Overview of extreme hot weather incidents and recent study on human thermal comfort in Japan

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ABSTRACT: It is still difficult to confirm from available data if global warming and climate changes have played a role in increasing heat-related injuries. However, it is certain that global warming can increase the frequency and intensity of heat waves, which, of course, can cause discomfort on the human body and in the worse case, can lead to more heat illness casualties. The recent worldwide natural disasters such as Haiti earthquake, landslides in China, Russian wildfire and Pakistan heatwave show that climate change is truly a fact. Heat-related death resulted from climate change is becoming increasingly serious around the world as such abnormal weather phenomena occur each year in the past decade causing a large amount of deaths particularly the elderly. It is thus important to carry out study on how human body system responses in an indoor environment under light or moderate wind conditions. This paper first gives an overview of the extreme hot weather incidents, then follows with an outline of human thermoregulation study approach and finally the description of current human thermoregulation study in Japan is shown.

Keywords: human thermoregulation, human subject experiment, heat wave, thermal models

1 INTRODUCTION

The world population has transcended more than 6 billion to date, with more than half of these population living in urban areas, and the urban population is expected to swell to almost 5 billion by 2030 (UNFPA, 2007). In line with population growth, rapid urbanization is expected to take place in most developing countries. As a result, occurrence of urban environmental problems is inevitable. As a city grows, the heat of the city builds. This hot city phenomenon has far-reaching environmental sustainability and human livability implications, ranging from the aggravation of health problems such as hyperthermia, increasing the intensity of urban air pollution, and contributing to extreme heat waves (National Weather Service, 2005). The impact of urbanization and industrialization on the quality of the environment also multiplies. There has been a lot of discussion in the media and among the public about the effect of urban climate change on urbanites (Smith, 1997; Swanson, 2007; Earth Observatory, 2008; NASA/Goddard Space Flight Center, 2002). The higher temperature of the city not only has significant impact on human health includes increases in morbidity and mortality, especially for the elderly during hotter and extended summer period atmosphere because urban areas typically have higher heat indexes (combinations of temperature and humidity), but also affects the weather around it. This urban localized weather is a condition that scientists refer to as the urban heat island effect (UHI). Due to urbanization, concentration of population is taking place, the area covered by the city is expanding and natural ground surfaces are modified. As a result, energy consumption and city metabolism heat increase significantly and eventually change the heat balance mechanism of urban climate. The other major contributor to UHI is anthropogenic heat, the heat created through human activity, which often includes the combustion of fuels for transport and industry and even in our own homes. Climate changes (regional or local) brought about by urbanization give various impacts on the physical environment, e.g. spatial variability of urban surface temperature are illustrated in Figure 1.

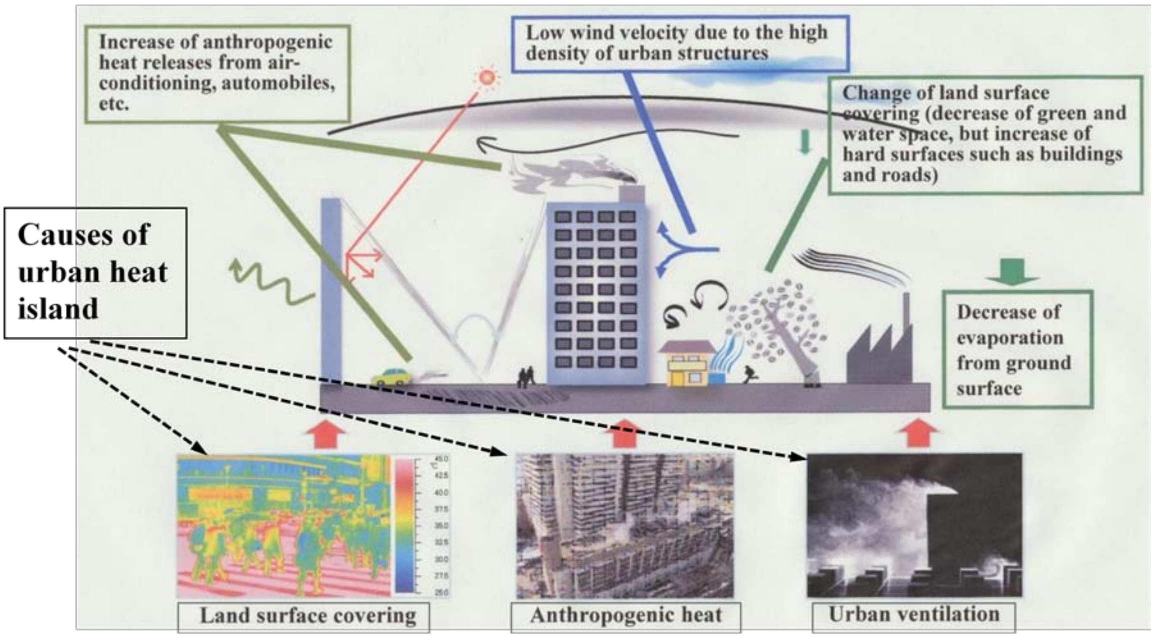


Figure 1. Various causes modify urban climate (Mochida and Lun, 2006)

The process of urbanization has promoted migration and population mobility from rural to urban areas. These rapidly expanding migrants not only enjoy higher living standards and material affluence, but also seek for a comfortable environment to live, work or spend their leisure time. Since people spend about 90% of their time indoors, they are exposed to indoor air much more than to outdoor air. The health effects of poor quality indoor air may therefore be very important and can have serious implications to the health, well-being and work efficiency of occupants. The emergence of the term ‘sick building syndrome’ highlights the prevalence of IAQ problems in buildings worldwide. Moreover, the people who are most vulnerable to such health effects are the very young, the elderly and the chronically ill; they are the ones most likely to spend the most time indoors.

Thermal Comfort can be roughly said to be classified into two categories, indoor and outdoor. The former concerns air temperature and humidity, the temperatures of exterior walls and windows, and the amount of air motion. Research into outdoor thermal comfort is relatively new and the issues involved differ from those faced indoors. Outdoor environments by nature experience far greater fluctuations and pose far less restrictions than indoors. As a result, the study of outdoor thermal comfort has to address a complicated amalgam of relationships between highly variable parameters that include user groups, activities and climate.

While people; especially young children, older adults, people who are obese and people born with an impaired ability to sweat, spend the vast majority of their time indoors, they are at high risk of heat stroke. Heat stroke is the most severe presentation of the heat-related problems, often resulting from exercise or heavy work in hot environments combined with inadequate fluid intake. When heat stroke happens, the core body temperature rises rapidly and the body loses its ability to sweat, and it finally becomes unable to cool down. In such case, the body temperature can rise to 41.1°C or 106°F or even higher within 10 to 15 minutes.

IPCC (2001) reported an analysis of the climate extremes and concluded that an increases probability of extreme warm days and decreased probability of extreme cold days would occur when increasing CO_2. Table 1 shows the carbon dioxide emissions in different places.

Table 1. Carbon dioxide emissions per capita in selected locations (Welford, 2008)

Location	Per capita carbon dioxide emissions (metric tons)	
	1990	2004
World	4.10	4.32
European Union (15)	8.60	8.42
USA	18.83	20.40
China	2.09	3.84
Japan	8.67	9.84
Hong Kong	4.59	5.36
Indonesia	1.17	1.67
Bangladesh	0.17	0.25

Japan's contribution to carbon dioxide emissions per capita is above the world's average, yet significantly below those to be found in places such as the USA. However, the emission rate is considerably high among Asian countries. Carbon emissions are one of the major causes of climate change. Climate change will mean that Japan will experience a warmer climate and at times this will come with significantly more rainfall, and also will further experience a significant increase in the frequency and intensity of extreme weather events, such as heat waves, typhoons and very heavy rainfall. The impacts of these changes on Japan will be an increase to the risks of flooding, droughts and dangerously hot weather. There will also have indirect impacts, including an increased risk of infrastructure damage, ground instability and landslides, and further increases in dangerously poor air quality periods. This will all impact on human health and quality of life. There will also be significant risks for the economy of Japan. The natural disasters happened no long ago including the heat waves around the world, the flooding in Pakistan, the drought and dust storms in China, and the forest fires in Russia both show the warning signs of global climate change.

This paper first gives an overview of the extreme hot weather incidents, then follows with an outline of human thermoregulation study approach and finally the description of current human thermoregulation study in Japan is shown.

2 HEAT WAVE

2.1 Major heatwave events from 19th century to 21st century

Heat, nowadays, is the primary weather-related cause of death in many developed countries such as France, Russia, Australia and the United States. Increasing heat and humidity, at least partially related to anthropogenic climate change, suggest that a long-term increase in heat-related mortality could occur.

Extreme weather and climate events can produce severe impacts on our society and environment. For instance, heat waves can be devastating for societies that are not used to coping with such extremes. More than 30,000 deaths were attributable to the heat wave incident in Europe 2003 (IFRCRC, 2004; Poumadere et al., 2005) which also led to the destruction of large areas of forests by fire, and effects on water ecosystems and glaciers (Gruber et al., 2004; Koppe et al., 2004; Kovats et al., 2004; Schär and Jendritzky, 2004), and the recent tragedy in Moscow over 14,300 deaths due to heat wave this summer was recorded (Sinclair, 2010).

