POSSIBLE EFFECTS OF GLOBAL WARMING ON SURVIVAL IN SEVEN AUSTRALIAN CITIES POST 2070 - (C.F. Forbes 2004)

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

POSSIBLE EFFECTS OF GLOBAL WARMING ON

SURVIVAL IN SEVEN AUSTRALIAN CITIES

POST 2070 - (C.F. Forbes 2004)

1 INTRODUCTION

This paper examines the possibility that as a result of global warming, by the year 2070, locally and episodically, conditions may be such as to render human life difficult if not impossible.

Temperature change projections from the recent C.S.I.R.O. publication[1] have been applied to climate data records[2] from seven Australian cities to create a synthetic record, in which daily maximum temperatures have been adjusted by the amounts shown in CSIRO's projections[1]for the year 2070. It being assumed that climate events of any one-year of this synthetic record would be as likely to occur in 2071 say as any one other year of that record. There is an obvious problem with this method in that projected temperatures in the 'new' record for years prior to 1990 may be slightly under estimates and for years after 1990 slightly overestimates, since global warming has taken place throughout the period. No attempt has been made to adjust for this.

CSIRO's publication[1] gives a range of values for its projections due to uncertainty in how greenhouse gas emissions may change and some uncertainty in climate response. The projections illustrated are based on nine recent climate model simulations designed to test those uncertainties. The maximum values for temperature change shown[1] have been adopted here for the same reason that one selects the probable maximum flood and assumes a full reservoir when designing a spillway for a structure located upstream of a large centre of population. This paper makes no attempt to defend the concept of global warming but merely strives to show what the effect that such projected climate change would have should it eventuate.

Since projected summer rainfalls are shown as remaining constant[1], or exhibiting little change at the locations studied, it was thought that this would require that relative humidity values would remain approximately similar to those experienced during the record period. Consequently relative humidity data from the original records[2] are adopted unchanged into the synthetic records. Wind speeds have also been adopted unchanged into the synthetic record. These are all important parameters when assessing the physiological effects of the environment on humans, other animals and plants. It is noted that Bureau of Meteorology's analyses[3] show that annual rainfall in South Western Australia has had a significant downwards trend in the period 1900-1997. However, this is largely due to the considerable reduction in winter and spring rainfall and the projections of [1] have therefore been used to justify adoption of Perth's recorded summer relative humidity values unchanged into the synthetic record.

The physiological effects of high temperatures and dehydration are reviewed so that any reader not familiar with these bodily processes and requirements will be able to appreciate the physiological stresses that will arise as a result of the anticipated climate changes detailed in the synthetic record.

This review is concerned with the effect on human health, both generally and in regard to certain susceptible categories in terms of age and some predisposing conditions. Throughout the world over the last century various indices have been proposed, in an attempt to assess the effect of the environment on humans engaged in various activities to serve as either a warning or as an environmental standard. Some of these have been examined in order to check their efficacy and applicability for use with the available data set.

2 PHYSIOLOGICAL REVIEW

Humans, together with the other mammals and birds, are warm-blooded animals. They must maintain their body temperature at fairly constant levels regardless of the external environment. See table 1[4,5,6] for average core body temperatures of some common animals.

TABLE 1. AVERAGE BODY TEMPERATURE °C

Subject	**Rectal**	**Mouth**
Human Adult (At rest)	37.6	36.4-37.1
Stallion	37.6	
Mare	37.8	
Beef Cow	38.3	
Dairy Cow	38.6	
Sheep	39.1	
Pig	39.2	
Poultry	40.6	

Exceptions to this are camels and some birds that allow their body temperatures to rise during the day and cool out at night in order to conserve moisture, they would otherwise use in evaporative cooling. However, most other birds and mammals must maintain their core body temperatures within a narrow range around their ‘normal’ temperatures. Normal temperature for humans lies within the range of 36-37.5°C, which we can maintain through a range of ambient temperature from 10°C in moist air, to higher than 40°C in dry air[7].

Humans must maintain their core body temperature (T_c) within ± 3.4°C of 37°C[8], in order to avoid the serious effects associated with hyper or hypo thermia[8]. See Table 2 from Koehler[9], which lists core temperatures and symptoms.

TABLE 2. CORE BODY TEMPERATURE SYMPTONS

Temperature°C (T_c)	Symptoms
28	Muscle Failure
30	Loss of body temperature control
33	Loss of consciousness
37	Normal
42	Central nervous system breakdown
44	Death, by irreversible protein ‘denaturation’.

2.1 Sources of Heat

2.1.1 Metabolic Heat

The human body continually generates heat, both from normal metabolic processes- the act of living and from muscular activity. In addition, in adverse environmental circumstances the body can also accrete heat from the environment, in conditions where the ambient temperature is above skin temperature Tsk and there is little or no wind, to facilitate effective cooling by sweat evaporation. Or in temperatures as above, combined with high humidity, even with considerable airflow.

Heat production (metabolic rate) can be as little as 294kJ/hr while at rest to as much as 4200 kJ/hr, during extreme exertion[8]. Different authorities suggest that as much as 80%[9]or 90%[7]of metabolic energy is given off as heat which must be dissipated to the environment if ‘normal’ core temperature is to be maintained. Table 3 lists average metabolic rates for various activities. (After[9, 10])

TABLE 3. AVERAGE METABOLIC RATES PER SQUARE METER OF BODY AREA – FOR ACTIVITIES

Activity	AvMetabolicRate $kJ/m^2.hr.$		
	100%	**80%**	**90%**
Sleeping (C4)	147	117	132
Sitting-inactive (A1)	210	168	189
Sitting plus moderate arm and trunk movement e.g.Typing, drafting, driving car in light traffic. (A2)	285	228	256
Sitting plus moderate arm and leg movement. e.g. General lab work-slow movement about an office.(A3)	344	275	309

TABLE 3. AVERAGE METABOLIC RATES PER SQUARE METER OF BODY AREA – FOR ACTIVITIES

Activity	AvMetabolicRate kJ/m^2.hr.		
	100%	80%	90%
Sitting plus heavy arm and leg movement e.g. Driving car in heavy traffic. (A4)	415	332	373
Standing at rest (B1	356	285	321
Standing plus light work at machine or bench. Some moving around, using table saw, driving truck in light traffic. (B2)	415	332	373
Standing plus light work at machine or bench – mainly arms. (B3)	344	275	309
Standing plus moderate work at bench or machine some walking about, replacing tyres, driving a car in heavy traffic. (B4)	499	399	449
Walking about with moderate lifting or pushing eg. Driving truck in moderate traffic, scrubbing in a standing position. (C1)	687	550	618
Intermittent heavy lifting, pushing or pulling. eg Sawing wood by hand, callisthenic exercise pick and shovel work. (C2)	997	798	898
Hardest sustained work. (C3)	1257	1006	1131
Walking – 4.8 Km/hr. (C5)	587	469	528
Bicycling. (C6)	1048	838	943
Washing and dressing. (C7)	419	335	377
Swimming. (C8)	1467	1173	1320
Running. (C9)	2514	2011	2263

2.1.2 Radiation

Both from the surrounding environment and the sun is also a source of heat to the human body. Radiation from local sources will not be considered since they are accounted for in the method used in assessing the cooling/warming power of the environment (see below).

Solar Radiation is of concern when considering outdoors activities. Limited available data[11, 12] has been analysed for significant days (Tdb ≥ 30°C and R.H.≥ 30%) for the time interval 10.30 to 14.30 to determine values of Global Exposure. Results are summarised in Table 4.

TABLE 4. AVERAGE GLOBAL EXPOSURE FOR SIGNIFICANT DAYS – KW/M^2

City	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
Perth	0.96	0.84	0.84	0.65	0.5	0.87	0.90	0.96
Sydney	0.86	0.90	0.77			0.91	0.73	0.96
Pt Hedland	0.94	0.89	0.85	0.80	0.63	0.96	0.94	0.99
Alice Springs	1.02	0.94	0.93	0.84		0.88	0.99	0.95
Townsville	0.53	0.48	0.49	0.41		0.57	0.53	0.56

FIGURE 1. HEAT LOAD DUE TO SOLAR IRRADIANCE VS SKIN AREA

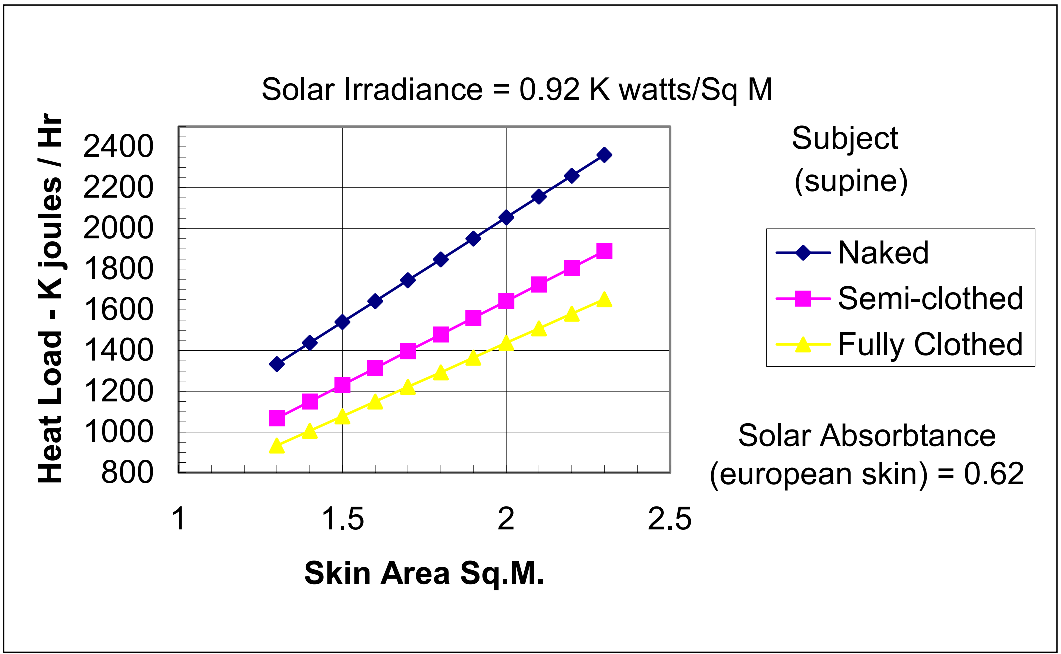


Fig 1 can be used to indicate the heat load due to solar radiation in kjoules/hr, for subjects with various skin areas and three modes of clothing, in the supine or prone position. This graph was calculated using 0.92 kW/m^2 for solar global exposure for the three summer months between the hours of 10.30 and 14.30 and absorptivity for Caucasian skin of 0.62, applied to half the total skin area. Because these data do not include reflected solar radiation; graphs in Terjung and Louie's paper[13] were used in the following assessment.

For persons in the standing position Terjung and Louie[13] give a graph showing seasonal daily total absorbed radiation (Kcal day^{-1}) as a function of latitude and surface albedo, for a person with skin area of 1.86 m^2.

On the basis of latitude and interpolation for a range of local albedos, values of daily total absorbed radiation were selected for the seven cities.

Using references (11 and 12) values were derived for the percentage of the total daily global exposure received during the four hours between 10.30 and 14.30, on clear days from November to March, at the seven cities studied. These percentages were used to derive values for absorbed radiation during this four-hour period from the values obtained from Terjung and Louie. The values so obtained were then adjusted to give Appendix 2 which lists, for the cities; Perth, Sydney, Liverpool, Melbourne, Port Hedland, Alice Springs and Townsville; solar radiative heat loads (Kjoules/hr) for nine subjects, with a range of skin areas and ground surface albedos. It is assumed that the portion of the daily heat load predicted by Terjung and Louie, falling between 10.30 and 14.30 would be proportional to the proportion of daily global exposure falling between those hours, at the various latitudes on clear sunny days.

Percent of global exposure received between 10.30 and 14.30, March to November.

Perth = 49.8%. Sydney = 49.7%. Liverpool = 49.7%. Melbourne = 49.5%.

Port Hedland = 50.2%. Alice Springs = 50.0%. Townsville = 50.3%.

2.2 Temperature Regulation

In order to maintain core body temperature within acceptable limits the excess heat produced as a bye-product of metabolism, plus any absorbed from the environment must be transferred to the environment. Heat transfer to the environment takes place at the skin through a combination of the following four processes.

Firstly **Conduction**. In this process heat is removed directly from the skin to various contact surfaces, such as the air in immediate contact with the skin, or from bare feet in contact with a cool tiled floor. In most situations conduction is not a very effective method for transferring large amounts of heat.

However, in combination with **Convection** whereby heated air close to the skin rises and is continuously replaced with cooler air (natural convection) or is moved by some external force at an appropriate velocity, (wind or forced ventilation) effective cooling can occur. Convection and conduction become increasingly less effective as the dry bulb temperature approaches skin temperature (T_{sk}). In fact when it reaches T_{sk} they become completely ineffective and at higher temperatures the environment has the potential to transfer heat to the body.

Electromagnetic radiation in the infrared, both from all surrounding surfaces and from the body itself is taking place continuously. Out of the sun, if the surrounding surfaces are cooler than skin temperature, nett radiation has a cooling effect. However, as temperature of surrounding surfaces become close to skin temperature radiation becomes less effective at cooling. When ambient temperatures of surrounding walls etc are greater than skin temperature radiation begins to heat the body.

Out doors on clear days, the effect of solar radiation is always to heat the body.

The fourth and perhaps the most important process employed by the body to remove heat to the environment is the **Evaporation of Sweat**. The latent heat of evaporation of water at body temperature is 580 cal/g[9] (2428 J/g). It is obvious that this is an effective process for body cooling. However, this process depends for its cooling effect on the actual evaporation of the sweat while it is in contact with the body. Sweat that drips off the body does not contribute to its cooling in any significant way. The air must be dry enough to evaporate the sweat, thus as the relative humidity of the air rises the cooling effect of sweating falls off, till at RH of 100% it ceases completely. Air speed is also an important factor, the cooling power of the air being proportional to the square root of air speed over the body. Unfortunately at Tdb above Tc (37°C) and at high humidity the cooling power of the air becomes a warming power that increases as air speed rises.

2.3 Contributions of Heat Loss Processes.

The total cooling/warming effect of the environment is specific to each individual and a given set of conditions, notwithstanding this, Table 5 is included to indicate in a general way the approximate contributions to body cooling by the various processes for a naked human at rest in particular constant environments with negligible air movement.

TABLE 5. HEAT LOSS DUE TO VARIOUS PROCESSES

(After Maskrey[14])

Ambient Temp.	25° C*	30° C*	35° C
Radiation	67%	41%	4%
Conduction & Convection	10%	33%	6%
Evaporation	23%	26%	90%

* Thermo neutral zone.

In a similar way Table 6 shows contributions to heat loss for a jogger with an oxygen consumption rate (VO_2) of 2.8litres/min with 140 W of solar radiation and relative humidity of 60%[14].

TABLE 6. HEAT LOSS DUE TO VARIOUS PROCESSES – JOGGER (VO_2 – 2.8 LTRS/MIN)

(After Maskrey[14] wind speed not given)

Ambient Temp.	**10° C**	**20° C**	**30° C**
Radiation	15%	5%	3%
Conduction & Convection	55%	40%	22%
Evaporation	30%	55%	75%

2.3.1 The Sweat Process

The body's moisture loss rate is highly variable depending not only upon ambient conditions and the activity being engaged upon but also on the individual and their degree of acclimation to both the task and the environmental conditions. Moisture is lost during respiration and from the skin by both sensible and insensible water loss. Sweat is produced from sweat glands of which there are two kinds, apocrine and eccrine. Apocrine glands are located on the forehead, back, palms of hands and armpits. They produce sweat containing protein and fat. Eccrine glands occur on those and all other skin areas, their sweat comprises mainly of water with minor amounts of NaCl and other electrolytes.

2.3.2 Respiratory and Insensible Sweat Rates

Stannier et al[15] suggests that at temperatures below 30° C with moderate relative humidity a human at rest dissipates 25% of its heat production by the evaporation of respiratory and insensible water loss. An adult losing about 650[16]- 900[15] g/d., approximately half of this is from the skin and the remainder from the respiratory system[16]. This gives a combined average loss rate of 25- 37.5 g/hr over a 24hr period. See Table 5.

Moss[17] measured respiratory and insensible rates of 9.5 g/hr., and 47.2 g/hr. respectively; a combined rate of 56.7 g/hr over a six hour period; for a resting subject in conditions of Tdb 27.3° C and Twb 17.7° C.

Rates of respiratory moisture loss are observed to rise both as a function of rising temperature and exertion. Moss[17] found in a resting subject, at Tdb 44.4° C, T wb 30.8° C, a respiration loss of 12.5 g/hr over two hours. He also estimated, a respiratory loss of 59.8 g/hr for a miner at work where Tdb and Twb were 21.1 and 15.6 ° C, with a breathing rate of 23.7 l/min.

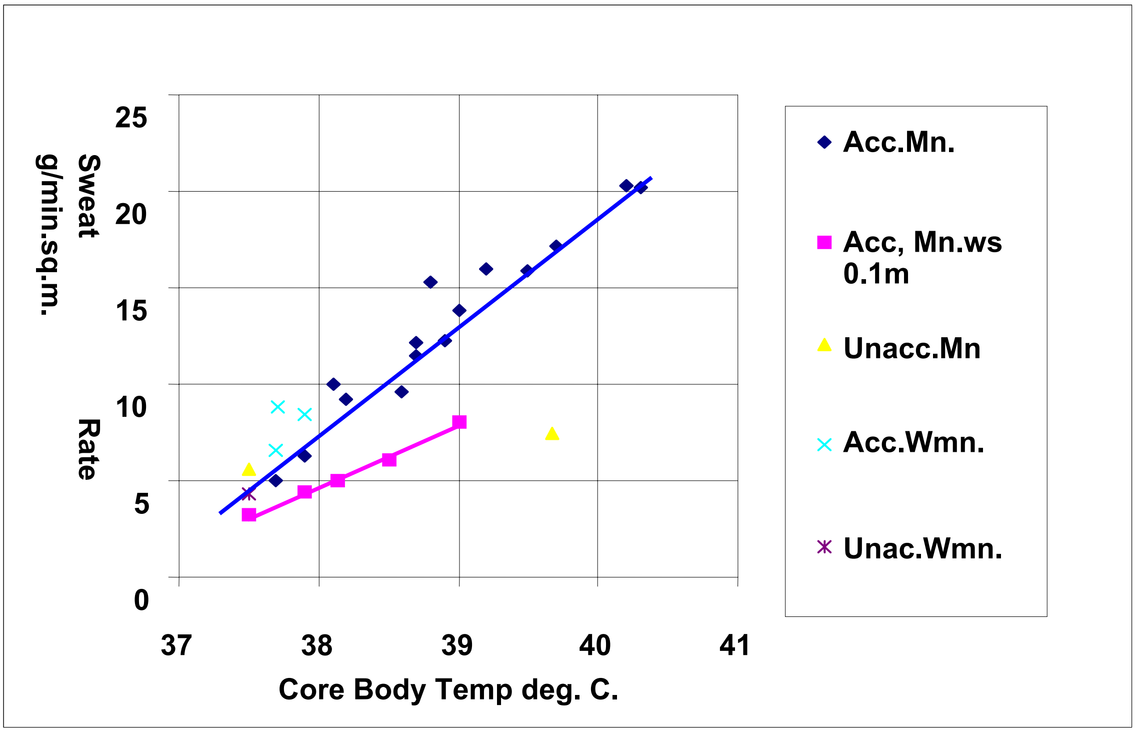
Adams[18] measured breathing rates of 110.4 and 124.8 l/min for an athlete in runs of 11.1 and 21.1 km, at a running rate of 293 m/min at Tdb 24.8°C. If Moss' rates are applied to this data, respiration moisture losses could be as high in this athlete as 278 and 315 g/hr respectively

2.3.3 Sensible Sweat Rates

In identical environmental and activity conditions, individuals sweat at different rates due both to individual differences and degree of acclimation. Table 7 shows a range of sweat rates given by various authorities

Figure 2 plotted from data in Adams, [18] Nadel et al, [19] and other authors, [20,21,22,23.] shows the strong correlation between sweat rate and Tc. The data correlated to the blue line, includes wind speeds ranging from zero to 4.9 m/s.

FIGURE 2. SWEAT RATES VS. CORE BODY TEMPERATURE



Note. - Acc. = Acclimated.

In Nadel's experiment; (pink) a wind speed of 0.1 m/s was experienced. The distinct divergence shown by graphs of the two data sets could suggest that wind speed might be a factor in controlling the sweat rate, possibly by lowering water vapour pressure in the skin boundary layer and hence the ease with which sweat can leave the glands. However, the majority of the data, as shown by the blue line, does not support this. Explanation the apparent divergence must lie in the experimental procedures

S.M. Frank etal[24] found that core body temperature and skin temperature equally affected the feeling of comfort. However, core temperature had between 2 and 4 times the effect of skin temperature on the onset of the sweat response. They also quoted results of Nadel who found the respective effects to be 7:1 and Wyss who found the ration to be 20:1.

As mentioned above sweat which is not evaporated will not contribute to cooling of the body. Many experimenters have measured the percentage; of total sweat production that is actually evaporated in the different circumstances.

Appendix 3 compiled using data from papers [20,21,22,23] shows that evaporated sweat ranges from as high as 100% of total for unacclimated individuals producing say 5g/min.m ^{2}, to as little as 55% for highly acclimated athletes producing 10g/min.m^2 of body area.

TABLE 7. RANGE OF HUMAN SWEAT RATES

Authority	Tdb ° C.	Twb ° C.	R.H.%	Moisture Loss l/hr	Comments – (Authorities).
Koehler[9]				4 1	For short periods Common for up to 6 hours
CUErgo[16]				1 1.7-2.5	Maximum continuous rate For up to 6 hours. (Never less than 0.65 l/day)
U Tas. Maskrey /Weller[14].				2 0.025-0.038	For limited periods for Acclimatised persons. Under thermo neutral Conditions (insensible)
Costill[25]				2.8	Warm conditions during a Marathon duration 2hrs 9mins.
Moss[17]	37.3	29.9		1.7 1.46 1.10	Mining 5hr Shift – Subject A. Ditto - Subject B. Ditto - Subject C.
V N H.[26]					15 Litres per day / soldier.

The composition of sweat varies widely. At low levels of activity it can comprise 98.8% water[17]. Table 8 adapted from Costill[25] gives a range of values for the mineral composition of sweat for individuals, presumably exercising at close to maximum rate.

TABLE 8. MINERAL CONCENTRATIONS IN SWEAT, PLASMA AND MUSCLE (MG/L)

	Na^+	Cl^-	K^+	Mg^+
Sweat	920-1380	1063-1773	156-196	18-61
Blood Plasma	3219	3582	156	18
Muscle	207	213	6333	377

The following changes in composition were also shown[25]. As the sweat rate rises from 0.1 to 1 l/hr the following changes were found: -

Na^+ - 345 to 990 mg/l.

Cl^- - 230 to 1348mg/l.

K^+ - constant 160mg/l

Ca^+ -184 fell to80mg/l

Mg^+ - 56 fell to 39mg/l (relatively constant)

Obviously prolonged periods of high exertion in hot conditions can result in large losses of electrolytes even though urinary excretion is reduced in such conditions[21]. However, the use of mineral supplements is considered to be unnecessary by most authorities[7, 25,26,27], and in many cases can be harmful[26]; they advise that a normal diet with adequate water intake is sufficient to keep the body in electrolyte balance.

