local health authority in consultation with meteorologists, after which the response deemed appropriate was operationalised *(Sheridan, 2004).*

6.5. The issuances of warnings and communications in Component 2 of the guidelines for a HHWS Thailand

The results of this study provide guidelines for a HHWS for Thailand, comprising four components. Component 1 was discussed in Section 6.4, on the selection of the threshold levels of a warning system. This section will discuss the issuance of warnings and communications.

The results of this study show that the participants from the focus group were unanimous that a HHWS should not be a stand-alone organisation because numerous linkages across various stakeholders in both the government and private sectors are required. Thus, to use a weather forecasting system linked with general emergency response arrangements is ideal for a HHWS for Thailand. The issue of whether an air–quality warning system should be combined with a HHWS was debated by the expert panel in the Delphi round and there was a consensus in Round 3 that both systems should indeed be combined. However, in the focus group phase, the policy makers did not fully agree with combining an air–quality warning system with a HHWS as they were concerned that the effects of air pollution may interfere with the heat effect in certain situations. One expert noted that:

> *The different seasons affect the INDEX. In the south of Thailand, most pollution is from burning on Sumatra Island. Additionally, personal health and heat are still concerns (see chapter 5.4.2).*

However, despite this assertion the policy makers and stakeholders also agreed that some periods of high pollution tended to occur in the hot/dry season. To date, several reports have shown that air pollution plays an important role as a confounder, especially regarding the ozone *(McMichael et al., 2008a; Qian et al., 2008; Green et al., 2010; Alessandrini et al., 2011; Li et al., 2012; Margolis, 2014; Gao et al., 2017)*. This study did not include air pollution in the Poisson model because the coverage of air pollution data was for only 21 of Thailand's 77 provinces (27.6%). Also, the decision not to include air pollution was based on Winquist and colleagues' (2016) hypothesis that causal relationships between ambient temperature, air pollution and emergency department visits generally do not support controlling air pollution purely as potential confounders since temperature is likely to influence the air pollution level rather than vice versa *(Winquist et al., 2016).*

Moreover, a number of researchers have built a relationship model controlling for air pollution and have not found any differences between the models that controlled for air pollution and those that did not *(Williams et al., 2012; Chen et al., 2015; Onozuka and Hagihara, 2016).* Williams and colleagues (2012) adjusted for O_3 and PM_{10} in the study to examine the heat threshold and relationship for mortality and morbidity and temperature in Adelaide, Australia and found that the ED heat-related model unadjusted RR = 6.486 (95%CI = 3.033-13.87) after adjusting, RR = 6.511 (95%CI = 2.785-15.22). Similar lines to a study in Italy by Onozuka and Hagihara (2016) who performed a sensitivity analysis to assess the impact on temperature and ED visits from May to September 2002 to 2006 when using NO_2 and O_3 daily mean concentrations as air quality indicators, distributed lag models applied to NO_2 and O_3 provided unreliable results with large confidence intervals. In a study in Nanjing, China, during 2007–2013, Chen *et al.* (2015) explored the differences between the heatwave definitions adjusted with PM_{10}, NO_2 and SO_2. The adjusted model gave the estimated impact of heatwaves on mortality, which remained similar after controlling for air pollutants, which 8.9% (95%CI = 3.6-14.6) increase in the estimated mortality risk on heatwave days in the unadjusted model and 8.9% for all air pollutions ($PM_{10,}$ 95%CI = 3.5-14.6), ($NO_{2,.}$ 95%CI = 6.5-14.5), ($SO_{2,}$ 95%CI = 3.6-14.6).

Apart from the statistical reason, a further disadvantage of combining an air quality system with a heat-health warning system was shown by Sheridan (2007), who examined the efficacy of a municipal heat watch system by surveying four cities in

North America (Toronto, Phoenix, Dayton and Philadelphia) with a total of 908 respondents. The study found that there was confusion in message warnings about the ozone precautions and heat alerts in both Toronto and Phoenix, where ozone alerts coincided with heat alerts *(Sheridan, 2007).* In Montreal, people refused to use air conditioning during heatwaves, in the mistaken understanding that this aggravates air pollution *(Alberini et al., 2011).* Therefore, combining the air–quality system with a HHWS for Thailand needs more research to support policy makers.

One important concern of a HHWS is about the validation and reliability of warning forecasts. The experts and participants in this study agreed that the frequency of warnings message should depend on the reality of the situation in the first place. The participants from the focus group added more information on the current weather forecasting system that can support unanticipated heat conditions up to five days in advance. It is crucial that the public understands the message being issued when excessive heat is forecast. The threshold level should not be set too low if so many heat warnings are be called that the public eventually disregards them. Conversely, if the threshold is set too high, a day that is significantly hazardous may go unheralded *(Margolis, 2014)*.

This study found that the communication channels seem to be judged by experts and participants in the focus group round as more important than the frequency of warnings. Regarding the methods used for communication, social media such as Twitter, Facebook and Line applications resulted in the highest agreement in the Delphi round and received focus group verification. The policy makers elaborated that social media are widely used by health professional services and certain subgroups of the population, notably teenagers and those whose income enabled access to smart phone and other digital technology.

Television and radio, particularly *local* radio stations, are still useful for most local people. Indeed, globally there is still widespread use of television and radio to announce heat warnings and provide practical advice on how to stay safe during hot weather *(Kovats and Ebi, 2006; Sheridan C.S., 2007; Fouillet et al., 2008; Hajat et al., 2010).* Sheridan (2007) found in her survey that the most important source of information for people to learn of warnings about heat in Toronto, Dayton, Phoenix and Philadelphia were TV (64%, 89%, 92% and 84%, respectively), radio (40%, 10%, 22%

and 25%, respectively), and newspapers (9%, 22%, 38% and 10%, respectively). A hotline is also feasible for Thailand for providing information at the alert level warning. Earlier indirect indicators of awareness during heat episodes were based on hotline calling. For example, in Philadelphia during summer 2002, the "Heatline" received over 2,300 calls about heat information. However, the hotline became unpopular after a decrease in advertising *(Bassil K, 2010)*. Another channel that could have high efficacy on health systems in Thailand is communicating proactively through health care volunteers who reside in a local area and are educated in various aspects of healthcare surveillance. They have the ability to directly contact local people and vulnerable populations within specified areas of responsibility. They must be prepared in the event of emergency responses and develop their knowledge of the dangers of HRIs.

This study has identified groups to be targeted for specific surveillance based on expert opinion and agreement. The participants agreed that the population aged over 60 and below the age of five are important target groups. In addition, people who work outdoors and people who have pre-existing diseases also count as target groups for a HHWS in Thailand. Indeed, this concurs with the strongest and most consistent observations in epidemiologic studies, which have identified the risk of heat exposure increasing among the elderly, people with chronic diseases (regardless of age) and people who work outdoors *(see section 2.4.3).* The stakeholders from the military sector added athletes and soldiers to the target groups due to reports of death from heat stroke among conscripts in the Royal Thai Army in 1989-1990 *(Chotomongkol V, 1989; Chuvichian P, 1990)*. Additionally, she was concerned that obesity is intimately related to increased risk of HRI. In fact, another report on army conscripts, this time by Nutong *et.al* (2018), has identified 53 subjects who had a BMI $\geq$ 30 kg/m^2 from a total of 809 men who enrolled on the study suffered from a HRI during their training was 3.41/100 person-months, 95%CI = 2.55-51.58 with RR = 2.66 (95%CI =1.01-7.03) *(Nutong et al., 2018)*. Nutong and colleagues *also* found that daily monitoring of body temperature, weight and urine colour reduced the risk of HRIs. The policymakers from the present study agreed that the methods Nutong discussed to monitor health are feasible and that conscripts with a BMI $\geq$ 30 kg/m^2 should be considered a vulnerable group.

6.6. Guidelines for interventions at the individual level for a HHWS for Thailand

The guidelines for intervention at the individual level for a HHWS in Thailand are listed in table 50. Most statements were verified for feasibility except the air-conditioning recommendation, which all experts agreed is an efficient method of protecting against the risk of HRIs but may not yet be practical.

Table 50. Interventions at the individual level of a HHWS for Thailand

Individual Intervention
Using air-conditioning, particularly for specific target populations
Keeping out of the sun between 11.00 a.m. and 4.00 p.m.
Avoiding extreme physical exertion
Wearing light, loose-fitting cotton clothes and a hat when going out
Having plenty of water (two to four glasses per hour), particularly on hot days
Avoiding excess alcohol consumption
Encouraging self-detected symptoms and signs of HRIs
Increasing self-awareness of how to maintain core body temperature
Considering putting up external shading outside windows

A discussion on the feasibility, effectiveness and disadvantages of each intervention follows; the issue of air-conditioning has been discussed globally. The air-conditioning was provided at homes for the elderly in France to protect them from the severe impact of the extreme heatwave of 2003 (*Vandentorren et al.; Ito et al., 2018*). A study in 1916 counties in the USA found strong evidence of a lower relative risk of heat stroke admission in counties with higher use of central air-conditioning during heatwaves (*Wang et al., 2016*). In contrast, Basu and Malig (2011) found that air-conditioning in California reduced only slightly the estimated relative risk. With a 10% increase in county air-conditioner prevalence for all non–accidental mortality, the authors found a reduction of only 0.5% (95% CI: 0.1–0.8%) in excess risk *(Basu and Malig, 2011*).

Moreover, air conditioning requires electrical power, which entails the production of fossil energy and contributes to greenhouse gases emissions *(Kjellstrom and McMichael, 2013)*. As a result, using renewable energy for air-conditioning will be essential to ensure more sustainable cooling methods or the environmental design of cooling cities (such as installing cool roofs and pavements which use lighter coloured material to reflect the sun's heat) should be the next strategies policy makers work on. Additional methods that can help promote cooler cities are planting trees (trees cool the air through evapotranspiration), shaded buildings, and increasing the relative amount of green spaces in urban areas. Use of fans is widely misunderstood among the general population, especially in Thailand, where every house has at least one. Based on the literature review and the general consensus among Thai experts, using fans indoors poses a significant risk when the heat index is higher than 37°C or the temperature is higher than 37.8°C because it increases heat stress by blowing air which is warmer than body temperature over the skin *(Luber and McGeehin, 2008).*

The recommendation to keep out of the sun between 11.00 a.m. and 3.00 p.m. is applicable in many countries[14]. However, the focus group in this study verified that this should be extended from 3.00 p.m. until 4.00 p.m. in Thailand because that is when the radiation of the sun is strongest and the temperature is at its highest. This recommendation is already followed by some target groups, such as the elderly (who are more likely to stay home during the day) and children (who are at school). For people working outdoors, other methods of protection should be considered to keep them safe because avoiding work during the day is simply not practical for many workers. Although applying sunscreen was not a method that saw the experts reach a consensus, in the focus group some stakeholders claimed that it may help protect against skin cancer even if it is less helpful against HRIs.

Drinking plenty of cold water or room temperature water is good practice for reducing the risk of HRIs. There was no consensus on the specific amount of fluid replacements beyond drinking regularly without waiting for thirst. Notably, alcohol intake should be avoided due to its diuretic effect, which varies according to the alcohol content, in addition to the impairment of judgement and the peripheral vasodilatation, all of which leads to an increased risk of HRIs. Regarding caffeine intake, a study by Hajat and colleagues showed no significant change in dehydration status when a no caffeine intake group was compared with a 253 mg per day intake group. The diuretic effect of caffeine may vary according to strength and/or level of consumption and the hydration status of the individual *(Hajat et al., 2010).* The participant from the Royal Thai Army

[14] Keeping out of the sun between 11.00 am to 3.00 pm is recommended in the UK, France, the USA, Toronto (Canada) and Australia.

recounted interesting procedures to reduce high body temperatures to protect against HRIs such as ice bathing, soaking the forearms and necks and rubbing the body with a wet towel. The stakeholders agreed that such measures would be easy and inexpensive to launch in the general population.

Overall, few studies that have noted the effectiveness of each intervention had been evaluated. Sheridan's (2007) cross-sectional survey of 908 participants in four cities (Dayton, Philadelphia, Phoenix and Toronto) found that people avoid exposure to the sun outdoors (recording the highest percentage in all four cities, at 59%-79%), followed by keeping hydrated (38%-63%) and staying in or seeking an air-conditioned location (20%-52%). Surprisingly, the other methods were negligible, such as utilising fans (0%-28%), avoiding over-exertion (7%-19%), light dressing (3%-9%), checking on neighbours or the elderly (1%-6%) *(Sheridan, 2007)*. Alberni and colleagues conducted another survey in five Canadian cities that do not have such systems (Winnipeg, Windsor Fredericton, Regina and Sarnia). This survey, commissioned by the Policy Research Initiative of the Government of Canada, found that most of the respondents indicated that they adopted common–sense approaches to coping with heat, such as staying in air conditioned environments and keeping well hydrated. From the 1,141 respondents, 58% spent most of their time in an air conditioned environment, 31% stayed inside a building, almost 50% stayed hydrated, 9% spent most of their time at a swimming pool, and 11% spent most of their time in shade *(Alberini et al., 2011).* The interesting point of Alberni's study was there was no programme had been implemented in any of those five cities. This is a good practice to apply in Thailand in terms of comparing pre- and post- programme knowledge by using a control–treatment design study in the future.

Finally, encouraging self–detection of symptoms and signs of HRIs and increasing self-awareness of how to maintain core temperature saw a consensus on the expert panel. For example, many older adults do not see themselves as old or at greater risk than they actually are. This hypothesis is related to the systematic review of Toloo and colleagues (2013), found that persons aged 75 and older did not consider themselves old or especially vulnerable to heat. Surprisingly, this group of participants considered other people in the same age group as vulnerable but not themselves *(Toloo et al., 2013b).* The same situation must be a concern in Thailand because Thai people are familiar with a hot climate and they use common sense rather than knowledge to protect them from the heat. As a result, misunderstandings may be common and need to be identified and managed. The specific topic of heat and health management should be provided for the general population, especially vulnerable target groups under specific surveillance. People need to know what the goals of a HHWS for Thailand are because understanding the goals is necessary to measure the effectiveness of the system. The government has to convey the message that raising public awareness is of the utmost importance. Education and raising awareness among the public are key to ensuring that the system will work smoothly and precisely with accurate forecasting and sufficient resources. Also, the public need to know who the vulnerable target populations are so as to acknowledge that greater surveillance of such groups is required.

6.7. Guidelines for interventions at the community level for a HHWS for Thailand

All experts and policy makers reached a consensus on the community level interventions shown in Table 51. A discussion on the feasibility, effectiveness and disadvantages of each intervention follows.

Table 51. Interventions at the community level of a HHWS for Thailand

Community interventions
Establishing a cooling centre or a temporary cooling shelter
Increasing the facilitation and capabilities of rapid surveillance teams
Establishing a buddy system to monitor on isolated, elderly, ill or very young people and ensure they are able to keep cool
Increasing medical staffing during warnings, in anticipation of higher demand
Monitoring in-house temperatures by use of a thermometer

As discussed in section 6.6. Guidelines for interventions at the individual level for a HHWS for Thailand, air-conditioning is one of the most powerful protection methods against HRIs. However, to provide air-conditioning in every household is as yet impractical for reasons of cost. Elderly people living on a fixed income may decide to endure the heat rather than incur large electricity bills *(Sheridan C.S., 2007; Bassil K, 2010; Toloo et al., 2013b; Khare et al., 2015)*. Alberni *et al.* (2011) also found that having air-conditioning at home was not related to the likelihood of reporting symptoms of HRIs in their survey of five Canadian cities *(Alberini et al., 2011)*. Thus, establishing a cooling centre or a temporary cooling shelter is an alternative choice for a government with a limited budget *(Price et al., 2018)*. This intervention has never been piloted in Thailand but the experience of Toronto indicates that cooling centres are not widely used because people tend to go to libraries, movie theatres and department stores instead. Also, these services are not locally available in all neighbourhoods. This is a problem given that people prefer to go to a place that is located in the immediate vicinity. In addition, cooling centres are only open during extreme heat alerts in Toronto. Furthermore, the option of going to one does not exist during heat alerts, posing a significant threat to human health *(Sheridan C.S., 2004)*. Consequently, the government of Thailand should liaise with department stores and local supermarkets large enough to contain more than 1,000 people in emergency situations. Although limitations do exist, cooling centres (in this case stores, cinemas, etc.) serve an important function as emergency rooms for backing up the emergency services.

Monitoring in-house temperatures is not a universally recommended method by HHWSs. But this intervention has been integrated and applied in the Royal Thai Army for three years, along with urine colour monitoring among new conscripts during their basic training period *(Nutong et al., 2018)*. Moreover, both of these interventions come at the earliest stages of recognising a health issue for soldiers. They will prepare the equipment and methods to protect themselves as discussed in section 5.3.4.

To achieve the goal of prevention at the community level, the expert and policy panels suggested collaboration among medical services like hospitals, doctors, nurses and health volunteers as all these medical service providers are informed about HRI risk factors relevant to their patients and can assess the severity of diseases for the management of that risk. To evaluate the awareness of key elements of a HHWS by healthcare professionals, Price and colleagues (2018) conducted a focus group and questionnaire survey among 13 local health administrative units in Montreal and gathered information from 21 seasonal reports (2010–2013), whichthe results showed that healthcare professionals in hospitals had a sound understanding of measures to be put in place and their respective roles during heat alerts. Consequently, the participants mentioned difficulties identifying the early signs of HRIs, particular amongst the elderly. Another challenge was the availability of sufficient health personnel, who also need good protection to avoid heat exhaustion while working in very hot environments *(Price et al., 2018).* However, many challenges were discussed that might be of concern in Thailand. For example, many healthcare workers in community organisations do not have a medical background (i.e. “health volunteers”). Thailand has rapid surveillance teams to respond to any health issues regarding communicable diseases. One of the stakeholders from the Medical Emergency Service Department verified that the rapid surveillance teams will be available for duty during heat events that may occur in the future. Moreover, the rapid surveillance teams must emphasise the role of the buddy system to vulnerable target populations. Communication between the medical teams could be operated by a “Line” application, which would be helpful to ensure a rapid response by medical service teams to communicate with each other when unexpected heat events happen. The buddy system is an effective intervention used worldwide *(Victorian Government, 2015; WHO, 2015; PHE, 2018)* and entails no additional budget and is most definitely feasible for a HHWS in Thailand.