A prolonged and atypical period of hot weather is commonly known as a 'heat wave', which may be accompanied by low humidity. There appears to be no universal definition of a heat wave and the term is relative to normal weather in an area. Global warming is increasing the earth's average temperature due to the buildup of CO_2 and other greenhouse gases in the atmosphere from human activities. It is also bringing more frequent and severe heat waves and the result will be serious for vulnerable populations. Severe heat waves can lead to deaths from heat stroke. Older people, very young children, and those who are sick or overweight are at a higher risk for heat-related death. Heat waves are the most lethal type of weather phenomenon, overall. Between 1992 and 2001, deaths from heat waves in the United States numbered 2,190, compared with 880 deaths from floods and 150 from hurricanes. If a heat wave occurs during drought conditions which dries out vegetation, it can contribute to wildfires, e.g. during the disastrous 2003 European heat wave, fires raged through Portugal, destroying over 3010 km² (740,000 acres) of forest and 440 km² (108,000 acres) of agricultural land and causing an estimated 1 billion pounds worth of damage.

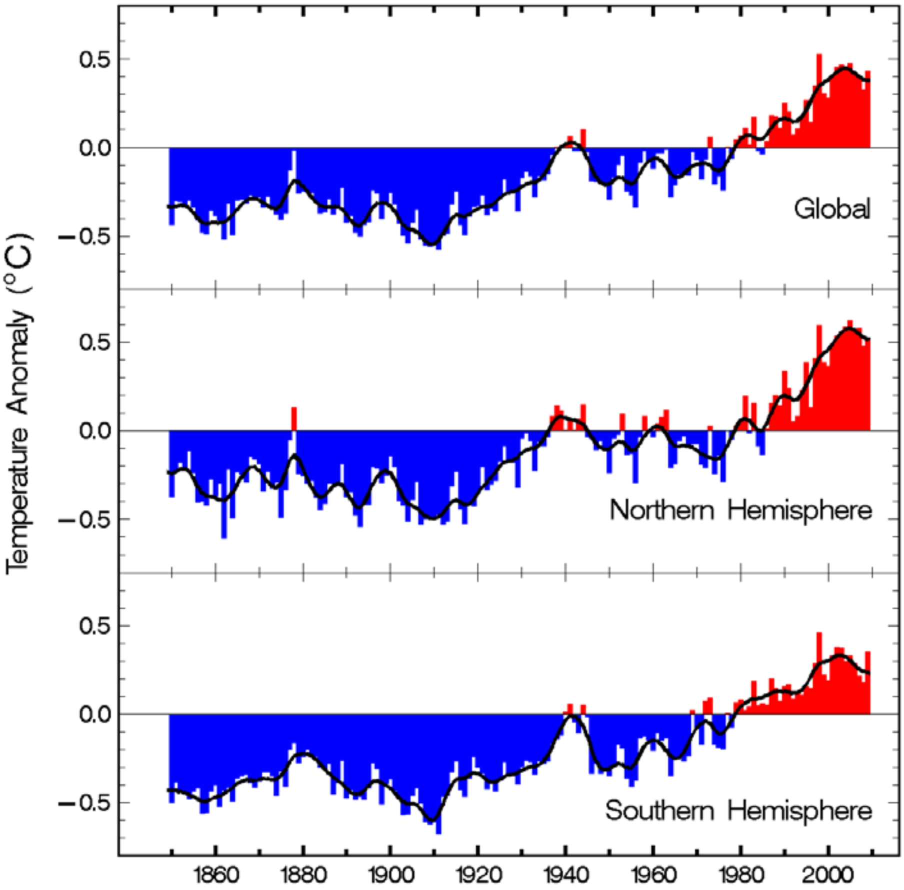


Figure 2. Global and hemispheric annual temperature anomalies from 1850 – 2009 (Jones et al. 2010)

Figure 2 shows the global and hemispheric annual temperature anomalies from 1850 to 2009. The annual mean temperature anomalies for the globe show relatively stable temperatures from the beginning of the record through about 1910, with relatively rapid and steady warming through the early 1940s, followed by another period of relatively stable temperatures through the mid-1970s. From this point onward, another rapid rise similar to that in the earlier part of the century is observed. The period 2001-2009 (approximately 0.44°C above 1961-90 mean) is roughly 0.2°C warmer than the decade of

1991-2000 (about 0.24°C above 1961-90 mean). The 1990s were the warmest complete decade in the series. The warmest year of the entire series has been 1998, with a temperature of 0.55°C above the 1961-90 mean. Fourteen of the fifteen warmest years in the series have occurred in the past fourteen years (1995-2009).

The northern and southern hemisphere annual temperature anomalies show some general similarities, e.g., little sign of trends before about 1900, a peak in the early 1940s, and the highest temperatures occurring after 1980. A steady period of warming is seen for the northern hemisphere from about 1910 through the mid-1940s. For the southern hemisphere, there is less warming observed from about 1910 through 1930, with sudden and rapid warming from about 1930 through the mid-1940s. The northern hemisphere record shows gradual cooling from the mid-1940s through the mid-1970s, followed by rather steady temperature increases thereafter. The southern hemisphere shows an abrupt shift to cooler temperatures after 1945, quite variable temperatures until the mid-1960s, followed by a gradual increase over the remainder of the record. In this Figure 2, the global and hemispheric annual temperature anomalies clearly show that temperature have been steadily rising in the north hemisphere as well as south hemisphere since 80s. The increase in annual mean temperature can be attributed to global warming and local effects such as urbanization.

In addition, climate change projections for Europe show that over the next century, heat waves will become more frequent, intense and will last longer, not only in Mediterranean regions, but also in Northern areas currently not characterized by heat wave events (Meehl and Tebaldi, 2004). These changes could contribute to the burden of disease and premature deaths, particularly in vulnerable populations with limited adaptation resources (IPCC, 2007).

For almost 19 centuries, between 1 A.D. and 1850, fluctuations of the Sun and erupting volcanoes were the main sources of greenhouse gases in the atmosphere, according to scientists (Basu et al, 1993; McLean, 1995). Temperature changes then were much less pronounced than the recent noticeable warming attributed to increases in the levels of greenhouse gases in the atmosphere since the mid-19th century. Table 2 shows some of worldwide major heatwave events from 19th century to 21st century, while Table 3 gives an outline of some major heatwaves involved with large mortalities over 3 centuries.

Australia has a long history of heatwaves. The first recorded heat wave incident was found in Adelaide during the November month of 1888 (cf. Tables 2 and 3). However, the worst recorded heatwave was in 1939 when 438 people died. This heatwave affected many places within the Australian territory and mostly in South Australia, Victoria and New South Wales. Not too long after, another heat wave hit the south-eastern part of Australia again at the end of 1895 causing 437 infants and old people died. They were mostly killed due to body overheated, lacking of clean water under poor living conditions. A 10-day heat wave killed 1,500 people during the summer of 1896 in New York City; many of them were poor tenement-dwellers in the old town of Lower East Side with no air conditioning, little circulating air and no running water.

In the first summer of the 20th century, the heatwave occurred in the Midwest of America killed 9,508 frail and elderly people; most of the victims were suffered by heat stroke and heat exhaustion (cf. Table 3). Between 1936 and 1975, as many as 15,000 Americans died from problems related to heat. In 1980, 1,250 people died during a brutal heat wave in the Midwest. In 1995, more than 800 people died in the city of Chicago and Milwaukee from heat related problems. A majority of these individuals were the elderly living in high-rise apartment buildings without proper air conditioning. Large concentrations of buildings, parking lots, and roads create an "urban heat island" in cities. Large urban areas pose unique problems during excessive heat situations. The elderly and infirm residing in urban areas are generally in the greatest danger during heat waves. Between 1992 and 2001, deaths from excessive heat in the United States numbered 2,190. The average annual number of fatalities directly attributed to heat in the United States is about 400 (Basu and Samet, 2002). The 1995 Chicago heat wave, one of the worst in US history, led to approximately 700 heat-related deaths over a period of five days (Dematte et al, 1998). It was noted that, in the United States, the loss of human life in hot spells in summer exceeds that caused by all other weather events combined, including lightning, rain, floods, hurricanes, and tornadoes (Klinenberg, 2000a, 200b). According to the Agency for Health care Research and Quality, about 6,200 Americans are hospitalized each summer due to excessive heat, and those at highest risk are poor, uninsured or elderly (AHRQ, 2008).

Europe has experienced an unprecedented rate of summer warming in recent decades (Klein-Tank et al., 2005; Klein-Tank and Konnen, 2003; Luterbacher et al., 2004). Over most of Europe the increase in the mean daily maximum temperature during the summer months has been between 0.5-1.5°C per decade in the period 1976-1999 (Klein-Tank and Konnen, 2003). The European 2003 heat wave was arguably one of the most significant climatic events since records began. The extreme heat wave and drought that hit Europe in summer 2003 had enormous adverse social, economic and environmental effects, such as the death of thousands of elderly people, the destruction of large areas of forests by fire, and effects on water ecosystems and glaciers (Gruber et al., 2004; Kovats et al., 2004; Schär and Jendritzky, 2004; Koppe et al., 2004; Kovats and Koppe, 2005). In Asia, India also got affected in the 2003 heatwave. During the month May, peak temperatures recorded between 45°C and 49°C in most places throughout the country, and in the state of Andhra Pradesh alone, some 1,200 people died from the heat.