The maximum rate of gastric emptying, i.e., the maximum rate at which the body can assimilate water, is variously given as 1.23-l/hr[28] and1.5-l/hr[7]. It is therefore obvious that during extended periods of high exertion in high temperatures the body can become dehydrated even when larger amounts of water are ingested.

The thirst mechanism cannot be relied upon as a guide to the body's water status since it is not activated till the body is 1-2% dehydrated[28]. Therefore to avoid mild dehydration one should learn to drink to a schedule and not rely upon the thirst stimulus. Marathon runners despite efforts to take fluids can lose as much as 6 litres during a race. This equates to some 8 to 10% of body mass[25, 18], resulting in severe dehydration.

Neufer, Young and Sawka [29,30] in their work with ten subjects of average skin area 1.78 m^2, found the following average rates of gastric emptying for water, with subjects at rest, walking, running, and exercising on a treadmill, at various percentages of maximum aerobic capacity (%VO_2 Max.)

At rest - 18.0 ml/min.	**Walking**
Running.	28% - 22.3 ml/min
57% - 22.0 ml/min.	41% - 22.1 ml/min.
65% - 20.7 ml/min.	56% - 20.5 ml/min.
75% - 17.9 ml/min.	
Exercise at 50% -	
Unacclimated.	**Acclimated**
Neutral (18°C)-21.0 ml/min	Warm (35°C) - 20.4 ml/min
Warm (35°C)-18.9 ml/min.	Hypohydrated (5%)- 15.7ml/min.
Hot (49°C) - 13.9 ml/min.	

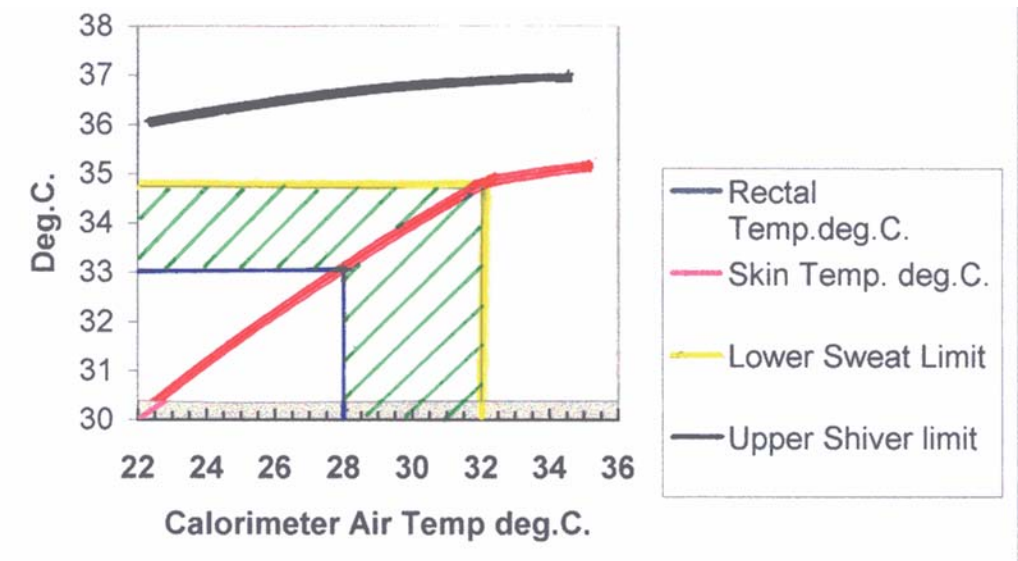
This work shows that water assimilation (gastric emptying) rates increase from about one litre per hour at rest to a maximum of 1.4 litres per hour with moderate exercise. However, as the exercise rate, the ambient temperature and the degree of dehydration increase, the rate of water assimilation can fall off to less than the rest rate.

2.4 Body Temperature Control

Heat exchange between the body and the environment takes place at the skin, whereas the bulk of heat production takes place well within the body. How then does the body convey this heat to the surface? Two processes are involved, firstly heat is transferred by the passive conduction of heat through the body tissues, and secondly by a process known as convection where heat is transferred via the blood. This convective heat exchange is controlled by vasodilation[31] in which the diameters of blood vessels close to the skin are increased in size thereby increasing their hydraulic conductivity and allowing an increased flow of hot blood to pass close to the skin increasing skin temperature and, dramatically increasing the rate of heat transfer to the skin and subsequently to the environment

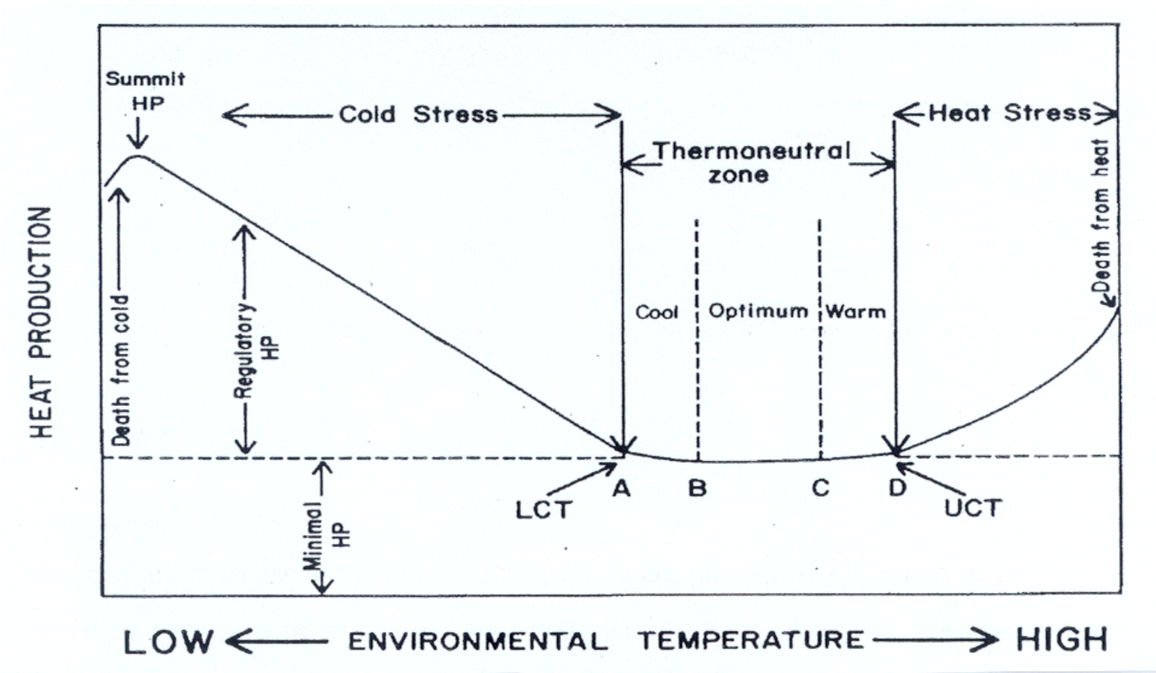
The operation of these processes is illustrated by Fig 3, which shows a difference of 4 and 2 degrees respectively between rectal and skin temperature for a subject in a calorimeter experiment when calorimeter temperature was 28°and 32° respectively[32]. This means the body has achieved the same heat flux with a 50% reduction in temperature gradient, as the temperature regulation process changes from passive conduction to combined conduction plus vasodilation. Increased blood flow close to the skin is not only a mechanism for ridding the body of heat but also ensures an adequate supply of blood to the body's periphery from which the sweat is derived. Vasodilation is mediated in the brain by the hypothalamus, in that the frontal portion responds to the temperature of the blood in the corticoid artery. However the final hypothalamic response is further augmented and modified by the temperature of sensors close to and in the skin and to extra hypothalamic body core temperature sensors[15] Stanier et al[15], suggest that under thermo neutral conditions (Fig.4.)

FIGURE 3. NEUTRAL ZONE: CLASSICAL EXPERIMENTAL DEFINITION (AFTER HARDY AND DEBOIS. 14)



i.e. at temperatures between 28 and 32° C, when the body is at rest, and neither stimulated to shiver in order to increase metabolic heat production or to sweat, in order to maintain normal Tc; blood supply to the skin is about 10 times that required to provide oxygen to the peripheral tissues. In very cold conditions the supply of blood to the superficial tissues is very much reduced and in high temperature conditions this blood flow can be increased to as much as half the resting cardiac output – 2.5 l/min, this, coupled with pooling of blood in the periphery can severely reduce blood supply to other organs especially the brain. As mentioned above, in hot conditions, heat regulation in humans is driven very largely by core body temperature and to a much smaller extent by skin temperature. This position reverses in conditions of extreme cold.

FIGURE 4. SCHEME OF THERMONEUTRAL ZONES OF ANIMALS (YOUSEF, 1985). LCT: LOWER CRITICAL TEMPERATURE. UCT: UPPER CRITICAL TEMPERATURE



2.5 Minor and Major Dehydration.

Several authors describe the physiological effects of hypo hydration[27, 33] that are listed below.

The effects of dehydration are to cause:

1. Reduction in total body blood volume.
2. Reduction in heart stroke volume.
3. Reduction in blood volume pumped by the heart (stroke volume).
4. Reduction in skin blood flow.
5. Heart rate to increase to maintain Cardiac output.
6. Higher body core temperature as the body tries to further stimulate peripheral blood flow.
7. A reduction in sweat rate due to decreased peripheral blood flow.

8. A reduction in the maximum oxygen uptake.

From the above it is obvious that hypo hydration reduces the body's ability to transfer heat to the environment and can be a potent factor in the onset of hyperthermia.

Hypo hydration also results in impairment of both mental and physical performance, Bates[7] see Table 9, shows how body moisture deficit affects physical performance.

TABLE 9. REDUCTION IN PHYSICAL CAPACITY – DUE TO WATER DEFICIT

Water Deficit % of Body Weight	% Reduction In Maximal Aerobic Power	% Reduction In Physical Work Capacity	Remarks
1-2		6-7	Moderate environment.
3-4	4-8	22	Same environment as above
4	25	50	Hot environment

He also reports that measurement of mental functions such as short-term memory, arithmetic accuracy and attention show significant impairment at 2% hypo hydration and that increased mental impairment results from and is proportional to, the degree of increased hypo hydration above 2%. It is also suggested that the measured impairment was entirely due to moisture deficit and not to elevated core body temperature and that due to reduced mental attention, complex tasks may not be adequately or safely performed by a person in the dehydrated condition.

2.6 Heat Related Illnesses

These range through a continuum in severity from heat cramp and heat exhaustion, to the most severe illness, heat stroke whose victims have a morbidity rate of 80%[7].

Heat cramp, this term is misleading in that heat in itself does not cause cramp, it was believed to be due entirely to loss of salt and other electrolytes. However, there is recent evidence that suggests regional microcirculatory changes also play a part[7]. Heat oedema (fluid accumulation) and syncope (fainting) are related symptoms. They are caused by prolonged peripheral vasodilation and peripheral (surface) blood pooling, with consequent low blood pressure when standing, resulting in reduced blood and consequently oxygen supply, to the brain.

2.6.1 Heat exhaustion

Heat exhaustion[7, 8] is due to the inability of the circulatory system to meet both metabolic and thermoregulatory demands; it arises from large reductions in blood plasma volume, often with low salt and other electrolyte levels and or peripheral blood pooling. The body temperature is normal or only slightly elevated (38 - 40°C[41]), sweating can vary from profuse to normal, and blood pressure is low and the skin pale. Symptoms can also include loss of appetite, nausea, vomiting, tachycardia (rapid heart beat) and headache. Where sweating is absent and skin dry, heat exhaustion may be due to pre-existing heat rash or sunburn that reduces the ability to sweat with a consequent rise in core body temperature (40- 41.1°C[41]). In this syndrome salt and water depletion is normally not present. For further details regarding the effects of heat see [41].

2.6.2 Heat Stroke

Heat stroke is the most serious heat induced illness and if untreated rapidly leads to death[7,8,9,33,34,26,35,36,37]. Heat stroke occurs when the body's thermoregulatory system breaks down and/or is unable to transport its heat load to the environment, resulting in reduction in the sweat rate. Core body temperature rapidly increases to 40.6°C and above (see Table 2). Death results from cell destruction principally, in the vascular system[34], the brain, liver and kidneys, due to overheating, together with the effects of blood clotting in the vascular system. Even if treated, in severe cases, death through renal failure from dehydration, rhabdomyolysis (muscle melt down) or both, or permanent injury, due to damage to the central nervous system can result. Such damage can affect gait, articulation, and/or cause hyperreflexia and nystagmus (abnormal eye movement).

Two types of heat stroke are recognised, classic heatstroke is caused by the environment preventing victims from dissipating their metabolic heat adequately whilst at rest or during low level activity. Classic heat stroke mostly affects the elderly and other at risk groups. Exertional heat stroke is brought about by exceptional exercise or paced work in hot but not exceptional conditions, and mostly affects young fit individuals engaged in exceptional sporting or occupational activities.

Table10[38] gives a comparison between symptoms of Classic and Exertional heat stroke.

TABLE 10. COMPARISON BETWEEN CLASSIC AND EXERTIONAL HEAT STROKE

Characteristic	Classic Heat Stroke	Exertional Heat Stroke
General Health	Predisposing health factors May be present	Usually a healthy Person
Age	Older or juvenile	Younger
Occurrence	Often occurs during high Temperatures	Occurs sporadically
Sweating	Absent	Present (Varies)

TABLE 10. COMPARISON BETWEEN CLASSIC AND EXERTIONAL HEAT STROKE

Characteristic	Classic Heat Stroke	Exertional Heat Stroke
Activity	Sedentary	Strenuous
Disseminated Intravascular Coagulation	Uncommon	Common
Acute renal failure	Uncommon	Common
Lactic acidosis	Uncommon	Common
Hyperuricemia	Moderate	Severe
Hypokalemia	Rare	Common
Rhabdomyolysis	Rare	Common

Heat stroke victims may experience dizziness, headache, nausea, weakness, restlessness or mental confusion, have a rapid bounding pulse and a hot, dry, flushed skin and suffer collapse. As victims descend deeper into coma they may develop a thin weak pulse and a more dusky skin and core body temperature rises alarmingly. Death usually follows within minutes. Table 11 lists four cases of heat related deaths and illnesses[39].

TABLE 11. CONDITIONS CONTRIBUTING TO THE RISK OF HEAT-RELATED ILLNESSES AND DEATHS

Gender	Age Yrs	Outdoors Tdb°C	R.H%	Tre°C	Remarks
Female	29	33.3	91	41.9	She died two days after admission to hospital
Female	68	35.6	45	42.7	This lady was obese-350 lbs, she died on the way to hospital
Female Male Female	44 53 72	41.1	36		All found dead in house. Mother died first mentally retarded children stayed in house and died.
Male Female Male	6 4 2	28.9	60		Children left locked in car for 10-20 minutes. On rescue they were found to be unresponsive, disoriented flushed and sweating profusely (heat exhaustion) and had delayed reflexes. Upon release they recovered in thirty minutes after treatment in the shade. Estimated temp. in the car ≥43.3°C. They were reported to be showing classic signs of early onset of Heat stroke.

In addition to these, what may be called direct effects of heat there are some more subtle effects. McLean[40] describes the effect, on the foetus of various mammalian species, including humans, of decreased uterine blood flow that occurs when the body diverts blood in the process of vasodilation in attempting to limit increases in body core temperature. Uterine blood provides the developing embryo with nutrients, oxygen and hormones and carries heat away. A reduction in this blood supply can cause death, damage or malformation to the foetus. Apart from death, damage can include skeletal abnormality, dwarfism and retardation. He states that a rise of 1-1.5°C above normal uterine temperature will kill an embryo. In cattle, ambient temperatures higher than those normal for the breed result in reduction in conception rates of from 20-30%, in severe cases conception may not occur and where it does, birth defects including dwarfism result.

The human foetus will be damaged, especially in the first trimester, when a woman's core temperature exceeds 38.5°C; this temperature can be reached after 15-25 minutes in a 40°C bath. Embryos are most at risk in the very early stages of development.

In addition to these effects on the embryo it is well known that male sperm may be killed or damaged due to heat, this is currently a problem for humans and other mammals and may become worse as global warming effects increase.

2.7 Heat Related Deaths

Hales et al[41] found an increase in total deaths of 1%; and 3% in respiratory related deaths in Christchurch N.Z., for every 1°C increase in temperature above 20.5°C (the 3rd quartile value in the daily maximum temperature range).

In years when no heat waves occur some 240 heat related deaths per year occur in the United States.

In 1980, 1983 and 1988 years with heatwaves 1700, 556 and 454 heat related deaths occurred[39].

In 1995 from the 12th to 20th July a heatwave occurred in Chicago[34] that resulted in more than 600 extra deaths and 3300 extra casualty department, hospital visits. Daily temperatures varied between 33.9 and 40.0°C. Both the maximum number of deaths and hospital admissions occurred on the 15th. This reference[34] provides detailed medical information of the episode, including follow up data on many of the surviving victims.

Geerts and Linacre[42] quoting data from the Natural Hazards Research Centre, at Macquarie University give the approximate average number of heat related deaths occurring annually in Australia in the period 1968-1992 as 23.

Andrews[43] states that a maximum temperature of 35°C in Sydney can increase total mortality by 10% and that maximum summer temperatures of 35°C are exceeded on average three times per year in Sydney.

Table 12 gives the number of hot days that would be experienced if the temperatures from the available climate data record were adjusted for the projected 2070 conditions as described above. This record suggests that, on average, 21 days per year could have temperatures equal to or greater than 35°C at Sydney Airport by 2070. Such conditions would result in a much higher morbidity than is experienced today. This possibility is explored in detail below and has recently been the subject of an important study by A. McMichael and R. Woodruff[44].

TABLE 12. NUMBER OF HOT DAYS IN CLIMATE DATA – ADJUSTED FOR 2070 CONDITIONS

Temp. Range	Perth Airport	Sydney Airport	Alice Springs	Townsville	Port Hedland	Liverpool N.S.W.
≥50°C	9	0	11	1	114	2
≥48°<50°	40	2	151	2	406	11
≥46°<48°	161	12	684	5	974	34
≥44°<46°	327	30	1411	18	1545	83
≥42°<44°	541	60	1945	72	2398	127
≥40°<42°	804	97	1957	300	2934	257
≥38°<40°	975	173	2058	2102	2768	385
≥35°<38°	1899	595	2798	8628	3546	1032
Total No. Data Days	20572	16695	21771	21884	19060	13066
Observation Period	3/6/1944-30/9/00	1/1/1955-30/9/00	4/11/41-19/6/01	1/11/40-30/9/00	18/7/48-30/9/00	1/8/65-19/6/01

Since 1983 approximately 5 people per year have died in Australia due to extreme heat and the rate has declined since the 1900's when more than 100 people per year died due to heat stress [43]. This decline is difficult to understand, in view of the much greater population. It is also reported[43] that in 1895/96, 431 deaths occurred and in 1938/39, 438 people succumbed.

Geerts and Linacre's[42] figures are conservative since they only include deaths attributed directly to heat. Deaths due to the effect of heat on predisposing conditions are not included.

2.8 Risk Factors for Heat-Related Illness.

Barrow and Clark[38] provide a summary of conditions that predispose an individual to heat related illness Table 13.

TABLE 13. CONDITIONS CONTRIBUTING TO THE RISK OF HEAT RELATED ILLNESS AND DEATHS

Physical Conditions	
	Fever
	Dehydration
	Medications
	Prolonged Exertion
	Chronic Illnesses
	Cardiac Conditions
	Cystic Fibrosis
	Uncontrolled Hypertension
	Uncontrolled diabetes
	Malignant Hyperthermia
	Eating Disorders
	Extensive Skin Disease or Damage or Both
	Peripheral Vascular Disease
	Psychiatric Conditions
	Autonomic Nervous System Disorders
	Hyperthyroidism
Age Related Factors	
Older Age Results in	
	Decreased Vasodilatory Response
	Decreased Maximum Heart rate resulting in decreased maximum cardiac output
	Decreased thirst response
	Decreased temperature sensing ability
	Decreased fitness Level
	Decreased mobility resulting in increased difficulty in obtaining fluids

TABLE 13. CONDITIONS CONTRIBUTING TO THE RISK OF HEAT RELATED ILLNESS AND DEATHS CONT'D

Younger Age Results In	
	Decreased ability to sweat
	Decreased cardiac output at a given metabolic rate
	Greater core temperature required to initiate sweating
	Slower acclimatisation
	More heat produced for the same level of activity
Increased body Mass Results In	
	More heat generated for the same level of activity
	Less efficient heat dissipation
	Fewer heat activated sweat glands in the skin
	Overlying adipose tissue
	Decreased cardiac output per unit of body weight
Additional Factors	
	Lack of access to air conditioning
	Living in Upper floors of tall buildings
	Sleep deprivation (decreases skin blood flow and rate of sweating)
	Previous heat stroke
	Use of equipment and heavy clothing (eg football player's padding, fire-fighter's equipment)
	Recent move from a temperate to a hot climate (poorly acclimated)
	Heatwave in late spring or early summer
	Urban Setting (urban areas can act as heat traps)

Table 14 adapted from[39] summarises the effect of age on heat related deaths as an average annual rate per million of populations of the various age categories for the United States of America.

TABLE 14. AVERAGE ANNUAL RATE HEAT DEATHS PER MILLION BY AGE GROUP

Age Group yrs	≥ 85	75 To 84	65 To 74	55 To 64	45 To 54	35 To 44	25 To 34	15 To 24	0 To 14
Number of deaths	11	6	3	2	1.3	0.8	0.5	0.3	0.2

Of the deaths that occur in the 0 to14 age group some 83% occur in the 0 to 4 age group.

As indicated in table 13 prolonged exercise and also repeated bouts of exercise in high heat results in increased risk of heat casualties. It has also been demonstrated[40] that exercise on mild days can result in alarmingly increased rates of heat injury, if on the preceding day exercise in the heat had been carried out. A similar result was found for heat related deaths.[41] The evidence is quite clear that the″effects of heat stress are both dose related and cumulative”. [42]

Certain medications and drugs can increase a person’s susceptibility to heat injury, by affecting the body’s ability to deal with heat. Some categories of prescription medicines and so-called recreational drugs, which harm the body’s heat dissipating mechanisms, are listed in table 15[38].

TABLE 15. MEDICATIONS CONTRIBUTING TO THE RISK OF HEAT ILLNESSES

Alpha agonists	Heroin
Amphetamines	Inhaled anaesthetics
Anticholinergic medications	Laxatives
Antihistamines	LSD
Anti-parkinsonian agents	Monoamine oxidase inhibitors
Beta-adrenergic blockers	PCP
Calcium-channel blockers	Phenothiazines
Cocaine	Sympathomimetic medications
Diuretics	Thyroid agonists
Ethanol (alcoholic drinks)	Tricyclic antidepressants

LSD=lysergic acid diethylamide; PCP=phencyclidine hydrochloride

An additional list of specific medications which reduce the bodies’ ability to deal with heat, may be accessed from the City of Toronto’s “Hot Weather Response Plan”[36]

2.9 Acclimatization

Acclimatization is the conditioning of the body for a particular activity in a particular set of environmental conditions. Acclimatization to a hot environment produces the following changes that are advantageous during subsequent heat exposure[7]: -

- It increases the blood volume by up to 25%.
- It causes sweating to commence at a lower core temperature.
- It increases the sweat rate for any given core temperature.
- It reduces the sodium lost in sweat by up to 50%
- Efficiency of peripheral blood circulation is increased

However, acclimatization does not help if environmental conditions are such that heat transfer from the body is less than heat production plus heat accumulation from the environment.

Acclimatization must be carried out in the conditions and at a work/exercise rate at which the person will be expected to function.