6.8. Strengths and limitations of this study

A full HHWS outline has been developed in this thesis to support the relevant government sectors. Based on available evidence, this novel study applies both quantitative and qualitative research to fill gaps in the existing research into the development of HHWSs, beginning from ascertaining suitable warning threshold levels through to proposing practical interventions for the general population and vulnerable target populations. In addition, the fact that 16 experts from the climate and health fields agreed to participate in the study strengthened the results from the Delphi round, which were in turn passed to policy makers and stakeholders for consideration in the focus group phase and focus groups filled the gap in the existing scholarship for the recommendation with co-operation by policymakers and stakeholders.

The key to the successful implementation of the recommendations of this study is the involvement of climate area experts and policy makers as stakeholders who see the need for a HHWS in Thailand and possess both the knowledge and the authority to realise one in the future. In this study, consensus among a panel of experts, policy makers and stakeholders was reached on the threshold levels and the suitable cut-off levels for a HHWS in all regions of Thailand. During this research, the Department of Health at Thailand’s Ministry of Public Health received funding from the WHO to develop a HHWS. The results from the Department of Health project provided threshold levels, which selected temperature alone as the climatic proxy to prepare for the warning temperature level in each region of Thailand. At that time, the results from the Ministry of Health's project did not show any significant threshold level for the southern region *(Department of Health, 2017)*.

The second strength of this study is that the relationship between the heat index and HRIs was identified by time-series analysis and a Poisson regression in every region of Thailand. The results of this quantitative element of the study indicate that the areas in the centre of Thailand have higher threshold alert levels than areas in other regions. Moreover, the threshold levels differ by region. This result supports the findings of many studies that show that this relationship differs according to geographical areas *(Sheridan C.S., 2007; Na et al., 2013; WHO, 2015; Morano et al., 2016; Phung et al., 2017; Price et al., 2018).*

The third strength of this study is that the more thorough and effective research methods have led to the proxy index including the heat index (in contrast to the Department of Health's study, which used only temperature as a proxy). Therefore, the results from this study can provide a threshold level for *all* regions, including the southern region, because, unlike the Department of Health's study, the heat index calculates both temperature *and* humidity. Heat is removed from the body by evaporation of sweat and high relative humidity reduces the evaporation rate. Hence, at low temperatures with high humidity, there is still a risk of HRI because the body is unable to release heat. For the southern region, where there are coastal areas, humidity plays an important role in the heat effect on the local population. This finding concurs with the study by Phung and colleagues (2017), which showed that in Vietnam, a country with large amounts of land adjacent to the coast, changes in the heat index are associated with increased risk of hospitalisations from infectious diseases and cardiovascular and respiratory problems.

This study inevitably suffers from a number of limitations. Firstly, air pollution was not used in the statistical model. Unfortunately, the completion of air pollution data covered only 19 from a total of 77 provinces and, therefore, air pollution data was not used in the analysis as it was not considered sufficiently representative of each region of the country. Secondly, the HRI data for Bangkok was not included in this study, which Bangkok is the capital city of Thailand and expecting to have UHI effect. The model in Central region may show the different result if data from Bangkok is included in the model. Thirdly, the incidence of HRIs may have been underestimated or misclassified due to under-reporting. The data were collected mainly from government hospitals, which receive severe cases for a serious treatment. Therefore, this study might have omitted mild cases of HRIs or cases that were treated in private hospitals. A further limitation of the outcome specific to HRIs is that doctors may be more likely to assign a heat-related diagnosis (represented by ICD-9-CM codes) if they are aware of a prolonged increase in temperature or on an intensely hot day. However, the degree to which this occurs (if it does occur) will most likely vary by region. The direction and the magnitude of the differential measurement bias on the effect of estimates between temperature/heat index and HRI is unclear. Fourthly, an investigation of personal risk factors such as medical condition, level of acclimation to occurrence of HRIs, gender, and occupation was not performed due to the lack of complete available data. Lastly, key members of the National Committee on Climate Change Policy (NCCCP) at Thailand's Ministry of Natural Resources were not able to participate in the focus group. This made it impossible to identify the actors for each intervention of a HHWS in the outline of a HHWS for Thailand in this study.

6.9. Conclusion

In conclusion, the thesis findings improve our understanding of the relationship between the daily heat index and daily HRI hospitalisations in Thailand. The methodology developed may be relevant to other Southeast Asian countries, where there is scant research exploring the relationship between climate and health. As Thailand has a humid and tropical climate, the use of the heat index when modelling the heat-health relationship is a more suitable metric of heat than temperature alone.

The relative risks at the 75th percentile of the heat index at lag 0 (on the same day of exposure to heat) in the Southern, Northern, Central and Northeast regions were 5.56 (95% CI = 1.62–19.04), 21.76 (95% CI = 11.33–41.81), 79.59 (95% CI = 33.76–187.64), and 39.75 (95% CI = 21.66–72.94), respectively. The threshold levels for a HHWS in each region were divided to three: pre-alert, higher alert and highest alert. Based on expert opinion, the pre-alert level is the level of the heat index below the 75th percentile; the higher level is the level of the heat index from the 75th percentile to the 90th percentile and the highest alert is for level of the heat index over the 90th percentile.

Based on the statistical results described above, threshold level cut–off points were selected by a panel of experts involved in the field of climate studies and subsequently verified by policy makers and stakeholders involved in the climate policy sector. Finally, an outline for a HHWS for Thailand was created comprising four components and the details of each component were verified and elaborated on for the feasibility of launching a HHWS for Thailand. A summary outline of a HHWS for Thailand is shown in figure 48.

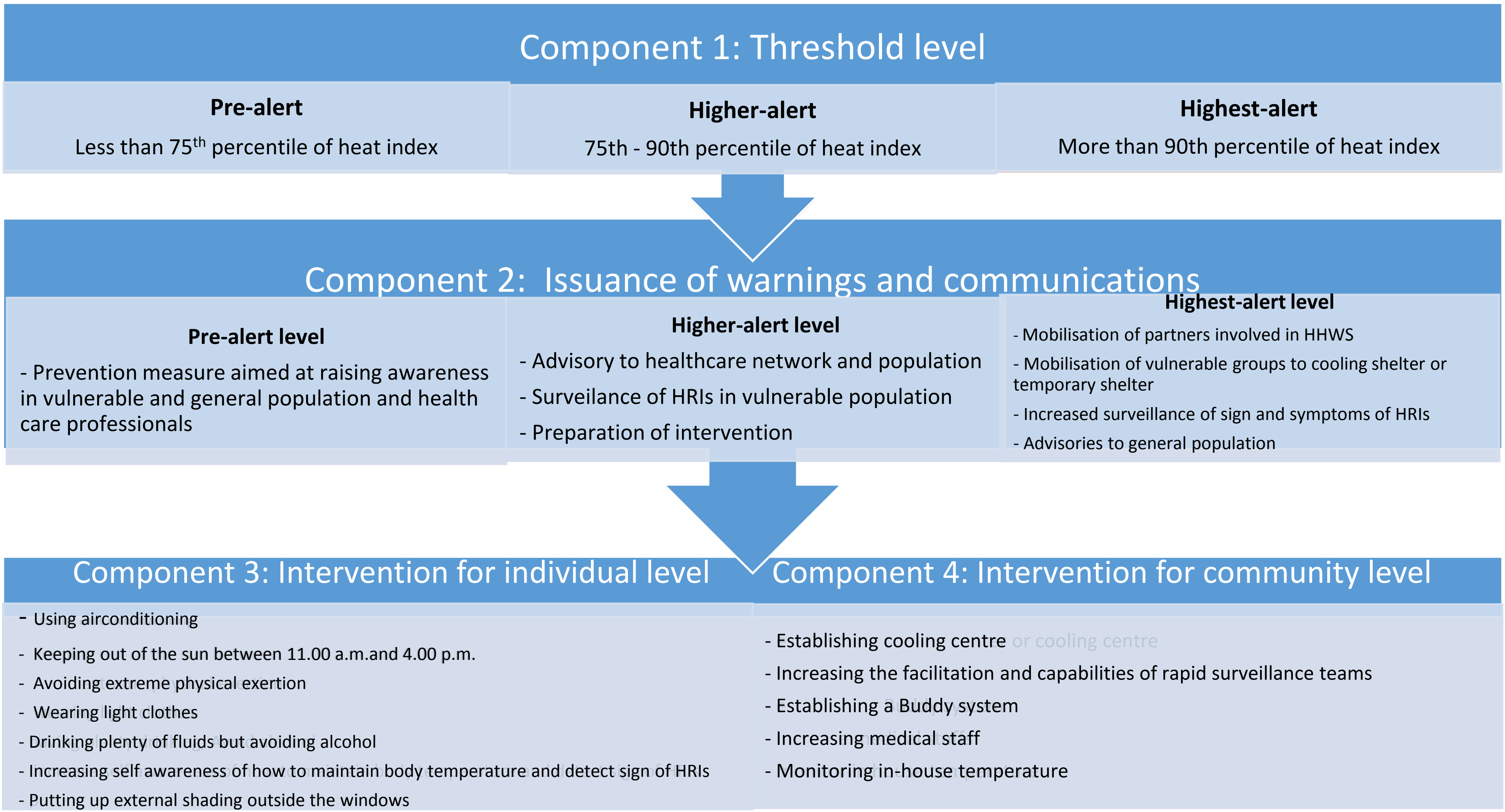


Figure 48. Outline of a HHWS for Thailand

6.10 Recommendations

A number of recommendations can be drawn from the results and some lessons can be learnt from this study. The results of this work have revealed the need for continued practices and further research in this field, especially in Thailand and Asia.

6.10.1. Recommendations for practice

Through this research an outline for a HHWS for Thailand has been devised. There are many benefits to be derived from developing a HHWS for Thailand in the near future. As discussed in Section 6.8, running a HHWS successfully requires the close collaboration of numerous local government agencies and actors in the private sector. Plans must identify a lead agency and describe and assign specific and detailed roles and responsibilities for the lead agency and all supporting agencies. Moreover, the plan should be reshaped regularly and be prepared well before heat events to review response protocols and to confirm the participation of the lead organisation. The coordination of local agencies is essential for defining a clear communication strategy and pathway from the lead agency to the first responders, the public and the media. This communication strategy must be defined before a heat event and should be maintained throughout the activation of the warning system. Importantly, hospital staff should be encouraged and supported to record HRIs more consistently.

The limitation in this study is that there are not clearly defined actors in Thailand's HHWS. However, a HHWS can learn from how actors in already established response plans for other types of emergency are defined and how they liaise for a HHWS. In the future, to develop practice for a HHWS, the actors involved should be identified clearly. They can be divided into two groups. The main actors in the first group are health care professionals and managers at local and referral hospitals and health volunteers. The main actors in the second group include municipal partners such as police and fire departments, public transport, and ambulance transport. All actors should know exactly what they responsible for when the alert system is operated. This study revealed that actors working with vulnerable populations were unclear as to their responsibilities and roles. The information on how to identify the most vulnerable groups and what needs to be done to protect them during alert periods (i.e. what to do when a vulnerable person needs to be relocated but are not willing to leave the home, and so on) should be structured by conducting brainstorming sessions with agencies that work with vulnerable populations, providing workshops for those working with vulnerable populations, and developing a registry template that could be used by the various agencies at city and regional levels that work with vulnerable populations.

Finally, developing a framework for evaluating public health interventions for heat is the next step to building on the findings of this thesis. Ideally, the evaluation process should be coordinated via national or international organisations to gain a comprehensive understanding of the effectiveness of the interventions that may operate in the future and the evaluation process could be conducted regularly, such as annually or every two or three years (*see Section2.9.5).* This is particularly important given the context of global warming as with changing climate, different interventions may become cost effective, or underlying statistical models may need refining.

6.10.2. Recommendation for future research

In terms of improving the accuracy of the evaluation of threshold levels of HHWS, the relationship between climate data and excess mortality or excess HRIs should be investigated to compare the results of this study. However, the accuracy for cause of death is the main concern *(see Section 2.7.1).* In addition, an observation of heat-related symptoms during the attendance at the emergency department should be conducted. This could enable a better understanding of early signs of heat related symptoms to support the identification on early surveillance.

Furthermore, the factor-specific categories where the heat-health relationship is strongest should be identified and the relative risks comparing between each alert level of warning should be compared. It is unclear to what extent mortality or morbidity reduction could be attributed to intervention efforts vis-a-vis meteorological factors or the reduced susceptibility of the population. To date, the elderly seem to be clearly targeted as a vulnerable group in all of HHWSs. However, there is no clear intervention for children. Children’s physical and emotional development and their location-time-activity patterns contribute to differences in heat exposure. For instance, young children may continue to play outside even when overheating and often do not know about or do not realise the need to drink fluids, while infants do not have the motor skills to remove blankets or remove themselves from a hot environment. It is thus a crucial recommendation that adults - parents, caregivers, and teachers – be given the requisite amount of assistance to encourage them to know how to protect children from heat hazards.

Another issue for future study concerns air pollution data, which should be controlled for in the statistical model if the coverage of monitoring stations is to increase and provide a good power for statistical model. Since there is a debate in existing studies as to whether air pollutions are the confounder to heat. In addition to this statistical point, there is the issue of how to make people understand messages when air–quality warnings or heat alerts are operated.

Lastly, the information of comparing pre- and post- programme knowledge by using control–treatment design study is recommended. It is important to know how individuals perceive the heat, what their experience of HRIs is, how they protect themselves from excessive heat, and how they acquire information about such protections before a HHWS is implemented. This information is necessary to define an effective intervention and fill existing gaps in our understanding of and attitudes to heat protection.

6.11 Chapter summary

This study has achieved all the purposes stated in Chapter 1; the identification of the HRIs nature in Thailand, examine associations between the heat index and heat-related hospitalisations within the general Thai population, and develop a structure for a HHWS model in Thailand based on the results of statistical analyses and expert opinion. The novel results of the findings provide an outline of a HHWS which includes all the necessary components. In particular, the threshold levels are tailored for warnings through agreement among a number of policy makers and stakeholders. A HHWS is a new programme of public health intervention in Thailand and the results of this study provide useful insights into every component of a HHWS for the country.

Appendices

Appendix A-1 Delphi round 1 questionnaire

Delphi Round 1

Delphi Round 1

Name

Your answer

Institute

Your answer

Email address

Your answer

Do you agree to take part in this research study?

○ Yes

○ No

NEXT

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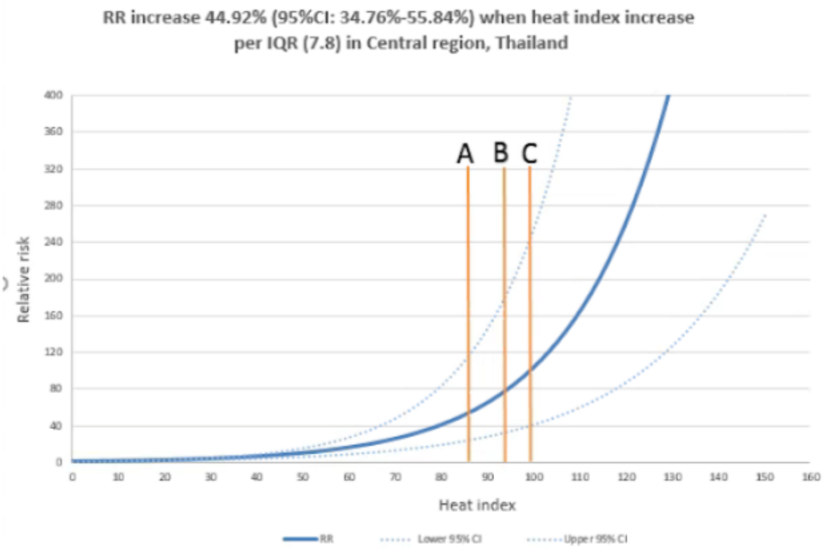
Delphi Round 1

Threshold level for Thailand's Heat Health Warning System

The WHO identifies three levels of heat warning; pre-alert, higher alert and highest alert.
Please consider and select points in each chart for
1) the threshold between pre – alert and higher alert and
2) the threshold between higher alert and highest alert for a heat health warning system.

Please note
RR is relative risk of heat related hospital admission
Point A is the 25th percentile of the heat index
Point B is the 75th percentile of the heat index
Point C is the 90th percentile of the heat index

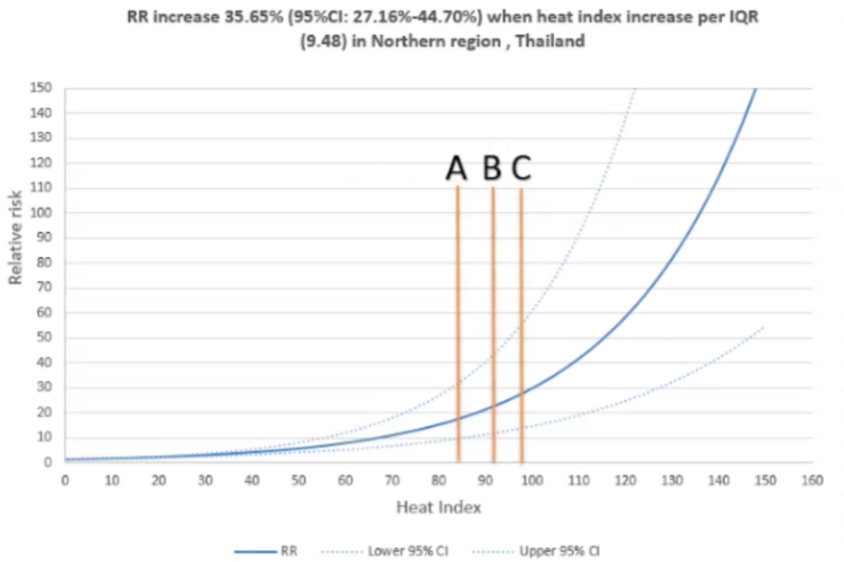
Chart 1. Central region



Based on 2014 data, there were 276 days/year more than point A, 111 days/year more than point B and 45 days/year more than point C, respectively.