In 2007, a heatwave first occurred in western North America around late June, it then spread across to the south and eastern North America, and eventually ended towards the end of October. Human toll due to heat-related causes was reported in many places, innumerable cases of heat-related illnesses were also reported and attributed to the excessive heat. Prolonged exposure to high temperatures poses an especially dangerous problem for elderly, children, and low-income residents without adequate air conditioning. Many cities and/or aid organizations provided free or low-cost fans, air conditioners, cool stations, bottled water, and vouchers for electric bills in order to assist those in need. Additionally, many schools without air conditioning dismissed students early or cancelled afternoon classes during the past few weeks. In the same year 2007, heatwave also happened in Asia (India, Bangladesh, Nepal, Pakistan, Russia, China and Japan) and Europe (southern and eastern). Nearly 200 people, including several children, were admitted to hospitals with symptoms of heat stroke in Bangladesh. There were 923 people death of hyperthermia by heat wave in around Japan, and worst heat stroke disaster of Japanese and North East Asia's history.

Year 2010 seems becoming one of the hottest recorded years around the globe. Hundreds of daily high maximum and high minimum temperature records were broken across many cities such as Baghdad (45.0 °C), Qalya (51.4 °C), Lefconica (46.6 °C), Doha (50.4 °C), Dongola (49.6 °C), and Jeddah (51.7 °C). In cases of heat stroke, the core temperature can rise to 41.0°C, at which point brain death begins. When the core temperature surpasses 45.0 °C, death is inevitable.

The number of extremely hot days is set to increase substantially in the world as a result of climate change. Hot weather will become more frequent and more intense. This has the potential to cause deaths, severe health problems and economic losses through damage to infrastructure (e.g. buckling rail lines and melting road surfaces), work day losses, increased water demand and increased energy demand for more cooling.

Table 2. Worldwide major heatwave events from 19th century to 21st century

Year	Major heat-wave incidents	Period of heat-wave	Peak temperature
1888	Adelaide	6 Nov – 11 Nov	38.7 ^{0}C
1895-96	New South Wales	1 Dec – 1 Jan	47.0 ^{0}C
1896	New York City	5 Aug - 13 Aug	32.2 ^{0}C
1901	Midwest United States	29 Jun - 6 Jul	38.3 ^{0}C
1907-08	South Australia	7 Dec – 8 Jan	41.3 ^{0}C
1911-12	Australia	1 Dec – 1 Feb	42.4 ^{0}C
1920-21	Australia	1 Dec – 1 Feb	40.7 ^{0}C
1926-27	South Australia	26 Dec – 27 Jan	41.8 ^{0}C
1936	North American	1 Jul – 31 Aug	43.3 ^{0}C
1938-39	South Australia	1 Dec – 28 Feb	42.7 ^{0}C
1953	Midwestern United States	23 Aug – 29 Aug	35.8 ^{0}C
1954	Midwestern United States	18 Jul – 24 Jul	35.7 ^{0}C
1955	Los Angeles	31 Aug – 7 Sept	36. 7 ^{0}C
1966	Missouri	9 Jul – 14 Jul	41.1 ^{0}C
1972	Northeastern United States	14 Jul – 26 Jul	34.4 ^{0}C
1975	New York City	30 Jul – 7 Aug	36. 7 ^{0}C
1975	France	1 Aug – 7 Aug	32.4 ^{0}C
1976	United Kingdom	22 Jun - 16 Jul	35.9 ^{0}C
1976	Northern France	28 Jun – 8 Jul	32.8 ^{0}C
1977	Seattle	30 Jul -13 Aug	35.6 ^{0}C
1980	Memphis	25 Jun – 20 Jul	42.2 ^{0}C
1980	Dallas	18 Jun – 27 Aug	45.0 ^{0}C
1981	Seattle	7 Aug -11 Aug	33.3 ^{0}C
1983	France	10 Jul – 15 Jul	31.6 ^{0}C
1983	Rome	19 Jul – 4 Aug	36.0 ^{0}C
1987	Athens	3 Jul – 25 Jul	45.0 ^{0}C
1988	Pennsylvania	4 Jul – 18 Jul	32.2 ^{0}C
1990	France	1 Aug – 7 Aug	33.5 ^{0}C
1993	Philadelphia	4 Jul – 14 Jul	38.3 ^{0}C
1994	Townsville Australia	6 Jan – 10 Jan	42.0 ^{0}C
1995	Chicago	11 Jul – 27 Jul	37.8 ^{0}C
1996	Western Australia	20 Jan – 20 Feb	42.4 ^{0}C
1997	Southern Australia	10 Jan – 15 Feb	40.0 ^{0}C
1998	Shanghai	30 Jun – 17 Aug	39.4 ^{0}C
1998	India	22 May – 12 Jun	49.8 ^{0}C
1998	Southern United States	1 Jun – 28 Jul	37.8 ^{0}C
1999	Midwest United States	17 Jul – 31 Jul	38.3 ^{0}C
2000	Southern United States	18 Jul – 30 Aug	43.9 ^{0}C
2001	France	30 Jul – 3 Aug	30.8 ^{0}C
2002	India	9 May – 15 May	50.0 ^{0}C
2003	European	Jun – Aug	40.0 ^{0}C
2003	Shanghai	12 Jul – 7 Sept	39.6 ^{0}C
2004	Brisbane	7 Feb – 26 Feb	42.0 ^{0}C
2005	Desert Southwest United States	9 Jul – 16 Jul	47.2 ^{0}C
2005	India	25 May – 22 Jun	51.1 ^{0}C
2005	Pakistan	25 May – 1 Jul	48.9 ^{0}C
2006	North American	15 Jul – 27 Aug	47.0 ^{0}C
2006	European	Jul - Aug	40.0 ^{0}C
2007	Southern European	17 Jun -27 Jun	46.2 ^{0}C
2007	Eastern European	20 Jul – 26 Jul	45.0 ^{0}C
2007	South Asian	May - Sept	43.3 ^{0}C
2007	Japan	16 Aug	40.9 ^{0}C
2007	Western North American	Jul	47.8 ^{0}C
2007	Bulgarian	19 Jul – 24 Jul	46.0 ^{0}C
2008	Eastern US	6 Jun – 10 Jun	38.3 ^{0}C
2009	Pacific Northwest United States	24 Jul – 2 Aug	41.1 ^{0}C
2010	Northern Hemisphere	May - Aug	

Table 3. Outline of some major heatwaves involved with large mortalities over 3 centuries

Year	Location	Hot consecutive days	Death toll	Victim	Causes related to death
1888	Adelaide	14	317	The poor, scavengers, factory workers, beggars, children, elderly	Heat exhaustion, dehydration, lacking of clean water, poor living conditions
1895	New South Wales	31	437	Factory workers, infants, elderly	Body overheated, lacking of clean water, poor living conditions
1896	New York	10	1,500	Poor labourers, Tenement-dwellers	Poor living conditions
1901	Midwest US	21	9,508	Frail and elderly	Heat illness including asthma, heat stroke and heat exhaustion
1936	North American	43	4768	Elderly and infants	Heat stroke, drowned trying to escape the stifling heat
1938	Victoria Australia	59	438	The poor, scavengers, elderly and infants	Lacking of clean water, poor living conditions, dehydration, heat illness
1972	Northeastern US	13	2,319	Over 65	Ischaemic heart disease, cerebrovascular accidents
1975	New York	9	1,960	Middle age and elderly	Ischaemic heart disease, cerebrovascular accidents
	France	5	12,507	Kids (5.6%), adults (32.6%), over 75 (61.7%)	Hyperthermia, dehydration, cardiovascular disease
1976	Birmingham	17	24	Kids, adults and elderly	Heat stroke, heat exhaustion
	France	11	5,100	Mostly adults and elderly	Heat stroke, hyperthermia, dehydration
1980	Midwest US	42	1,250	Kids, adults and elderly	Ascribed mainly to weather-related mortality such as hot and humid days
1981	Portugal	10	1,906	Elderly living alone	Heat-related deaths
1983	Rome	16	2,182	Mostly over 65	Cardiovascular-related death
	France	4	10,301	Kids (4.4%), adults (26.5%), over 75 (69.1%)	Heat stroke, hyperthermia, dehydration, cardiovascular and respiratory disease, and ischaemic heart disease
1987	Athens	23	926	Elderly	Heat-related deaths
1988	Chicago	7	454	Mostly elderly	Heat-related deaths; victims were generally found inside apartments or houses
	Pennsylvania	15	3,674	Mainly over 65 and mostly women	Body overheated caused heart attack
1990	France	5	10,838	Kids (5.5%), adults (26.6%), over 75 (67.9%)	Elderly alone at home without air conditioning or at overwhelmed nursing homes and hospitals
1991	Portugal	10	997	Mostly elderly	High temperatures caused decreasing in blood viscosity and increasing in thrombosis, also older persons have impaired kidney function and thermoregulation
1993	Philadelphia	11	118	Infants, elderly	Excessive heat, hyperthermia, cardiovascular disease
1995	Chicago	17	739	Males, Blacks, and persons aged ≥75 years	Infirm residents living on the top floors of inner-city apartments with no air-conditioning.
	Milwaukee	17	85	Mostly elderly	Heat-related deaths
1998	India	22	1,359	Mainly the poor	Sun-stroke, vomiting blood, high fever
1999	Midwest US	15	232	The poor	Most of the deceased lived in large cities with an old infrastructure of non-air-conditioned brick buildings.
2000	Southern US	44	140	Mostly elderly	Heat stroke, hyperthermia, dehydration, cardiovascular and respiratory disease