If conditions become more stressful the person needs to be further conditioned for the new circumstances.

In order to retain a state of acclimatization a person needs to be exposed on an almost daily basis to the stressful conditions, since acclimatization can be rapidly lost.

It was originally thought that a significant degree of acclimatization could be reached in only 4 - 5 days, and that full acclimatization could be reached in 14 days[7]. However, recent research carried out by the United States' Navy[26] proves that acclimatization is a complex process requiring up to 21 days to complete, (table 16).

TABLE 16.[26] PERCENT OPTIMUM HEAT ACCLIMATIZATION

	Percent Achievement On			
Physiologic Parameters	**Day 1**	**Day 7**	**Day 14**	**Day 21**
Tympanic Membrane Temperature	6	37	71	100
Deep Oesophageal Temperature	51	82	93	100
Mean Skin Temperature	80	93	98	100
Heart Rate	8	37	67	100
Systolic Blood Pressure	11	38	56	100
Diastolic Blood Pressure	7	36	70	100
Pulse Pressure	9	36	63	100
Mean Arterial Blood Pressure	4	35	79	100
Est., Total Vascular Resistance	8	37	70	100
Rectal Temperature	6	38	72	100

TABLE 16.[26] PERCENT OPTIMUM HEAT ACCLIMATIZATION

	Percent Achievement On			
Physiologic Parameters	**Day 1**	**Day 7**	**Day 14**	**Day 21**
Est., Cardiovascular Reserve	7	36	69	100
Sweat Rate	3	37	76	100
Urine Electrolyte Concentration	3	39	78	98
Overall Percent Achievement	13	45	78	99.6

Data given above relating to heat related morbidity for Christchurch N.Z., Chicago U.S.A., and Sydney Aust., indicate to some extent how acclimatisation affects the ability of a population to handle heat at different levels and how within physiologically compensatable limits it is the degree of elevation of ambient temperature above the norm rather than the actual temperature that can cause stressful conditions.

Kalkstein[45] describes the incidence of heat related mortality in a range of cities in the U.S.A., and illustrates the beneficial influence of acclimatisation in those southern cities not subject to the extreme temperature variations experienced by the northern and mid western cities. He suggests that if the degree of acclimatisation currently achieved by residents of some southern cities is achieved by residents in those cities with current high summer mortality rates; as a result of gradual global warming, to the levels predicted by recent modelling; then heat deaths may not increase and in fact may possibly be reduced. This must assume that the present temperature variability experienced in these cities is reduced to that experienced in the southern cities. He finally suggests that if the projected temperature rises occur, it is possible that certain areas might simply become uninhabitable", because temperature and humidity will lie above the compensatable range.

Acclimatisation is a highly complex process that includes the generation of so called Heat Shock Proteins; they are produced universally in all organisms[37] and increase the body's ability to withstand heat in a minor way. This has been demonstrated by Weshler et al 1984 as reported in[37], in experiments with rats they showed that after conditioning at 41.8º C for 60 min., the 20% survival rate for rats exposed to 42.5º C body temperature one day after conditioning; was increased from 42 min for unconditioned rats to 72 min for conditioned animals. This reduced to 68 min four days post conditioning. The effect had disappeared completely in subjects six days after conditioning. Gisolfi and Mora do not comment on the neurological condition of animals surviving this experiment. It is possible that residents living in cities where there are lengthy spells of cool weather, between sudden onset heat waves, may be at greater risk of heat damage than in locations where heat waves build slowly over several days.

3 SYNTHETIC DATA SET

It was first envisaged that a synthetic data set would be obtained by using a random number generator to construct a set of numbers around the new average summer temperatures projected for 2070. However, it was soon realised there would be insurmountable difficulties. What would be the upper and lower temperature bounds? How would wind speed and humidity values be assigned?

It was then realised that sets of numbers, actually produced by the systems to be considered already existed i.e. the actual climate records. CSIRO's publication[1] and John Cramb[46]suggested that new temperatures could be predicted by simply adding the modelled increases in average temperature to the existing temperature record.

But how can one assign values for humidity and wind speed? As indicated above it was decided to adopt humidity values directly from the actual record since average summer rainfall at the locations being considered are projected to remain the same[1] or similar and only summer data are of interest. The present author had no guide for assigning new values for wind speeds, and whilst it might be expected that wind speeds could increase with more energy in the climate 'engine' without any reliable guide for adjustment, wind speeds from the record have been adopted directly in this assessment.

Temperature values in the climate records[2] were adjusted to represent 2070 conditions by using data from CSIRO's report [1] as follows. For Sydney, Port Hedland, Alice Springs, Townsville and Liverpool 6°C was added directly to the recorded temperature values.

Perth is shown in the 5.2° C 'block' in CSIRO's (see figure 3[1]) report[1], but is quite close to the 6.8°C block. To assume that there would be no gradual transition would be patently wrong and so a value of 6°C has also been adopted for Perth. For Melbourne temperature values in the climate record have been increased by the projected 5.2°C.

In this study the following data sets obtained from the Bureau of Meteorology and listed in Table 17 have been utilised. Temperatures were adjusted by adding the amounts noted above based on the 2070 projections[1] directly to the recorded dry bulb temperatures. Adjusted temperatures from the climate Data Set 1 were used to compile Table 12.

TABLE 17. DATA SETS UTILISED

Station	Data Set 1	Period
Perth Airport	Tmax, Tmin R.H.at1500, Rain.	3/06/44-30/09/00.
Sydney Airport	Ditto	01/01/55-30/09/00
Townsville	Ditto	01/11/40-30/09/00
Port Hedland	Ditto	10/07/48/30/09/00
Alice Springs	Tmx, Tmn, R.H.at0900&1500, Rain	4/11/41-19/06/01
Liverpool	Ditto	1/08/65-19/06/01

TABLE 17. DATA SETS UTILISED CONT'D

Station	Data Set 2.	Period
Perth Airport	T, R.H., Rain, Wind spd &dirctn.	1/01/90-24/12/01
Sydney Office	Ditto	Ditto
Melbourne Office	Ditto	Ditto
Alice Springs	Ditto	Ditto
Townsville	Ditto	Ditto
Port Hedland	Ditto	Ditto
Liverpool	Ditto	Ditto

For Data Set 2, the elements were read at 3 hourly intervals between the times 0200hr and 2300hr daily.

Data Set 2 has been utilised for detailed assessment of physiological effects because it is the most recent decade and also in order to reduce the volume of data to be assessed.

4 HEAT EFFECT INDICATORS

There have been many attempts to create the perfect heat index that could be used to both assess the effects of the local environment on workers, sportspeople or merely passive bystanders and also for use in planning safe work and sport schedules[47]. To date the only one which seems to approach the ideal is the Wet Bulb Globe Temperature (WBGT) index[10] which has been calibrated against actual physiological experiments in a suitably wide range of environments, activities and physiological subjects and is now widely used in industrial[48], military[10] and sporting[49] applications.

In addition to the WBGT index, the National Weather Service (NWS) heat Index (H I) [50] and the Wet and Dry Kata Cooling Power indices[17] were considered for use in this study.

4.1 Wet Bulb Globe Temperature Index

This index factors in four physical variables: -

- Air temperature
- Humidity.
- Radiation temperature.
- Air movement.

Air velocity measurements are not needed since the globe thermometer integrates radiant heat and convective cooling or heating into one value. The globe temperature is neither a measure of radiant nor what is termed mean radiant, temperature but is a composite measure of radiant and convective heat transfer. The WBGT Index is calculated using the following expression.[10]

$$\text{WBGT index} = (0.7\times T_{WB}) + (0.2\times T_{MBGT}) + (0.1\times T_{DB}) \qquad (1)$$

T_{WB} = Shielded psychrometric wet bulb temperature - ° C.

T_{MBGT} = Matte black globe temperature - ° C. (rad.15 cm).

T_{DB} = Shielded dry bulb temperature - ° C.

Results from complex heat- work, physiological experiments carried out through 1968-1975 in a large number of heat stress and work situations, both ashore and afloat for the U.S.Navy resulted in the development of its Physiological Heat Exposure Limits [10] graphs which enable safe exposure times to be determined for a range of activities, in any environment for which the WBGT Index can be determined or predicted.

Unfortunately this index could not be used in the present study, as the available data does not include globe thermometer temperatures, nor can they be derived from the available data.

4.2 National Weather Service Index.

The National Weather Service of the United States of America has devised a Heat Index (H.I) that is calculated using values of dry bulb temperature and relative humidity. The graph Fig 5 has been adapted from[50] and was originally plotted from values obtained from a formula in the N.W.S. publication 'What is the Heat Index [52]'

This index does not include the effects of radiation or air speed but nevertheless is widely used in the United States.

Since H.I. values are devised for shady light wind conditions, exposure to full sunshine can increase H.I. values by up to 8.5°C. Also, strong winds, particularly with very hot, dry air can be extremely hazardous.[50]

Since no attempt is made in this index to allow for either wind speed or solar radiation it has not been used in these assessments.

4.3 Kata Cooling Power Indices

Kata thermometers were introduced by Hill[17] and were used extensively in assessing mining and industrial environmental conditions and are still referred to as a method for assessing environmental conditions in mines in recent publications[51]. Their use has now been largely superseded by the WBGT index except in mining practice. However, since Kata cooling powers can be calculated from the data available and include the effects of both wind speed and radiation, they have been used in this study to define environmental conditions. There are two instruments, the dry and wet Kata.

It is worth remarking that the trace of values of Wet Kata Cooling Power of 3; for an air speed of 0.2 km/hr and environmental factors from the graph of H.I.; plotted on Fig 5, coincides with the boundary between the graph's zones of Danger and Extreme Danger, to the most severe heat stress illnesses.

Moss[17]gives some wet and dry Kata standards for factory workers. Here it is assumed that the rate of heat loss or gain of the Kata thermometers will be the same as for the human body. Moss[17] states that –'The cooling effect of air in motion on the bulb of the wet Kata thermometer is practically the same as that on an unclothed man who is sweating freely'. Additional work needs to be done to confirm or refine this assumption.

4.3.1 Dry Kata Cooling Power (DKCP)

The Dry Kata integrates local radiation, ambient air temperature and wind speed, into a single value called the Dry Kata Cooling Power, which is expressed in milli calories per second per sq cm of the thermometer bulb. This value is then scaled up to human surface area to index human heat exchange. Dry Bulb temperatures measured inside a Stephenson screen adjusted to 2070 projected conditions have been used here in calculating DKCP values. The term quantifying the solar radiation contribution to the natural wet bulb temperature (Tn) equation (7) suggests that the direct solar radiation contribution to Tn is quite small and in the case of unshielded mercury thermometer could be even smaller. In any event use of the screen temperature should be conservative.

Bedford and Warner[52] developed new equations for obtaining the DKCP.

These are given below using modern units.

For wind speed zero. $H = 0.27\ (36.5 - T_{db})^{1.06}$ (2)

For wind speed ≤ 3.6 km/hr. $H = (0.20 + 0.211\times\sqrt{V})\ (36.5 - T_{db})$ (3)

For wind speeds >3.6 km/hr. $H = (0.13 + 0.248\times\sqrt{V})(36.5 - T_{db})$ (4)

H = DKCP. (m.cal / cm^2.sec.)

V = Wind speed. (km / hr)

$T_{db.}$ = Dry bulb temperature. (° C)

To assess the effect of a given environment on human heat balance, the DKCP's must be adjusted for the cooling effect of **evaporated** sweat. In humid and semi humid environments this can be achieved by using the Wet Kata, however, in dry very high temperature conditions the individuals evaporated sweat rate may be exceeded and WKCP's are inappropriate.

4.3.2 Wet Kata Cooling Power Index (WKCP)

The Wet Kata thermometer[17] integrates the relative humidity, local radiation, air speed and air temperature into a single value called the Wet Kata Cooling Power, which is expressed in millicalories per second per sq cm of the thermometer bulb. Heat exchange to/from the wet Kata bulb is assumed to be similar to the sweating human skin.[17]

Rees' equation[17] can be used to calculate the WKCP of an environment where it is assumed the immediate surroundings are at ambient temperature. His equation with units modified for modern practice is shown below

$$H = 0.648\ \theta + 0.439\ \theta\ \sqrt{V} \qquad (5)$$

Where H = Wet Kata Cooling Power (m.cal/cm^2.sec.)

$\theta = (36.4 - T_N)$

V = Air/wind speed (Km/ hr.)

T_N = Natural wet bulb temperature (°C.)

Use $H_1 = 150.84$ H. (to convert m.cal/cm^2 sec to kJ/m^2.hr.) (6)

Rees' formula requires use of temperature obtained from the fully exposed, unventilated, wet bulb thermometer (natural wet bulb temperature). Since there was no extant formula to derive Tn from the available meteorological records, a prediction formula was derived empirically. Several weeks of Tn measurements were made in Perth, and the simultaneously measured dependent variables were used to predict Tn using multiple linear regression techniques,

$$Tn = 0.85Tdb + 0.17RH - 0.61\sqrt{V} + 0.0016S - 11.62. \quad (7)$$

Tn = Natural wet bulb temperature (deg C.)

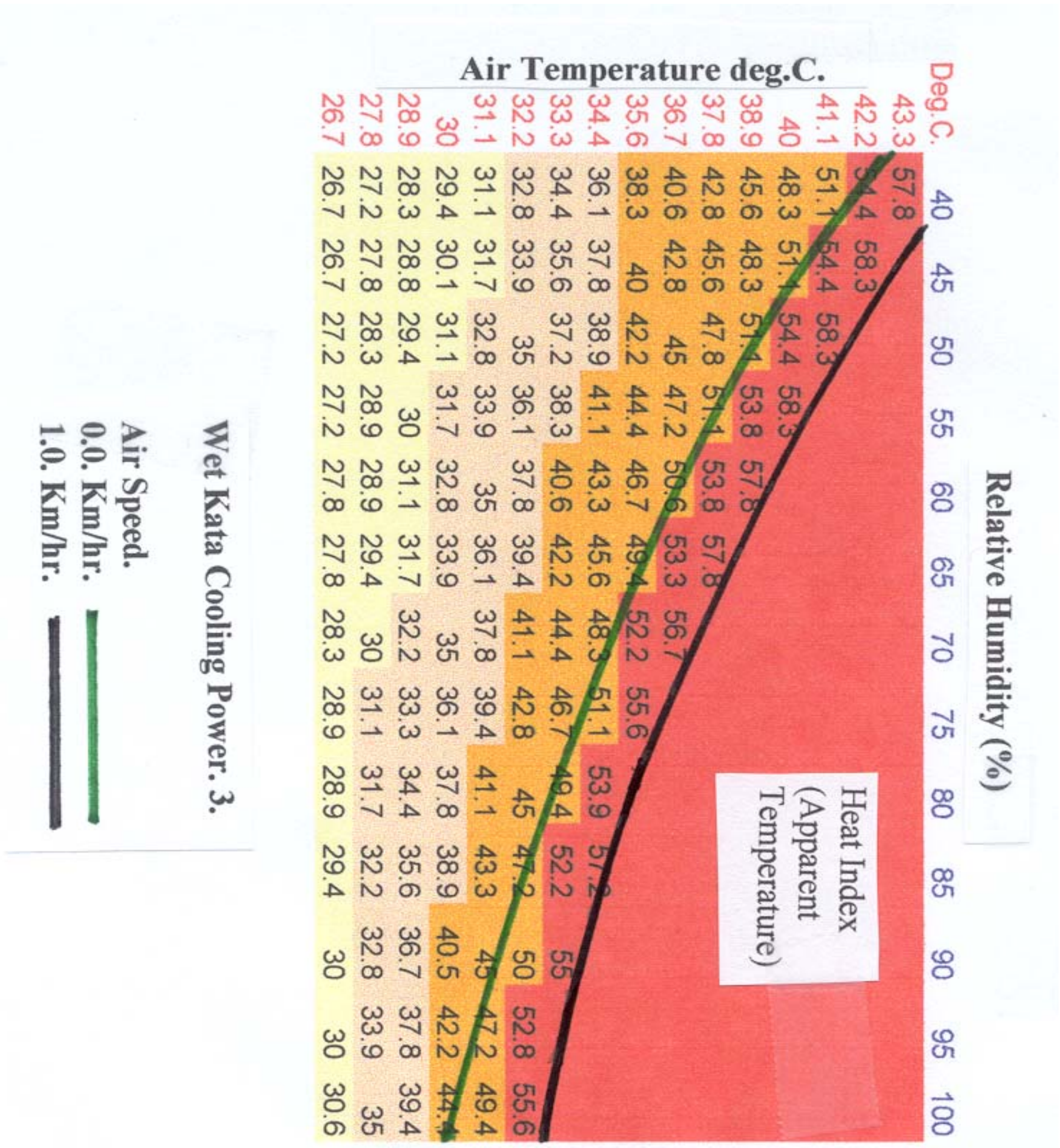
Tdb = Dry bulb temperature (deg C.)

RH = Relative humidity (%.)

V = Air speed (m/sec.)

S = Solar irradiance (W/m^2.)

In using this formula to obtain values of natural wet bulb temperature the recorded data with Tdb adjusted for 2070 conditions as described above was used.



Deg.C.	40	45	50	55	60	65	70	75	80	85	90	95	100
43.3	57.8												
42.2	54.4	58.3											
41.1	51.1	54.4	58.3										
40	48.3	51.1	54.4	58.3									
38.9	45.6	48.3	51.1	53.8	57.8								
37.8	42.8	45.6	47.8	51.1	53.8	57.8							
36.7	40.6	42.8	45	47.2	50.6	53.3	56.7						
35.6	38.3	40	42.2	44.4	46.7	49.4	52.2	55.6					
34.4	36.1	37.8	38.9	41.1	43.3	45.6	48.3	51.1	53.9	57.2			
33.3	34.4	35.6	37.2	38.3	40.6	42.2	44.4	46.7	49.4	52.2	55		
32.2	32.8	33.9	35	36.1	37.8	39.4	41.1	42.8	45	47.2	50	52.8	55.6
31.1	31.1	31.7	32.8	33.9	35	36.1	37.8	39.4	41.1	43.3	45	47.2	49.4
30	29.4	30.1	31.1	31.7	32.8	33.9	35	36.1	37.8	38.9	40.5	42.2	44.4
28.9	28.3	28.8	29.4	30	31.1	31.7	32.2	33.3	34.4	35.6	36.7	37.8	39.4
27.8	27.2	27.8	28.3	28.9	28.9	29.4	30	31.1	31.7	32.2	32.8	33.9	35
26.7	26.7	26.7	27.2	27.2	27.8	27.8	28.3	28.9	28.9	29.4	30	30	30.6

Exposure and/or Physical Activity

Extreme Danger
Heat stroke or Sunstroke extremely Likely
Danger
Sunstroke, muscle cramps, and/or heat exhaustion likely
Extreme Caution
Sunstroke, muscle cramps and/or heat exhaustion possible
Caution
Fatigue possible

FIGURE 5. N. W. S. HEAT INDEX CHART

5 EVALUATING EFFECTS OF NETT HEAT LOAD

5.1 Preamble

The aim of this work was to assess the heat risk effect of the projected 2070 environment, on persons engaged in any one of a number of activities, with any one of up to three clothing regimes, either in the shade, indoors, or in the sun. Whether acclimated or unacclimated in the seven nominated Australian cities.

Firstly this required the ability to evaluate the heat load (arising from metabolic processes, and solar radiation - if so exposed - and environmental warming should ambient conditions be such that they have a warming rather than a cooling effect) that a person would need to shed in order to maintain a stable core body temperature, and an adequate degree of hydration.

Secondly it required the ability to determine if the cooling power of the air over the period of exposure is adequate for safety (i.e. allows for sufficient heat loss) and if not, how long before such exposure would result in harm to the subject due to increasing core body temperature or dehydration or a combination of both factors.

Thirdly it required the ability to estimate the probable environmental conditions indoors which could be reasonably expected from ambient outdoors conditions and to assess their effect. Since on days of extreme conditions it can be expected most people would take shelter indoors.

5.2 Assessment of Heat Load

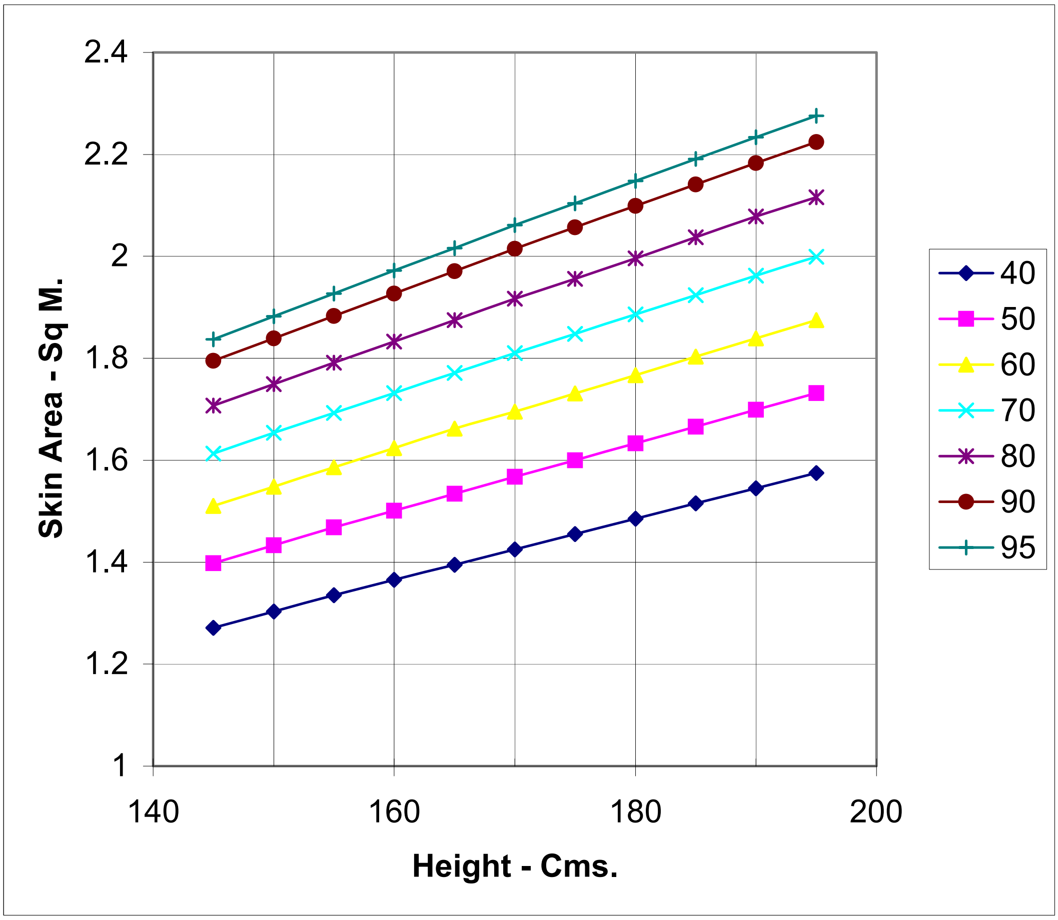
As discussed above the heat load that a person accrues arises from the normal heat generated by resting metabolic processes, plus that produced as a result of any activity being undertaken plus that gained from the external environment. Heat gained from the local environment includes net radiant heat gains from walls and other objects where they are at a higher temperature than the person, together with heat from the atmosphere when the ambient temperature is greater than skin temperature. In this paper we use Kata Cooling Powers to account for heat transfers between persons and the immediate environment. We will only assess heat load due to metabolic processes plus solar radiation where subjects are so exposed.