- ◯ A and B
- ◯ A and C
- ◯ B and C

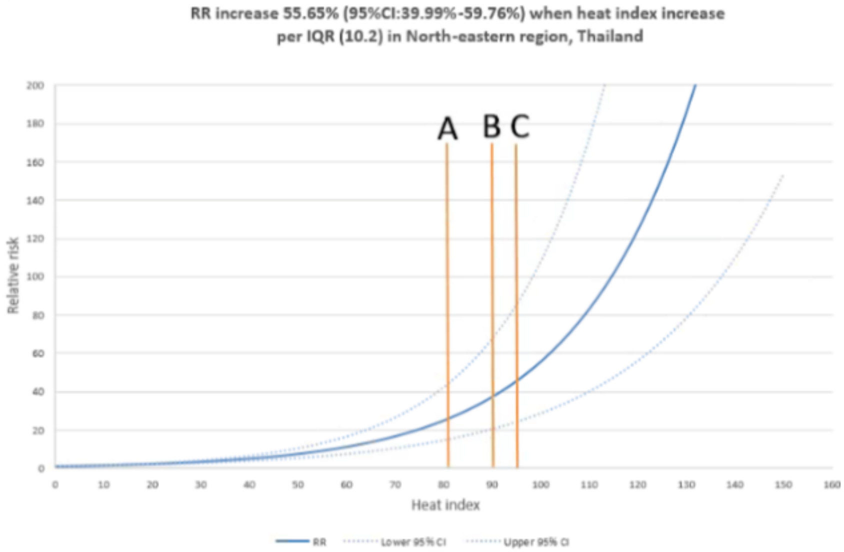
Chart 2. Northern region



Based on 2014 data, there were 275 days/year more than point A, 109 days/year more than point B and 37 days/year more than point C, respectively.

- ◯ A and B
- ◯ A and C
- ◯ B and C

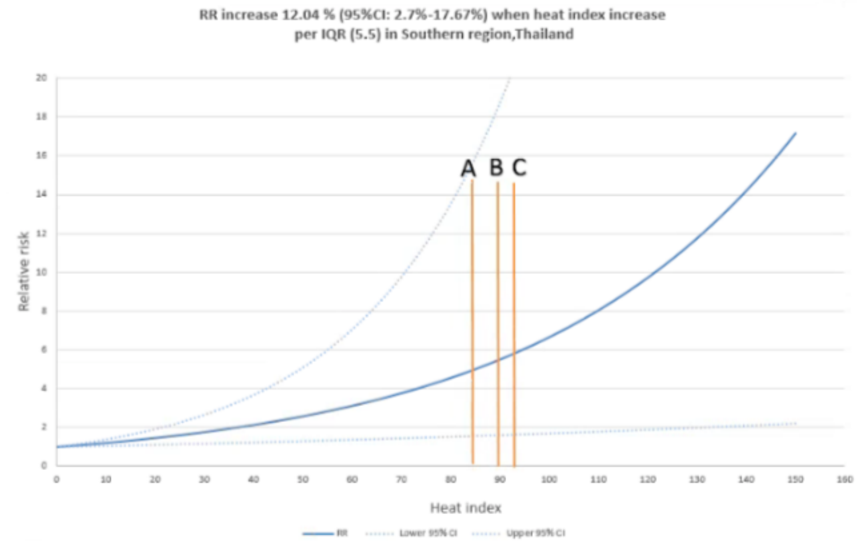
Chart 3. Northeastern region



Based on 2014 data, there were 285 days/year more than point A, 101 days/year more than point B and 48 days/year more than point C, respectively.

- A and B
- A and C
- B and C

Chart 4. Southern region



Based on 2014 data, there were 256 days/year more than point A, 101 days/year more than point B and 17 days/year more than point C, respectively.

- ◯ A and B
- ◯ A and C
- ◯ B and C

2. Why did you choose those cut - off points?

Your answer

If you have any additional comments regarding the threshold level considerations, please state below

Your answer

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Delphi Round 1

Issuance of warning and communication

Please consider and give an agreement on the statements below.

3. The heat health warning system of Thailand should be combined with the air - quality warning system.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

Comments for question 3

Your answer

4. The heat information centre should be established on its own to improve by the quality of information, the capacity of surveillance and rapid response on heat related illness.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 4.

Your answer

5. The heat information centre can join with the national public health system by adding heat information, capacity of surveillance and rapid response on heat related illness.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 5.

Your answer

6. The population who are more than 60 years old are an important target group for surveillance.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 6.

Your answer

7. The population who are below 5 years old are an important target group for surveillance.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 7.

Your answer

8. The population who work outdoors are an important target group for surveillance

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 8.

Your answer

9. The population who have underlying disease are an important target group for surveillance

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 9.

Your answer

10. The warning system should issue a warning once a day (any morning or afternoon or evening)

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 10.

Your answer

11. The warning system should issue warnings three times a day (morning, afternoon and evening)

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 11.

Your answer

12. At the critical period, the best media to spread the warning message is

- Television
- Radio
- Social media such as Facebook, Twitter, Line
- Short messaging system (SMS)
- Web service
- I don't have an opinion
- Other:

If you have any additional comments regarding , issuance of warning and communication, please state below

Your answer

BACK NEXT

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Delphi Round 1

Interventions for individual level

Please consider and give an agreement on the statements below

13. Using air conditioning can reduce the individual risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 13.

Your answer

14. Using a fan can reduce the individual risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 14.

Your answer

15. Increasing self- awareness of how to maintain their core body temperature can reduce the risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 15.

Your answer

16. Encouraging self - detected symptom and sign of heat related illness can reduce risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 16.

Your answer

17. Keeping out of the sun between 11.00 a.m. and 3.00 p.m. is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 17.

Your answer

18. Avoiding extreme physical exertion and wear light, loose-fitting cotton clothes is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 18.

Your answer

19. Applying sunscreen and wearing a hat and light scarf are good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 19.

Your answer

20. Having plenty of cold drinks (two to four glasses) can reduce the risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 20.

Your answer

21. Avoiding excess alcohol drinking can the reduce risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 21.

Your answer

22. Avoiding excess caffeine drinking can the reduce risk of disease

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 22.

Your answer

23. Avoiding excess hot drink can the reduce risk of disease

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 23.

Your answer

24. Keeping windows that are exposed to the sun closed during the day and open at night when the temperature has dropped are good practices for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 24.

Your answer

25. Keeping indoor plants and bowls of water in the house as evaporation helps cool the air is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 25.

Your answer

26. Considering putting up external shading outside windows; growing trees and leafy plants near windows to act as natural air-conditioners are good practices for prevention of heat exposure

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

Comments for question 26.

Your answer

If you have any additional comments regarding interventions for individual level, please state below

Your answer

BACK NEXT

Delphi Round 1

Interventions for Community level

Please consider and give an agreement on the statements below

27. Using artificial rain to reduce the surface temperature in order to reduce risk at population level is useful in preventing heat related illness.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 27.

Your answer

28. Establishing a cooling centre or a temporary cooling shelter are good practices for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 28.

Your answer

29. Increasing facilitation and capability of rapid surveillance team are good practices for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 29.

Your answer

30. During heat events, buddies system should be provided to keep an eye on isolated, elderly, ill or very young people and make sure they are able to keep cool.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question .30.

Your answer

31.The medical service should increase staffing during warnings in anticipation of higher demand.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Comments for question 31.

Your answer

If you have any additional comments regarding intervention for community level, please state below

Your answer

BACK SUBMIT

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Appendix A-2 Delphi round 2 questionnaire

Delphi Round 2

Please reconsider your response in the context of the feedback provided. You can either keep your response as the first round or change your response if you wish.

Name

Your answer

Page 1 of 6 NEXT

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Delphi Round 2

Threshold level for Thailand's Heat Health Warning System

The WHO identifies three levels of heat warning; pre-alert, higher alert and highest alert.
Please reconsider and select points in each chart for
1) the threshold between pre – alert and higher alert and
2) the threshold between higher alert and highest alert for a heat health warning system.

Please note
RR is relative risk of heat related hospital admission
Point A is the 25th percentile of the heat index
Point B is the 75th percentile of the heat index
Point C is the 90th percentile of the heat index
Heat index in this study was calculated in Fahrenheit.

Round 1 overall response for chart 1

Chart 1. Central region

16 responses

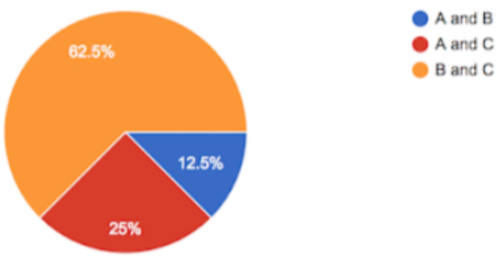
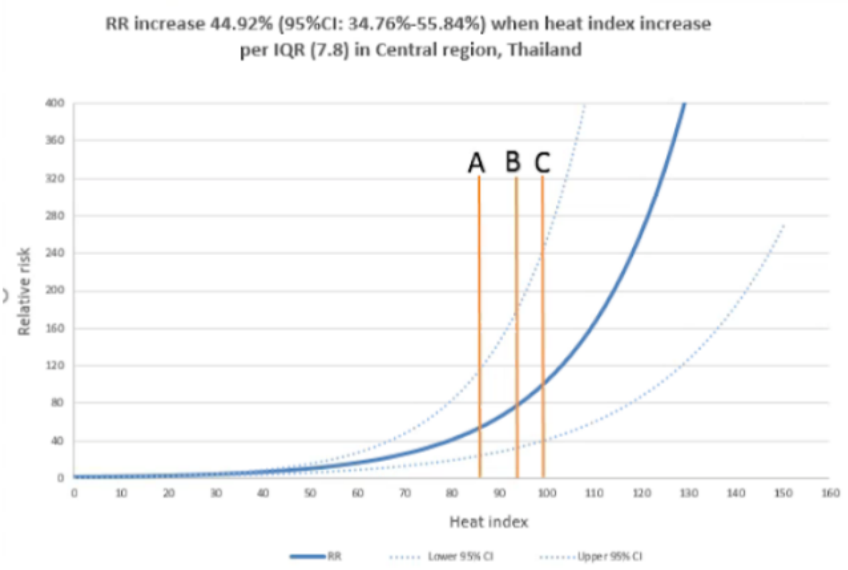


Chart 1. Central region



Based on 2014 data, there were 276 days/year more than point A, 111 days/year more than point B and 45 days/year more than point C, respectively.

- ◯ A and B
- ◯ A and C
- ◯ B and C

Round 1 overall response for chart 2

Chart 2. Northern region

16 responses

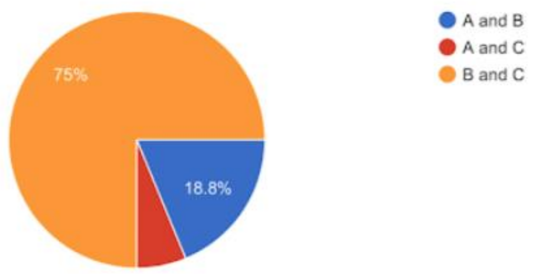
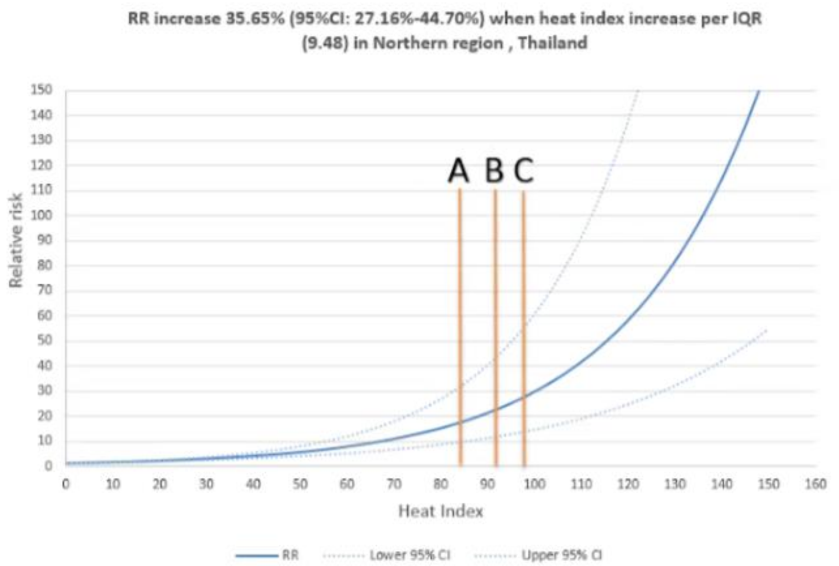


Chart 2. Northern region



Based on 2014 data, there were 275 days/year more than point A, 109 days/year more than point B and 37 days/year more than point C, respectively.

- ○ A and B
- ○ A and C
- ○ B and C

Round 1 overall response for chart3.

Chart 3. Northeastern region

16 responses

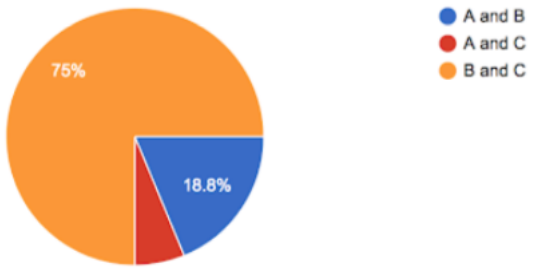
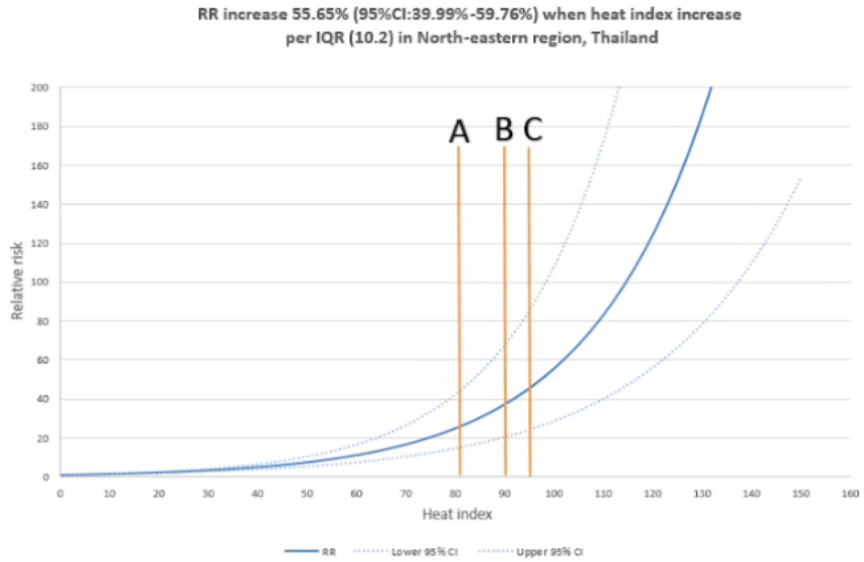


Chart 3. Northeastern region



Based on 2014 data, there were 285 days/year more than point A, 101 days/year more than point B and 48 days/year more than point C, respectively.

- ◯ A and B
- ◯ A and C
- ◯ B and C

Round 1 overall response for chart 4.

Chart 4. Southern region

16 responses

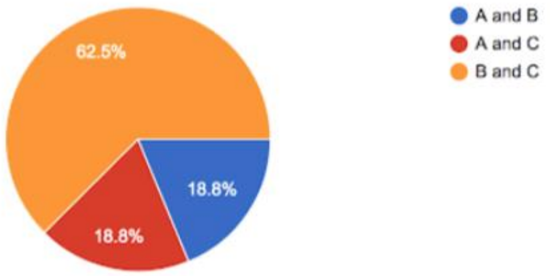
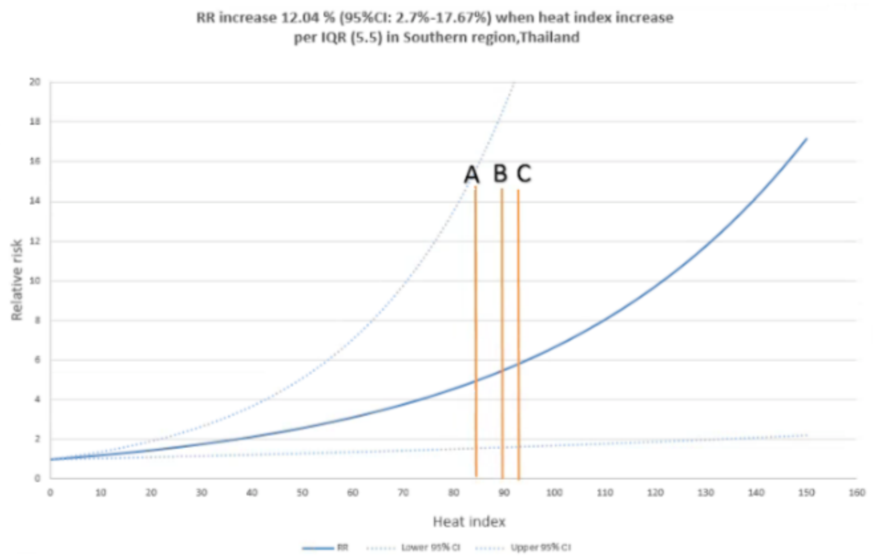


Chart 4. Southern region



Based on 2014 data, there were 256 days/year more than point A, 101 days/year more than point B and 17 days/year more than point C, respectively.

- ◯ A and B
- ◯ A and C
- ◯ B and C

Page 2 of 6 BACK NEXT

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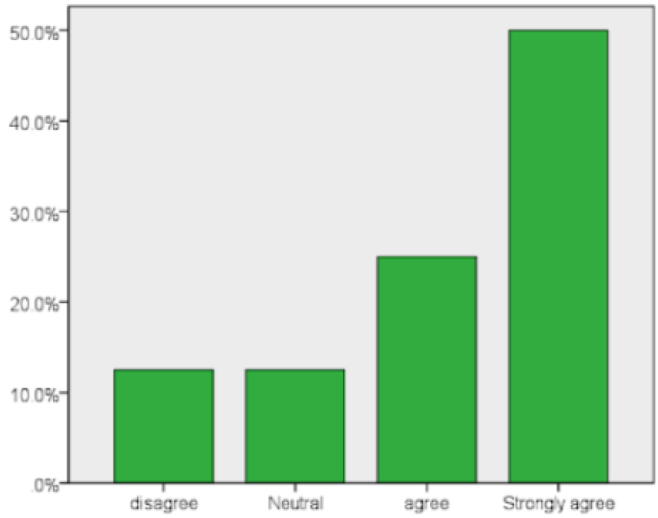
Delphi Round 2

Issuance of warning and communication

Please reconsider and give an agreement on the statements below.