2001	France	9	20,560	Kids (2.0%), adults (21.6%), over 75 (76.4%)	Heat stroke, heat exhaustion, hyperthermia, dehydration, cardiovascular and respiratory disease, and ischaemic heart disease
2002	Southeastern India	7	1,030	Elderly, the poor	Unable to withstand the brutal heat, dehydration, sunstroke
2003	France	19	14,802	Mostly among the elderly	Elderly living alone did not know how to react or were too mentally or physically impaired by the heat to make the necessary adaptations themselves
	Spain	92	4,200	Mostly aged ≥75 years	Cardiovascular and other chronic diseases
	Italy	92	4,000	Aged 65 and more	Heat-related mortality by respiratory and cardiovascular diseases
	UK	10	2,045	Mostly aged ≥75 years	Heat-related mortality
	Netherlands	14	1,400	Largely the elderly	Heat stroke, hyperthermia, dehydration
	Portugal	16	1,300	Aged ≥75 years	Heat stroke, and disorders of fluid, electrolyte, and acid-base balance
	Belgium	62	1,250	Aged 65 and more	Heat-related deaths
	India	62	1,900	Daily wage labourers, rickshaw pullers or construction workers	Heat stroke, hyperthermia, dehydration
2004	Brisbane	20	12	Elderly people	Dehydration, cardiovascular disease and non-external causes
2005	India	29	334	The poor, beggars, street hawkers, children, elderly	Heat-related reasons, sunstroke, dehydration
	Pakistan	38	196	Scavengers, drug addicts, children, elderly	Seriously ill from heat stroke and gastroenteritis
2006	North America	44	>225	People with chronic diseases, socially isolated individuals, elderly	Heat-related maladies
	France	18	2065	Mostly aged ≥75 years	Heat-related problems
	Belgium	12	940	Elderly	acute renal insufficiency, dehydratation, respiratory disease
	Pakistan	14	232	Children, elderly	Heat stroke, diarrhea, gastroenteritis
2007	Bulgaria	6	8	Elderly	Heat stroke, dehydration, chronic diseases
	Hungary	8	500	Children, and mostly elderly	Heat stroke, cardiovascular problems and other illnesses aggravated by the heat
	Romanians	39	30	Elderly	Heat stroke, hyperthermia
2008	Orissa	34	67	The poor	Sun-stroke death
2009	Southeastern Australia	16	374	Mostly elderly	Heat stroke and other effects of the heat wave
2010	Japan	54	170	Elderly	Heat stroke
	India	47	250	Children, the poor and elderly	Heat exhaustion and food poisoning
	Russia	62	10,935	Children, elderly, people with chronic diseases	Heat wave, pollution, smog
	Victoria Australia	7	374	People aged >65	Heart attacks and strokes
	Southern California	8	25	Age from 26 to 87	Heat-related deaths

Heat waves do not have defined geographic boundaries as the floods do, and they are therefore much more difficult to handle. However, given that much of the cities worldwide are urbanized it is important to factor in so-called urban heat island effects. Urban areas are characterized by much higher temperatures than rural areas surrounding them due to the modification of land surfaces and waste heat generated by energy use. The dense nature of urban areas, e.g. Tokyo, is highly susceptible to heat waves and consequent impacts on human health.

Heat waves also mean that there will be an increase in demand for energy for cooling. This is likely to increase social inequity relating to those who live in poorly designed and overcrowded buildings, those unable to afford higher energy bills and those unable to protect themselves by installing blinds, awnings and cooling systems.

Prolonged periods of very high temperatures, particularly when night time temperatures remain high, have significant impacts on human health. People live in densely cities will experience increasing discomfort levels, illnesses and even deaths. Particularly vulnerable will be the very young and the elderly who are often unable to deal with very high temperatures. Women will be more vulnerable than men because of a higher core body temperature that may affect menopause. Those with pre-existing diseases such as heart and respiratory disease, those taking certain types of medications and those with dementia will also be at risk.

2.2 *Heatstroke situation in Japan*

Japan is a country surrounded by water, on traditional typhoon tracks and with a dense urban setting, makes it particularly vulnerable to climate change. Climate-related impacts on infrastructure in Japan could be very costly, but it also needs to be recognized that the full effects of climate change will impact on human health, community cohesiveness, longer term economic values, competitiveness, biodiversity and the ability to recruit and retain talented human resources.

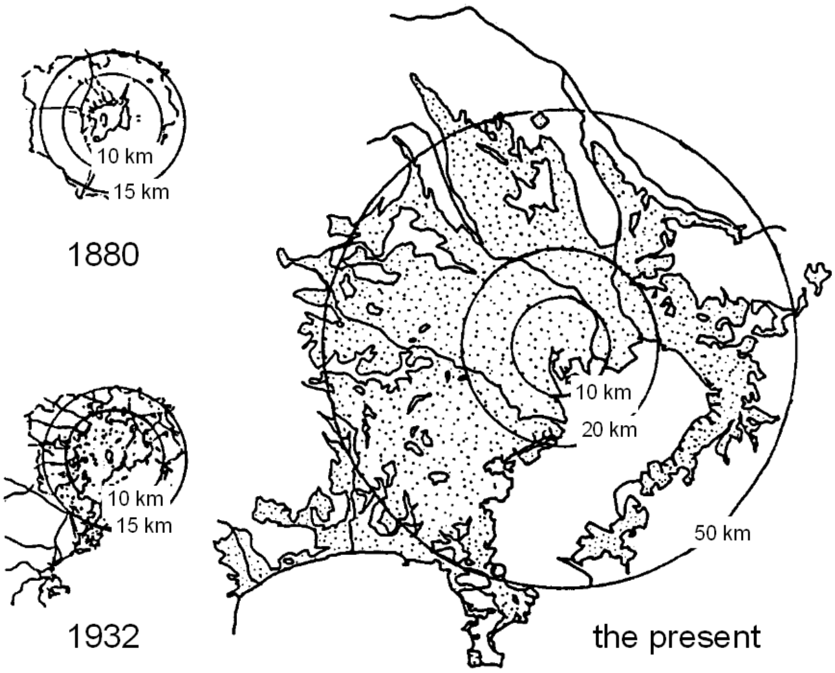


Figure 3. Development of urbanization in Tokyo (Ojima, 1991)

Most of the large and densely-populated cities are in Asia, for instance Tokyo (approximately 13 million) is among the world largest and most densely populated cities.

In the Tokyo Metropolitan area, about half of the land is occupied by buildings and about half of the anthropogenic exhaustion heat generated in the summer in this area comes from the buildings' facilities (Murakami, 2006). Figure 3 shows the development of urbanization in Tokyo since the Meiji period (Ojima, 1991), while Figure 4 demonstrates that temperatures have been steadily rising in the capital over a period of 100 years. In the year from 1870, after the national capital was transferred from Kyoto to Edo which was renamed Tokyo, to 1980 there has been a 2°C increase in average annual temperature within the capital area over that time which is greater than the rise recorded across the rest of the globe. The increase in annual mean temperature can be attributed to global warming as well as local effects such as urbanization. Figure 5 shows the rise in daily maximum temperature in Tokyo area of August for 3 different years. The existence of an urban heat island around Tokyo is clearly and remarkably indicated from these figures.

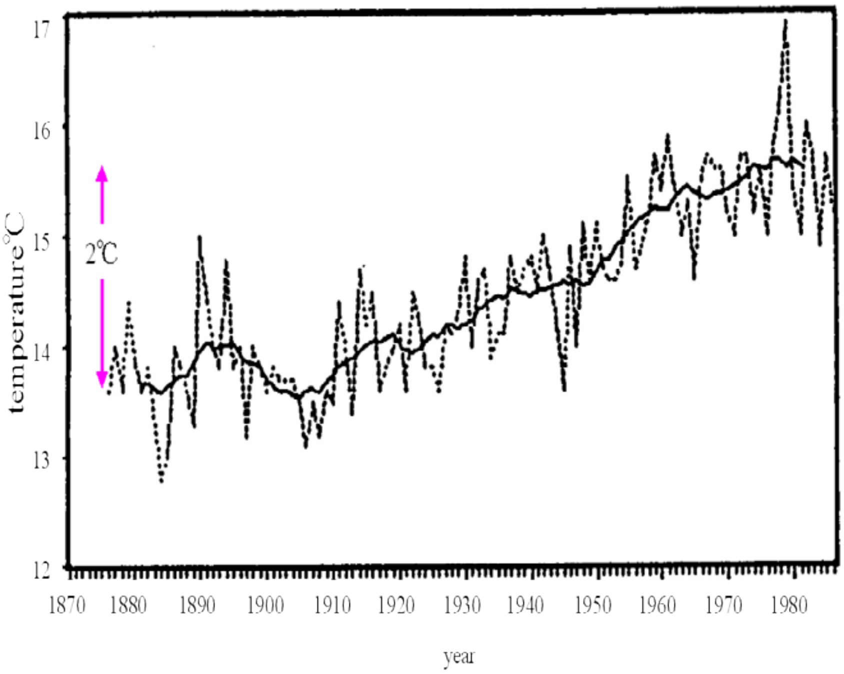
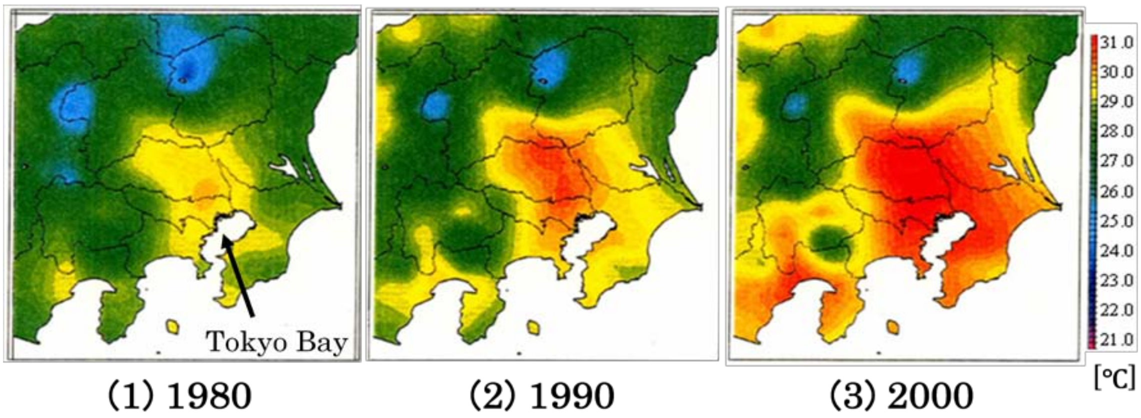