Calculation of heat fluxes using Kata Cooling Powers requires knowledge of body surface area. Human surface area was calculated from Mass and Height using a formula derived by Du Bois[17] (Eqn 8; Fig 6).

$$S = 0.007184 \times W^{0.425} \times H^{0.725} \qquad (8)$$

S = Skin area (m^2). W = Mass (kg.) H = Height (cms)

FIGURE 6. SKIN AREA VS HEIGHT AND MASS



Total Metabolic heat production was calculated for individuals of different body Mass and Height using Fig 6 in conjunction with Table 3.

In using table 3 to obtain a value to apply in figure 7, a decision had to be made whether to adopt a value of 80%[10] or 90%[7] of the total metabolic heat generated for the amount of heat that must be lost. The human body is an inefficient heat engine only ten to twenty percent of the energy generated in metabolic processes during any activity is used gainfully the balance must be dissipated as waste heat. The United States Navy use's a value for this waste heat of 80%, and this has been used in preparing appendix 1.

When exposed to direct solar radiation an additional heat load must be added.

For subjects lying prone or supine, as they would be if they had fainted (as often happens during the early onset of heat stress) a value for solar heat load is obtained from Fig 1. In this position the solar heat load is maximised and Tc increases rapidly.

Appendix 2 lists estimated solar heat loads accruing to nine standing individuals with skin areas ranging from 1.49 m^2 to 2.32 m^2, in each of the seven cities. The tables have been calculated for four different environmental albedos. The albedo for human skin and clothing was assumed to be 0.42, for Caucasians.

As a matter of interest, figure 8 derived from Costill [25] gives estimated energy expenditure for a group of athletes' average height 177.3 cm, weight 63.0 Kg and skin area approximately 1.78 m^2 for various running speeds. This could be used for approximating heat loads for persons so engaged.

FIGURE 7. TOTAL HOURLY HEAT PRODUCTION VS HEAT PRODUCTION RATES AND SKIN AREAS

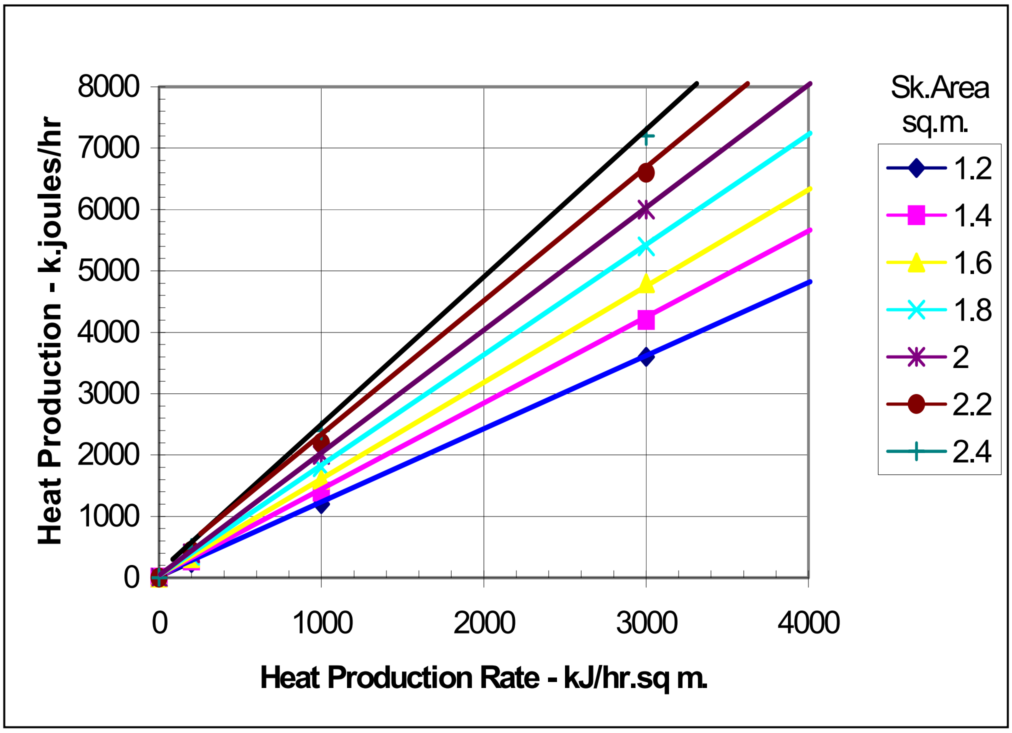
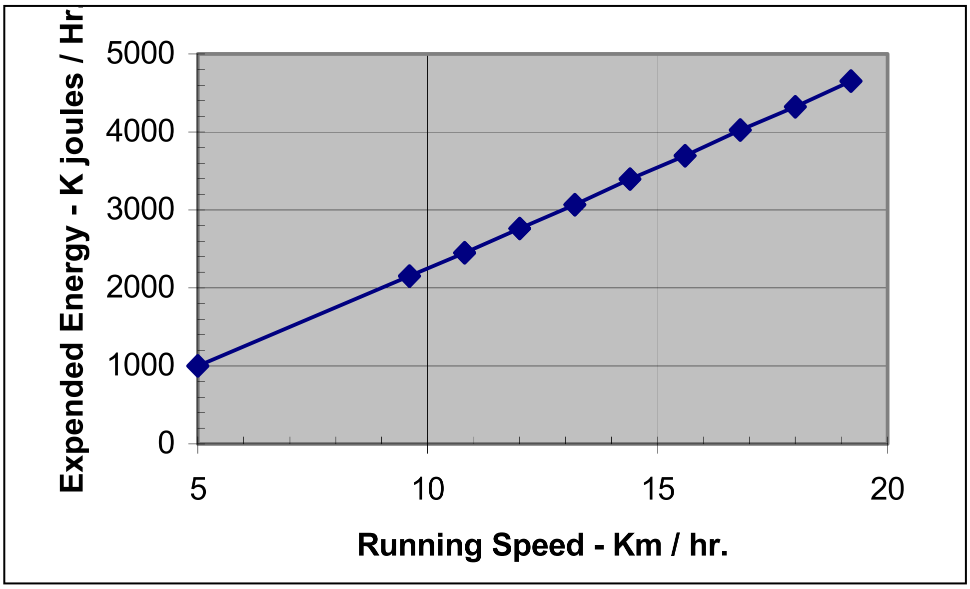


FIGURE 8. ESTIMATED ENERGY VS RUNNING SPEED (AFTER COSTILL)



6 HEAT TRANSFERENCE TO THE ENVIRONMENT

6.1 General

Heat transfer from a person to the environment involves the processes of convection, conduction, radiation, and sweat evaporation as detailed above. These processes can only operate to maximum effect where people are completely unclothed. Where people are fully or partially covered by clothing heat exchange is hindered [10] and environmental cooling processes must be increased to cover these inefficiencies. For a fully clothed individual (long trousers and long sleeved shirt) Virtual Naval Hospital[10]give a value of 30% for this inefficiency, this has been adopted here together with a value of 20% (arbitrarily chosen) for a partially clothed person (shorts and shirt). In this work this inefficiency has been compensated for by increasing the heat that clothed and semi clothed persons have to dissipate to the environment in order to maintain a stable Tc, by amounts of 30% and 20% rather than adjusting the environments cooling or warming power.

Appendix 1 gives the heat loads that must be dissipated by 9 individuals of various masses and heights engaged in the activities listed at Table 3, in the naked semi clothed and fully clothed condition, in order to maintain stable core body temperature (Tc).

In estimating heat loads due to solar radiation on **standing persons**, Terjung and Louie [13] appear to make no allowance for this effect, and adopted an albedo for man of 0.42. Appendix 2 follows this practice.

The sweat rate of individuals cannot be converted directly to net heat loss because in many cases all sweat is not evaporated. Limits to work in the heat for women and men were studied by Kamon etal [21,22] and psychrometric limits and critical evaporative conditions for men and women by Kenney etal [23] . Data from this work was used to derive Appendix 3 which can be used to obtain values of evaporated sweat for ambient temperatures up to 52° C and for core body temperatures of approximately 38° C. The observed evaporated sweat rates occurred even though the evaporative power of the environment was greater than that needed to evaporate all sweat produced. In many cases, reported total sweat rates were greater than the evaporated rates by up to 51%. In other words sweat was being produced faster than it could be evaporated; which means that any increases in sweat rate that may arise due to subsequent increases in core body temperature would not have caused an increase in the evaporative cooling effect but will contribute to dehydration.

Kamon et al [21,22] define the critical point in any environment / activity continuum, as that at which the bodies' temperature regulation mechanism can no longer maintain a stable value. They measured core body and skin temperatures for men and women through a wide range of ambient conditions and found the following average values at the critical point.

Women Tc = 37.9°C. Tsk = 36.1°C. Temp. Drive = 1.8°C.

Men Tc =37.9°C. Tsk = 36.2°C. Temp. Drive = 1.7°C.

Temperature drive is the term given for the difference between core body and skin temperatures. It is the temperature gradient that drives heat transfer within the body from its core to its periphery via the processes of passive conduction and convection.

7 ASSESSMENT OF ENVIRONMENTAL EFFECTS

In order to assess the effect of a set of environmental conditions on an individual of known sex, height and weight, engaged in any of the activities listed at Table 3, the following procedure was applied.

1. For a body temperature at the critical point and for the given ambient temperature a maximum evaporative sweat rate was obtained from appendix 3, having regard to gender, and degree of acclimatisation.

   The subjects skin area was obtained from Fig 6 and used to calculate the total evaporated sweat rate (g/hr).

2. From the calculation of the evaporated sweat, the heat loss equivalent was calculated using a specific heat of 2.4 kJ/g.
3. Total heat production was determined using table 3.This was adjusted for clothing status and if applicable solar radiation load, obtained with reference to Appendix 2, was added to give the effective heat dissipation requirement.
4. The effective heat dissipation requirement was converted into Kata Cooling Powers using Figure 9.
5. WKCP and DKCP's for the environmental conditions were calculated.
6. Tsk., of 36°C was adopted regardless of sex.

7.1 Criteria

For each three-hour period of each day in the climate record, the likelihood of heat related pathology was assessed as follows:

A. If ambient temperature is less than or equal to Tsk, (36 °C) and the environmental WKCP is great enough to remove the effective heat load the subject is in no danger of heat stress.

B. If WKCP is less than the effective heat load, assess the heat gain and calculate time to reach critical body core temperature for likely onset of heat stroke, using Figure 12b.

   Compare this time with likely length of time that critical environmental conditions are likely to continue, to assess seriousness of the situation.

C. If ambient temperature is equal to or greater than Tsk (36°C), the subjects entire heat load must be dissipated by the evaporative process. Also any environmental warming component must also be overcome by evaporation of sweat. When this occurs the procedure at D should be adopted in addition to procedure B.

D. Subtract the value of the subjects total heat load from the evaporative heat loss determined at 2 above. This will be positive if the evaporative heat loss is greater than the subjects heat load, convert this value to KCP's and add the value of the DKCP for the environment as calculated at 5 above to the subjects remaining heat load. If the combined value is positive there is no danger of heat stress. However, should it be negative the subject is increasing their store of heat with time and the procedure described at B above is adopted to calculate time to reach a critical core body temperature.

8 ASSESSING BODILY RESPONSE

Figure 9 allows a subjects rate of heat transference to or from the environment to be determined given their skin area and the Kata Cooling/ Warming Power of the air.

Figure 10 is a plot of human body specific heat against body weight, and has been obtained using a value of 3.5 kJ / kg of body mass [9,53,54] for the human body.

Figure 11 shows the amount of heat required to raise a subject's body from 36.8°C to 40,42,and 44°C respectively, knowing their body mass.

Once a subject's rate of heat storage has been determined and the amount of heat required to increase their temperature from normal core body temperature to any given dangerous level is assessed using Figure 11, the time of exposure required to reach that temperature can be readily calculated.

Figures12A, B, and C, may be used to obtain time required to increase a subjects core body temperature from 36.8°C to 40,42, or 44°C, if their rate of heat storage and body mass is known.