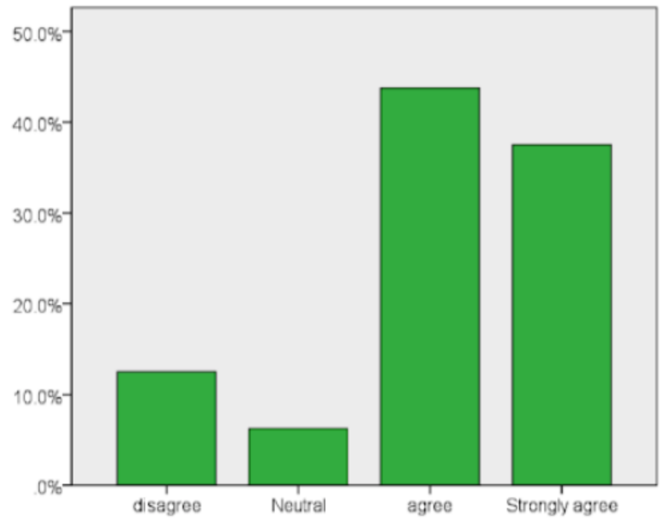
Round 1 overall response for question 3.



3. The heat health warning system of Thailand should be combined with the air - quality warning system.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

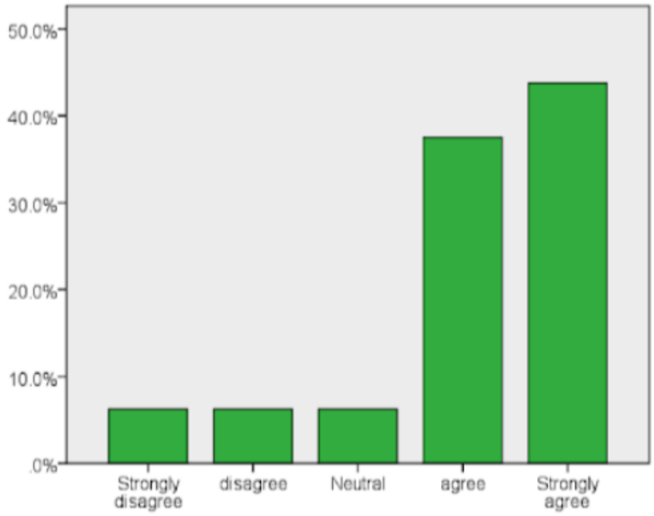
Round 1 overall response for question 4.



4. The heat information centre should be established as stand alone organization to improve the quality of information, the capacity of surveillance and rapid response on heat related illness.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

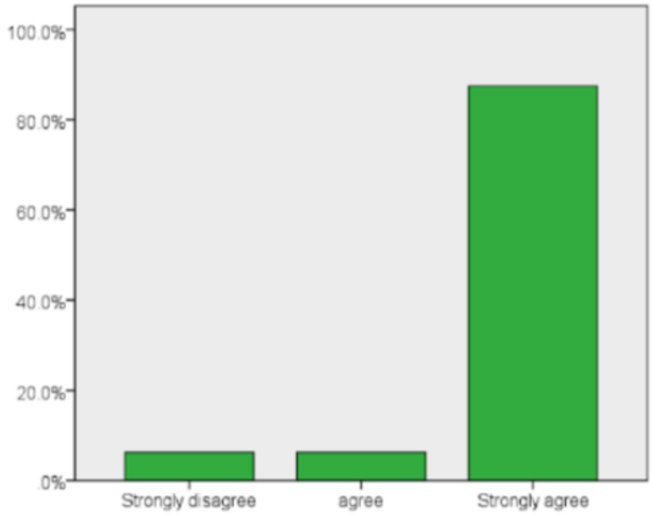
Round 1 overall response for question 5.



5. The heat information centre can join with the national public health system by adding heat information, capacity of surveillance and rapid response on heat related illness.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

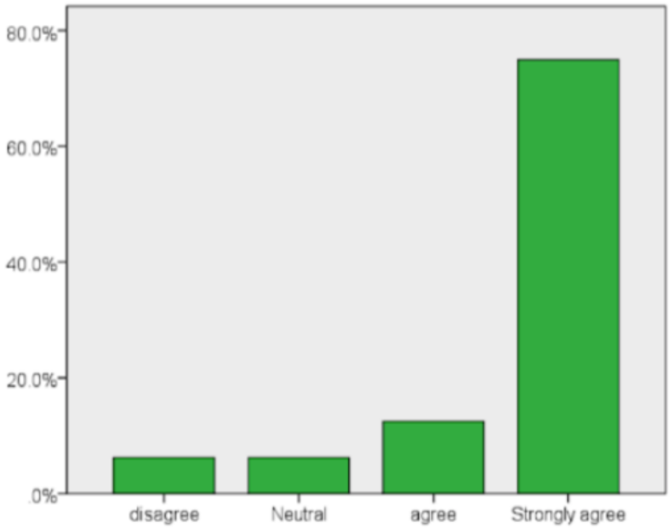
Round 1 overall response for question 6.



6. The population who are more than 60 years old are an important target group for surveillance.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

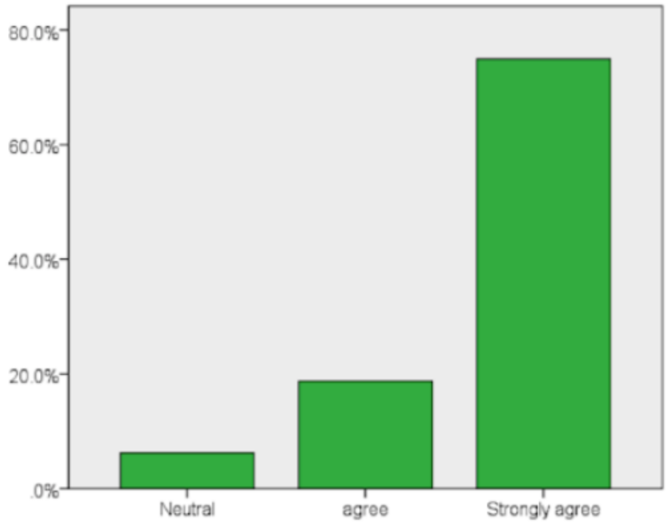
Round 1 overall response for question 7.



7. The population who are below 5 years old are an important target group for surveillance.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

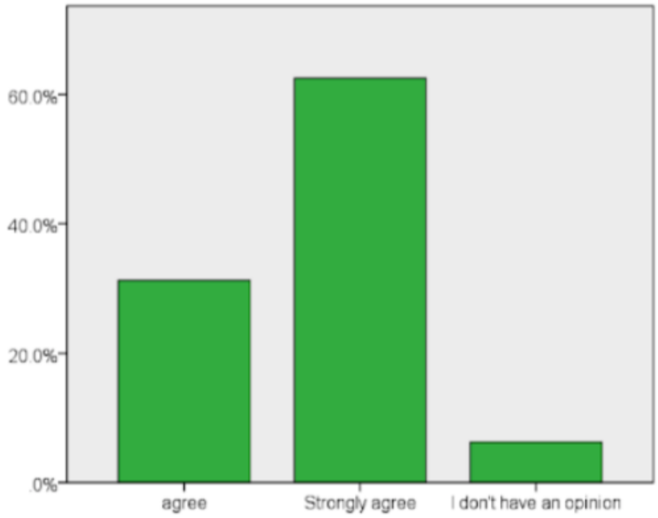
Round 1 overall response for question 8.



8. The population who work outdoors are an important target group for surveillance

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

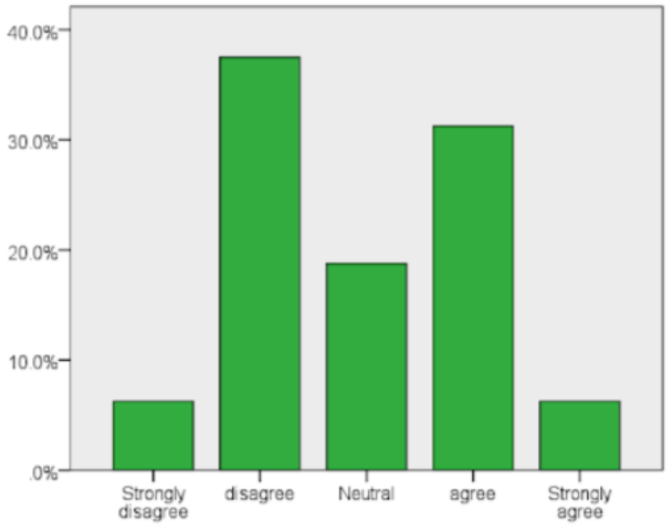
Round 1 overall response for question 9.



9. The population who have underlying disease are an important target group for surveillance

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

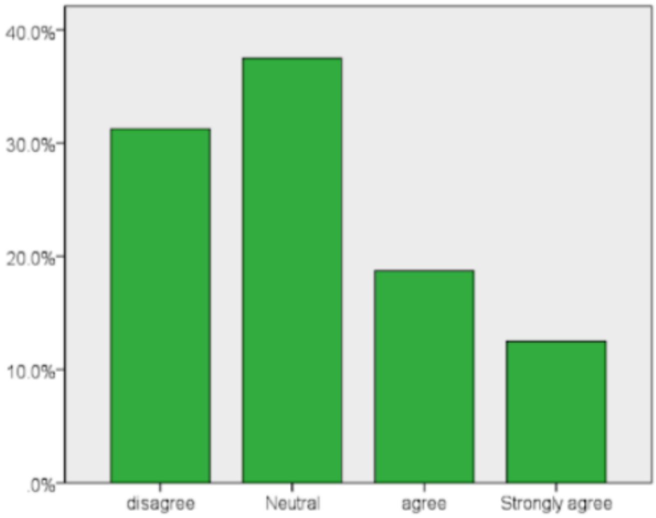
Round 1 overall response for question 10.



10. The warning system should issue a warning once a day (any morning or afternoon or evening)

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

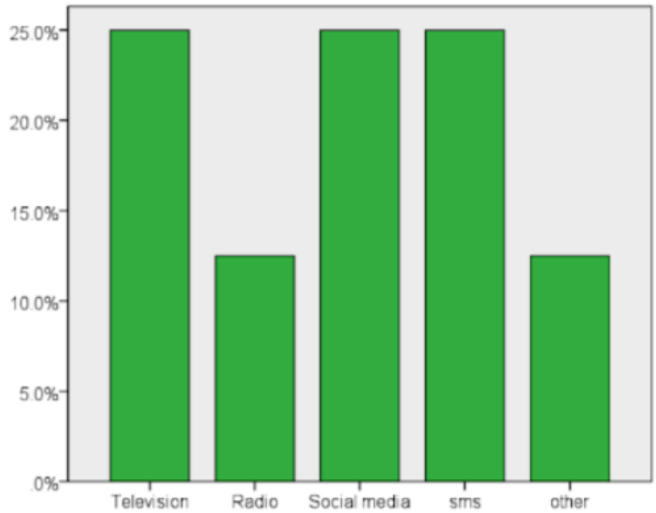
Round 1 overall response for question 11.



11. The warning system should issue warnings three times a day (morning, afternoon and evening)

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Round 1 overall response for question 12.



12. At the critical period, the best media to spread the warning message is

- ◯ Television
- ◯ Radio
- ◯ Social media such as Facebook, Twitter, Line
- ◯ Short messaging system (SMS)
- ◯ Web service
- ◯ Other:

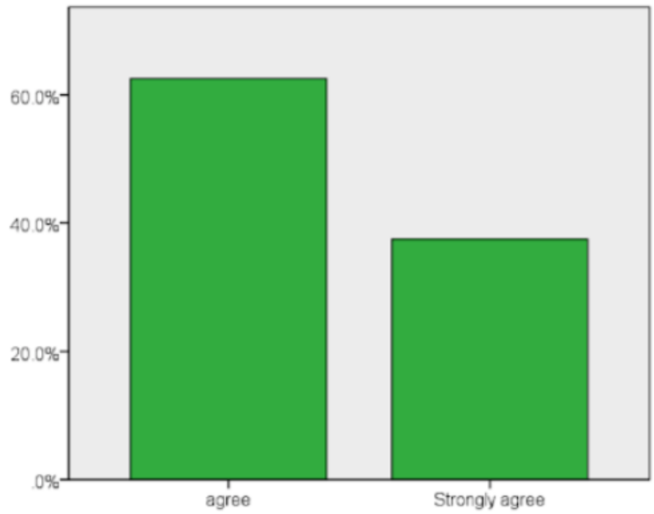
Page 3 of 6 BACK NEXT

Delphi Round 2

Interventions for individual level

Please reconsider and give an agreement on the statements below

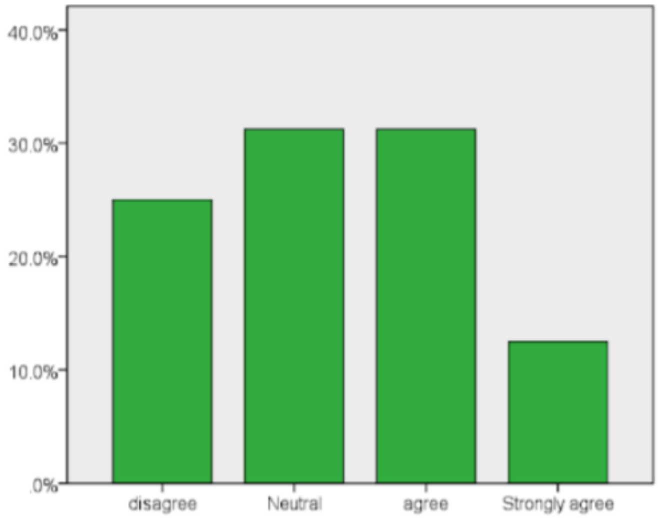
Round 1 overall response for question 13.



13. Using air conditioning can reduce the individual risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

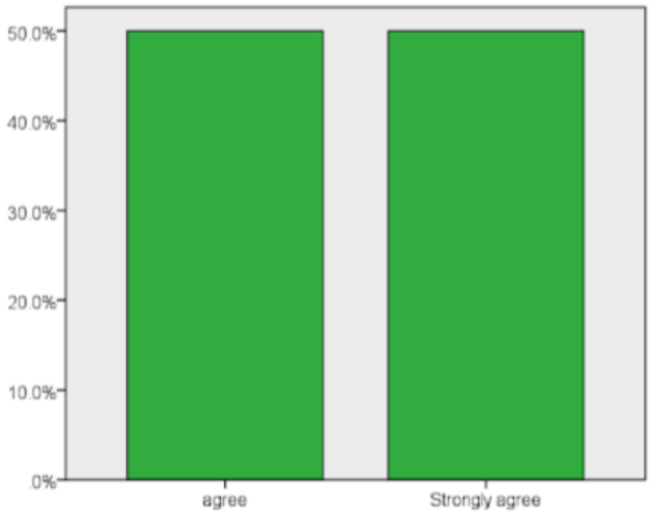
Round 1 overall response for question 14.



14. Using a fan can reduce the individual risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

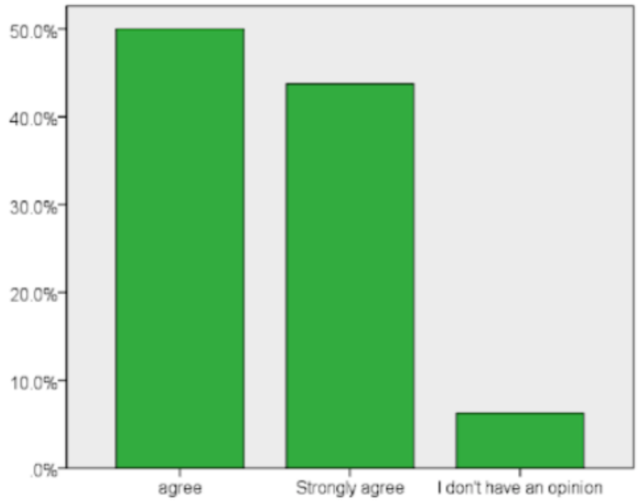
Round 1 overall response for question 15.



15. Increasing self- awareness of how to maintain their core body temperature can reduce the risk of disease.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

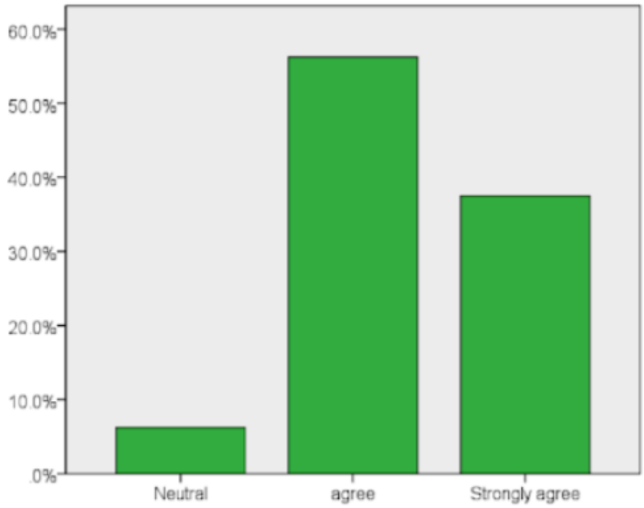
Round 1 overall response for question 16.



16. Encouraging self - detected symptom and sign of heat related illness can reduce the risk of disease.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

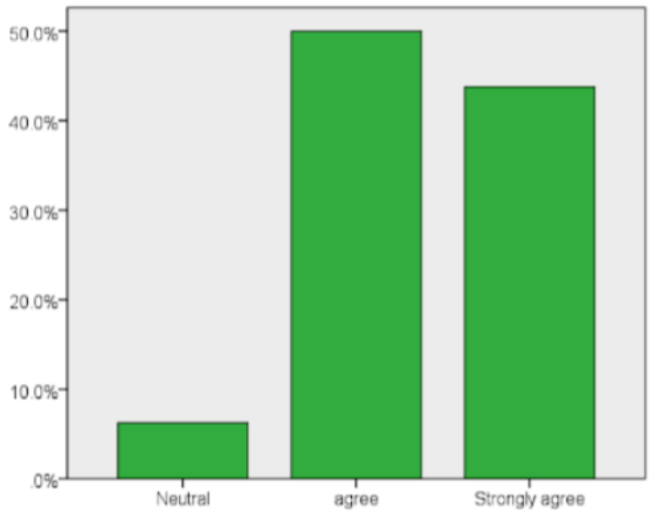
Round 1 overall response for question 17.