Figure 4. Increase of air temperature in Tokyo (height of about 1.5 m) (Ooka, 2007)



(1) 1980 (2) 1990 (3) 2000

Figure 5. Rise in daily maximum temperature in Tokyo area of August (Japan Meteorological Agency)

Increasing temperatures are likely to increase deaths from cardiopulmonary diseases. Heat-related illnesses such as heat cramps, heat exhaustion and heat stroke are all likely to increase. In addition, higher temperatures will also increase perspiration and evaporation, so increasing the risk of dehydration. Older people and the young are most at risk.

Amongst the elderly thirst responses decrease with age and involuntary dehydration increases. The young require more hydration to maintain their growth and energy demands. Over time, dehydration impacts on mental health, causing anxiety irritableness, short attention spans, impatience and mild depression. It can in turn affect learning amongst the young and work performance amongst the working population (Foltz and Ferrara, 2006).

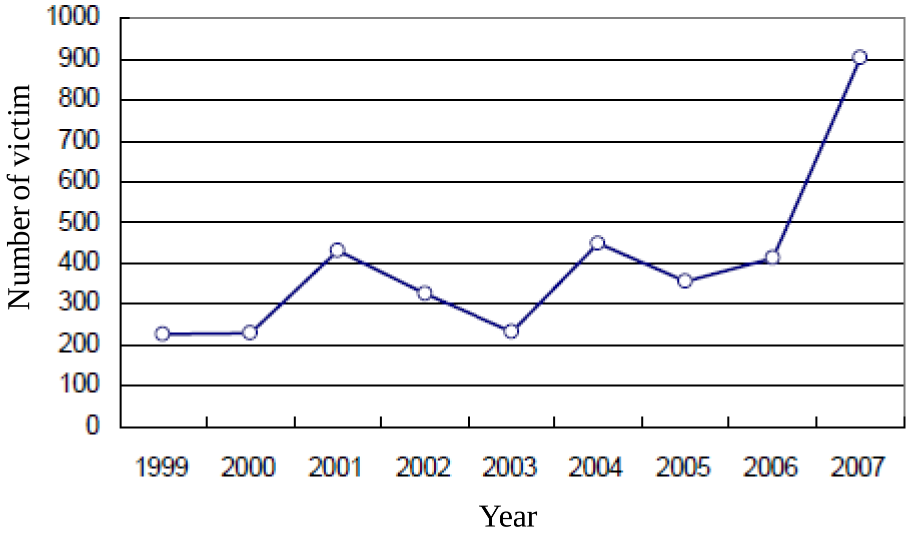


Figure 6. Number of mortality of heat stroke

In Japan, urban heat island effect has caused various problems such as heat stroke, large electric power demand for cooling devices etc. Figure 6 shows the annual number of deaths due to heat stroke in Japan. The number of mortality of heat stroke increased sharply reaching 904 people in 2007 because there was a heat wave occurred in the summer with peak temperature up to 40.9 ^{0}C (cf. Table 2). The mortality rate of Japan is given in Table 4. Heat stroke is estimated as 0.3 per 100,000 populations annually, which is above the group of natural disaster and just below the group of Murder.

Table 4. Mortality rate of Japan in 2007

Death	Mortality rate (per 100,000 populations annually)
Cancer	250
Overweight	140
Heart disease	127
Suicide	24
Traffic accident	9
Fire	1.7
Murder	0.52
Heat stroke	0.3
Hazardous chemical substance	0.3
Natural disaster	0.1
HIV/AIDS	0.04
Plane crash	0.013

3 THERMAL MODELS

Thermal comfort research evolved in two distinct paths over the last 40 years. The first path focused on climate chamber research to understand the relationship between the human body and the environment, i.e. physical model. This research methodology evolved into comfort models such as Predicted Mean Vote (PMV) and thermal comfort standards.

The second path focused on holistic human environment relationship, which led to the field research and the development of adaptive thermal comfort models (de Dear, 2004). A new trend in thermal comfort study is seen recently as computational power has increased dramatically over the past decade, together with advances in computer software, allowing engineers/researchers to more accurately simulate many types of specific case, for examples; body core temperature, localized body segment temperatures, metabolic rates, respiratory heat losses and evaporation from the skin etc.

Physical models are like measuring instruments that respond to those factors of the environment to which human respond. The response is usually in terms of temperature, though it may be in terms of mass or vapour loss of heat transfer, for example. Because physical models respond to important factors related to human response and simple physical models often provide a single temperature value that can be can be related to human response, these models are often used to provide thermal index values, e.g. WGT,WBGT, etc. More elaborate thermal models closely represent the shape and response of the human body. The most sophisticated of these is the ‘family’ of thermal manikins.

Over the last few decades, a vast majority of researchers have been exploring the thermal, physiological and psychological response of people in their environment in order to develop mathematical models to predict these responses. These mathematical models (or human thermoregulation models) provide a rational representation of the human body involving both heat transfer between the body and the environment, the anthropometry and thermal properties of the body and a dynamic representation of the human thermoregulation system. Human thermoregulation models can be roughly classified into 3 categories as shown in Table 5.

There are many human thermoregulation models proposed over the years, ranging from simple cylinder models to complex multi-segment and even 3D models. Few notable adopted models are shown and outlined in Table 6.

Fanger (1967) developed a thermal comfort equation which consists of 6 variables: air temperature, humidity, mean radiant temperature, relative air velocity, activity level, and insulation value of the clothing. In 1972, Fanger used the data obtained from experimental test chamber together with his thermal comfort equation to develop an expression that predicts thermal sensation, on a 7-point cold to hot sensation scale for a large population of people exposed to a certain environment. This expression is known as the predicted mean vote (PMV). PMV model is a method for the calculation of steady state thermal comfort index derived from the heat balance calculations and climate chamber studies. It is based on the linear relationships of mean skin temperature and evaporative heat loss required for comfort at different activity levels. It assumed that long exposures to a constant thermal environment with constant metabolic rate (i.e. steady-state) results in a heat balance between heat production and heat dissipation by the human body. However, the PMV equation can be applied to conditions with steady state fluctuations. PMV sometimes overestimates the thermal sensation of warmth for occupants in non-air-conditioned buildings in warm climates. In these climates people are expected to adapt to a higher indoor temperature and not ask for lower temperatures.

Table 5. Human thermoregulation models

Model Category	Reference	Description
Empirical model :	Givoni and Goldman (1972, 1973)	Exposing human subjects to a range of thermal environments and fitting the mathematical models to the obtained human response data
Database model :	Parsons and Bishop (1991)	Computer database model to predict human responses to thermal environment using a method of ‘matching’ the conditions for which responses are required with those in the database
Rational model :	Gagge et al (1971) Stolwijk and Hardy (1977)	Dynamic mathematical simulation of the human body and its response to thermal environment, involving both a passive and controlling system for the body as well as mechanisms of heat transfer