FIGURE 9. HEAT TRANSFERENCE VS KATA COOLING/WARMING POWER AND SKIN AREA

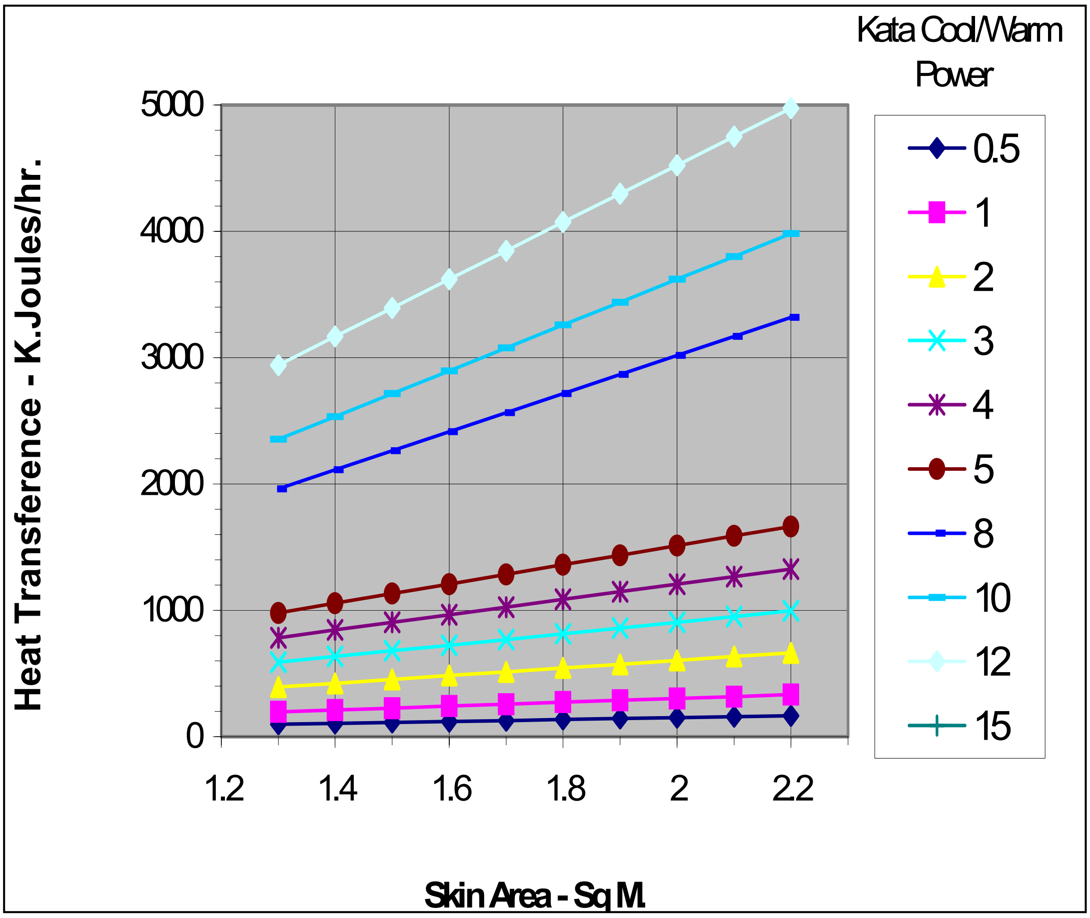


FIGURE 10. SPECIFIC HEAT OF HUMAN BODY VS. BODY MASS

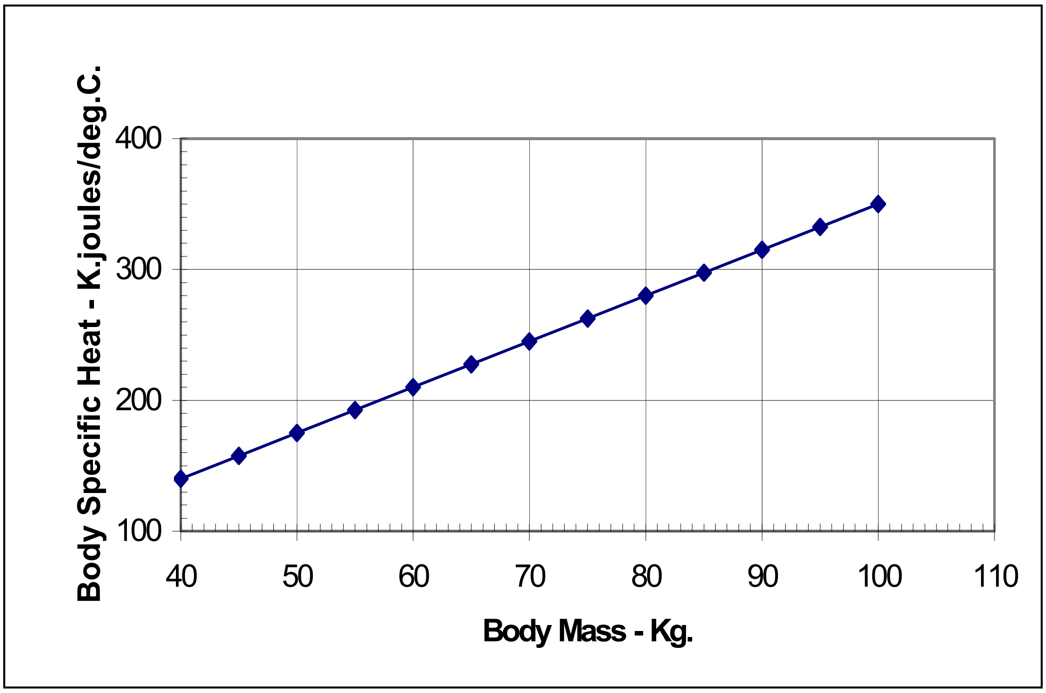


FIGURE 11. HEAT TO RAISE TC FROM 36.8 TO 40, 42, AND 44 DEG C VS. BODY MASS

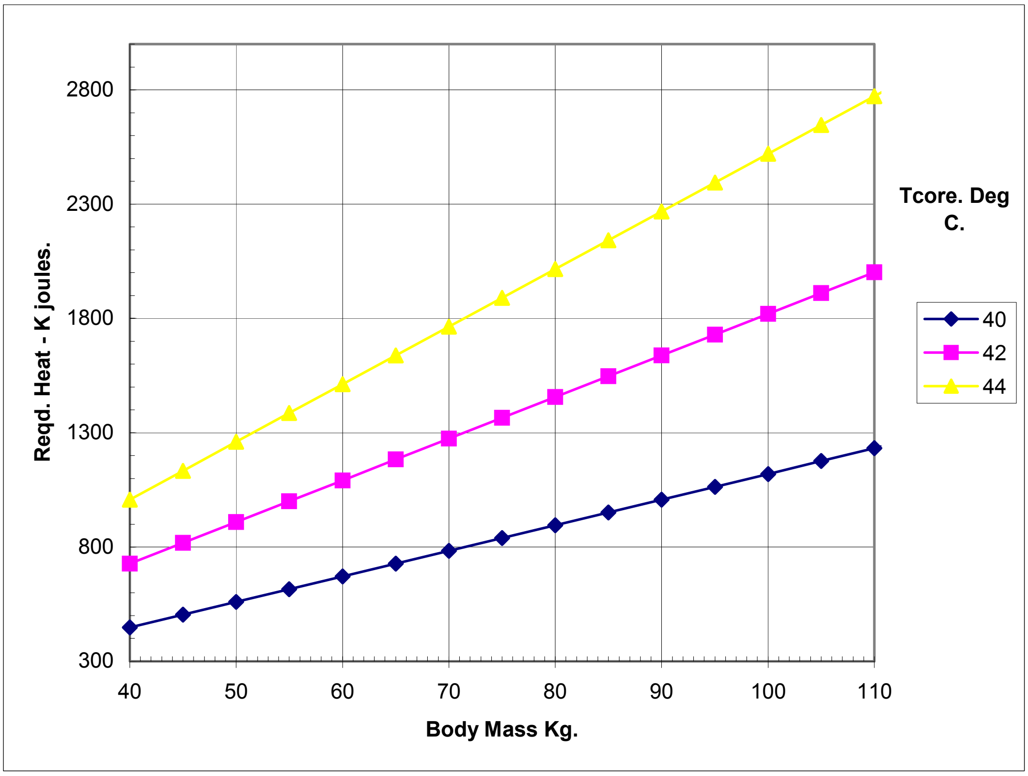


FIGURE 12A. TIME FOR TC TO REACH 40 DEG.C. VS. RATE OF HEAT STORAGE AND BODY MASS

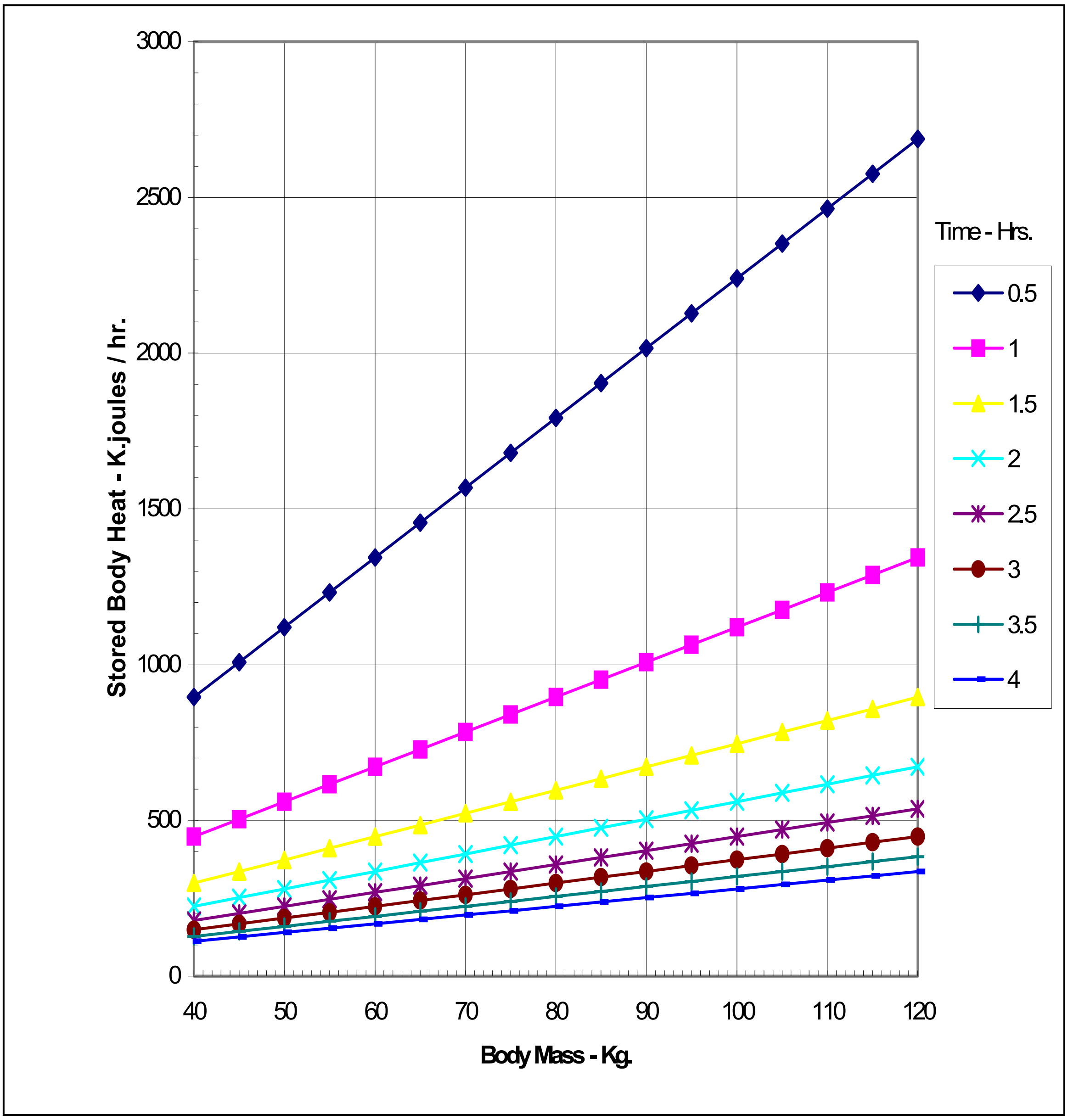


FIGURE 12B. TIME FOR TC. TO REACH 42 DEG. C. VS RATE OF HEAT STORAGE AND BODY MASS

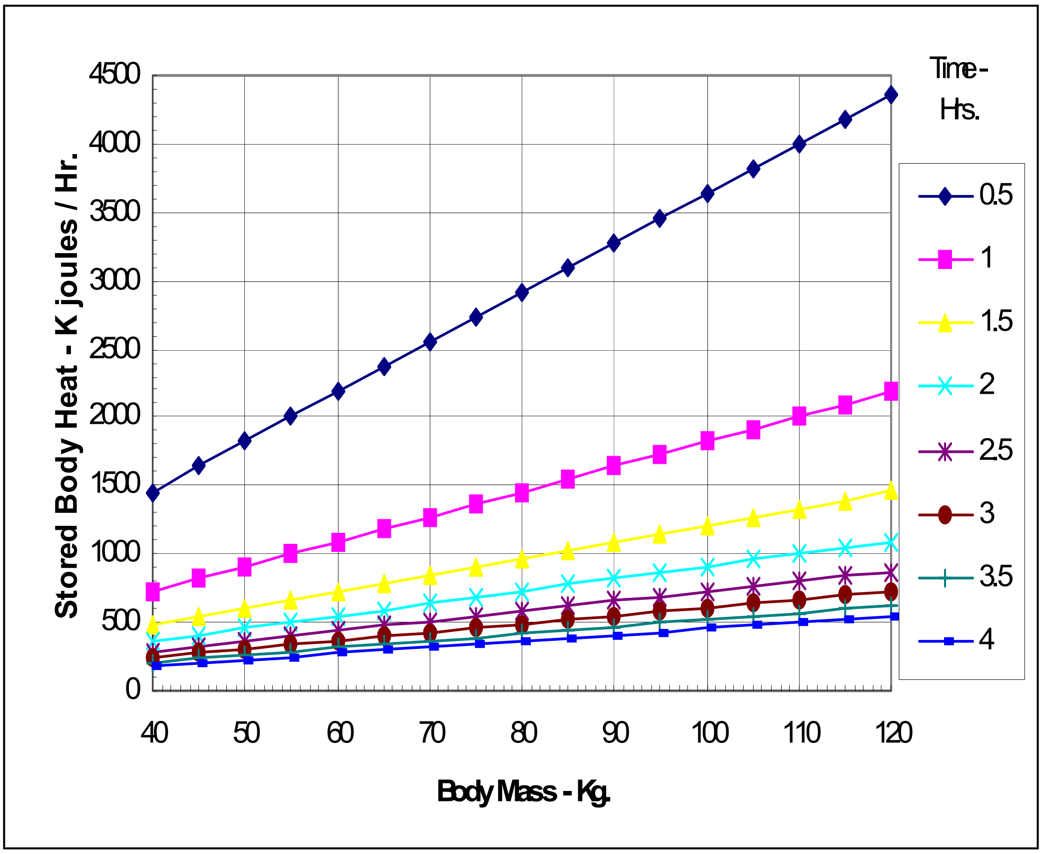
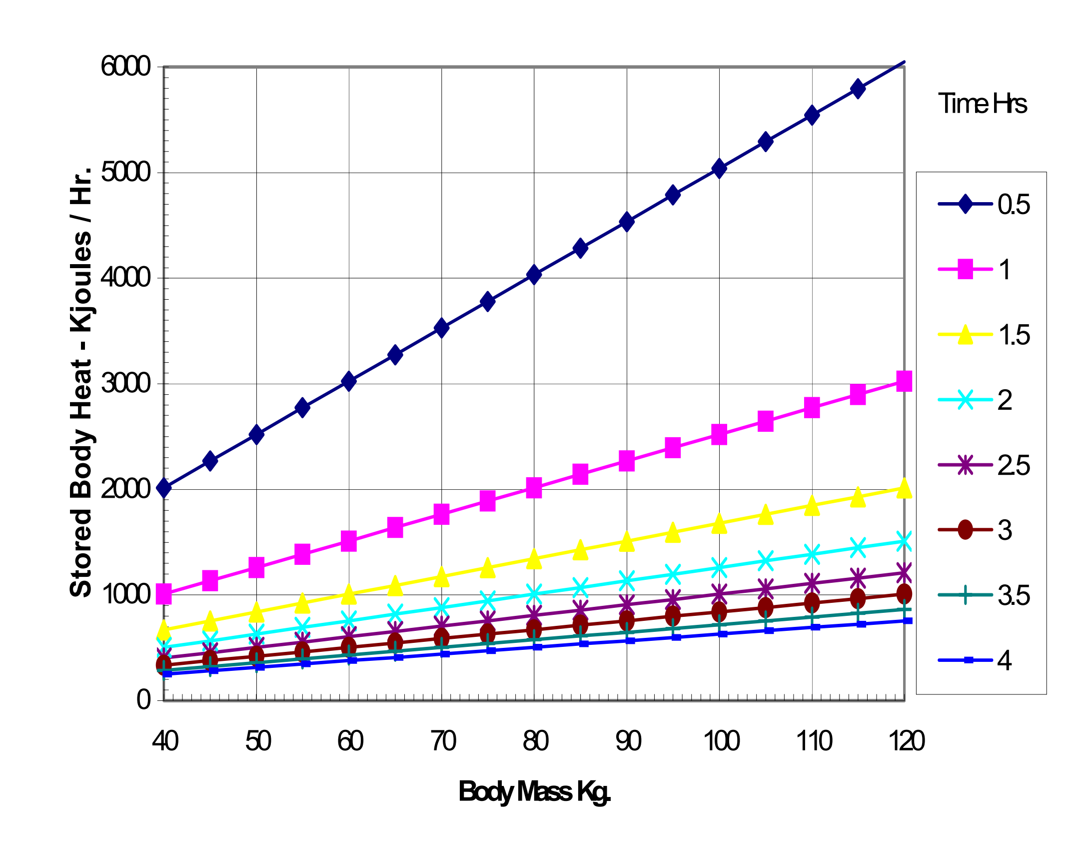


FIGURE 12C. TIME FOR TC TO REACH 44. DEG C VS. RATE OF HEAT STORAGE AND BODY MASS

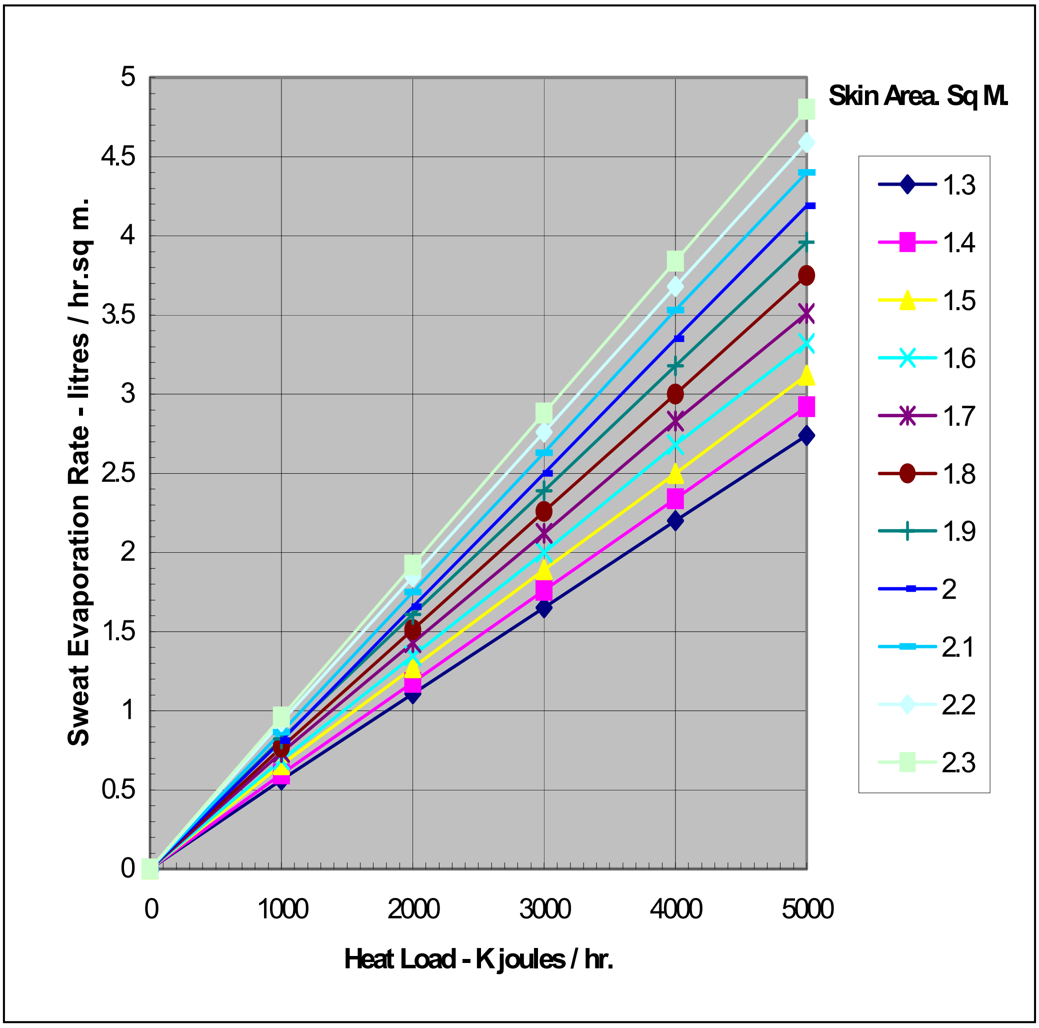


9 DEHYDRATION RATE

Figure 13 may be used to obtain the required rate of sweat evaporation to maintain a subject at a steady core body temperature, knowing their total heat load /m^2 and skin area.

Obviously the sweat evaporation rate does not always equal the total sweat rate, since in fully acclimated individuals where excessive sweat runs off the body or is taken up in wetting clothing, some sweat is not evaporated and is of little value in cooling the body. Of course especially in unacclimated individuals their total sweat rate can be less than required.

FIGURE 13. SWEAT EVAPORATION RATE TO MAINTAIN CONSTANT TC. VS HEAT LOAD AND SKIN AREA



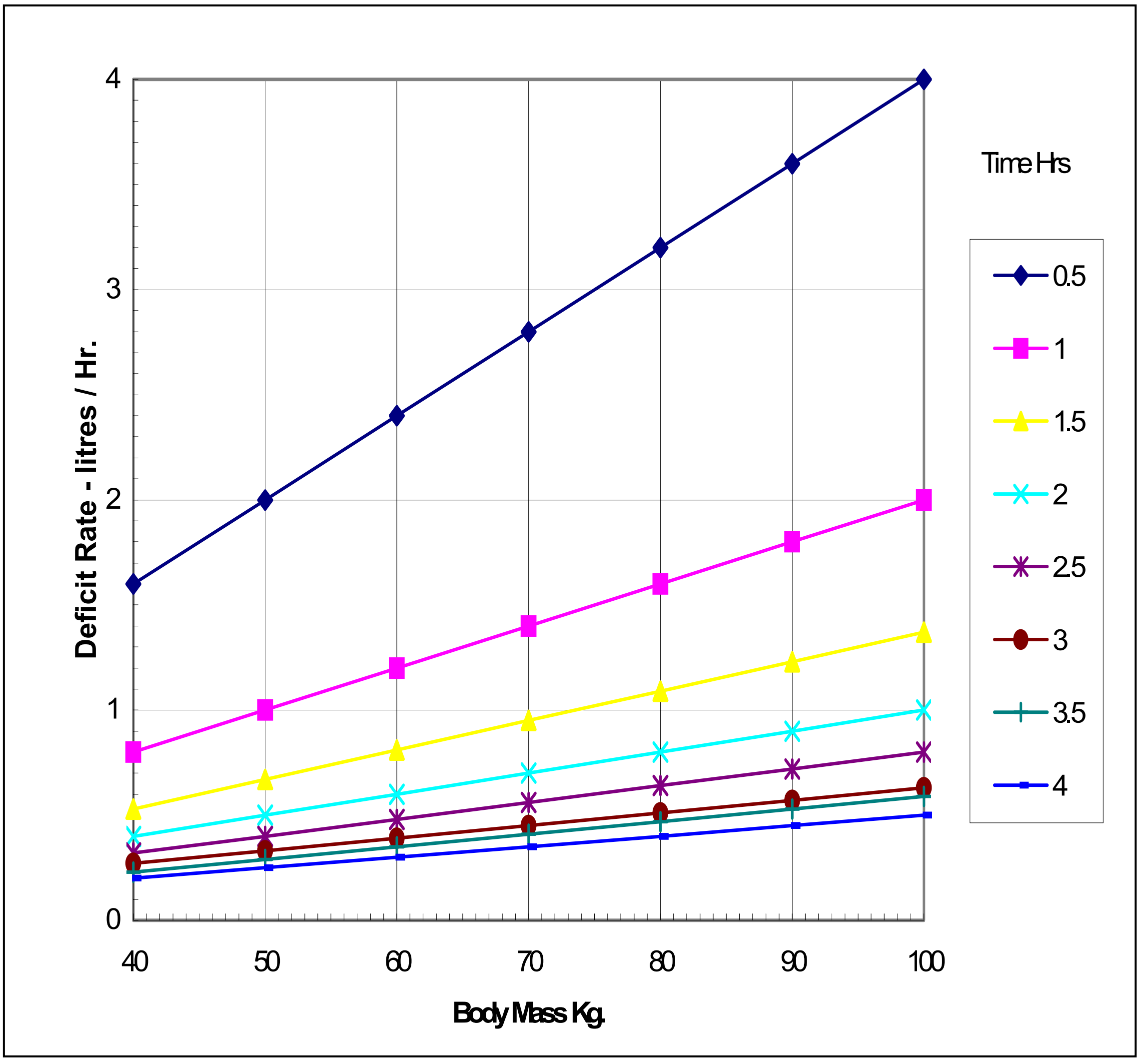
Knowing the probable sweat rate of a subject by using the information given at Appendix 3 and his body mass, the time taken to reach a body water content deficit of 2% may be obtained from Figure 14.

Where the subject attempts to maintain water balance, by drinking adequate amounts of water, net moisture loss/gain can be estimated by subtracting the subject's actual water absorption – gastric emptying - rate (see section on sensible sweat above) from their sweat rate, and the nett rate used to enter Figure 14.

Values for the time to reach a body water content loss other than for 2%, as a percent of body mass, can be readily estimated by multiplying the value obtained from Figure 14 by the appropriate ratio.

The physiologic effects of such body water losses are described in the section on Minor and Major Dehydration above.

FIGURE 14. TIME TO REACH MOISTURE DEFICIT OF 2% OF BODY MASS VS BODY MASS AND SWEAT RATE



10 EFFECT OF THE BUILT ENVIRONMENT

During heat waves many people will take shelter indoors, it is therefore important to be able to predict what conditions will be indoors at such times. Data from many studies, both published and unpublished have been used to gain an appreciation of the likely response of some typical housing types.

Ballinger, Prasad and Rudder [55] report on a study conducted on some typical Australian housing designs where temperatures were measured at regular intervals over a three-year period. Table 18 derived from [55] lists the range of temperatures found in four houses as a result of various ambient temperatures.

TABLE 18. MEASURED TEMPERATURE RESPONSE VARIOUS HOUSE DESIGNS

(a) Timber Floor over crawl space. 4ins glass fibre over ceiling. Clad fibro cement

Max.Ambient Temp. deg.C.	Max. Indoor Temp Range deg.C
30	27-33
35	32-37
40	38-42

(b) Standard brick veneer construction. Timber floor and ceiling insulation as above.

Max.Ambient Temp. deg.C.	Max. Indoor Temp Range deg.C
30	26-32
35	31-35
40	36-38

(c) Timber frame plasterboard lining. Cladding compressed wood fibre re planking laid over double sided reflective foil.Ceiling insulation as above. Slab on ground.

Max.Ambient Temp. deg.C.	Max. Indoor Temp Range deg.C
30	25-30
35	27-32
40	32.5-35

(d) Double brick with wall cavity insulation. Ceiling insulation as above. Slab on ground, Traditional passive solar house.

Max.Ambient Temp. deg.C.	Max. Indoor Temp Range deg.C
30	29-30
35	26.5-31
40	28-32

Data either measured or modelled for houses of double brick construction with timber floors were not available for this study; this was unfortunate since a very large number of houses with this form of construction exist in the older suburbs of all major Australian cities. Here it is assumed their thermal response will lie midway between the upper and lower values of those of the house at (b) in table 18.

The data of table 18 (c)-(d), clearly shows the benefit of concrete floor, slab on ground construction in reducing maximum indoors temperature.

Walsh, Gurr and Ballantyne, in a 1982 paper[56] gave details of modelling studies of thermal response, of lightweight (brick veneer with timber frame and floor) and heavyweight (double brick cavity wall with single brick internal walls and concrete slab on ground floor) housing. The modelling study covered both winter and summer conditions, for Alice Springs, Brisbane, Darwin, Melbourne, Perth, Wagga (Canberra) and Williamstown (indicative of Sydney conditions). Here we are only interested in summer effects. Table19 lists the number of hours per year when indoors temperatures can be expected to exceed 30°C.

TABLE 19. MODELLED TEMPERATURE RESPONSE LIGHT AND HEAVYWEIGHT HOUSE CONSTRUCTION

City	Waking Hours With Temp. Above 30 deg.C.					
	% Ambient		% Indoors Heavyweight		% Indoors Lightweight	
Williamtown (Sydney)	2.5	136	0.9	49	4.9	268
Melbourne	2	109	0.4	22	3.1	170
Perth	5.8	318	4.7	257	10.7	586
Brisbane	1.4	77	1.5	82	8.7	476
Wagga (Canberra)	3	164	1.8	99	8.7	477

Waking hours average 15 per day.1% = 54.8 hours/year

Tables 20, 21 and 22 list measured temperature responses for three houses in the Perth region.

Table 20, gives maximum and minimum temperatures both ambient and indoor for the period December 30th 1994 to January 31st 1995. This is a well-managed passive solar house belonging to Professor and Mrs Catchpole in the Perth W.A. Hills District. Construction is of double brick with concrete slab on ground. Data abstracted from Professor Catchpole's unpublished records.

Table 21, gives maximum indoors temperatures resulting from official maximum Perth temperature for a week in February 1976 for a double brick concrete slab on ground house in Rossmoyne a Perth suburb. This data is abstracted from fig.18, from Jenkins and James [57].

Table 22, is for hot periods during the 2001-2002 summer for a house in the Perth suburb of Coogee. The data, measured by the author, comprises the highest measured temperatures downstairs and upstairs and in the shade outdoors. The house is of double brick slab on ground downstairs, with a brick veneer upstairs, which has a compressed wood floor. Upstairs there is a reverse cycle air conditioner, which was used sparingly as indicated in Table 22.

These data will be used as a guide when assessing the conditions people will experience when sheltering in their houses from the extreme temperatures predicted post 2070. It will be further assumed that the predicted increases in temperature will result in equivalent increases in indoors temperatures as suggested by Albrecht Stocklein of BRANZ's[58] (personal communication).

TABLE 20. TEMPERATURE RESPONSE FOR A PASSIVE SOLAR HOUSE LOCATION PERTH HILLS

Date 1994dec	Temp Mx.degC Outdoors	Temp.Mx.degC Indoors	Temp.Min.degC Outdoors	Temp.Min.degC Indoors	Diff. Mx deg.C.	Diff.Min. deg.C.
30	40.5	27	20.4	21.5	13.5	1.1
31	39	28.4	23.5	25	10.6	1.5
1995jan 1	36.2	27	18.6	22.6	9.2	4
2	35.7	27.5	19.1	22.6	8.2	3.5
3	35.7	27.5	20.5	23.1	8.2	2.6
4	29.6	25.1	18.6	21.5	4.5	2.9
5	27.5	23.5	12.4	18.6	4	6.2
6	33.2	25.1	15.5	19.5	8.1	4
7	36.2	26.6	20	22.6	9.6	2.6
8	29.7	26.6	20.5	23.6	3.1	3.1
9	27.5	23.6	16	21	3.9	5
10	30.3	24.1	16	20	6.2	4
11	36.3	26	17.5	21.1	10.3	3.6
12	39.5	28	21	23.2	11.5	2.2
13	30.7	26.1	18.7	22.1	4.6	3.4
14	34.3	26.1	18	21.5	8.2	3.5
15	36.2	27.6	20	23.1	8.6	3.1
16	39	29.1	24.1	26.1	9.9	2
17	38.2	29.2	22.6	25.2	9	2.6
18	39	30.2	22.6	25.1	8.8	2.5
19	34.7	28.6	20.5	24.2	6.1	3.7
20	31.1	24.6	16.5	20	6.5	3.5
21	36.2	26.1	16.6	19.5	10.1	2.9
22	31.7	26.2	18	21.6	5.5	3.6
23	23.5	23.1	15.6	20.5	0.4	4.9
24	28.2	23.6	16.5	20	4.6	3.5
25	31.2	25.1	17.5	21	6.1	3.5
26	34.7	25.5	17	20.5	9.2	3.5
27	34.7	27.1	22.2	24.2	7.6	2
28	26.1	25.1	19.5	22.7	1	3.2
29	24.5	23.7	13.4	20	0.8	6.6
30	32.3	23.5	12.9	19.1	8.8	6.2
31	32.8	25.2	16	20.6	7.6	4.6

TABLE 21. PERTH HOUSE DATA (COMPILED FROM FIG. 18[57])

Date	Official Shade Temp.deg.C.	Indoor Temp deg.C.	Lag Time hours.	Attenuation deg.C
16/02/76	**31.25**	**28.2**	**5**	**3**
17/02/76	**30**	**26.2**	**2.5**	**3.8**
18/02/76	**29**	**24.6**	**6.4**	**4.5**
19/02/76	**32**	**26.8**	**3.7**	**5.2**
20/02/76	**33.7**	**27.5**	**5**	**6.2**
21/02/76	**33.6**	**28.8**	**2.5**	**4.8**
22/02/76	**39**	**31**	**2.6**	**8**
Average Lag Time = 4 hrs. Average Attenuation = 5 deg C.				