17. Keeping out of the sun between 11.00 a.m. and 3.00 p.m. is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

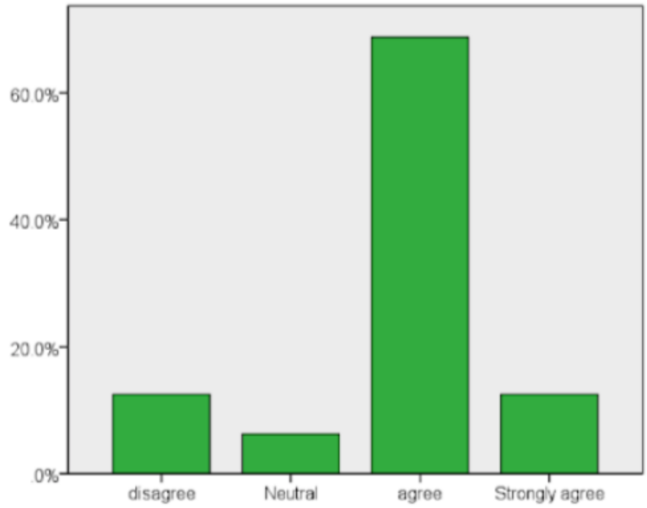
Round 1 overall response for question 18.



18. Avoiding extreme physical exertion and wear light, loose-fitting cotton clothes is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

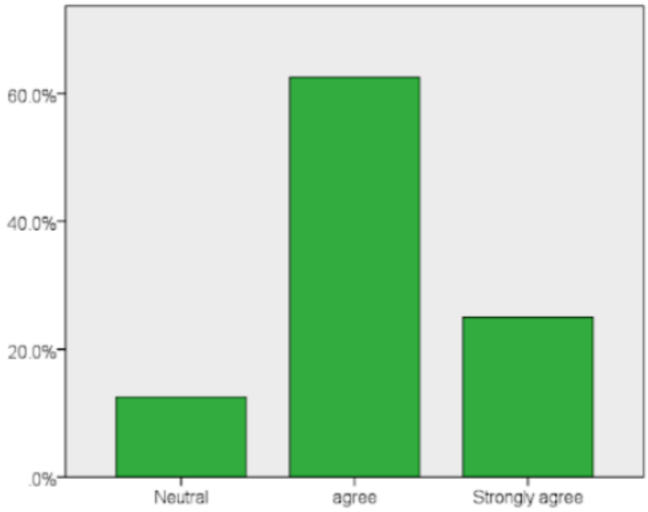
Round 1 overall response for question 19.



19. Applying sunscreen and wearing a hat and light scarf are good practice for prevention of heat exposure.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

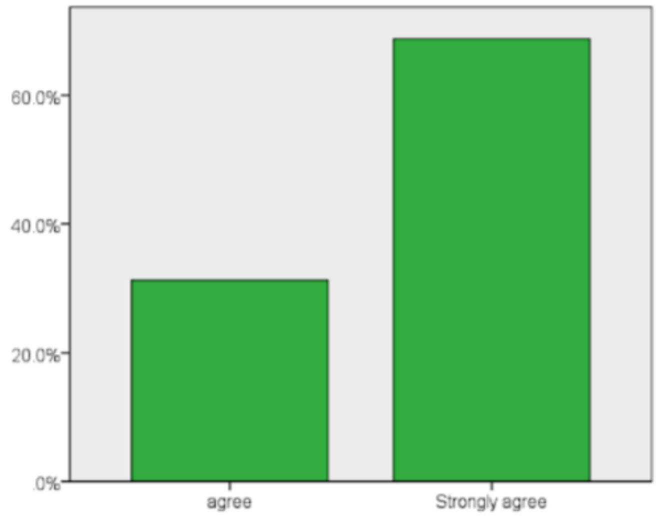
Round 1 overall response for question 20.



20. Having plenty of cold drinks (two to four glasses) can reduce the risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

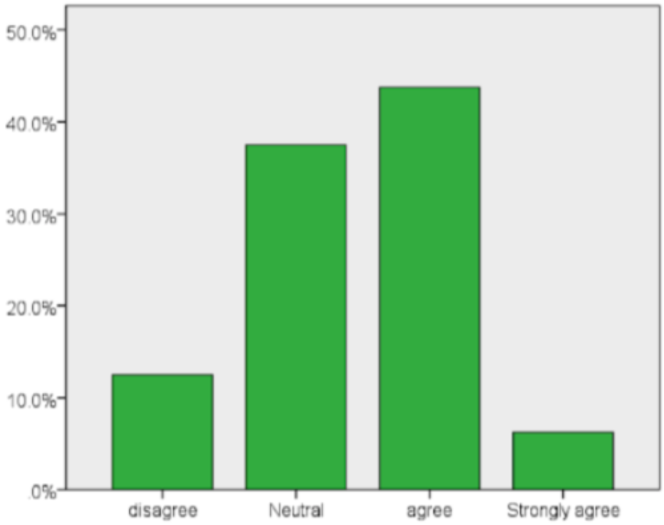
Round 1 overall response for question 21.



21. Avoiding excess alcohol drinking can the reduce risk of disease.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

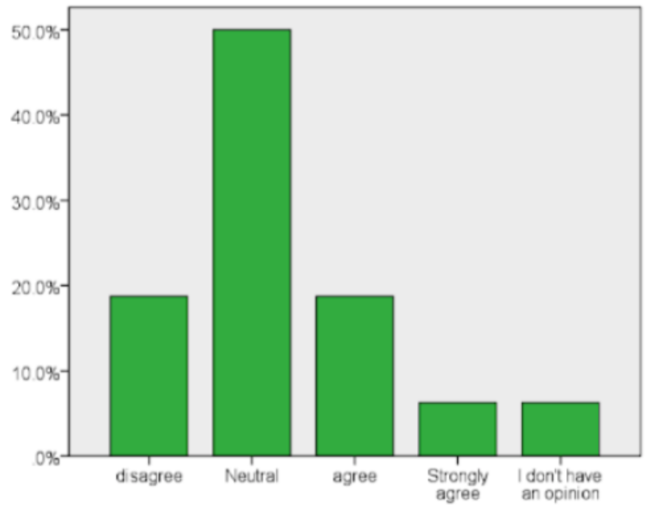
Round 1 overall response for question 22.



22. Avoiding excess caffeine drinking can the reduce risk of disease

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

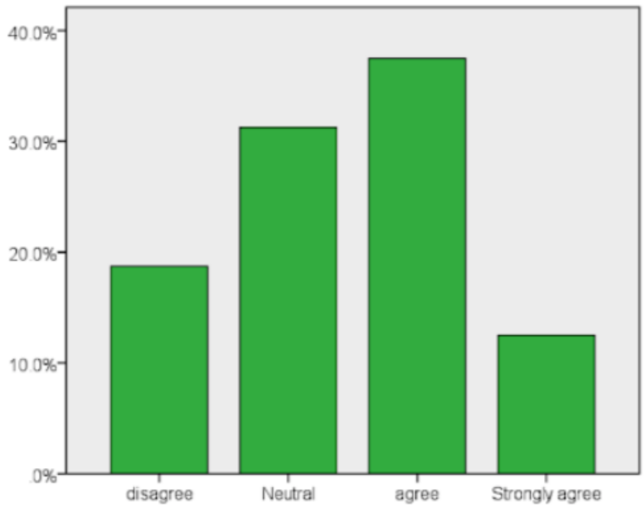
Round 1 overall response for question 23.



23. Avoiding excess hot drink can the reduce risk of disease

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

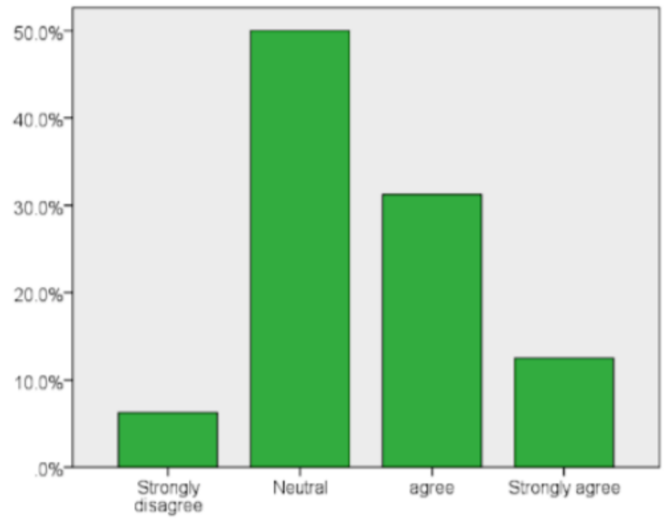
Round 1 overall response for question 24.



24. Keeping windows that are exposed to the sun closed during the day and open at night when the temperature has dropped are good practices for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

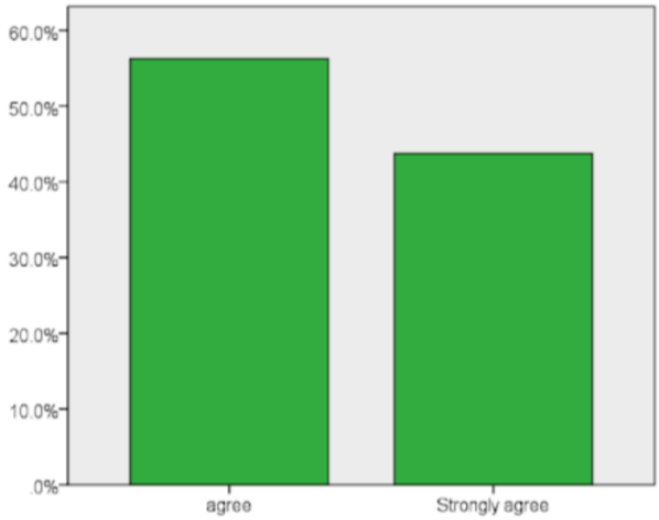
Round 1 overall response for question 25.



25. Keeping indoor plants and bowls of water in the house as evaporation helps cool the air is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Round 1 overall response for question 26.



26. Considering putting up external shading outside windows; growing trees and leafy plants near windows to act as natural air-conditioners are good practices for prevention of heat exposure

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

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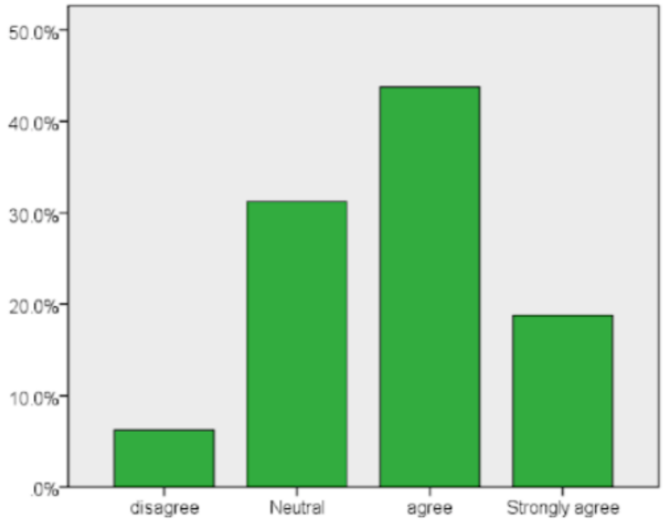
Delphi Round 2

Interventions for Community level

Please reconsider and give an agreement on the statements below

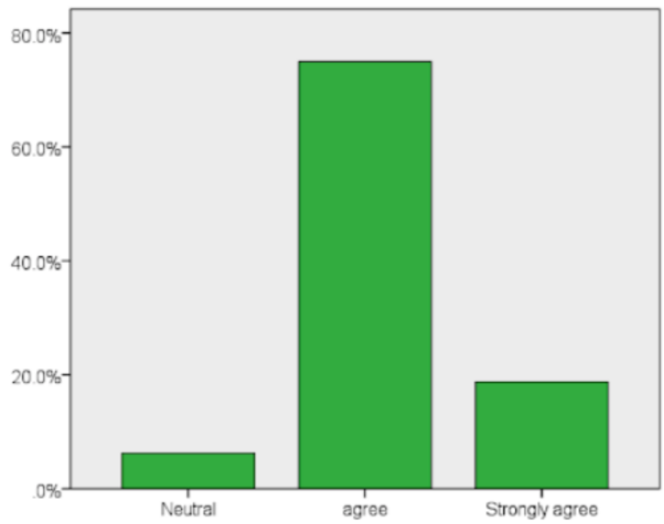
Round 1 overall response for question 27.



27. Using artificial rain to reduce the surface temperature in order to reduce risk at population level is useful in preventing heat related illness.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

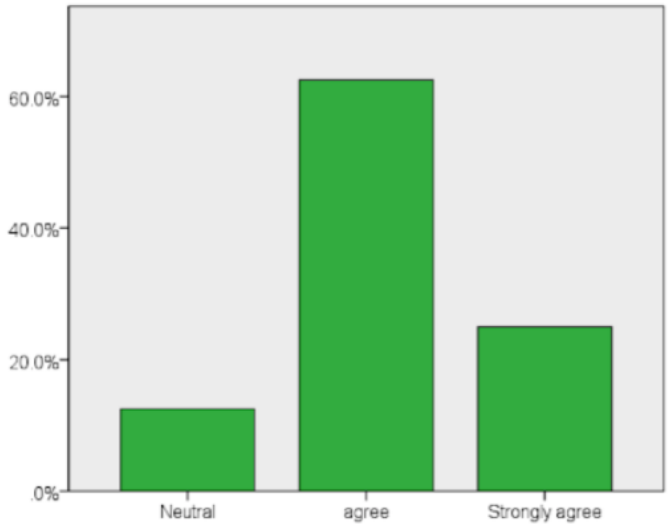
Round 1 overall response for question 28.



28. Establishing a cooling centre or a temporary cooling shelter are good practices for prevention of heat exposure.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

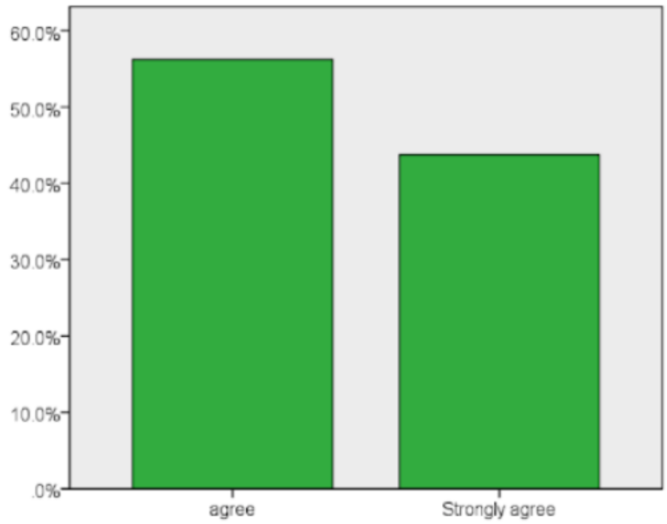
Round 1 overall response for question 29.



29. Increasing facilitation and capability of rapid surveillance team are good practices for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

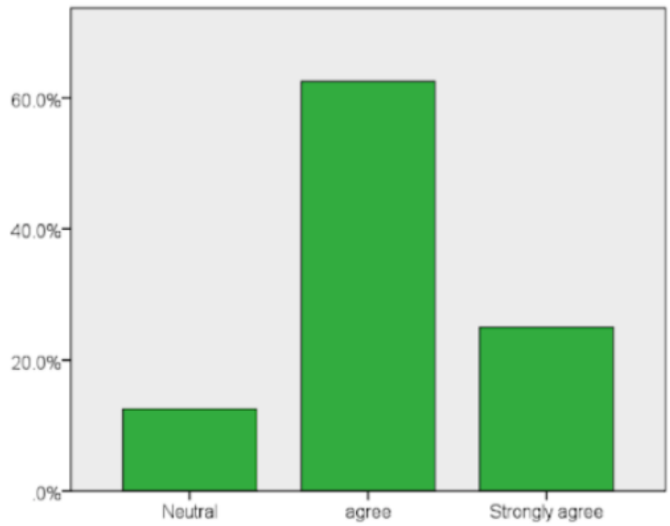
Round 1 overall response for question 30.



30. During heat events, buddies system should be provided to keep an eye on isolated, elderly, ill or very young people and make sure they are able to keep cool.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

Round 1 overall response for question 31.



31.The medical service should increase staffing during warnings in anticipation of higher demand.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Page 5 of 6 BACK NEXT

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Appendix A-3: Delphi round 3 questionnaire

11/9/2018 Delphi Round 3

Delphi Round 3

The researcher has removed section 1; threshold level for Thailand's Heat Health Warning System due to the consensus was achieved. Hence, there are 30 statements start from section 2; question 3.

Please reconsider your opinions in the context of the feedback provided. You can either keep your opinions as the second round or change your opinions in this round.

Name

Your answer

Page 1 of 4 NEXT

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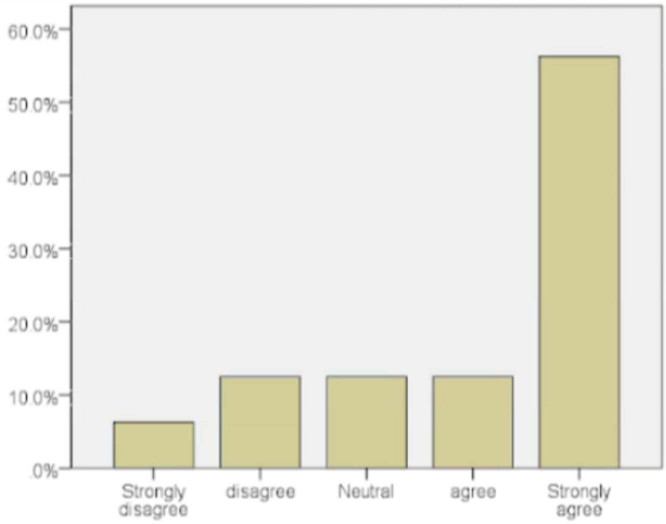
https://docs.google.com/forms/d/e/1FAIpQLSd4laGzX7_sION3T2TxDXTFmaI009X9hzcfiroPEr4r0up3Bw/viewform 1/1

Delphi Round 3

Issuance of warning and communication

Please reconsider and give an agreement on the statements below.