Table 6. Some notable thermal comfort models

Types of Model	Reference	Research Particulars
One-node model	Fanger (1972): developed a model to predict physiological responses to the thermal environment and use these values to estimate thermal comfort	Four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity) and two personal variables (clothing insulation and activity level)together formed an index that can be used to predict thermal comfort
	Givoni and Goldman (1972): developed a system of equations to characterize the resultant rectal temperature	The formulas involved the metabolic heat production, ambient climatic conditions (air temp., vapour pressure and velocity), and the total thermal resistance and evaporative coefficient of the clothing
Two-node model	Gagge et al (1970): developed a 2-node mathematical model of the human thermoregulatory system	Considered body as two concentric thermal compartments representing the skin and core of the body. The temperature within each compartment is assumed to be uniform, so that the only temperature gradients are between compartments.
	Bruse (2005): presented some basic dynamics of a simple dynamic 2-node model of the human thermoregulatory system and its application in a multi-agent simulation system	Temperatures of skin, core, clothing and local mean radiant, total energy balance of the body, energy fluxes per skin surface area, fraction of wet skin and associated absolute and relative wind speed
	Kohri et al (1995): applied a two-node model to 11 body parts to calculate standard effective temperatures (SET*) in the vehicle environment	SET* includes the effects of convection, radiation, and evaporation on the body
	Arens et al (1986): described the development of a chart in which lines of equal comfort are plotted across a wide range of environmental conditions	The measure for comfort index, predicted by the J.B . Pierce Foundation Laboratory 2-node thermophysiological model, used in the chart is based on skin temperature alone in cold conditions, and on skin wettedness (fraction of the skin covered by water) alone in hot conditions
Multi-node model	Stolwijk and Hardy (1966): contributed a mathematical model of temperature regulation for the purposes of theoretical analysis of experimental results and evaluation of hypothetical concepts	The human body was represented by 3 cylinders; head, trunk and extremities with concentric layers to show the anatomical and functional differences important in temperature regulation. A regulator was supplied with signals pertaining to temperature deviations in the brain and from the skin. The regulator then caused heat loss or heat production in the appropriate parts of the body
	Stolwijk (1971): developed a dynamic mathematical model which simulated the behaviour of man's thermoregulatory system	The human body is divided into 6 segments linked together via the appropriate blood flows. Each segment represents volume, density, heat capacitance, heat conductance, metabolism and blood flow of a certain part of the body. The temperature and rate of change of temperature of each segment is available as an input into the controlling system, and any effector output from the controlling system can be applied to any part of the passive controlled system
	Werner and Webb (1993): described the basics of a 6-cylinder model of human thermoregulation for use on personal computers	Emphasis was laid on the problems and status of validation, simulation results for core, muscle, subcutaneous and skin temperatures were compared with experimental results
	Tanabe et al. (2002): developed a 65-node thermoregulation model which combines with radiation exchange model and CFD	Steady state results include the effect of solar (short wave) radiation, convective heat transfer from the body was calculated from empirical heat transfer coefficients rather than from CFD simulation
Coupled human thermal model with CFD	Murakami et al (2000): used a simplified shape to represent a human body in CFD and coupled this with a two-node thermal model for predicting heat release from a human body	Flow, temperature and moisture fields were investigated using CFD while the sensible and latent heat transfer from the human body were examined using the two-node thermo-physiological model
	Streblow et al (2008): coupled a multi-node thermal regulatory model with CFD to predict thermal sensation and comfort	The local and overall thermal sensation as well as the thermal comfort were investigated

Gagge et al (1971) developed a thermal comfort model, in order to improve the effective temperature equation formulated by Houghten and Yaglou (1923), based on body heat generation and regulatory sweating which was suitable for low and medium activity levels. This model is a simplification of more complex and specialized thermoregulatory multi-node models and has been found effective at predicting physiological response near the comfort zone under conditions of low to moderate activity. For the purposes of evaluating thermal comfort, the model considered the human body consists of two thermal compartments (or nodes); the skin and the core. The skin compartment simulates the epidermis and dermis. The temperature within each compartment is assumed to be uniform, so that the only temperature gradients are between compartments. The Gagge model predicts thermal sensation by first standardizing the actual environment. The standard environment produces the same physiological effects as the actual environment and is typical of a common indoor environment. Gagge's two node model is based on steady state experimental measurements on people. However, reaching steady state takes at least an hour when the person is exposed to a constant room condition. There are many instances where the transient heat transferred from the body must be accounted for.

In the past few decades, multi-node models of human thermoregulation have been developed. These models simulate phenomena of the human heat transfer inside the body and at its surface taking into account the anatomical, thermal and physiological properties of the human body. Environmental heat losses from body parts are modeled considering the inhomogeneous distribution of temperature and thermoregulatory responses over the body surface. Multi-segmental models are thus capable of predicting ‘local’ characteristics such as skin temperatures of individual body parts (which are the critical variables in the risk of frostbite and skin damage). Most of the models available today are based on the work of Stolwijk (25-node model), who modelled the body as a composite of several cylinders representing the head, the corpus, and the upper and lower extremities (Stolwijk, 1971; Stolwijk and Hardy, 1977). The 25-node model has become the standard anatomical approach to modeling human temperature regulation. The adoption of the Stolwijk and Hardy approach by the National Aeronautics and Space Administration (NASA) has probably contributed to the relatively widespread acceptance of the Stolwijk and Hardy model.

Stolwijk multi-node model composes of main divisions; controlled (passive) system and controlling system. The passive controlled system consists of 6 segments (5 cylinders and 1 sphere), 4 compartments per segment and the central blood compartment which is thermally connected to all the nodes; make a total of 25 nodes. Heat is transferred through the tissues within individual segments by conduction. The body and the environment exchange heat by convection, radiation, evaporation and respiration. Heat exchange between local tissues and blood flow is simplified as the heat exchange between local tissues and the central blood compartment. The controlling system consists of a temperature sensing system, an integrating system and an effector system. It is a simple representation of the human thermoregulatory system based on set points. Multi-node models are useful when people are exposed to non-uniform environments. Although Stolwijk multi-node model accounts for thermoregulatory response to due to environmental conditions, it does not predict comfort, or incorporate the effects of clothing. Thermoregulation based upon average response values, however, it is a physiologically based model that was developed over a period of more than two decades and was validated by numerous human studies, and remains valid today. Unlike some of the more recent models, source code, model parameters, and extensive commentary are readily available.

Tanabe et al (2002) developed a thermoregulation model which consists of a thermal radiation model and CFD. The thermoregulation model contains sixty-five nodes (65MN) and is based on the earlier Stolwijk multi-node model, which has less segments and an inherently symmetrical description of the thermal state of the human body. The integrated model is used to predict the physiological and physical state of the human body standing in a room exposed to direct solar radiation from a window and a cooling panel in the ceiling. The advantage of Tanabe's model is apparent for the modelling of responses to asymmetrical environmental conditions. Tanabe model, like many of the similar models, is based on an average man with a weight of 74.43 kg and a surface area of 1.87m^2. The 65MN means counting 4 layers of tissue (core, muscle, fat and skin tissue) in 16 different body segments, supplemented with a central blood compartment (as the 65th node which exchanges convective heat with all other nodes via the blood flow), would end up with totally 65 nodes.

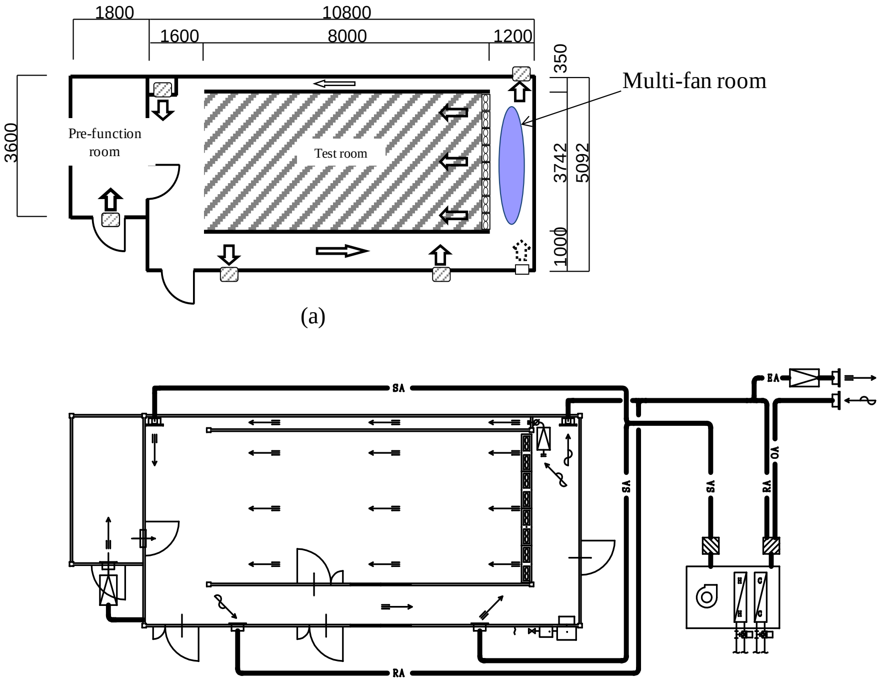
4 TPU HUMAN THERMOREGULATION STUDY USING CLIMTAE CONTROLLABLE WIND TUNNEL

Predicting human thermal sensation based on heat transfer principles in moderate, homogenous, and steady-state environments is relatively straightforward and well-understood (Fiala et al, 2003). Physiological responses to transient conditions introduce complexity and differ significantly from the steady state conditions. The predictive models of transient responses require verification through controlled experiments.

The proposed objectives for the study would include: a) to assess the indoor air movement acceptability for thermal perception using human subject experiments; b) to estimate the benefits that could be derived when such parameters and indoor air movement acceptability are extensively applied to various extents of hot condition, including heat stroke condition, on human body; c) to analyze human thermoregulation and comfort responses by implementing human subject experiments, in non-uniform and transient wind conditions for indoor environment.

Thermal manikins were adopted in few studies concerning with clothing insulation recently, however these works were only carried out in conditions of still air or during sedentary activities. Also, thermal manikin only provides mechanical responses instead of actual human body responses. Thus, human subject investigation is significantly important as this approach can reflect how the body system will generate immediate response to specific situation, because the human body employs physiological processes (e.g. sweating, shivering, regulating blood flow to the skin) in order to maintain a balance between the heat produced by metabolism and the heat lost from the body.

The Climate Controllable Wind Tunnel in TPU is capable of analyzing human thermoregulation and comfort responses in non-uniform and transient wind conditions, whereas other existing chambers can only consider uniform flow of air. This unique feature makes it to become a superior competitor among others in the field of human thermal comfort studies. The design of the Climate Controllable Wind Tunnel in TPU(cf. Figures 7 and 8) setup focused on delivering airflow to exposed skin on the hands, feet and face of the human body to test transient effects as well as the effects of asymmetrical conditions on human comfort. Human thermoregulation and comfort responses of human subjects in non-uniform and transient wind conditions are measured and analyzed, thus the relation between the local thermal comfort and the whole body thermal comfort for different environmental conditions can be revealed (Ohba et al, 2010).