TABLE 22. HOUSE RESPONSE – HOT PERIODS SUMMER 2001-2002

Perd.	Date	TempMx. Outdoors deg.C.	Temp.Max.Indoors dn.stairs deg.C	Temp.Max.Indoors up stairs deg.C	Time With Temp. above28dC. Dn. Stairs Hrs.	Dn. Stairs Mins.	Up Stairs Hrs.	Up Stairs Min.	Remarks
	11.11.01	31.3	25.7	27.2	0	0	0	0	
	12.11.01	34.9	26.7	29.7	0	0	2	53	
1	13.11.01	30.9	27	26.6	0	0	0	0	A/cn.1500
	14.11.01	29.5	27.1	28.1	0	0			
	8.12.01	24.7	24.2	26.8	0	0	0	0	
	9.12.01	30.7	25.4	26.8	0	0	0	0	
	10.12.01	30.5	25	26.3	0	0	0	0	
	11.12.01	30.8	27.1	29.1	0	0	1	54	
2	12.12.01	30.7	27	28	0	0	1	21	
	13.12.01	28.7	25.9	27.2	0	0	0	0	
	14.12.01	32.3	26.3	27.8	0	0	0	0	
	15.12.01	31.1	27.4	29	0	0	3	47	
	16.12.01	28.6	25.9	26	0	0	0	0	
	13.01.02	34.6	28	29.9			7	35	
3	14.01.02	36.7	28.3	30.8	1	31	5	07	A/cn.1940
	15.01.02	34.5	28.4	29.8	1	08	6	02	A/cn.1540
	16.01.02	37	28.8	30.8	1	51	1	08	A/cn.1423
	2.02.02	30.9	27.4	27	0	0	0	0	
	3.02.02	35	29	30.6	9	32	6	07	
	4.02.02	34	29.7	30.2	7	43	7	43	
	5.02.02	33.3	30	29.7	7	31	1	49	A/cn.1445
4	6.02.02	38.5	31	34.1	10	50	8	12	A/cn.1805
	7.02.02	33.2	28.9	30	8	48	5	23	A/cn.1858
	8.02.02	34.4	28.7	29.1	5	48	0	57	A/cn.1331
	9.02.02	36.4	29	31.5	5	47	6	58	A/cn.1955
	10.02.02	35	31	32.1	7	19	6	0	A/cn.1645
	11.02.02	34.7	31	31.8	0	39			A/cn.1430
	22.02.02	34.5	28.7	29.1	2	49	4	56	
5	23.02.02	35.5	30	32.8	5	39	8	29	
	24.02.02	33.8	28.7	30.6	9	36	10	55	
	27.02.02	31	27.8	29.3	0	0			
	28.02.02	33.5	29.1	29.1	7	05	4	0	
6	1.03.02	32.9	28.5	28.6	2	45	2	45	
	2.03.02	33.8	28.3	29.8	0	40	5	39	A/cn.2100
	3.03.02	31.4	28.3	28.5	2	01	2	01	
	4.03.02	27.4	26.2	25.2	0	0	0	0	

10.1 Humidity Change

The reduction in temperature observed in some house types can produce quite marked increases in indoors relative humidity. In addition to humidity increase due to change in temperature there will be increases due to human and animal respiration, indoor plant transpiration and evaporation from free water surfaces. Another possible source of increased humidity would be evaporative air coolers where they are used.

Such increases in humidity would to some extent offset the ameliorative effect of the reduction to ambient temperature achieved by certain types of housing construction.

Increases in indoors relative humidity due to such temperature reductions are readily evaluated; assuming no change in barometric pressure between indoors and outdoors; using the following expressions.

$$RH_2 = Vp / Vp_{(2)}s \times 100 \qquad 9.$$

Where

RH_2 = Indoors relative humidity - %.

Vp = Water vapour pressure – mm Hg.

$Vp_{(2)}s$ = Saturation water vapour pressure at T_2 - mm Hg.

T_2 = Indoors temperature - °C.

And

$$Vp = (RH_1 \times Vp_{(1)}s) / 100. \qquad 10.$$

RH_1 = Relative humidity at T_1 - %.

$Vp_{(1)}s$ = Saturation water vapour pressure at T_1 – mm Hg.

T_1 = Outdoors temperature - °C.

As an example, take a day when the outdoor temperature was 38°C and relative humidity was 51%. Assuming indoor temperature in a double brick slab on ground house is 32°C. From published tables the saturated water vapour pressures at 38°C and 32°C are found to be 50.2 mm Hg and 36.1 mm Hg respectively. The indoor relative humidity is then calculated to be 71%, and with presence of several humans and indoor plants it can be expected to be even higher, hence the WKCP may be less indoors than outside which will increase the difficulty of maintaining a stable core body temperature.

As a further example Table 23 lists the results of a series of measurements taken at the Coogee house on the 4th of April 2002.

TABLE 23. REL. HUMIDY COMPARISON INSIDE VS. OUTSIDE

Time	Wet Bulb Deg.C.	Dry Bulb Deg.C.	Rel.Humid %	Diff.in R.H Out/in. %	Check D.B. Temp.degC	Remarks
1331	14	22.6	36.5		22.5	Inside
1337	14.4	24.1	33	3.5	24.7	Outside
1345	14.4	24.8	31		25	Outside

TABLE 23. REL. HUMIDY COMPARISON INSIDE VS. OUTSIDE

Time	Wet Bulb Deg.C.	Dry Bulb Deg.C.	Rel.Humid %	Diff.in R.H Out/in. %	Check D.B. Temp.degC	Remarks
1436	14.1	22.6	36.5	5.5	22.6	Inside
1445	14.4	25	30		25.5	Outside
1546	14.1	22.9	37	7	22.9	Inside
1557	14.1	24.1	31	6	25.1	Outside
1651	14.6	23.2	38	7	23.1	Inside
1701	13.8	23.8	31	7	24	Outside

Calculation, using the above expressions, indicates a rise of only 2.5 % in relative humidity resulting from the difference in indoors and outdoors temperature, for times 1546/1557. This compares with the measured difference of 6 %; the difference of 3.5%, in this case can only be due to processes of respiration, transpiration and evaporation within the house, where limited ventilation has allowed the atmosphere in the house to reach a different 'equilibrium' condition from the external air.

Wind speed is an important factor in determining the cooling or warming power of the air. Air speed inside houses usually bears little relationship to that obtaining outdoors. If windows and doors are shut in order to keep the heat out or if mechanical ventilation is absent or inadequate as in the homes of the poor, or when there are power outages, which often occur on extreme days, air speed inside can approach zero. Outdoors in the city and suburbs, airspeed can vary considerably from that recorded at official weather stations due to tree plantings, height of buildings and the orientation of streets in relation to that of wind direction. These factors cause actual airspeeds at individual locations to have values much below or in some cases above that of the recorded values. The effect of any such reduction in wind speed can be seen in appendices 4-35, which give results of physiological effects on the persons studied for ambient wind speeds and wind speeds of 0.5 kmh.

10.2 Urban Heat Island Effect

Official weather stations at Sydney and Melbourne are reasonably close to their respective CBD's, however, Perth's weather station is located some distance from its CBD. It was thought therefore that because of a possible heat island effect its record might not have been truly representative of conditions in the city proper. However, study of Morris and Simmonds work [59] for Melbourne and comparison of records from the Sydney regional office and Sydney airport suggest that daytime heat island effects are negligible and Perth's office record may be taken as representative of CBD conditions. Obviously results from a single weather station can only be indicative of conditions near the locations studied. To assess conditions over an entire city, data from an adequate number of sampling points are required.

In every city there is the possibility of heat traps where, because of exposure to direct and reflected radiation and shelter from wind, areas can exist where the temperature can be up to three or more °C higher than in adjacent parts of the city[60]. City people should be aware of this and avoid such obvious danger areas.

11 2070 CONDITIONS – ASSESSMENT OF EFFECTS

Using the data and methods described above it is possible to determine the effect of any given environmental conditions on either acclimated or unacclimated people performing the activities and clothed in the manners described.

The assessment was used to demonstrate the effect of the weather of each year1990-2001 inclusive (each years record being adjusted to the projected 2070 conditions) on a man and a woman, each being 178 cms tall, each weighing 70 kg, with skin areas 1.87 sq m, assuming that they were firstly in the unacclimated and secondly in the fully acclimated condition.

Data set 2 of table 17 were used to create the synthetic data set; temperatures were adjusted for 2070 conditions by adding 5.2°C to each value for Melbourne and 6°C to each value for all other cities. All other parameters were adopted as measured. Only diurnal data (0900h – 1700h) were used in the assessments reported here.

In order to evaluate the effect on people indoors the above data was further adjusted as set out below. As indicated previously these adjustments were only made to **diurnal data**, **nocturnal** data was **not used,** this means that for Port Hedland, Townsville and possibly, Sydney, Perth, Liverpool and Alice Springs, the results especially those for indoors may be an under estimate and therefore not conservative. It is anticipated that results will be updated to include nighttime data in a future study.

11.1 Evaluation Criteria:-

11.1.1 Evaporated Sweat Rate – Heat Loss Equivalents

Evaporated Sweat Rate –	Acclimated men	= 897.6 g/hr. (8g/min.sq.m)
	Acclimated women	= 841.5 g/hr. (7.5g/min.sq.m.)
	Unacclimated men	= 628.3 g/hr. (5.6g/min.sq.m.)
	Unacclimated women	= 482.5 g/hr (4.3g/min.sq.m.).

These rates were adopted from appendix 3, for an assumed ambient temperature of 44°C and skin areas of 1.87 sq m.

Using 2.4Kj/g for the latent heat of evaporation of sweat these values convert to –

Heat Loss Equivalents of –	Acc men	= 2154.2kj/hr. = 14.3 Kcp
	Acc women	= 2019.6kj/hr. =13.4 Kcp.
	Unacc men	= 1507.9kj/hr. =10.0 Kcp.
	Unacc women	= 1157.9kj/hr. = 7.7 Kcp.
	(Kcp = Kata cooling power).	

11.1.2 Indoors Temperature

Indoors Temperature (projected) :-

Double Brick House Slab Floor T = T2070 (ambient) – 5.

Brick Veneer House Slab Floor T = T2070 (ambient) – 4.

Brick Veneer House Tmbr. Flr. T = T2070 (ambient) – 2.

Timber/Fibro House Tmbr. Flr. T = T2070 (ambient) + 2.

11.1.3 Indoors Relative Humidity

Indoors Relative Humidity (projected):-

Double Brick House Slab Floor RH = RH (ambient) × 1.3 + 4.

Brick Veneer House Slab Floor RH = RH (ambient) × 1.24 + 4.

Brick Veneer House Tmbr. Flr. RH = RH (ambient) × 1.11 + 4.

Timber/Fibro House Tmbr. Flr. RH = RH (ambient) × 0.9 +4.

11.1.4 Solar Heat Loads

Solar heat loading was added to the total personal heat load of subjects when appropriate by using the following method.

For temperatures ≤ 28°C, solar heat load was assumed to be zero.

For temperatures ≥ 36°C the full solar heat load was added.

For temperatures between 28° and 36° solar heat loads were added on a linear pro rata basis. It was assumed that the insulating effect of clothing would be cancelled by its effect on a subject's ability to shed heat.

Solar heat loadings were only applied during the time periods 0900 – 1500. Since applying solar loadings to data sets outside these hours was considered to be inappropriate as it would be unlikely that the lesser radiative effect would elevate temperatures experienced at these times to dangerous levels.

11.2 Required Heat Dissipation Capacity to Maintain Stable Core Temperature

Using table 3 and Appendix 2 for an albedo of 0.25 and making allowance for the insulating effect of clothing Table 24 was obtained. This shows the rate of cooling, expressed in both k.joules/hour and the equivalent Kata cooling powers, required for a subject; 178 cms tall, weighing 70 Kg and having skin area of 1.87 sq m, to maintain stable core body temperature when engaged in any of the six activities examined; in either the naked, semi or fully clothed state, either when in the shade or in **full sun** outdoors, or inside in any of the four house types considered.

TABLE 24. REQUIRED HEAT DISSIPATION CAPACITY TO MAINTAIN STABLE CORE BODY TEMPERATURE

Perth	Subject. Height – 178cms. Weight - 70kg. Skin area - 1.87 sq.m.					
	HEAT DISSIPATION REQUIREMENT. kJ. /hr.& Kata C.P.					
Location	In shade or indoors.			In full sun		
Clothed state	Naked	Semi.	Fully	Naked	Semi.	Fully
Activity (See table 3)	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.
C4	275 - 1.8	330 - 2.2	358 - 2.4	2200 - 14.6	2255 - 14.9	2283 - 15.1
A1	393 - 2.6	472 - 3.1	511 - 3.4	2219 - 14.7	2298 - 15.2	2337 - 15.5
B1	666 - 4.4	799 - 5.3	866 - 5.8	2492 - 16.5	2625 - 17.4	2692 - 17.8
B2	697 - 4.6	836 - 5.6	906 - 6.0	2523 - 16.7	2662 - 17.6	2732 - 18.1
C2	1492 - 9.9	1790 - 11.9	1940 - 12.9	3318 - 22.0	3616 - 24.0	3766 - 25.0
C5	877 - 5.8	1052 - 7.0	1140 - 7.6	2703 - 17.9	2878 - 19.1	2966 - 19.7

Sydney&	Subject. Height - 178cms. Weight - 70kg. Skin area - 1.87 Sq.m.					
Liverpool	HEAT DISSIPATION REQUIREMENT. kJ./hr.& Kata C.P.					
Location	In shade or indoors.			In full sun		
Clothed state	Naked	Semi.	Fully	Naked	Semi.	Fully
Activity (See table 3)	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.
C4	275 - 1.8	330 - 2.2	358 - 2.4	2200 - 14.6	2255 - 14.9	2283 - 15.1
A1	393 - 2.6	472 - 3.1	511 - 3.4	2231 - 14.8	2310 - 15.3	2349 - 15.6
B1	666 - 4.4	799 - 5.3	866 - 5.8	2504 - 16.6	2637 - 17.5	2704 - 17.9
B2	697 - 4.6	836 - 5.6	906 - 6.0	2535 - 16.8	2674 - 17.7	2744 - 18.2
C2	1492 - 9.9	1790 - 11.9	1940 - 12.9	3830 - 22.1	3628 - 24.1	3788 - 25.0
C5	877 - 5.8	1052 - 7.0	1140 - 7.6	2715 - 16.7	2890 - 19.2	2978 - 19.7

TABLE 24. REQUIRED HEAT DISSIPATION CAPACITY TO MAINTAIN STABLE CORE BODY TEMPERATURE CONT'D

Melbourne	**Subject. Height - 178cms. Weight - 70kg. Skin area - 1.87 Sq.m.**					
	HEAT DISSIPATION REQUIREMENT. kJ./hr.& Kata C.P.					
Location	**In shade or indoors.**			**In full sun**		
Clothed state	**Naked**	**Semi.**	**Fully**	**Naked**	**Semi.**	**Fully**
Activity (See table 3)	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**
C4	275 - 1.8	330 - 2.2	358 - 2.4	2200 - 14.6	2255 - 14.9	2283 - 15.1
A1	393 - 2.6	472 - 3.1	511 - 3.4	2283 - 15.1	2362 - 15.7	2401 - 15.9
B1	666 - 4.4	799 - 5.3	866 - 5.8	2556 - 16.9	2689 - 17.8	2756 - 18.3
B2	697 - 4.6	836 - 5.6	906 - 6.0	2587 - 17.2	2726 - 18.1	2796 - 18.5
C2	1492 - 9.9	1790 - 11.9	1940 - 12.9	3382 - 22.4	3680 - 24.4	3830 - 25.4
C5	877 - 5.8	1052 - 7.0	1140 - 7.6	2767 - 18.3	2942 - 19.5	3030 - 20.1

Pt. Hedland	**Subject. Height - 178cms. Weight - 70kg. Skin area - 1.87 Sq.m.**					
	HEAT DISSIPATION REQUIREMENT. kJ./hr.& Kata C.P.					
Location	**In shade or indoors.**			**In full sun**		
Clothed state	**Naked**	**Semi.**	**Fully**	**Naked**	**Semi.**	**Fully**
Activity (See table 3)	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**	**kJ/hour. Kata C.P.**
C4	275 - 1.8	330 - 2.2	358 - 2.4	2200 - 14.6	2255 - 14.9	2283 - 15.1
A1	393 - 2.6	472 - 3.1	511 - 3.4	2130 - 14.1	229 - 14.6	2248 - 14.9
B1	666 - 4.4	799 - 5.3	866 - 5.8	2403 - 16.0	2536 - 16.8	2603 - 17.3
B2	697 - 4.6	836 - 5.6	906 - 6.0	2434 - 16.1	2573 - 17.1	2643 - 17.5
C2	1492 - 9.9	1790 - 11.9	1940 - 12.9	3229 - 21.4	3527 - 23.4	3677 - 24.4
C5	877 - 5.8	1052 - 7.0	1140 - 7.6	2614 - 17.3	2789 - 18.5	2877 - 19.1

TABLE 24. REQUIRED HEAT DISSIPATION CAPACITY TO MAINTAIN STABLE CORE BODY TEMPERATURE CONT'D

Alice Springs	Subject. Height - 178cms. Weight - 70kg. Skin area - 1.87 Sq.m.					
	HEAT DISSIPATION REQUIREMENT. kJ./hr.& Kata C.P.					
Location	In shade or indoors.			In full sun		
Clothed state	Naked	Semi.	Fully	Naked	Semi.	Fully
Activity (See table 3)	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.
C4	275 - 1.8	330 - 2.2	358 - 2.4	2200 - 14.6	2255 - 14.9	2283 - 15.1
A1	393 - 2.6	472 - 3.1	511 - 3.4	2146 - 14.2	2225 - 14.8	2264 - 15.0
B1	666 - 4.4	799 - 5.3	866 - 5.8	2419 - 16.0	2552 - 16.9	2619 - 17.4
B2	697 - 4.6	836 - 5.6	906 - 6.0	2450 - 16.2	2589 - 17.2	2659 - 17.6
C2	1492 - 9.9	1790 - 11.9	1940 - 12.9	3245 - 21.5	3543 - 23.5	3693 - 24.5
C5	877 - 5.8	1052 - 7.0	1140 - 7.6	2630 - 17.4	2805 - 18.6	2893 - 19.2

Townsville	Subject. Height - 178cms. Weight - 70kg. Skin area - 1.87 Sq.m.					
	HEAT DISSIPATION REQUIREMENT. kJ/hr.& Kata C.P.					
Location	In shade or indoors.			In full sun		
Clothed state	Naked	Semi.	Fully	Naked	Semi.	Fully
Activity (See table 3)	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.	kJ/hour. Kata C.P.
C4	275 - 1.8	330 - 2.2	358 - 2.4	2200 - 14.6	2255 - 14.9	2283 - 15.1
A1	393 - 2.6	472 - 3.1	511 - 3.4	2118 - 14.0	2197 - 14.6	2236 - 14.8
B1	666 - 4.4	799 - 5.3	866 - 5.8	2391 - 15.9	2524 - 16.7	2591 - 17.2
B2	697 - 4.6	836 - 5.6	906 - 6.0	2422 - 16.1	2561 - 17.0	2631 - 17.4
C2	1492 - 9.9	1790 - 11.9	1940 - 12.9	3217 - 21.3	3515 - 23.3	3665 - 24.3
C5	877 - 5.8	1052 - 7.0	1140 - 7.6	2062 - 17.3	2777 - 18.4	2865 - 19.0

11.3 Environmental Kata Cooling Power Deficits:-

The environmental cooling power deficits required to achieve rises in the above subjects core body temperatures from Tc = 36.8°C to 40°C, 42°C, and 44°C in one, two, and three hours, are listed at Table 25.

Should the environmental cooling power be less than that required to maintain stable Tc (obtained from table24) by an amount of 6.3 say (Table 25) then the subjects Tc would reach 40° C in one hour.

TABLE 25. KATA COOLING POWER DEFICITS

Core Body Temp °C.	Hours of Exposure	Kata Cooling Power Deficit (Warming power)
40	**1**	**6.3**
	2	**3.2**
	3	**2.1**
42	**1**	**8.04**
	2	**4.02**
	3	**2.7**
44	**1**	**9.8**
	2	**4.9**
	3	**3.3**

11.4 Time Distribution of Environmental Conditions

The data sets give readings only at three hourly intervals. The question then arises as to how long any particular set of readings is representative of the intervening period.

In this work one, two and three hour assessments are made. Here it is assumed that a set of readings applies for up to two hours. However, for a dangerous condition to apply over a three-hour period, two consecutive sets of readings must be critical.

Adopting this criteria means that sometimes there are a fewer dangerous days where a given core body temperature is reached within three hours than for either one or two hours, even though the rate of heat storage required (nett Kata warming power) to reach a specified temperature is smaller for three hours than for either for one or two hours, see table 25.

12 RESULTS

Calculations were made to obtain the following information: -

12.1 Dangerous days

Dangerous days occurring in each year, when the data was adjusted for the projected conditions of 2070. Dangerous days are defined as those on which the subjects core body temperature would reach the specified temperature i.e. 40°C, 42°C or 44°C **within** the times specified, 1,2 or 3 hours.

1. **Dangerous days** occurring each year, for the base data i.e. the actual data from the period 1999 – 2001. These were obtained for comparison with both those obtained from the adjusted data and also with recorded heat affected deaths from the period.
2. Days in each year on which subjects would store heat for the predicted conditions for 2070. These results include all days on which body temperature would rise even though the subject's core body temperature may not become dangerous.
3. Days in each year, on which subjects would store heat for the base (1999 – 2001) data.
4. Statistics showing yearly averages and standard deviation of number of dangerous days, for the adjusted data – for 2070.
5. Statistics showing yearly averages and standard deviation of number of dangerous days for the actual base (1999 – 2001) data.
6. Statistics showing yearly averages and standard deviation for number of days on which a subject stores heat for the adjusted data - for 2070.
7. Statistics showing yearly averages and standard deviation for number of days on which a subject would store heat for the base (1990 – 2001) data.

Results of these calculations are shown in appendices 4 – 35.

Appendices are listed in the appendices tables and are arranged as follows.

1. **Dangerous days**, appendices 4 to 10 are for the data adjusted for projected 2070 conditions and those numbered 11 to 17 are for the base, 1990 – 2001 data.
2. **Days on which heat is stored,** (all negative KCP days) are in appendices numbered 18 to 24 for the adjusted data and 25 – 31 for 1990 – 2001 base data.

Cities are treated in alphabetical order and their appendices numbered accordingly. Each appendix contains results for a single city for example, Alice Springs' dangerous days results are in numbers 4 and 11 being the dangerous days results for 2070 and for the period 1990 – 2001, respectively.

Each appendix contains 36 tables. For example tables 4(1) and 4(1a) are for male and female subjects respectively, fully clothed and **sitting still** for Alice Springs post 2070. Similarly tables 4(2) and 4(2a) are for the same subjects, city and period, **standing still**. There are therefore 2 tables for each of the six activities making twelve tables for each of the three clothing states. Making 36 tables for each of the seven cities in each of the above four categories.

12.2 Statistics Appendices

These are organised differently, again there are two categories:

12.2.1 Dangerous days

Dangerous days, appendix 32 for projected 2070 conditions, and appendix 33 for the base data (1990 – 2001).

12.2.2 Days on which heat is stored

Days on which heat is stored (all negative nett KCP days), appendix 34 for 2070 and appendix 35 for the base data (1990 – 2001).

Each of these appendices contains 28 tables, seven cities with four tables per city. For example tables 32(1), (1a), (1b), and (1c) contain the statistics for all activities, temperatures, clothing states and times, 32(1) is for (a) acclimated males, (b) acclimated females, (c) unacclimated males and (d) unacclimated females respectively for Alice Springs, for predicted 2070 conditions. Tables 32(2) etc., are for Liverpool, 32(3) etc., are for Melbourne and so on. Appendices 33,34, and 35 are organised similarly.

13 COMMENTS ON PROCEDURE AND RESULTS.

13.1 Procedure

Gisolfi and Mora, suggest [37] that at a Tc of 40.4°C 50% of people will enter heat stroke, and at 42°C most people will die. Koehler [9] states that at 44°C all would be dead. Gisolfi and Mora also state that at Tc of 40°C sweat glands can become fatigued and begin to reduce sweat production. As a subjects Tc is raised to and above 40°C, with exposure to dangerous conditions, his sweat production rate will decrease and may cease altogether, thereby increasing dramatically the dangerous effects of dry heat conditions.