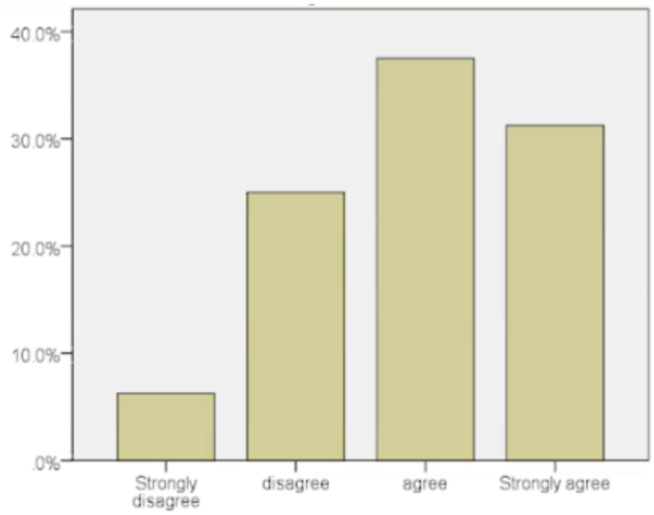
Round 2 overall responses for question 3.



3. The heat health warning system of Thailand should be combined with the air - quality warning system.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

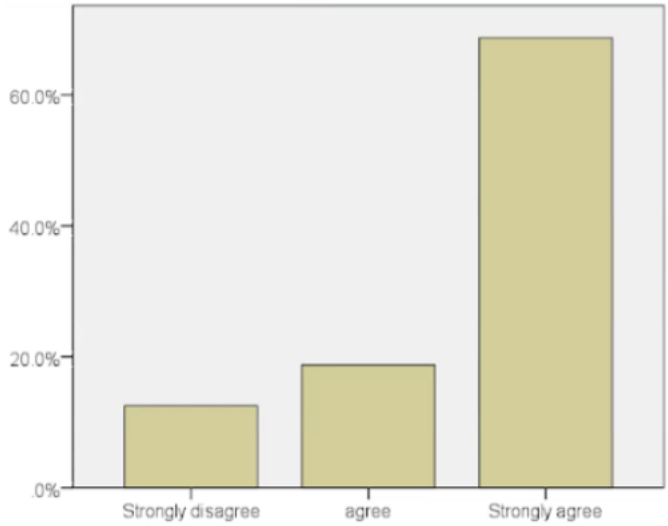
Round 2 overall responses for question 4.



4. The heat information centre should be established as stand alone organization to improve the quality of information, the capacity of surveillance and rapid response on heat related illness.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

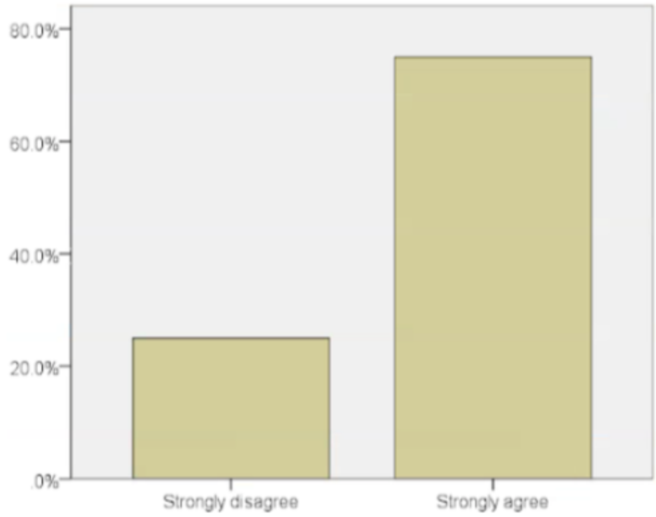
Round 2 overall responses for question 5.



5. The heat information centre can join with the national public health system by adding heat information, capacity of surveillance and rapid response on heat related illness.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

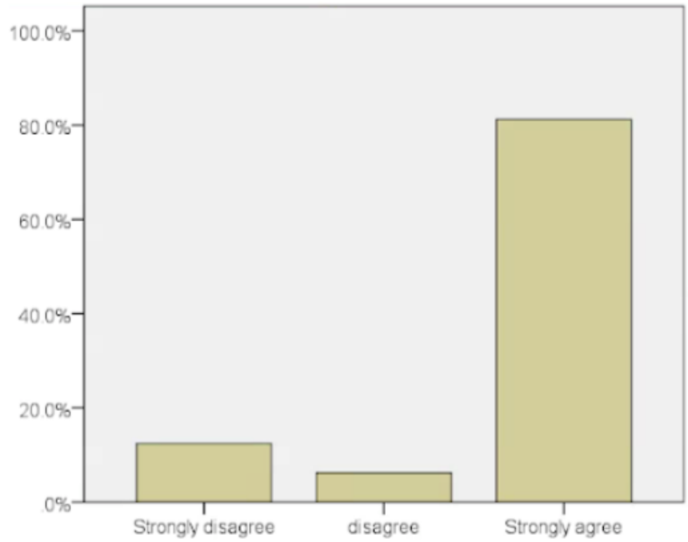
Round 2 overall responses for question 6.



6. The population who are more than 60 years old are an important target group for surveillance.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

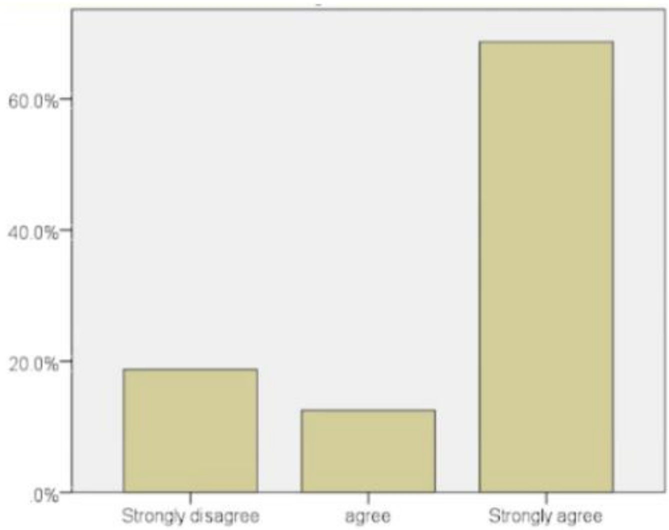
Round 2 overall responses for question 7.



7. The population who are below 5 years old are an important target group for surveillance.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

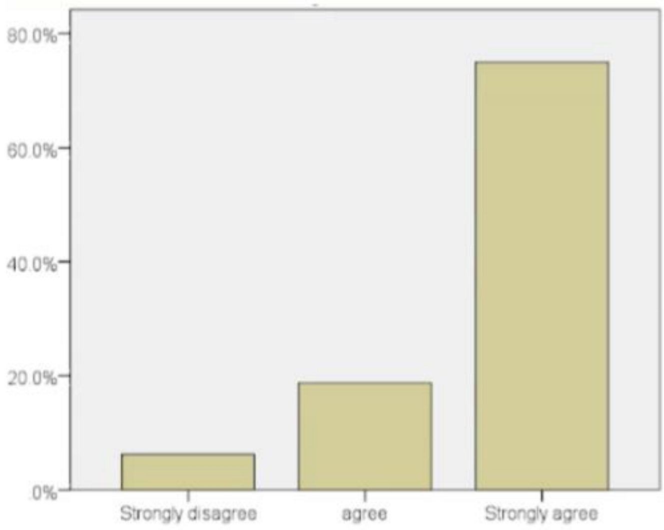
Round 2 overall responses for question 8.



8. The population who work outdoors are an important target group for surveillance

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

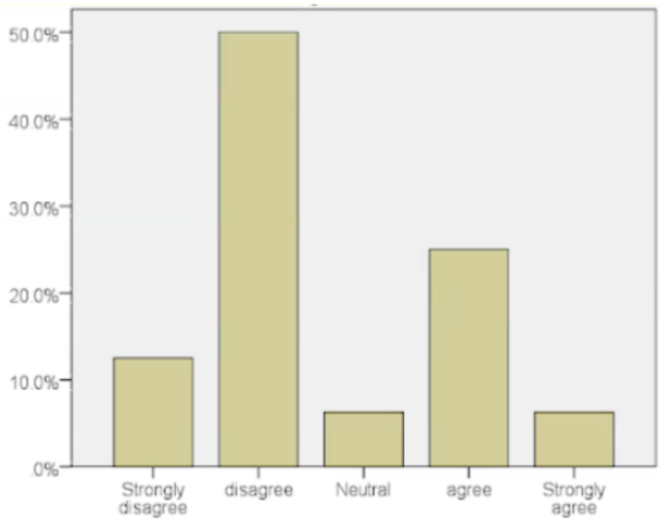
Round 2 overall responses for question 9.



9. The population who have underlying disease are an important target group for surveillance

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

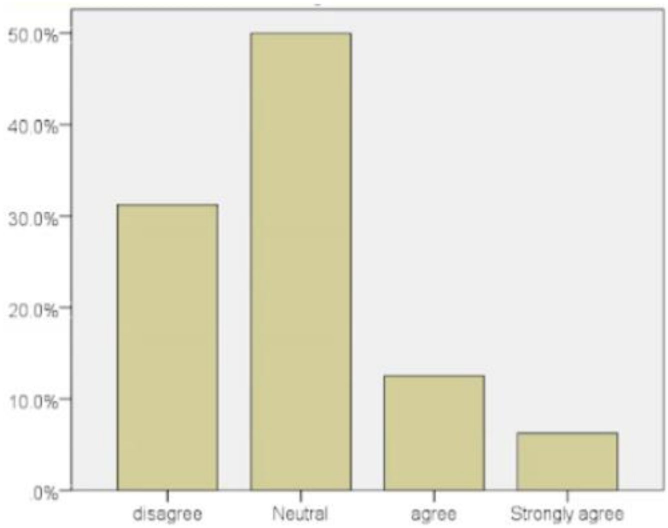
Round 2 overall responses for question 10.



10. The warning system should issue a warning once a day (any morning or afternoon or evening)

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

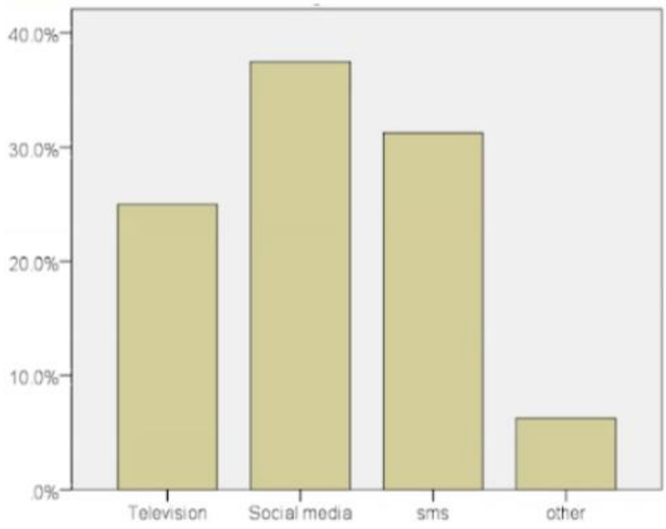
Round 2 overall responses for question 11.



11. The warning system should issue warnings three times a day (morning, afternoon and evening)

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Round 2 overall responses for question 12.



12. At the critical period, the best media to spread the warning message is

- ◯ Television
- ◯ Radio
- ◯ Social media such as Facebook, Twitter, Line
- ◯ Short messaging system (SMS)
- ◯ Web service
- ◯ Other:

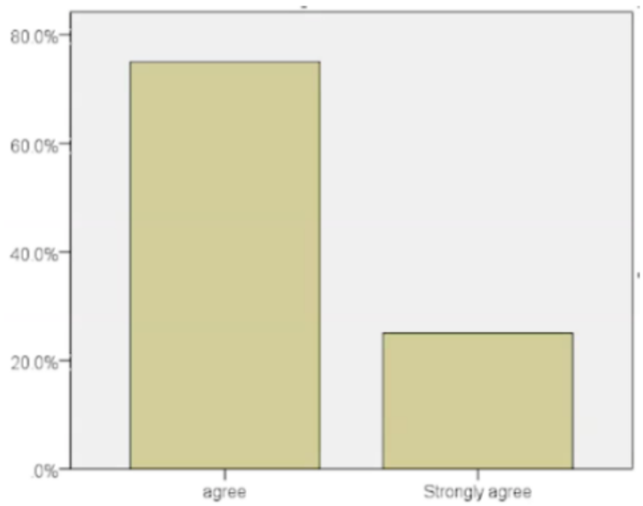
Page 2 of 4 BACK NEXT

Delphi Round 3

Interventions for individual level

Please reconsider and give an agreement on the statements below

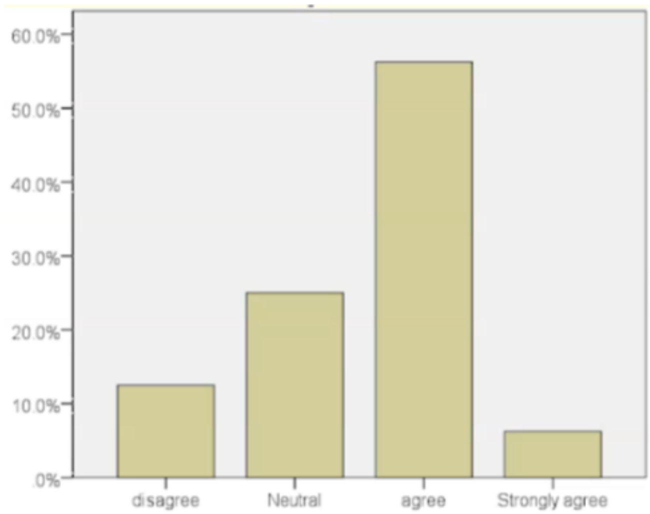
Round 2 overall responses for question 13.



13. Using air conditioning can reduce the individual risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

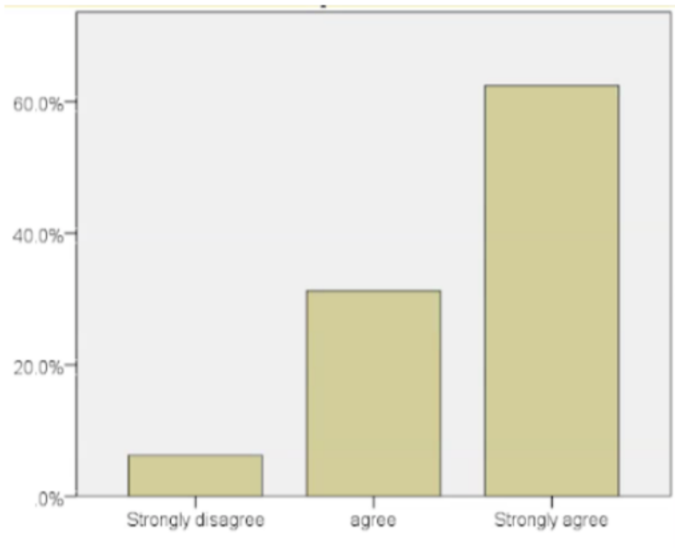
Round 2 overall responses for question 14.



14. Using a fan can reduce the individual risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

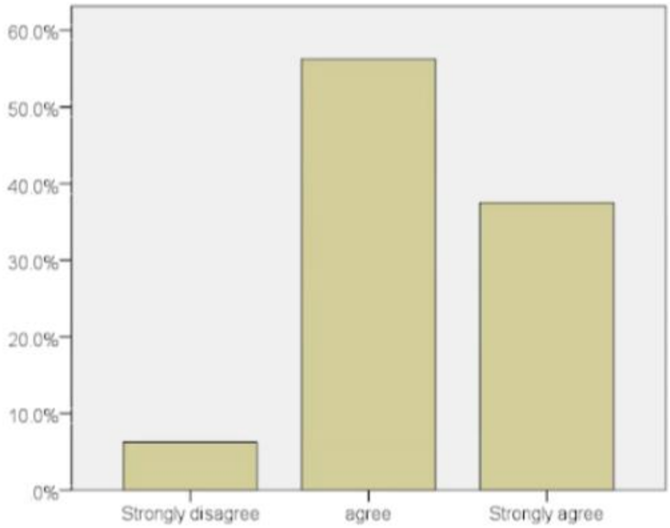
Round 2 overall responses for question 15.



15. Increasing self- awareness of how to maintain their core body temperature can reduce the risk of disease.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

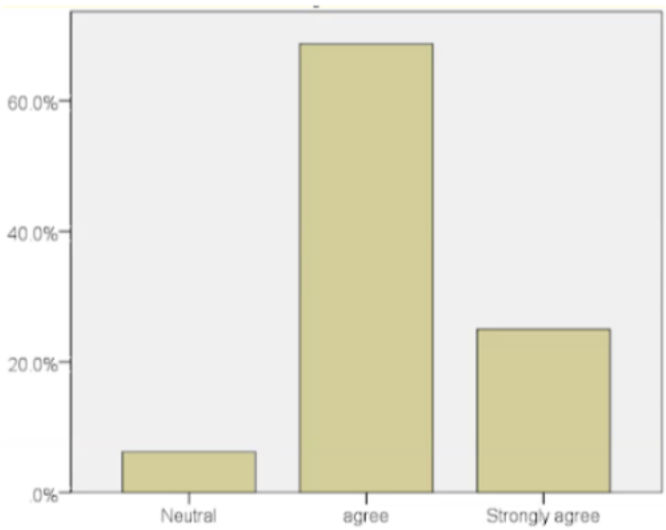
Round 2 overall responses for question 16.



16. Encouraging self - detected symptom and sign of heat related illness can reduce the risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

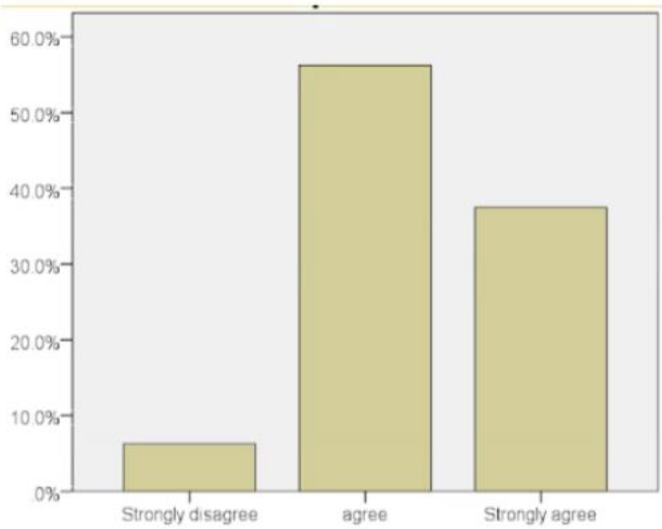
Round 2 overall responses for question 17.