(a)

(b)

Figure 7. Schematic diagram of the Climate Controllable Wind Tunnel in TPU


(a) Multi-fan room (b) Test room

Figure 8. Internal view of test room and multi-fan room

This study, on one hand, implies the importance of maximizing utilization of natural ventilation and minimizing the reliance on mechanical systems for indoor thermal comfort control. On the other hand, it intimates that the quality and safety of indoor environment deserves serious attention, as people spend most of the time within buildings. Poor indoor condition or thermally unpleasant indoor space can have serious implications to the health, well-being and work efficiency of occupants. The recent extreme weather during summer caused thousands of victims suffered from heat stroke or death around the world is clearly indicated. The outcome will reveal the most important information on human thermal comfort about what/how the responses of body system would be in an indoor environment under light or moderate wind conditions.

Experiments using thermal manikin have been carrying out in the Climate Controllable Wind Tunnel for various tasks of the project. Figure 9 shows an example of the experiment results of sensible heat loss (Sato et al. 2010). Combined used of CFD and human subject experiments is needed in this project in which CFD is used to simulation the effects of wind conditions on various human body responses. A schematic diagram of the integrated human heat balance model with CFD is shown in Figure 10. While the computational methods can provide a great deal of data, it is also required experimental data to compliment and verify the investigation work. A main goal of the computational program is to help to prioritize our experimental work toward the most promising outcomes.

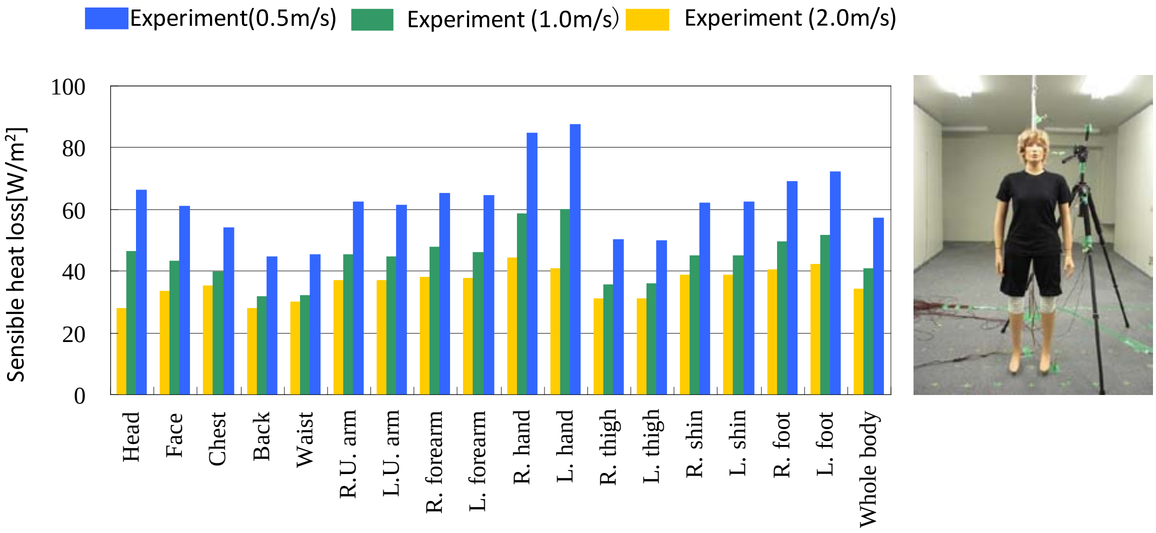


Figure 9. Results of sensible heat loss under various air velocity conditions in standing position using thermal manikin

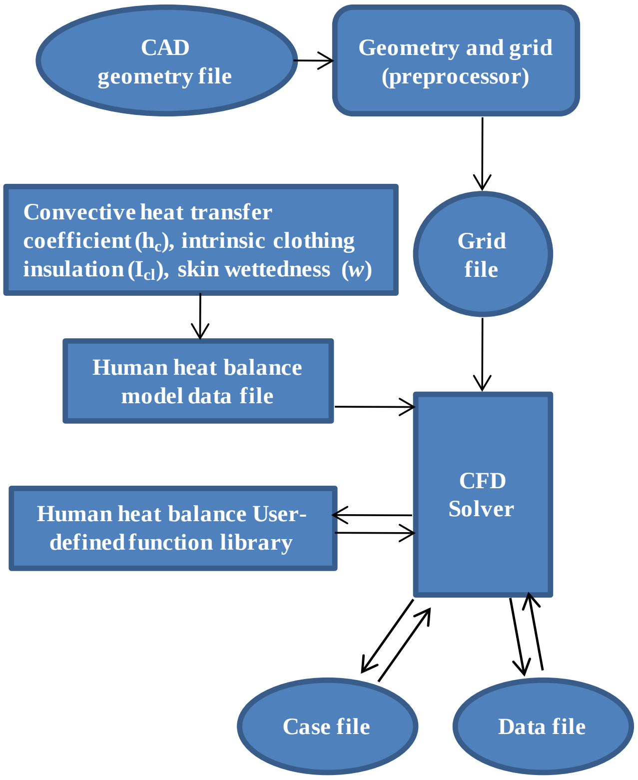


Figure 10. Integration of human heat balance model with CFD

5 CONCLUDING REMARKS

Humans are altering the climate worldwide there is no doubt about that, and climate has an effect on eco-systems around the world. The overviewed extreme hot weather incidents over 3 centuries in this paper show strong evidence of this fact.

In Japan, mortality due to hot weather happens every year and the numbers of death toll are increasing each year. The recent heat wave raged across Japan had killed 173 people. Many of these deaths may be preventable with adequate warning and appropriate response to heat emergencies.

The human body is a very complex system, made up of millions of cells with different functions, and the body system responses of extreme events such as hot or cold is, of course, still fraught with uncertainties. Thus human thermoregulation studies have become one of the most important topics in thermal comfort. There are various thermal models proposed and some of the notable models were outlined in this paper. However, human thermoregulation mathematical models and physical models (i.e. thermal manikins) can only provide mechanical responses in comparison with real human subject where emotional and psychological effects also play an important role in human body responses.

Research investigation directly using human subjects for real environment is still lacking, especially in non-uniform and transient indoor environment, and thus reliable data from human subject test are scarce. Through human subject experiment we can grab the important knowledge of how human thermoregulation system responses to sudden extreme environmental conditions. It is thus required immediate action to enhance knowledge in human responses against hot climate through collaborative work and research exchange. When the amounts of experimental data and field measurements as well as experience are available, such casualties could be minimized or even avoided.

6 REFERENCES

AHRQ (2008). Most People Struck Down by Summer Heat Are Poor. Newswise.

Ando,M., K. Tamuru, S. Yamamoto, C. Liang, Y. Wu, J. Zhang, M. Yang (1996). Direct health impacts of climate change in Japan and China. In: P. Curson, C. Guest and E. Jackson, eds., Climate Change and Human Health in Asia-Pacific Region, Australian Medical Association, (2), 75-77.

Andrews, K. (1994). The consequences of heatwaves in Australia. Hons. thesis, School of Earth Sciences, Macquarie University, Sydney.

Arens, E., Gonzalez, R., Berglund, L. (1986). “Thermal Comfort under an Extended Range of Environmental Conditions”, ASHRAE Transactions 92 (1).

Basu, R., Samet, J.M. (2002). "Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence". Epidemiologic Reviews, 24 (2): 190–202.

Basu, A.R., Renne, P.R., DasGupta, D.K., Teichmann, F., Poreda, R.J. (1993). Early and late alkali igneous pulses and a high 3He plume origin for the Deccan flood basalts: Science, v. 261, pp.902-906.

Bruse, M. (2005). ITCM – a simple dynamic 2-node model of the human thermoregulatory system and its application in a multi-agent system. Ann. Meteorol. (41), 398-401

de Dear, R. (2004). Thermal comfort in practice. Indoor Air, 14 (Suppl 7), 32-39.

Dematte, J.E., O'Mara, K., Buescher, J., Whitney, C.G., Forsythe, S., McNamee, T., Adiga, R.B., Ndukwu, I.M. (1998). Near-Fatal Heat Stroke during the 1995 Heat Wave in Chicago. Annals of Internal Medicine, Vol. 129 Issue 3.

Earth Observatory (2008) A change in the weather?
http://earthobservatory.nasa.gov/Study/AncientForest/ancient_forest7.html Last update: November 6, 2008.

Fanger, P. O. (1967). Calculation of thermal comfort: Introduction of a basic comfort equation. ASHRAE Transactions, 73(2), III4.1-III4.20.

Fanger, P.O. (1972). Thermal comfort. Analysis and applications in environmental engineering, McGraw-Hill, New York.

Fiala, D., Lomas, K.J., Stohrer, M. (2003). First principles of modeling of thermal sensation responses in steady-state and transient conditions. ASHRAE Transactions, 109(1), 179-186.

Flynn A, McGreevy C, Mulkerrin EC. (2005). Why do older patients die in a heatwave? QJM; 98:227–9.

Foltz B.D., Ferrara J. (2006). “Dehydration's hidden symptoms,” in Chiropractic Journal: a publication of the World Chiropractic Alliance

Gagge, A.P., Stolwljk, J.A.J., Nishi, Y. (1970). An effective temperature scale based on a simple model of human physiological regulator response ASHRAE Trans 70(1), 247-260

Gagge, A.P., Stolwijk, J.A.J., Nishi, Y. (1971). An effective temperature scale based on a simple model of human physiological regulatory response. ASHRAE Transactions, 77: 247-257.