In this paper constant evaporated sweat rates have been adopted throughout the range of core body temperature studied because the author knows of no reliable method of apportioning variable sweat rates with increasing Tc. This means that estimates of dangerous days attributable to dry hot days may be considerably underestimated.

From personal experience the author knows that as core body temperature rises, it becomes impossible to continue in any activity on a continuous basis. Values have been obtained for 42°C and 44°C in order to demonstrate the extreme nature of effects that will arise if subjects continue in the activities studied. Results for all three temperatures, for the three time periods and for the three clothing states, are available in the appendices. However, in the body of the report only those results relating to a rise in Tc to 40°C **within** the two-hour time frame are illustrated.

Study of results for negative days, i.e. those days on which heat is stored and core body temperature rises, regardless of whether or not a dangerous temperature is reached, is important since once core body temperature begins to rise uncontrollably a person begins to experience extreme discomfort and efforts will be made to bring their body temperature back into equilibrium. In other words work and heat storage must stop.

Unfortunately the basic data used in this work were not always complete. Data for the major cities and Port Hedland are substantially complete, however, those for Liverpool, Alice Springs and Townsville are deficient in that for some times, readings are missing and on many other days the data is incomplete in that Relative Humidity or Wind speed values are missing. Times for which data is incomplete or missing were not included, which means that the results may be an underestimate of the actual conditions.

The results derived from the data adjusted for 2070 conditions are styled in the appendices, 2070 (90), 2070 (91) ---------- 2070 (01), indicating results for the year 2070 if the climate data for the years 1990, 1991 -----------2001, (adjusted for 2070 projected conditions) had occurred in 2070.

Six activities were selected for examination; C4, A1, B1, B2, C5, and C2, see Table 3. Metabolic heat production for **our** subjects resulting from these activities, in Kj/hr is 275, 393, 666, 697, 877 and1492 respectively. The results should be applicable to people engaged in other activities with similar rates of metabolic heat generation and the same skin area.

Examination of the results reveals several apparent anomalies. The first is that in a few cases, for a particular set of conditions the numbers of dangerous days for a subject in full shade is greater than those for the same year and conditions than for the subject in full sun. This is explained as follows. Firstly, the solar contribution to a subjects heat load has been applied only between the hours of 09.00 and 15.00, and dangerous occurrences for full sun are only counted in that time interval and also within that time restriction solar heating is applied fully at temperatures of 36° and above and only partially between 28° and 36°as explained above.

In the second anomaly, it will be observed that; and especially in the case of females and particularly unacclimated females; for the same exposure (shade or sun) values are sometimes smaller for out of the wind i.e. wind speed 0.5 kph, than they are for exposure to full ambient wind speed. This apparent anomaly is explained as follows. When the ambient temperature, predicted or actual, is above 36.5°C dry Kata cooling power is negative and inversely proportional to wind speed. Where the subjects evaporated sweat rate is insufficient to overcome this warming power dangerous events can arise. This will happen more frequently in full ambient wind speeds and especially in case of unacclimated females because they have the smaller-evaporated sweat rates.

13.2 Results

Results for each city are examined in turn, and selected results displayed as tables. The results shown here in the body of the report as tables are for our male and female subjects in both the acclimated and unacclimated condition, in the **semi clothed state**, outdoors in shade or sun with ambient wind speed and indoors for only two housing types.

The tables show the average number of days per year on which core body temperature Tc, would reach 40°C **within** two hours for the twelve-year period; data adjusted for 2070 predicted conditions; and also for the period 1990 – 2001, with data unadjusted.

Maximum negative and positive, deviation from these mean's, and standard deviations are also shown, so both the maximum and minimum numbers of days can be readily assessed.

The house types chosen are either those considered most representative of existing housing stocks, in cities where almost no other house type would exist, or those types in which people would be most at risk and which are well represented in a cities housing stock.

For Alice Springs and Port Hedland, double brick and brick veneer houses with slab floors were chosen.

For Townsville, houses of brick veneer with slab floors and timber/fibro with timber floor.

For the other cities, brick veneer with timber floor; chosen as they are thought to be fairly representative of double brick houses with timber floors, a house type very common in older suburbs in all major cities and the timber/fibro house with timber floor, which is very common in many older areas, as well as in the humid tropics.

Modern houses are mostly either double brick or brick veneer, with slab on ground floors. These houses have much better thermal properties; and their occupants are at much less risk of heat stress as shown in these results.

The results are for daytime conditions only. The situation can be quite different during night hours especially in summer rainfall areas.

Full results for subjects exposed to the complete range of conditions, clothing and acclimation states, are shown in Appendices 4 – 35.

13.2.1 Alice Springs

Tables 26, 27, and 28 show selected results for Alice Springs. Comparisons between tables 26 and 27 show the great increase in danger to life that will occur if the CSIRO’S climate change predictions eventuate. They also imply that activities important for the economy will be severely impacted.

In summer sun, it will be quite impossible to perform on a continuous basis any of the activities studied. Even in the shade, work will not be possible on many days.

Whilst it is unlikely that moderately heavy work will be performed inside people’s houses, conditions indoors in workshops and factories will be similarly quite dangerous for many occupations on very many days.

TABLE 26. ALICE SPRINGS 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1	2.1	2.9	1.1	1.3	110.7	24.3	28.7	15.1								
	B1	6.1	6.9	4.1	3.2	146.8	21.2	43.8	17.1								
	B2	7.0	8.0	4.0	3.7	151.8	21.3	43.8	16.9								
	C2	68.8	23.2	24.8	13.4	200.0	19.0	41.0	15.6	27.3	15.8	12.3	8.3	38.3	14.7	12.3	8.8
	C4	1.2	0.8	0.2	0.4	112.5	25.5	28.5	14.5								
	C5	11.8	6.3	5.8	4.5	167.8	21.2	43.8	15.9					1.0	0.0	0.0	
Male - Unacc	A1	14.3	6.8	7.3	4.6	170.2	20.8	44.2	15.8								
	B1	33.6	10.4	18.6	7.8	185.9	20.1	45.9	16.1								
	B2	38.1	15.9	21.1	9.9	188.0	19.0	45.0	15.9								
	C2	135.3	24.8	37.3	15.2	227.3	22.8	31.3	14.4	30.9	13.1	12.9	7.2	42.2	11.8	13.2	7.3
	C4	9.8	7.3	4.8	4.3	170.5	20.5	43.5	15.5								
	C5	58.3	21.8	23.3	13.4	196.8	21.3	40.8	15.3					1.0	0.0	0.0	

TABLE 26. ALICE SPRINGS 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	3.3	3.7	2.3	1.8	126.8	24.2	33.8	14.2								
	B1	8.8	7.3	4.8	4.1	162.9	23.1	46.9	17.2								
	B2	9.8	7.3	4.8	4.3	166.0	22.0	45.0	16.6								
	C2	79.8	27.3	26.8	15.1	207.6	17.4	37.6	14.9	27.3	15.8	12.3	8.3	38.3	14.7	12.3	8.8
	C4	2.1	2.9	1.1	1.3	128.3	24.7	35.3	14.5								
	C5	18.0	10.0	9.0	5.4	174.8	21.3	43.8	15.7					1.0	0.0	0.0	
Female - Unacc	A1	34.8	11.2	17.8	7.8	186.9	19.1	45.9	16.0								
	B1	66.0	25.0	23.0	14.0	199.8	19.2	40.8	15.4								
	B2	70.8	28.3	23.8	15.0	202.4	19.6	39.4	15.3								
	C2	171.7	21.3	42.7	15.3	241.5	25.5	28.5	14.4	133.3	19.8	23.3	10.8	152.2	19.8	30.2	13.3
	C4	26.1	10.9	16.1	7.4	186.9	19.1	45.9	16.0								
	C5	91.1	23.9	26.1	15.4	212.0	19.0	38.0	14.6					1.0	0.0	0.0	

TABLE 27. ALICE SPRINGS 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1					15.6	10.4	9.6	6.6								
	B1					41.8	20.3	22.8	11.7								
	B2					46.6	17.4	21.6	12.0								
	C2	3.5	5.5	2.5	2.4	94.6	24.4	27.6	15.6	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	C4					16.7	10.3	9.7	6.9								
	C5					61.6	18.4	25.6	14.0								
Male - Unacc	A1					64.7	18.3	27.7	14.6								
	B1	1.3	0.8	0.3	0.4	78.7	24.3	27.7	15.1								
	B2	1.2	0.8	0.2	0.4	80.5	25.5	29.5	15.7								
	C2	32.3	19.7	16.3	9.8	125.3	22.8	32.3	13.4	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	C4					65.3	18.8	27.3	14.6								
	C5	2.2	3.8	1.2	1.6	90.6	25.4	28.6	15.5								

TABLE 27. ALICE SPRINGS 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1					26.3	15.7	14.3	9.1								
	B1					55.9	21.1	24.9	13.8								
	B2					60.1	17.9	25.1	13.8								
	C2	6.3	5.8	5.3	3.9	101.2	22.8	27.2	14.5	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	C4					27.8	17.2	15.8	9.4								
	C5					68.3	18.7	28.3	14.7								
Female - Unacc	A1	1.2	0.8	0.2	0.4	79.5	25.5	28.5	15.6								
	B1	3.0	5.0	2.0	2.2	94.2	24.8	27.2	15.4								
	B2	4.0	4.0	3.0	2.7	95.8	24.3	25.8	14.8								
	C2	66.2	19.8	28.2	14.7	142.8	21.3	39.8	16.2	27.5	20.5	14.5	9.8	42.4	19.6	22.4	11.6
	C4					79.5	25.5	28.5	15.6								
	C5	9.2	7.8	5.2	4.8	105.5	22.5	27.5	14.9								

TABLE 28. ALICE SPRINGS 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	9.1	7.9	5.1	4.5	164.1	21.9	47.1	17.1								
	B1	23.8	9.3	13.8	6.8	179.3	20.8	42.3	15.4	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	B2	26.6	10.4	16.6	7.4	180.7	20.3	43.7	15.5	1.0	0.0	0.0	0.0	1.4	0.6	0.4	0.5
	C2	120.6	24.4	31.6	14.6	221.7	19.3	35.7	14.7	107.7	32.3	23.7	15.5	121.2	32.8	29.2	15.0
	C4	6.4	7.6	4.4	3.5	165.2	20.8	45.2	16.5								
	C5	43.7	14.3	20.7	9.7	189.6	18.4	42.6	15.3	4.8	6.2	3.8	3.2	8.1	6.9	6.1	4.5
Male - Unacc	A1	48.1	16.9	20.1	11.5	192.6	20.4	41.6	15.3								
	B1	77.6	29.4	28.6	15.7	206.1	16.9	37.1	14.5	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	B2	82.2	26.8	32.2	16.0	208.3	17.8	38.3	14.7	1.0	0.0	0.0	0.0	1.4	0.6	0.4	0.5
	C2	190.2	17.8	43.2	15.3	245.0	26.0	23.0	14.0	188.9	17.1	25.9	10.5	204.3	15.8	29.3	11.4
	C4	34.8	11.2	17.8	7.8	191.8	20.2	43.8	15.8								
	C5	105.0	28.0	26.0	15.3	217.7	20.3	37.7	15.2	4.8	6.2	3.8	3.2	8.1	6.9	6.1	4.5

TABLE 28. ALICE SPRINGS 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	12.8	7.2	6.8	4.8	169.4	20.6	43.4	15.6								
	B1	31.6	11.4	17.6	7.4	184.3	19.7	45.3	15.8	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	B2	35.3	11.7	18.3	7.9	187.0	20.0	46.0	16.2	1.0	0.0	0.0	0.0	1.4	0.6	0.4	0.5
	C2	135.2	23.8	38.2	15.6	226.5	22.5	33.5	15.2	107.7	32.3	23.7	15.5	121.2	32.8	29.2	15.0
	C4	9.1	7.9	5.1	4.5	169.8	20.2	43.8	15.7								
	C5	56.9	18.1	23.9	12.3	195.8	21.3	41.8	15.6	4.8	6.2	3.8	3.2	8.1	6.9	6.1	4.5
Female - Unacc	A1	79.0	29.0	30.0	16.3	207.8	18.3	37.8	14.8								
	B1	114.9	27.1	29.9	14.3	221.0	18.0	35.0	14.4	1.0	0.0	0.0	0.0	1.3	1.7	0.3	0.7
	B2	120.1	25.9	32.1	14.2	223.3	20.7	35.3	14.7	1.3	0.7	0.3	0.5	3.4	3.6	2.4	2.0
	C2	226.1	23.9	35.1	15.6	258.3	20.8	19.3	11.8	279.3	20.7	18.3	13.3	291.1	19.9	20.1	13.3
	C4	67.4	27.6	23.4	14.5	205.8	17.2	37.8	14.6								
	C5	144.8	22.3	43.8	17.1	229.3	20.7	31.3	14.3	32.1	18.9	14.1	8.3	48.8	15.3	16.8	9.3

Tables 26,27 and 28 illustrate the benefit of acclimation in hot dry conditions and show the potential danger for unacclimated temperate zone tourists. This could well have severe consequences for the tourist industry. It must be realised that acclimation mostly improves the ability to sweat and can only be of value in cooling a person to the extent to which that sweat is evaporated on their body. It has only a limited effect on a persons ‘innate’ ability to tolerate heat.

Table 28 shows conclusively just how very uncomfortable conditions can become. Especially when it is realised that as a persons temperature starts to rise activity must stop, if danger is to be avoided.

It is perhaps no exaggeration to say that for lengthy periods in summer, daytime activities in Central Australia will have to be abandoned, and conditions indoors will become extremely unpleasant, if not, intolerable.

13.2.2 Liverpool

Tables 29, 30 and 31 show selected results for our four subjects in the semi clothed condition for Liverpool. This city was chosen as being the only one with available data illustrative of conditions in the Sydney hinterland away from the coast. Windsor or Richmond would have been chosen if data had been available. As mentioned above data for this city were not complete and hence the results are probably an underestimate.

Comparison between tables 29 and 30 illustrates the profound effect that the predicted climate change will have on the numbers of dangerous days that will be experienced both outdoors and in those housing types considered to give least protection against extreme heat and are well represented in that cities older housing stock.

Table 31 shows just how extremely uncomfortable conditions will become if global warming proceeds as predicted, conditions indoors at Liverpool will clearly be more uncomfortable than those at Alice Springs.

TABLE 29. LIVERPOOL 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1	1.0	0.0	0.0		16.8	12.2	8.8	6.2								
	B1	1.0	0.0	0.0	0.0	26.6	20.4	14.6	9.3	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	B2	1.0	0.0	0.0	0.0	28.1	20.9	15.1	10.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C2	9.3	8.7	6.3	4.9	58.3	19.7	21.3	14.0	34.3	19.8	24.3	11.6	61.5	19.5	30.5	16.2
	C4					15.3	9.7	8.3	5.4								
	C5	1.7	1.3	0.7	0.7	35.3	19.8	18.3	10.4	1.2	0.8	0.2	0.4	3.7	2.3	2.7	1.7
Male - Unacc	A1	2.0	1.0	1.0	0.8	34.8	21.3	17.8	10.8								
	B1	2.7	2.3	1.7	1.3	45.0	23.0	22.0	13.8	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	B2	2.8	2.2	1.8	1.4	45.9	23.1	21.9	14.1	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C2	23.6	17.4	17.6	8.3	79.1	30.9	30.1	19.3	34.3	19.7	24.3	11.6	61.6	19.4	30.6	16.3
	C4	1.2	0.8	0.2	0.4	32.9	20.1	16.9	10.6								
	C5	4.5	3.5	2.5	2.0	53.6	23.4	21.6	14.6	1.2	0.8	0.2	0.4	3.7	2.3	2.7	1.7

TABLE 29. LIVERPOOL 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	1.0	0.0	0.0	0.0	21.3	16.8	13.3	8.2								
	B1	1.2	0.8	0.2	0.4	31.8	19.2	17.8	10.4	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	B2	1.2	0.8	0.2	0.4	32.5	19.5	18.5	10.7	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C2	11.2	7.8	7.2	4.7	62.5	21.5	23.5	15.9	34.3	19.8	24.3	11.6	61.5	19.5	30.5	16.2
	C4	1.0	0.0	0.0		19.5	14.5	11.5	7.3								
	C5	2.7	1.3	1.7	1.0	38.9	22.1	18.9	11.2	1.2	0.8	0.2	0.4	3.7	2.3	2.7	1.7
Female - Unacc	A1	2.7	2.3	1.7	1.3	45.1	21.9	22.1	13.8								
	B1	5.3	4.7	3.3	2.4	55.2	22.8	23.2	15.0	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	B2	5.1	6.9	4.1	3.3	56.2	23.8	23.2	15.3	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C2	37.9	21.1	21.9	10.9	93.2	25.8	31.2	20.0	52.4	20.6	22.4	12.8	100.7	27.3	33.7	19.8
	C4	2.4	1.6	1.4	1.2	42.9	22.1	19.9	13.5								
	C5	8.1	7.9	6.1	4.6	63.6	22.4	26.6	17.2	1.2	0.8	0.2	0.4	3.7	2.3	2.7	1.7

TABLE 30. LIVERPOOL 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1					2.3	1.8	1.3	0.8								
	B1					4.7	3.3	3.7	2.2								
	B2					5.0	3.0	4.0	2.3								
	C2	2.5	1.5	1.5	1.5	11.1	9.9	8.1	5.5	2.2	1.8	1.2	1.1	5.3	3.7	3.3	2.2
	C4					2.1	0.9	1.1	0.6								
	C5					6.3	4.7	5.3	3.2								
Male - Unacc	A1					5.8	4.3	4.8	3.5								
	B1					7.5	10.5	6.5	4.9								
	B2					8.0	11.0	7.0	5.1								
	C2	3.5	1.5	2.5	1.1	18.7	15.3	11.7	7.9	2.2	1.8	1.2	1.1	5.5	3.5	3.5	2.0
	C4					6.4	3.6	5.4	3.0								
	C5	1.0	0.0	0.0		10.0	11.0	7.0	5.6								

TABLE 30. LIVERPOOL 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1					3.5	1.5	1.5	0.9								
	B1					5.9	3.1	4.9	2.7								
	B2					5.9	3.1	4.9	2.7								
	C2	2.0	2.0	1.0	1.4	12.8	11.3	7.8	6.0	2.2	1.8	1.2	1.1	5.3	3.7	3.3	2.2
	C4					2.9	2.1	1.9	1.2								
	C5					6.3	5.7	5.3	3.7								
Female - Unacc	A1					7.5	10.5	6.5	4.8								
	B1	1.0	0.0	0.0	0.0	10.8	10.3	7.8	5.9								
	B2	1.0	0.0	0.0	0.0	10.9	10.1	7.9	5.8								
	C2	6.0	4.0	5.0	3.3	23.6	19.4	11.6	8.9	6.9	7.1	5.9	4.1	22.9	19.1	12.9	9.3
	C4					7.3	8.8	6.3	4.5								
	C5	1.3	0.8	0.3	0.4	13.5	11.5	9.5	6.6								

TABLE 31. LIVERPOOL 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1	1.2	0.8	0.2	0.4	32.8	18.3	17.8	10.3	1.0	0.0	0.0	0.0	1.8	1.3	0.8	0.8
	B1	3.1	2.9	2.1	1.6	41.7	21.3	20.7	12.3	3.3	3.7	2.3	2.3	8.6	6.4	7.6	4.2
	B2	2.8	3.2	1.8	1.6	42.5	20.5	20.5	12.3	3.7	5.3	2.7	2.6	10.9	7.1	9.9	4.8
	C2	32.8	31.2	25.8	17.0	73.8	26.2	26.8	18.8	123.3	43.8	50.3	27.5	160.1	43.9	56.1	30.9
	C4	1.0	0.0	0.0	0.0	30.3	20.7	15.3	10.2	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C5	4.3	5.8	3.3	2.8	49.7	21.3	19.7	13.3	9.9	8.1	7.9	4.6	26.8	11.3	18.8	9.1
Male - Unacc	A1	3.4	2.6	2.4	1.7	50.1	23.9	22.1	14.6	1.0	0.0	0.0	0.0	1.8	1.3	0.8	0.8
	B1	6.6	6.4	5.6	3.9	60.3	22.8	25.3	16.6	3.3	3.7	2.3	2.3	8.6	6.4	7.6	4.2
	B2	7.3	6.8	6.3	3.9	61.6	23.4	25.6	16.9	3.7	5.3	2.7	2.6	10.9	7.1	9.9	4.8
	C2	61.4	34.6	34.4	17.7	100.0	26.0	32.0	21.2	134.9	41.1	47.9	26.8	184.8	36.3	69.8	32.9
	C4	2.7	2.3	1.7	1.3	46.9	23.1	21.9	14.3	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C5	12.9	11.1	9.9	5.5	69.5	25.5	23.5	17.3	9.9	8.1	7.9	4.6	26.8	11.3	18.8	9.1

TABLE 31. LIVERPOOL 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	1.8	1.2	0.8	0.7	35.3	20.8	18.3	10.9	1.0	0.0	0.0	0.0	1.8	1.3	0.8	0.8
	B1	3.1	3.9	2.1	1.9	45.4	20.6	22.4	13.3	3.3	3.7	2.3	2.3	8.6	6.4	7.6	4.2
	B2	3.0	4.0	2.0	1.8	46.2	21.8	23.2	13.7	3.7	5.3	2.7	2.6	10.9	7.1	9.9	4.8
	C2	37.5	28.5	30.5	17.3	79.7	29.3	29.7	19.5	123.3	43.8	50.3	27.5	160.1	43.9	56.1	30.9
	C4	1.2	0.8	0.2	0.4	33.6	19.4	17.6	10.5	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C5	5.1	4.9	4.1	3.0	54.3	22.8	21.3	14.3	9.9	8.1	7.9	4.6	26.8	11.3	18.8	9.1
Female - Unacc	A1	6.5	7.5	5.5	3.9	60.0	23.0	26.0	16.8	1.0	0.0	0.0	0.0	1.8	1.3	0.8	0.8
	B1	13.4	13.6	9.4	6.2	70.8	29.2	26.8	18.5	3.7	3.3	2.7	2.2	9.3	5.7	8.3	4.4
	B2	14.9	14.1	9.9	6.7	72.3	29.8	26.3	18.5	4.1	4.9	3.1	2.6	12.3	6.8	9.3	5.1
	C2	94.8	43.2	35.8	23.6	117.1	30.9	39.1	26.0	231.4	31.6	71.4	33.7	314.3	35.7	77.3	40.0
	C4	5.0	5.0	4.0	2.7	56.7	24.3	23.7	15.9	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
	C5	22.8	18.3	16.8	8.8	82.6	27.4	27.6	18.9	12.8	6.3	8.8	5.2	34.0	18.0	18.0	11.0

13.2.3 Melbourne

Tables 32, 33 and 34 show selected results for the four subjects in the semi-clothed condition for Melbourne.

Comparison of tables 32 and 33 further illustrates the dangerous effect that global warming can have and table 33 shows that conditions in Melbourne will also be most uncomfortable on many days.