17. Keeping out of the sun between 11.00 a.m. and 3.00 p.m. is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Round 2 overall responses for question 18.



18. Avoiding extreme physical exertion is a good practice for prevention of heat exposure.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

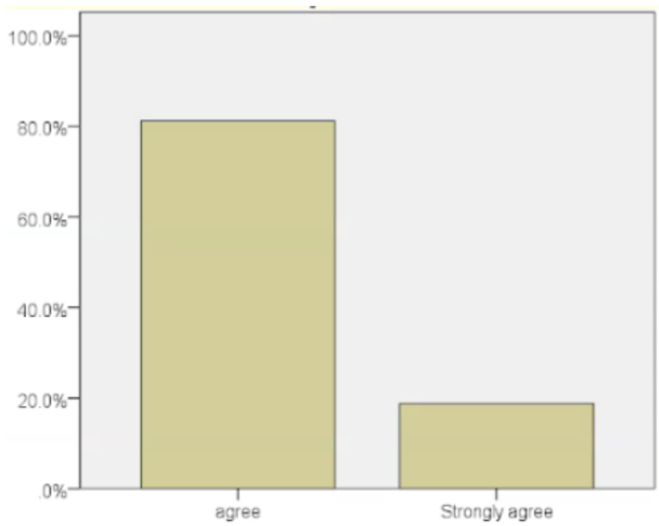
19.1 Applying sunscreen is a good practice for prevention of heat exposure.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

19.2 Wearing a hat is a good practice for prevention heat exposure

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

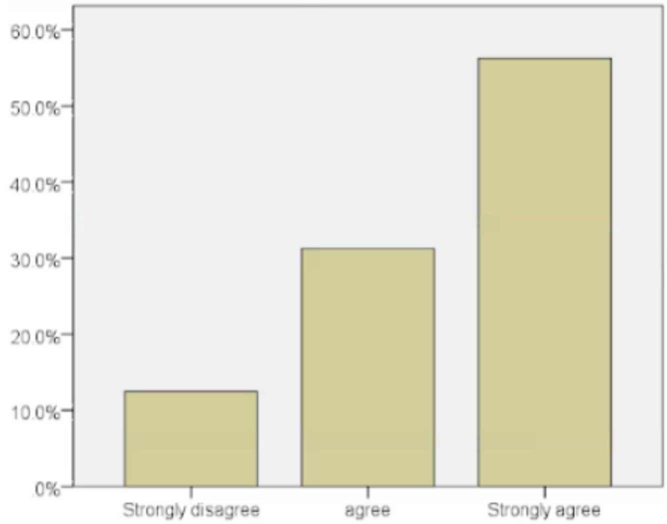
Round 2 overall responses for question 20.



20. Having plenty of cold drinks (two to four glasses) can reduce the risk of disease.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

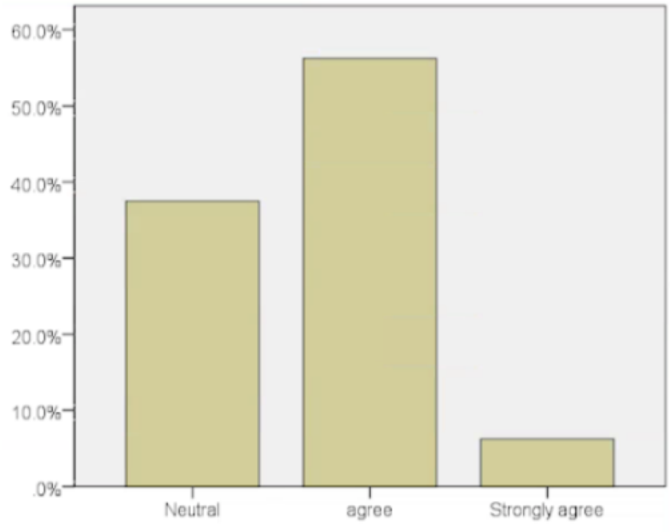
Round 2 overall responses for question 21.



21. Avoiding excess alcohol drinking can the reduce risk of disease.

- ○ Strongly disagree
- ○ Disagree
- ○ Neutral
- ○ Agree
- ○ Strongly agree
- ○ I don't have an opinion

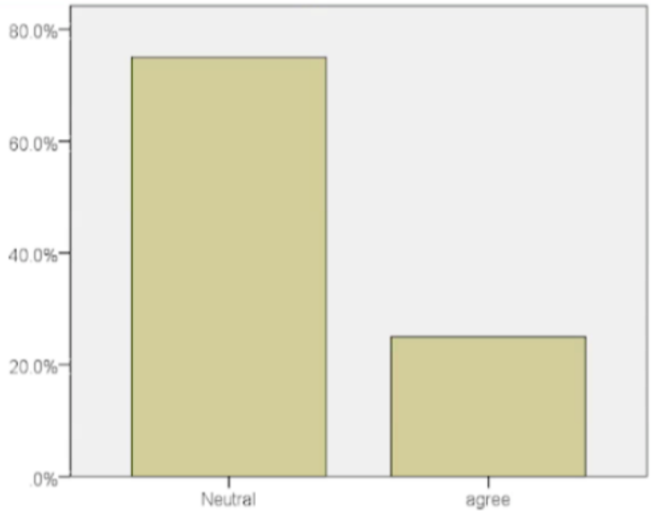
Round 2 overall responses for question 22.



22. Avoiding excess caffeine drinking can the reduce risk of disease

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

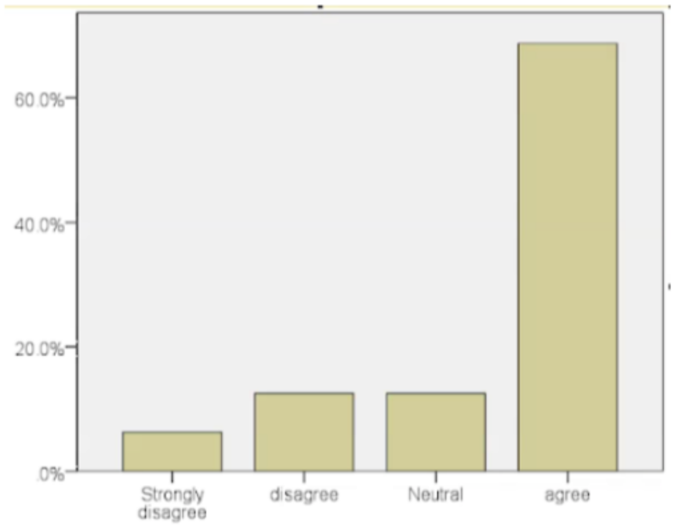
Round 2 overall responses for question 23.



23. Avoiding excess hot drink can the reduce risk of disease

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

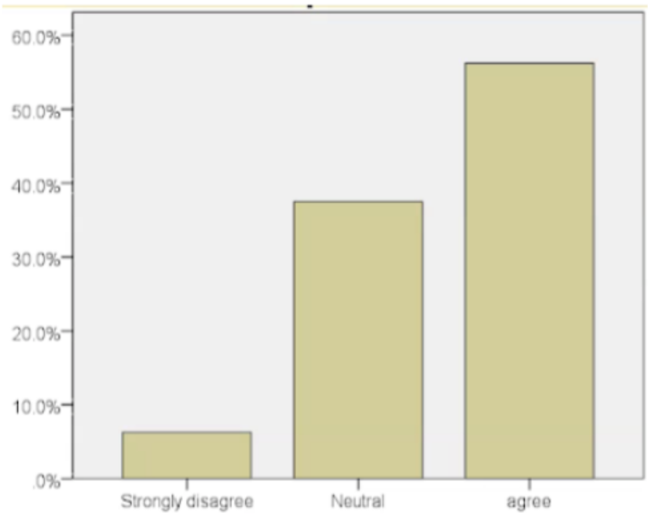
Round 2 overall responses for question 24.



24. Keeping windows that are exposed to the sun closed during the day and open at night when the temperature has dropped are good practices for prevention of heat exposure.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

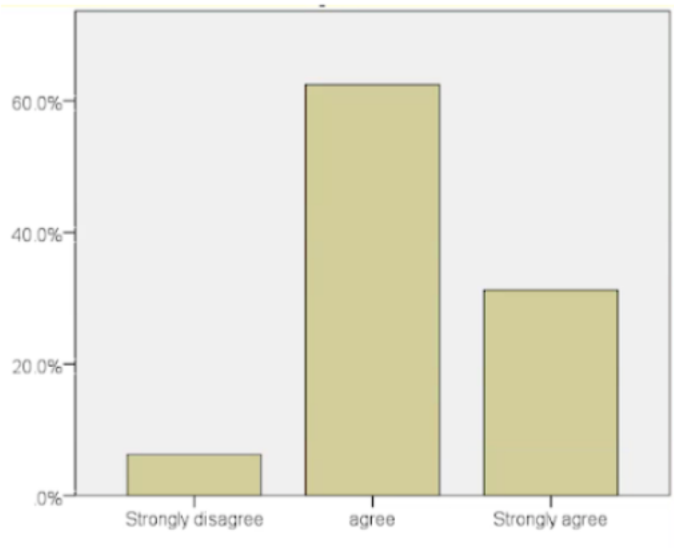
Round 2 overall responses for question 25.



25. Keeping indoor plants and bowls of water in the house as evaporation helps cool the air is a good practice for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Round 2 overall responses for question 26.



26. Considering putting up external shading outside windows; growing trees and leafy plants near windows to act as natural air-conditioners are good practices for prevention of heat exposure

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

Page 3 of 4 BACK NEXT

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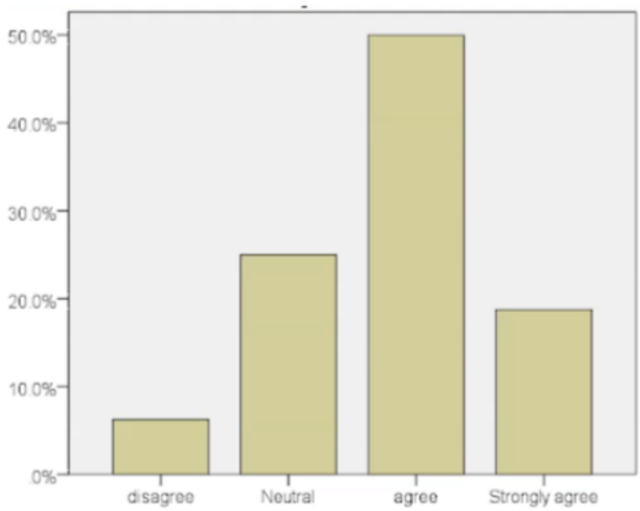
Delphi Round 3

Interventions for Community level

Please reconsider and give an agreement on the statements below

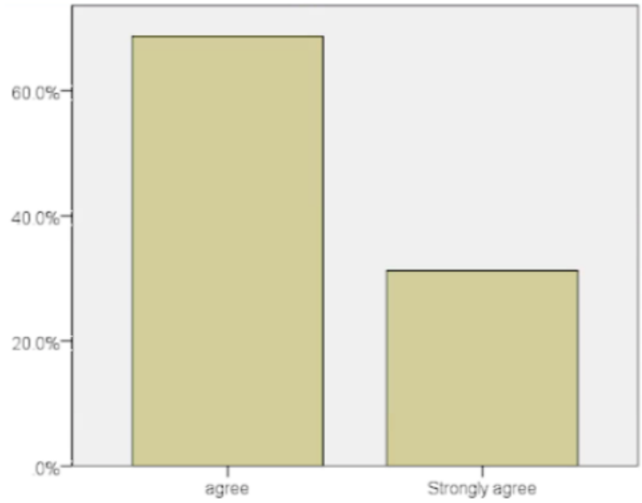
Round 2 overall responses for question 27.



28. Establishing a cooling centre or a temporary cooling shelter are good practices for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

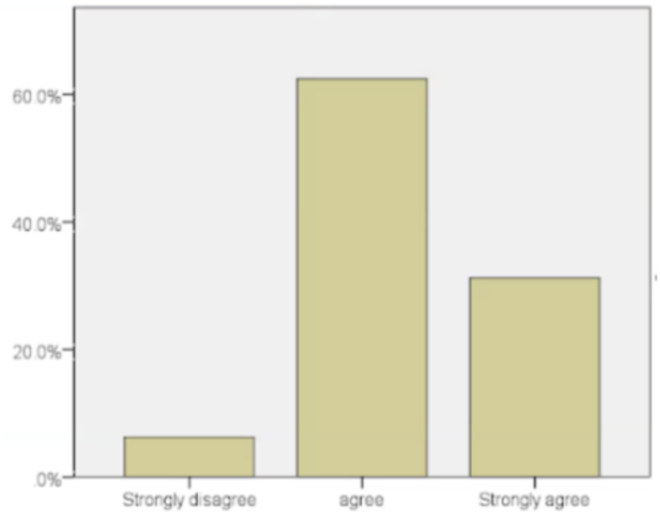
Round 2 overall responses for question 29.



29. Increasing facilitation and capability of rapid surveillance team are good practices for prevention of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

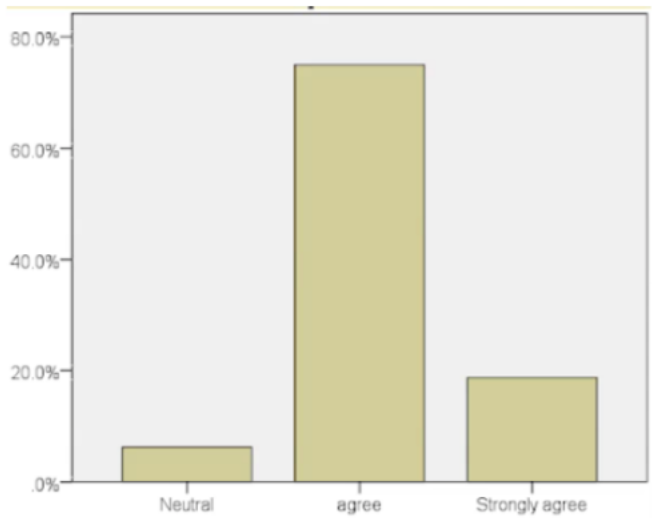
Round 2 overall responses for question 30.



30. During heat events, buddies system should be provided to keep an eye on isolated, elderly, ill or very young people and make sure they are able to keep cool.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

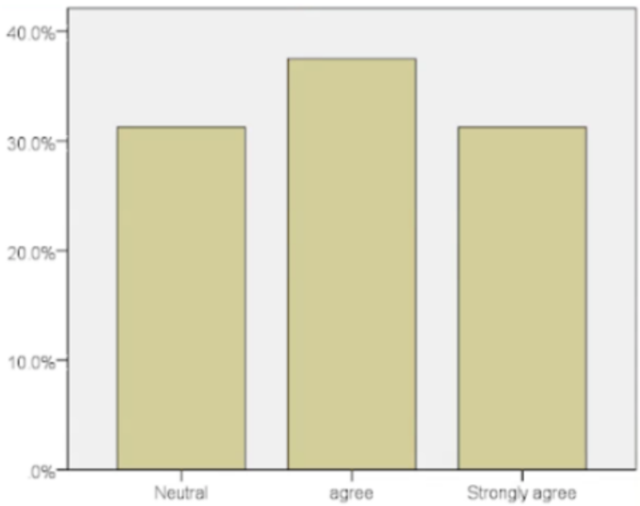
Round 2 overall responses for question 31.



31.The medical service should increase staffing during warnings in anticipation of higher demand.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

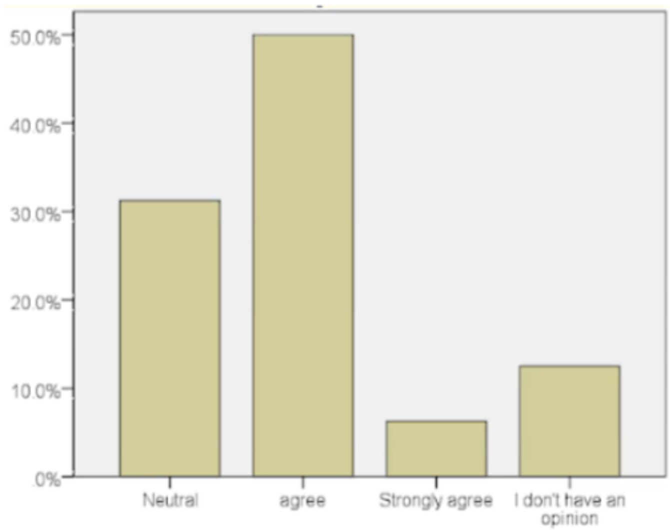
Round 2 overall responses for question 32.



32. Monitoring in house temperature by using a thermometer is a good practice for awareness of heat exposure.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree
- I don't have an opinion

Round 2 overall responses for question 33.



33. Monitoring urine color in the critical period is a good practices to detect the risk of disease.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree
- ◯ I don't have an opinion

If you have any additional comments regarding any statements in this round, please state below

Your answer

Page 4 of 4 BACK SUBMIT

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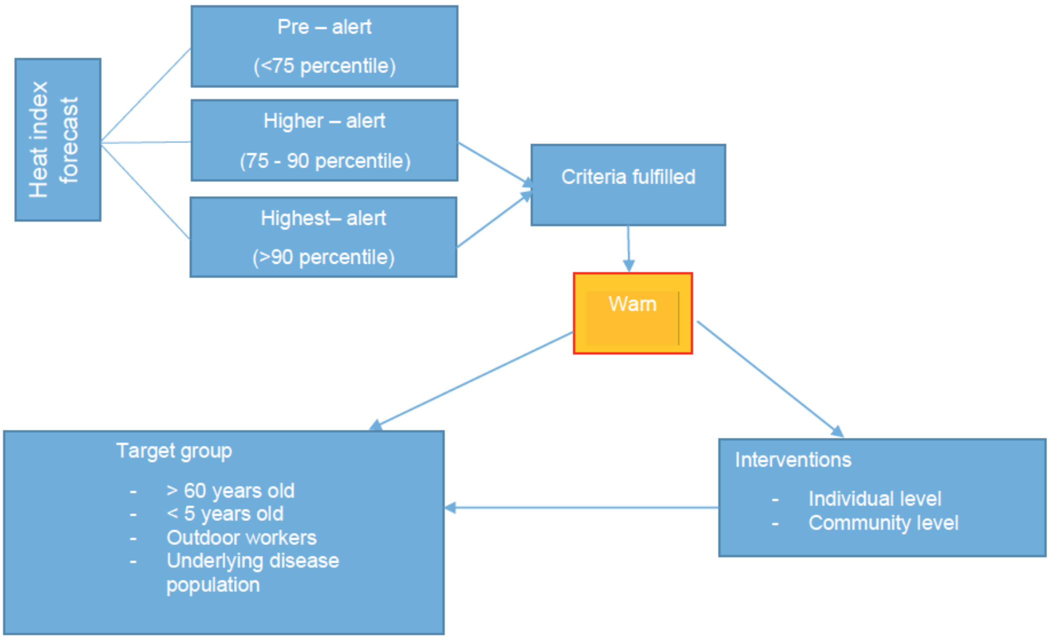
Appendix – B: Topic guide for focus group

Topic guide for focus group meeting on

Thailand heat health warning system development

<u>The outline of heat health warning system Thailand is shown in the diagram below.</u>



1. The outline of heat health warning system composes of 3 main components, which are;

   Component 1 Threshold level for warning

   Component 2 Issuance of warning and communication

   Component 3 Interventions for individual and community level

   - Do you think these components are proper for Thailand? Are there any components necessary to complete the system?