Givoni, B. and R.F. Goldman (1972). Predicting rectal temperature response to work, environment and clothing. J. Appl. Physiol. 32: 812-822.

Givoni, B. and R.F. Goldman. (1973). Predicting heart rate response to work, environment and clothing. J. Appl. Physiol. 34: 201-204.

Gruber S., Hoelzle M., Haeberli W. (2004). Permafrost thaw and destabilization of Alpine rock walls in the hot summer of 2003. Geophysical Research Letters 31(13):L13504

Guest, C. (1996). Heat stress, extreme weather events, climate variability and human health. In Curson et al. (2), 29-34.

Havenith G., Inoue Y., Luttikholt V., Kenney W.L. (1995). Age predicts cardiovascular, but not thermoregulatory, responses to humid heat stress. Eur J Appl Physiol; 70:88–96.

Houghten F.C., Yaglou C.P. (1923). Determining lines of Equal comfort. ASH&VE Transactions, 28, 361- 384.

Huynen M., Martens P., Schram D., Weijenberg M.P., Kunst A.E. (2001). The impact of heat waves and cold spells on mortality rates in the Dutch population. Environ Health Perspect; 109:463–70.

IFRCRC (International Federation of Red Cross and Red Crescent) (2004): World disasters report.
Retrieved 17 September 2010 from http://www.ifrc.org/publicat/wdr2004/chapter2.asp

IPCC (2001). Working Group I: The Scientific Basis

IPCC: Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Edited by: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL. United Kingdom and New York, NY, USA. Cambridge University Press; 996.

Jones, P.D., D.E. Parker, T.J. Osborn, and K.R. Briffa. 2010. Global and hemispheric temperature anomalies—land and marine instrumental records. In *Trends: A Compendium of Data on Global Change.* Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/cli.002

Keatinge WR, Coleshaw SR, Easton JC, et al. (1986). Increased platelet and red cell counts, blood viscosity, and plasma cholesterol levels during heat stress, and mortality from coronary and cerebral thrombosis. Am J Med; 81:795–800.

Klein-Tank, A.M.G., Konnen, G.P. (2003) Trends in Indices of Daily Temperature and Precipitation Extremes in Europe, 1946-99. Journal of Climate 16(22):3665-3680

Klein-Tank, A.M.G., Konnen, G.P., Selten, F.M. (2005) Signals of anthropogenic influence on European warming as seen in the trend patterns of daily temperature variance. International Journal of Climatology 25(1):1-16

Klinenberg, Eric (2002a). Heat Wave: A Social Autopsy of Disaster in Chicago. Chicago, IL: Chicago University Press.
Klinenberg, Eric (2002b). Dead Heat: Why don't Americans sweat over heat-wave deaths?

Kohri I., Kataoka, T., Fusada, Y. (1995). Evaluation method of thermal comfort in a vehicle by SET* using thermal manikin and theoretical thermoregulation model in man. IMechE Paper C496/022

Koppe, C., Kovats, R., Jendritzky, G. and Menne, B. 2004: Heat-waves: impacts and responses. Technical report, Word Health Organisation Regional Office for Europe, Copenhagen, Sweden. Health and Global Environmental Change Series no. 2.

Kovats, R., Hajat, S. and Wilkinson, P. (2004). Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, United Kingdom. Occupational and Environmental Medicine 61, 893–98.

Kovats R, Koppe C (2005) Integration of public health with adaptation to climate change: lessons learned and new directions, Kap. Heatwaves: past and future impacts, Lisse, Swets & Zeitlinger

Luterbacher J, Dietrich D, Xoplaki E, Grosjean M, Wanner H (2004) European seasonal and annual temperature variability, trends, and extremes since 1500. Science 303(5663):1499-1503

Meehl, G.A., Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. Science, 305:994-997

McLean, D. M., 1995, K-T transition greenhouse and embryogenesis dysfunction in the dinosaurian extinctions: Journal of Geological Education, v. 43, p. 517-528.

Michelozzi P., de Donato F., Accetta G., Forastiere F., D'Ovidio M., Perucci C.A., Kalkstein L. (2004). Impact of heat waves on mortality - Rome, Italy, June–August 2003. JAMA; 291:2537–38.

Mochida, A., Lun, I.Y.F. (2006). Environmental Impacts of Urban Heat islands and their Countermeasures -Experience of Japanese dense cities- , Proceedings of PGBC Symposium on Green Building in Hong Kong, December 6, Hong Kong Observatory, pp.24-31 (keynote)

Murakami, S. (2006) 'Technology and policy instruments for mitigating the heat island effect', in Proceedings of 1st International Conference on Countermeasures to Urban Heat Islands, 3–4 August, Tokyo, pp.1–13.

Murakami S., Kato S., Zeng J. (2000) "Combined simulation of airflow, radiation and moisture transport for heat release from a human body." Building and Environment, 35(6): 489-500.

NASA/Goddard Space Flight Center (2002, June 19). NASA Satellite Confirms Urban Heat Islands Increase Rainfall Around Cities. ScienceDaily. Retrieved November 7, 2008, from
http://www.sciencedaily.com /releases/2002/06/020619074019.htm

National Weather Service, (2005) Heat Wave: A Major Summer Killer.
http://www.nws.noaa.gov/om/brochures/heat_wave.shtml Retrieved on 2008-10-19.

Ohba, M., Morogami, S., Tsukamoto K., Lun I., Mizutani, K., Iino, Y. (2010), Subject experiment on evaporative heat loss and wind fluctuation using climate controllable wind tunnel Part 1 Skin surface temperature and skin wettedness on steady wind condition, Summaries of technical papers of annual meeting AIJ, D-2, 515-516.

Ooka, R. (2007). Recent development of assessment tools for urban climate and heat-island investigation especially based on experiences in Japan. Int. J. Climatol. 27: 1919-1930.

Parson, K.C., Bishop, D. (1991), A data base model of human responses to thermal environment, in E.J. Lovesey (Ed.), Contemporary Ergonomics, London: Taylor & Francis, pp.444-449.

Pirard P, Vandentorren S, Pascal M, Laaidi K., Le Tertre A., Cassadou S., Ledrans M. (2005). Summary of the mortality impact assessment of the 2003 heat wave in France. Euro Surveill;10:153–6.

Poumadere, M., Mays, C., Le Mer, S. and Blong, R. 2005: The 2003 heat wave in France: dangerous climate change here and now. Risk Analysis 25, 1483–94.

Rooney C., McMichael A.J., Kovats R.S., Coleman M.P. (1998). Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. J Epidemiol Community Health; 52:482–86.

Sato, K., Kurabuchi, T., Ogasawara, T., Sahashi, N., Ikehara, S., Ohba, M., Iwamoto, S. (2010), A study on convective heat transfer coefficient and thermal resistance of clothing under cross ventilated situation, 3rd International Conference on Passive & Low Energy Cooling for the Built Environment (PALENC2010), 1-7 (e-format).

Schär, C. and Jendritzky, G. 2004: Climate change: hot news from summer 2003. Nature 432, 559–60.

Sinclair, L. (2010). "Death Rate Surges In Russian Heatwave". *Sky News Online HD*.
http://news.sky.com/skynews/Home/World-News/Russias-Heatwave-Continues-With-Mortality-Rate-Rising-By-More-Than-A-Third-In-July/Article/201008115678202?f=rss. Retrieved 7 August 2010.

Smith, K. (1997) Do skyscrapers affect weather in cities? If so, how? http://www.madsci.org/posts/archives/dec97/875205167.Es.r.html Retrieved on 2008-10-21.

Stolwijk, J.A. (1971). Mathematical model of thermoregulation. In: Gagge AP, Stolwijk JA, editors. Physiological and behavioral temperature regulation. Illinois: Charles Thomas. pp703-721.

Stolwijk J.A., Hardy J.D. (1966) Temperature regulation in man-a theoretical study. Pflügers Arch, 291(2): 129-162.

Stolwijk, J.A., Hardy, J.D. (1977). Control of body temperature. In: Handbook of Physiology. Reactions to Environmental Agents. Bethesda, MD: Am. Physiol. Soc., sect. 9, ch. 4, pp.45–84.

Streblow, R., Müller, D., & Gores, I. (2008). A coupled simulation of the therm. Environment and thermal comfort with an adapted Tanabe model. IndoorAir 2008, Denmark.

Swanson, B. (2007) Human effects on weather. http://www.usatoday.com/weather/resources/askjack/archives-human-effects.htm Retrieved on 2008-10-21.

Tanabe, S., Kobayashi, K., Nakamo, J., Ozeki, Y., Konishi, M. (2002). Evaluation of Thermal Comfort Using Combined Multi-Node thermoregulation (65MN) and radiation models and Computational Fluid dynamics (CFD). Energy and Building 34:637-46.

UNFPA (United Nations Population Fund) (2007) State of World Population 2007 – Unleashing the Potential of Urban Growth, UNFPA report

Welford, R. (2008) Climate Change Challenges for Hong Kong: An Agenda for Adaptation

Werner J., Webb P. (1993). A six-cylinder model of human thermoregulation for general use on personal computers. Ann Physiol Anthropol 12: 123–134.

Whitman S., Good G., Donoghue E.R., Benbow N., Shou W., Mou S. (1997). Mortality in Chicago attributed to the July 1995 heat wave. Am J Public Health;87:1515–18.