2. <u>Component 1 Threshold level for Heat health warning system</u>

   Consensus was gained on the following threshold level

1

Region	Pre – alert	Higher - alert	Highest alert
North-eastern	< 92	92 - 95	> 95
Northern	< 90	90 - 94	> 94
Central	< 94	94 - 98	> 98
Southern	< 90	90 - 92	> 92

Please note heat index is in Fahrenheit unit.

- Do you think these thresholds are feasible to apply for Thailand HHWS? Please give the reason why it feasible or not feasible?
- How to make this component achieve in practical?
- Who has the main authority on this component?
- The expert from Delphi round concerns about the meteorological differences from 2 different part of the coast (SW-SE) in the Southern region of Thailand and it may effected to the result of threshold level in Southern region. What do you think about the available of the meteorological data and the completion of data?

3. Component 2 Issuance of warning and communication

Consensus was gained on the following statements

	Consensus level
The heat health warning system of Thailand should be combined with the air - quality warning system.	81.3%
The heat information centre can join with the national public health system by adding heat information, capacity of surveillance and rapid response on heat related illness.	93.8%
The population who are more than 60 years old are an important target group for surveillance.	87.5%
The population who are below 5 years old are an important target group for surveillance.	87.5%
The population who work outdoors are an important target group for surveillance	100%
The population who have underlying disease are an important target group for surveillance	87.5%

2

- Do you think these statements are feasible to apply for Thailand HHWS? Please give the reason why it feasible or not feasible?
- How to make this component achieve in practical?
- Who has the main authority on this component?

No consensus was reached on following statements

'The heat information centre should be established as standalone organization to improve the quality of information, the capacity'

'The warning system should issue a warning once a day (any morning or afternoon or evening)'

'The warning system should issue warnings three times a day (morning, afternoon and evening)'

'At the critical period, what is the best media to spread the warning message?'

- Do you have any additional ideas on each statement?

4. Component 3 Interventions for individual level

Consensus was gained on the following statements;

	Consensus level
Using air conditioning can reduce the individual risk of disease.	100%
Increasing self- awareness of how to maintain their core body temperature can reduce the risk of disease.	93.8%
Encouraging self - detected symptom and sign of heat related illness can reduce the risk of disease	100%
Keeping out of the sun between 11.00 a.m. and 3.00 p.m. is a good practice for prevention of heat exposure.	100%
Avoiding extreme physical exertion and wear light, loose-fitting cotton clothes is a good practice for prevention of heat exposure.	100%
Having plenty of cold drinks (two to four glasses) can reduce the risk of disease.	100%
Avoiding excess alcohol drinking can reduce the risk of disease.	93.8%
Considering putting up external shading outside windows; growing trees and leafy plants near windows to act as natural air-conditioners are good practices for prevention of heat exposure	100%

- Do you think these statements are feasible to apply for Thailand HHWS? Please give the reason why it feasible or not feasible?

- How to make this component achieve in practical?
- Who has the main authority on this component?

No consensus was reached on following statements

'Using a fan can reduce the individual risk of disease.'

'Applying sunscreen is a good practice for prevention of heat exposure.'

'Wearing a hat and light scarf are good practice for prevention of heat exposure'

'Avoiding excess caffeine drinking can reduce the risk of disease'

'Keeping windows that are exposed to the sun closed during the day and open at night when the temperature has dropped are good practices for prevention of heat exposure.'

'Keeping indoor plants and bowls of water in the house as evaporation helps cool the air is a good practice for prevention of heat exposure.'

- Do you have any additional ideas on each statement?

5. <u>Component 3 Interventions for Community level</u>

Consensus was gained on the following statements;

	Consensus level
Establishing a cooling centre or a temporary cooling shelter are good practices for prevention of heat exposure.	100%
Increasing facilitation and capability of rapid surveillance team are good practices for prevention of heat exposure.	100%
During heat events, buddies system should be provided to keep an eye on isolated, elderly, ill or very young people and make sure they are able to keep cool.	100%
The medical service should increase staffing during warnings in anticipation of higher demand	100%
Monitoring in house temperature by using a thermometer is a good practice for awareness of heat exposure.	81.3%

- Do you think these statements are feasible to apply for Thailand HHWS? Please give the reason why it feasible or not feasible?
- How to make this component achieve in practical?
- Who has the main authority on this component?

No consensus was reached on following statements

‘Using artificial rain to reduce the surface temperature in order to reduce risk at population level is useful in preventing heat related illness.’

‘Monitoring urine colour in the critical period is a good practices to detect the risk of disease.’

- Do you have any additional ideas on each statement?

Appendix – C: Ethical Approval Letter from FMS Ethics Committee at Newcastle University.

Newcastle University

Faculty of Medical Sciences
Newcastle University
The Medical School
Framlington Place
Newcastle upon Tyne
NE2 4HH United Kingdom

Chuleekorn Tanathitikorn
Institute of Health & Society

FACULTY OF MEDICAL SCIENCES: ETHICS COMMITTEE

Dear Chuleekorn,

Title: An investigation of associations between climate change and heat related diseases and heat warning system development in Thailand.
Application No: 01075/2016
Start date to end date: 05/01/2015 to 05/01/2019

On behalf of the Faculty of Medical Sciences Ethics Committee, I am writing to confirm that the ethical aspects of your proposal have been considered and your study has been given ethical approval.

The approval is limited to this project: **01075/2016**. If you wish for a further approval to extend this project, please submit a re-application to the FMS Ethics Committee and this will be considered.

During the course of your research project you may find it necessary to revise your protocol. Substantial changes in methodology, or changes that impact on the interface between the researcher and the participants must be considered by the FMS Ethics Committee, prior to implementation.*

At the close of your research project, please report any adverse events that have occurred and the actions that were taken to the FMS Ethics Committee.*

Best wishes,

Yours sincerely

Kimberley Sutherland
On behalf of Faculty Ethics Committee

cc.
Professor Daniel Nettle, Chair of FMS Ethics Committee
Ms Lois Neal, Assistant Registrar (Research Strategy)

*Please refer to the latest guidance available on the internal Newcastle web-site.

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fax: +44 (0) 191 208 6621

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Appendix – D: International Conference

Appendix: D-1 Abstract for oral presentation in TSAC 2017

Innovation for sustainable life conference on 1st -3rd September 2017, Geneva Switzerland.

TSAC 2017
INNOVATION FOR SUSTAINABLE LIFE

O-17

A TIME SERIES ANALYSIS OF ASSOCIATIONS BETWEEN CLIMATE CHANGE AND HEAT RELATED ILLNESSES AND DEVELOPMENT OF HEAT HEALTH WARNING SYSTEM IN THAILAND

Tanathitikorn C.[a], *McNally R.*[a] *and Namdeo A.*[b]

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The earth's climate is changing in the ways that could cause serious consequences for public health. In Thailand, the heat health warning system is not set up and there is an increasing number of heat - related illnesses (HRI) yearly. As a result of this, the objectives of this work are to investigate the statistical associations between climatic variables and heat related illnesses and trends of illnesses through time.

Daily HRI of hospital admissions from the ICD10 database with diagnosis T67 (Effects of heat and light) were collected between January 2010 to December 2014 from the Bureau of Policy and Strategy, Department of Disease Control, Ministry of Public Health, Thailand. Daily temperature and humidity from the same period were obtained. Then, the heat index was calculated according to the Steadman equation. Time series and Generalised linear model with Poisson regression were used to find out the relationship between HRI and heat index controlling for day of the week and holiday indicator, for lag times of 1– 7 days.

There were 6,895 HRI visits. The overall incidence was 2.14 visits per 100,000 persons per year. The highest frequency of HRI visits was in the Northeastern region, where there were 2,167 visits. The incidence per 100,000 persons per year was 3.41 visits in the Southern region and 3.17 visits, in the Northern region, respectively. By provinces, Pichit took the top spot with an incidence rate of 10.26 per 100,000 persons per year. The majority of patients were female. The highest incidence was in the 80 – 84 years old group with an age – standardized incidence rate of 7.21 per 100,00 persons per year. There is a statistically significant relationship between HRI and change in level of heat index. The relative risk of HRI visits increased by 26% for the mean of heat index at lag 0 from 25th to 75th percentile changed.

The level of heat index has a positive association with heat related illnesses visits. A suitable warning threshold level of heat index for Thailand will be investigated in the next stage of the study.

Keywords:
Time series analysis, Heat related illnesses, Heat index, Heat health warning system, Climate change

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Appendix D-2: The poster presentation in Northeast Postgraduate Conference on 30th October 2017.

TIME SERIES ANALYSIS OF ASSOCIATIONS BETWEEN CLIMATE CHANGE AND HEAT RELATED ILLNESSES IN THAILAND

Newcastle University

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Introduction

The earth's climate is changing in the ways that could cause serious consequences for public health. In Thailand, the heat health warning system is not set up and there is an increasing number of heat - related illnesses (HRI) yearly. As a result of this, the objectives of this work are to investigate the statistical associations between climatic variables and heat related illnesses and trends of illnesses through time.

Method

❖ Daily HRI of hospital admissions from the ICD10 database with diagnosis T67 (Effects of heat and light) were collected between January 2010 to December 2014.

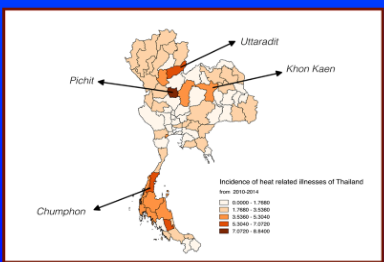
❖ Daily temperature and humidity from the same period were obtained. Then, the heat index was calculated according to the Steadman equation.

❖ Time series and GLM with Poisson regression were used to find out the relationship between HRI and heat index controlling for day of the week and holiday indicator, for lag times of 1- 7 days.

Results

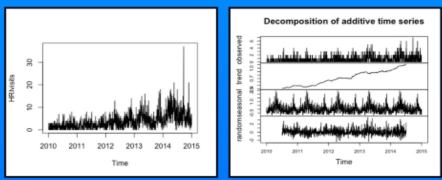
❖ The overall incidence was 2.14 visits per 100,000 persons per year.

❖ The incidence per 100,000 persons per year was 3.41 visits in the Southern region and 3.17 visits, in the Northern region, respectively.

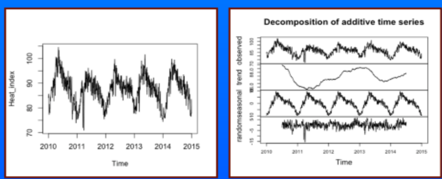


❖ The majority of patients were female.

❖ The highest incidence was in the 80 - 84 years old group with an age - standardized incidence rate of 7.21 per 100,00 persons per year.



Time series and decomposition plot of daily heat related illness visits



Time series and decomposition plot of daily heat related illness visits

❖ The relative risk of HRI visits at 25th percentile of the mean of heat index at lag 0 was 31.44.

❖ The relative risk of HRI visits at 75th percentile of the mean of heat index at lag 0 was 42.53.

Conclusion

❖ The level of heat index has a positive association with heat related illnesses visits.

❖ A suitable warning threshold level of heat index for Thailand will be investigated in the next stage of the study.

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Appendix D-3: Abstract submitted and accepted for poster presentation in ISEE young conference on 19th 20th March 2018, Freising, German.

A TIME SERIES ANALYSIS OF ASSOCIATIONS BETWEEN CLIMATE CHANGE AND HEAT RELATED ILLNESSES AND DEVELOPMENT OF A HEAT HEALTH WARNING SYSTEM IN THAILAND

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Abstract

Background: Thailand has no heat health warning system. However, there is an increasing number of heat - related illnesses (HRI) yearly. Thus, the objective of this work was to investigate the statistical associations between climatic variables and heat related illnesses with an aim to set up a suitable threshold level for Heat Health Warning System in Thailand.

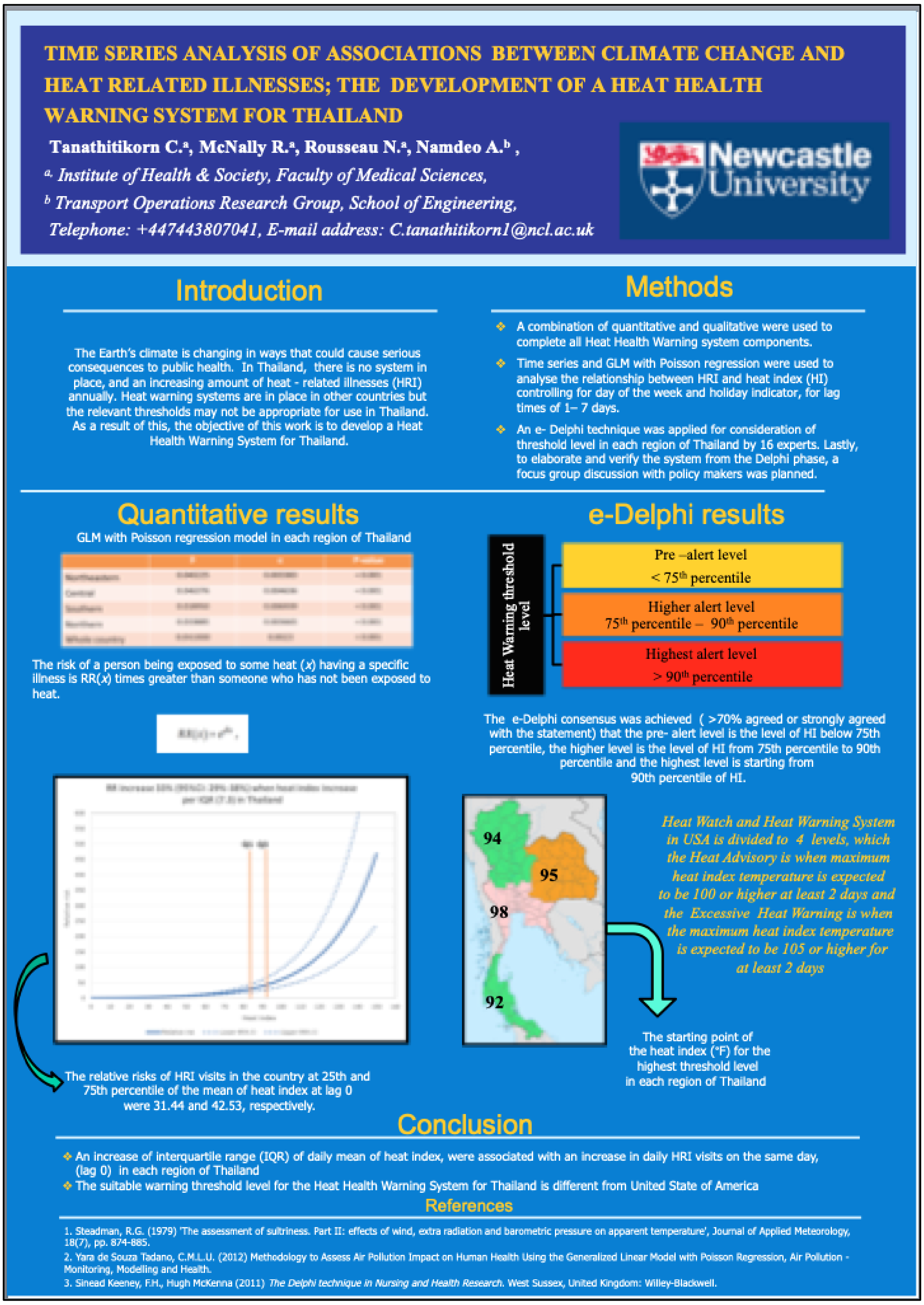
Method: Daily HRI of hospital admissions from the ICD10 database with diagnosis T67 (Effects of heat and light) were collected between January 2010 to December 2014 from the Bureau of Policy and Strategy, Department of Disease Control, Ministry of Public Health, Thailand. Daily temperature and humidity from the same period were obtained from Meteorological Department Ministry of Digital Economy and Society. Heat index was calculated according to the Steadman equation. Time series and Poisson regression analysis were used to find out the relationship between HRI and heat index controlling for day of the week and holiday indicator, for lag times of 1– 7 days.

Results: There were 6,895 HRI visits. The overall incidence was 2.14 visits per 100,000 persons per year. The incidence per 100,000 persons per year was 3.41 visits in the Southern region and 3.17 visits, in the Northern region, respectively. The majority of patients were female. The highest incidence was in the 80 – 84 years old group with an age – specific incidence rate of 7.21 per 100,000 persons per year. The relative risks of HRI visits in the country at 25th and 75th percentile of the mean of heat index at lag 0 were 31.44 and 42.53, respectively. The in-country regional relative risks at 25th percentile of the mean of heat index at lag 0 of the Southern, Northern, Central and Northeast regions were 5.01, 15.79, 55.37 and 26.38, respectively. Similarly, the relative risks at 75th percentile of the mean of heat index at lag 0 of Southern, Northern, Central and Northeast regions were 5.56, 21.76, 79.59, and 39.75, respectively.

Conclusion: The level of heat index has a positive association with heat related illnesses visits. A suitable warning threshold level of heat index for Thailand will be investigated in the next stage of the study.

Keywords: *Time series analysis, heat related illnesses, heat index, heat health warning system, climate change*

Appendix D- 4: Poster presentation in ISES – ISEE 2018 on 26th -30th August 2018, Ottawa, Canada.



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