TABLE 32. MELBOURNE 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1					10.3	4.7	7.3	3.2								
	B1	1.0	0.0	0.0		17.5	9.5	11.5	5.9								
	B2	1.0	0.0	0.0	0.0	18.3	9.7	12.3	5.9								
	C2	4.0	4.0	3.0	2.4	30.4	7.6	8.4	5.7	5.9	7.1	4.9	3.1	17.3	6.8	12.3	5.0
	C4					8.3	5.7	7.3	3.6								
	C5	2.3	0.8	1.3	0.8	20.4	8.6	7.4	5.0					1.0	0.0	0.0	
Male - Unacc	A1	2.8	2.3	1.8	1.5	20.7	7.3	7.7	5.0								
	B1	2.5	2.5	1.5	1.7	24.8	6.2	7.8	4.8								
	B2	2.6	2.4	1.6	1.7	25.8	7.2	7.8	5.1								
	C2	12.8	5.3	7.8	3.7	41.8	10.2	10.8	6.4	6.1	6.9	5.1	3.0	17.3	6.7	12.3	5.1
	C4	1.7	1.3	0.7	0.9	19.7	8.3	8.7	5.1								
	C5	3.0	4.0	2.0	2.4	28.3	8.8	8.3	5.6					1.0	0.0	0.0	

TABLE 32. MELBOURNE 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1					13.2	5.8	8.2	4.3								
	B1	2.0	1.0	1.0	1.0	19.3	8.7	10.3	5.3								
	B2	1.7	1.3	0.7	0.9	19.8	8.3	8.8	5.1								
	C2	5.0	5.0	4.0	2.8	32.4	9.6	10.4	6.2	5.9	7.1	4.9	3.1	17.3	6.8	12.3	5.0
	C4					11.1	4.9	8.1	3.5								
	C5	2.6	2.4	1.6	1.5	22.3	7.8	7.3	4.8					1.0	0.0	0.0	
Female - Unacc	A1	2.5	2.5	1.5	1.7	25.4	7.6	7.4	5.0								
	B1	3.4	3.6	2.4	2.3	29.4	6.6	7.4	5.5								
	B2	3.7	4.3	2.7	2.3	30.3	6.7	8.3	5.5								
	C2	20.6	9.4	9.6	5.1	50.1	11.9	13.1	8.0	22.3	5.8	8.3	4.8	48.7	7.3	9.7	6.4
	C4	2.5	2.5	1.5	1.6	23.3	6.7	8.3	4.8								
	C5	5.3	5.8	4.3	3.2	34.4	7.6	10.4	5.9					1.0	0.0	0.0	

TABLE 33. MELBOURNE 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1					3.1	2.9	2.1	2.2								
	B1					3.7	5.3	2.7	2.7								
	B2					3.8	5.3	2.8	2.7								
	C2					9.4	6.6	8.4	4.3					2.3	1.7	1.3	1.1
	C4					2.8	2.2	1.8	1.9								
	C5					4.8	6.2	3.8	3.4								
Male - Unacc	A1					5.3	6.8	4.3	3.5								
	B1					6.9	6.1	5.9	3.6								
	B2					7.3	5.7	6.3	3.8								
	C2	2.9	4.1	1.9	2.3	14.4	9.6	9.4	5.5					3.2	1.8	2.2	1.7
	C4					4.7	6.3	3.7	3.3								
	C5					8.7	7.3	7.7	4.3								

TABLE 33. MELBOURNE 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Female - Acc	A1					3.2	4.8	2.2	2.5								
	B1					4.5	6.5	3.5	3.3								
	B2					4.6	6.4	3.6	3.4								
	C2	1.5	0.5	0.5	0.5	10.5	6.5	8.5	4.5					2.3	1.7	1.3	1.1
	C4					3.1	2.9	2.1	2.2								
	C5					5.5	6.5	4.5	3.5								
Female - Unacc	A1					7.2	5.8	6.2	3.8								
	B1					9.3	6.7	8.3	4.3								
	B2					9.6	6.4	8.6	4.3								
	C2	4.8	6.2	3.8	3.3	17.3	10.8	12.3	6.4	5.4	5.6	4.4	3.2	17.5	8.5	11.5	5.7
	C4					6.5	6.5	5.5	3.5								
	C5	1.8	1.3	0.8	0.8	11.0	6.0	9.0	4.7								

TABLE 34. MELBOURNE 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	2.0	1.0	1.0	1.0	19.5	8.5	9.5	5.1					1.0	0.0	0.0	
	B1	2.3	2.7	1.3	1.5	23.0	9.0	8.0	4.9	1.0	0.0	0.0		2.7	2.3	1.7	1.5
	B2	2.5	2.5	1.5	1.6	23.9	9.1	8.9	5.2	1.0	0.0	0.0		3.4	2.6	2.4	2.0
	C2	15.9	7.1	10.9	5.1	39.6	12.4	10.6	7.0	41.7	16.3	13.7	9.3	70.4	18.6	16.4	10.9
	C4	1.0	0.0	0.0		18.3	9.7	12.3	5.9								
	C5	3.0	4.0	2.0	2.2	27.2	10.8	9.2	5.8	2.0	2.0	1.0	1.1	6.4	6.6	5.4	3.6
Male - Unacc	A1	2.9	4.1	1.9	2.3	26.8	7.3	7.8	5.4					1.0	0.0	0.0	
	B1	4.5	4.5	3.5	2.6	31.9	8.1	9.9	5.9	1.0	0.0	0.0		2.7	2.3	1.7	1.5
	B2	4.3	5.7	3.3	2.9	32.8	8.3	10.8	5.9	1.0	0.0	0.0		3.4	2.6	2.4	2.0
	C2	31.3	14.7	12.3	6.9	53.3	13.7	12.3	8.1	53.6	15.4	13.6	8.5	91.7	21.3	20.7	11.8
	C4	2.5	2.5	1.5	1.7	25.8	7.3	7.8	5.1								
	C5	7.0	7.0	6.0	3.8	37.0	11.0	10.0	6.3	2.0	2.0	1.0	1.1	6.4	6.6	5.4	3.6

TABLE 34. MELBOURNE 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	2.5	1.5	1.5	1.1	20.8	7.3	7.8	4.9					1.0	0.0	0.0	
	B1	2.6	2.4	1.6	1.6	25.3	7.8	9.3	5.2	1.0	0.0	0.0		2.7	2.3	1.7	1.5
	B2	2.5	2.5	1.5	1.7	26.2	8.8	9.2	5.4	1.0	0.0	0.0		3.4	2.6	2.4	2.0
	C2	18.3	9.8	11.3	5.3	41.6	10.4	10.6	6.6	41.7	16.3	13.7	9.3	70.4	18.6	16.4	10.9
	C4	2.0	1.0	1.0	1.0	19.6	8.4	8.6	4.9								
	C5	3.0	4.0	2.0	2.4	28.5	9.5	8.5	5.8	2.0	2.0	1.0	1.1	6.4	6.6	5.4	3.6
Female - Unacc	A1	4.3	5.8	3.3	2.9	31.8	8.2	9.8	5.9					1.0	0.0	0.0	
	B1	8.6	5.4	6.6	3.5	39.0	11.0	10.0	6.7	1.0	0.0	0.0		3.3	4.7	2.3	2.5
	B2	9.3	4.8	7.3	3.6	39.8	10.2	10.8	6.9	1.0	0.0	0.0	0.0	4.1	4.9	3.1	2.9
	C2	48.4	18.6	17.4	10.2	62.8	21.3	13.8	9.7	136.3	22.7	25.3	14.7	240.1	21.9	22.1	12.0
	C4	3.5	4.5	2.5	2.4	30.2	6.8	8.2	5.4								
	C5	13.3	7.8	8.3	4.4	43.8	9.2	10.8	6.9	4.5	5.5	3.5	3.0	14.8	7.2	9.8	5.2

It must be noted that since Melbourne has a more decidedly temperate climate its inhabitants may well have a lower degree of acclimation to heat than citizens of more northerly cities. Especially so in late spring or early summer, a heat wave at this time would be most devastating. Results for unacclimated individuals may be a better guide to the effects of global warming in that city than those for acclimated individuals.

13.2.4 Perth

Tables 35, 36 and 37 show results for the four subjects in semi-clothed state and the six activities. Study of table 35 shows that the projected climate change will produce difficult and on many days' dangerous conditions in Perth, comparison of tables 35 and 36 illustrates the profound effect that the predicted climate change will have on the numbers of dangerous days to be experienced. Table 37 indicates days on which heat would be stored these are days of extreme discomfort and disruption to normal activities, there are very many days on which heat storage will occur. Perth will be perhaps the fourth most adversely affected city, after Port Hedland, Alice Springs and Townsville.

TABLE 35. PERTH 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1	2.3	0.7	1.3	0.9	37.9	9.1	13.9	6.6								
	B1	2.3	1.7	1.3	1.3	57.3	17.7	18.3	9.6					1.5	0.5	0.5	0.5
	B2	2.0	2.0	1.0	1.2	58.6	16.4	17.6	9.5					2.0	0.0	0.0	0.0
	C2	20.3	11.8	8.3	5.7	97.0	16.0	19.0	11.1	27.3	11.8	7.3	5.0	63.9	24.1	13.9	9.2
	C4	1.3	0.7	0.3	0.5	34.4	10.6	11.4	6.7								
	C5	2.8	2.2	1.8	1.5	68.5	20.5	17.5	9.7	1.0	0.0	0.0		2.2	2.8	1.2	1.4
Male - Unacc	A1	3.3	1.7	2.3	1.7	68.8	17.3	22.8	10.5								
	B1	7.5	5.5	3.5	3.3	80.4	15.6	14.4	10.4					1.5	0.5	0.5	0.5
	B2	8.3	4.8	4.3	3.4	82.3	16.8	15.3	10.5					2.0	0.0	0.0	0.0
	C2	47.1	14.9	10.1	7.5	120.8	19.2	18.8	12.2	28.2	10.8	7.2	4.7	65.0	24.0	14.0	9.7
	C4	2.3	2.7	1.3	1.3	66.6	16.4	22.6	10.3								
	C5	13.1	6.9	7.1	4.4	91.7	15.3	18.7	11.4	1.0	0.0	0.0		2.2	2.8	1.2	1.4

TABLE 35. PERTH 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Female - Acc	A1	1.8	2.2	0.8	1.2	45.3	13.8	16.3	7.9								
	B1	2.2	2.8	1.2	1.4	64.2	19.8	19.2	10.5					1.5	0.5	0.5	0.5
	B2	2.3	2.7	1.3	1.3	65.3	19.8	19.3	10.3					2.0	0.0	0.0	0.0
	C2	24.3	12.8	9.3	5.8	102.1	17.9	17.1	11.2	27.3	11.8	7.3	5.0	63.9	24.1	13.9	9.2
	C4	2.3	0.7	1.3	0.9	42.3	14.7	15.3	7.5								
	C5	3.6	3.4	2.6	2.1	73.0	18.0	12.0	8.9	1.0	0.0	0.0		2.2	2.8	1.2	1.4
Female - Unacc	A1	7.6	5.4	3.6	3.4	80.9	17.1	17.9	10.8								
	B1	15.6	7.4	5.6	4.3	95.2	16.8	22.2	12.4					1.5	0.5	0.5	0.5
	B2	16.9	6.1	5.9	4.3	96.2	17.8	21.2	12.3					2.0	0.0	0.0	0.0
	C2	69.8	24.2	13.8	9.4	133.8	23.2	15.8	11.3	77.2	20.8	15.2	10.7	138.7	24.3	15.7	12.2
	C4	5.8	5.2	3.8	3.2	77.3	15.8	17.3	9.9								
	C5	24.4	11.6	9.4	6.3	105.3	18.7	22.3	12.5	2.0	0.0	0.0		2.4	2.6	1.4	1.3

TABLE 36. PERTH 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1					4.1	4.9	3.1	2.6								
	B1					10.8	6.2	5.8	4.3								
	B2	1.0	0.0	0.0		11.8	7.2	5.8	4.5								
	C2	2.0	3.0	1.0	1.5	27.7	10.3	6.7	5.6	1.0	0.0	0.0	0.0	4.5	5.5	3.5	2.8
	C4					3.7	5.3	2.7	2.5								
	C5	2.0	0.0	0.0		16.0	8.0	8.0	5.0								
Male - Unacc	A1	2.0	0.0	0.0		16.0	6.0	7.0	4.6								
	B1	2.0	0.0	0.0		21.2	8.8	7.2	4.8								
	B2	2.0	0.0	0.0		21.9	8.1	7.9	4.9								
	C2	6.2	5.8	3.2	2.9	41.1	15.9	14.1	8.6	2.0	1.0	1.0	1.0	4.8	6.2	3.8	3.2
	C4	2.0	0.0	0.0		15.5	6.5	7.5	4.8								
	C5	1.8	1.3	0.8	0.8	25.0	10.0	9.0	5.6								

TABLE 36. PERTH 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Female - Acc	A1					6.5	5.5	4.5	2.9								
	B1	1.0	0.0	0.0		14.3	5.7	7.3	5.0								
	B2	2.0	0.0	0.0		14.9	9.1	6.9	5.3								
	C2	2.6	3.4	1.6	1.9	31.3	11.8	9.3	7.3	1.0	0.0	0.0	0.0	4.5	5.5	3.5	2.8
	C4					5.4	6.6	3.4	2.9								
	C5	2.0	0.0	0.0		17.7	8.3	8.7	4.9								
Female - Unacc	A1	2.0	0.0	0.0		21.2	7.8	7.2	4.7								
	B1	2.0	1.0	1.0	1.0	26.9	10.1	8.9	6.1								
	B2	2.3	1.8	1.3	1.3	27.5	9.5	8.5	5.9								
	C2	16.2	8.8	8.2	4.8	48.3	14.7	18.3	8.8	17.3	6.7	8.3	4.9	49.8	14.2	20.8	10.2
	C4	2.0	0.0	0.0		19.8	7.3	7.8	4.6								
	C5	2.1	2.9	1.1	1.4	32.4	12.6	11.4	8.0								

TABLE 37. PERTH 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	2.3	2.7	1.3	1.3	64.6	19.4	18.6	10.2	1.0	0.0	0.0		2.0	2.0	1.0	1.4
	B1	5.2	4.8	3.2	2.7	75.6	15.4	12.6	8.9	2.4	1.6	1.4	1.2	8.4	4.6	5.4	3.0
	B2	6.2	6.8	4.2	3.3	77.3	14.8	12.3	8.8	2.5	2.5	1.5	1.6	10.8	4.3	5.8	3.0
	C2	54.8	29.2	20.8	16.5	114.3	22.8	21.3	12.8	121.4	15.6	38.4	15.0	182.1	22.9	31.1	13.1
	C4	2.1	1.9	1.1	1.3	62.7	20.3	19.7	10.6					1.5	0.5	0.5	0.5
	C5	10.3	4.8	4.3	2.9	86.1	17.9	12.1	9.6	7.0	6.0	5.0	3.5	28.9	9.1	5.9	4.5
Male - Unacc	A1	10.8	4.3	5.8	3.5	87.3	18.8	16.3	10.7	1.0	0.0	0.0		2.0	2.0	1.0	1.4
	B1	19.6	7.4	6.6	4.7	100.8	19.2	19.8	11.9	2.4	1.6	1.4	1.2	8.4	4.6	5.4	3.0
	B2	21.2	9.8	7.2	5.2	102.4	17.6	20.4	12.1	2.5	2.5	1.5	1.6	10.8	4.3	5.8	3.0
	C2	96.3	28.8	22.3	15.0	139.0	23.0	19.0	12.1	152.3	15.7	22.3	12.0	217.8	29.3	19.8	14.0
	C4	7.6	5.4	3.6	3.4	84.1	18.9	17.1	10.5					1.5	0.5	0.5	0.5
	C5	30.5	10.5	11.5	6.6	110.5	21.5	23.5	13.1	7.0	6.0	5.0	3.5	28.9	9.1	5.9	4.5

TABLE 37. PERTH 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Female - Acc	A1	3.0	2.0	2.0	1.6	68.8	20.3	19.8	10.0	1.0	0.0	0.0		2.0	2.0	1.0	1.4
	B1	6.9	6.1	3.9	3.2	80.0	14.0	13.0	9.2	2.4	1.6	1.4	1.2	8.4	4.6	5.4	3.0
	B2	7.8	6.2	3.8	3.4	81.7	15.3	12.7	9.8	2.5	2.5	1.5	1.6	10.8	4.3	5.8	3.0
	C2	61.6	30.4	20.6	15.9	120.3	19.7	18.3	12.2	121.4	15.6	38.4	15.0	182.1	22.9	31.1	13.1
	C4	2.3	2.7	1.3	1.3	66.5	19.5	19.5	9.9					1.5	0.5	0.5	0.5
	C5	13.3	6.7	6.3	3.9	91.8	16.2	17.8	11.2	7.0	6.0	5.0	3.5	28.9	9.1	5.9	4.5
Female - Unacc	A1	19.9	7.1	6.9	4.7	100.6	18.4	18.6	12.1	1.0	0.0	0.0		2.0	2.0	1.0	1.4
	B1	34.8	12.2	16.8	7.5	113.3	23.8	23.3	13.6	2.4	1.6	1.4	1.2	13.4	6.6	8.4	4.6
	B2	37.4	12.6	15.4	7.4	115.5	21.5	21.5	13.2	3.8	3.2	2.8	1.9	18.3	6.7	8.3	4.4
	C2	130.1	28.9	24.1	13.6	153.4	19.6	19.4	12.4	263.9	16.1	24.9	14.4	350.3	9.8	12.3	6.9
	C4	16.1	6.9	6.1	4.4	97.5	18.5	21.5	12.1					1.5	0.5	0.5	0.5
	C5	49.4	13.6	19.4	9.6	124.8	21.2	18.8	11.7	19.5	6.5	7.5	4.3	53.7	15.3	12.7	9.2

13.2.5 Port Hedland

Tables 38 and 39 show numbers of dangerous days that would be experienced for predicted 2070 conditions and the period 1990 – 2001 respectively. Table 40 gives days on which heat would be stored and body temperature would rise uncontrollably for predicted 2070 conditions.

TABLE 38. PORT HEDLAND 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	5.1	6.9	4.1	3.2	170.9	44.1	42.9	28.2								
	B1	10.9	11.1	7.9	5.4	216.6	30.4	33.6	21.4					1.0	0.0	0.0	0.0
	B2	12.6	11.4	8.6	5.9	223.7	32.3	33.7	21.2	1.0	0.0	0.0	0.0	1.3	1.7	0.3	0.7
	C2	101.8	46.2	41.8	29.8	294.5	18.5	22.5	13.5	171.3	21.8	20.3	10.9	182.4	24.6	23.4	12.7
	C4	4.1	3.9	3.1	2.1	177.3	42.7	43.3	26.7								
	C5	23.2	15.8	14.2	9.3	247.7	30.3	22.7	18.7	11.3	15.7	6.3	6.3	15.8	13.2	7.8	7.3
Male - Unacc	A1	25.2	16.8	15.2	10.3	250.3	28.8	21.3	17.7								
	B1	50.9	28.1	23.9	18.2	271.8	24.2	21.8	15.3					1.0	0.0	0.0	0.0
	B2	55.8	32.3	26.8	18.7	274.4	22.6	23.4	15.6	1.0	0.0	0.0	0.0	1.3	1.7	0.3	0.7
	C2	204.5	34.5	40.5	25.9	327.7	19.3	18.7	12.3	172.2	20.8	21.2	10.8	183.3	23.8	24.3	12.9
	C4	18.3	13.8	11.3	7.3	252.7	29.3	21.7	17.1								
	C5	81.7	40.3	35.7	23.8	287.3	16.7	22.3	14.1	11.3	15.7	6.3	6.3	15.8	13.2	7.8	7.3

TABLE 38. PORT HEDLAND 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	6.5	7.5	5.5	4.2	190.0	42.0	39.0	25.2								
	B1	16.4	12.6	12.4	7.1	236.0	33.0	29.0	19.8					1.0	0.0	0.0	0.0
	B2	18.3	13.8	11.3	7.3	241.7	31.3	25.7	19.2	1.0	0.0	0.0	0.0	1.3	1.7	0.3	0.7
	C2	123.2	45.8	46.2	30.7	302.8	19.2	23.8	14.8	171.3	21.8	20.3	10.9	182.4	24.6	23.4	12.7
	C4	5.1	6.9	4.1	3.2	196.8	38.3	38.8	24.7								
	C5	31.3	18.8	16.3	12.0	256.6	28.4	21.6	17.0	11.3	15.7	6.3	6.3	15.8	13.2	7.8	7.3
Female - Unacc	A1	52.7	29.3	25.7	18.1	272.4	23.6	22.4	15.5								
	B1	92.9	42.1	35.9	24.9	292.7	19.3	22.7	13.3					1.0	0.0	0.0	0.0
	B2	100.0	40.0	38.0	26.1	295.8	19.3	23.8	14.5	1.0	0.0	0.0	0.0	1.3	1.7	0.3	0.7
	C2	253.1	25.9	25.1	18.1	340.2	14.8	16.2	9.9	224.8	33.3	24.8	16.1	241.8	36.3	23.8	17.7
	C4	40.4	21.6	20.4	15.3	273.5	22.5	23.5	15.4								
	C5	138.7	41.3	49.7	29.2	306.5	22.5	25.5	15.0	11.3	15.7	6.3	6.3	15.8	13.2	7.8	7.3

TABLE 39. PORT HEDLAND 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1					22.3	24.7	15.3	11.2								
	B1	1.0	0.0	0.0	0.0	48.6	33.4	24.6	18.6								
	B2	1.0	0.0	0.0	0.0	53.9	34.1	28.9	20.0								
	C2	10.7	20.3	9.7	8.0	126.7	52.3	46.7	31.1	28.9	20.1	12.9	9.6	36.3	21.7	15.3	10.3
	C4					23.9	26.1	14.9	11.8								
	C5	1.0	0.0	0.0	0.0	73.8	38.2	34.8	24.8								
Male - Unacc	A1	1.0	0.0	0.0	0.0	74.9	39.1	34.9	24.1								
	B1	2.7	3.3	1.7	1.6	96.2	42.8	40.2	27.5								
	B2	3.0	3.0	2.0	1.6	100.5	45.5	43.5	28.0								
	C2	42.5	36.5	22.5	17.9	177.9	41.1	48.9	29.5	29.0	20.0	13.0	9.7	36.5	21.5	15.5	10.3
	C4	1.0	0.0	0.0	0.0	77.1	37.9	36.1	24.3								
	C5	5.3	7.7	3.3	3.3	117.8	46.2	46.8	29.2								

TABLE 39. PORT HEDLAND 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	1.0	0.0	0.0		30.9	30.1	15.9	13.6								
	B1	1.0	0.0	0.0	0.0	64.8	37.3	31.8	23.7								
	B2	1.0	0.0	0.0	0.0	70.3	37.8	34.3	24.4								
	C2	14.1	20.9	12.1	9.2	137.9	51.1	50.9	30.7	28.9	20.1	12.9	9.6	36.3	21.7	15.3	10.3
	C4					35.0	35.0	17.0	15.4								
	C5	1.5	1.5	0.5	0.8	82.2	39.8	37.2	25.3								
Female - Unacc	A1	2.8	3.2	1.8	1.6	96.8	45.2	39.8	27.5								
	B1	6.3	11.7	5.3	4.6	125.2	49.8	46.2	30.1								
	B2	7.6	11.4	6.6	5.1	128.6	50.4	46.6	30.5								
	C2	79.1	39.9	39.1	26.3	202.1	44.9	44.1	28.4	56.7	27.3	25.7	18.6	75.8	25.2	34.8	20.8
	C4	1.8	1.3	0.8	0.8	99.4	45.6	42.4	27.5								
	C5	14.8	13.3	10.8	7.0	145.3	46.7	49.3	29.9								

TABLE 40. PORT HEDLAND 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside – Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	17.0	12.0	13.0	7.2	236.3	33.7	29.3	19.8	3.3	3.8	2.3	2.1	4.6	4.4	3.6	2.6
	B1	39.8	26.2	23.8	15.7	263.3	25.7	19.3	15.8	61.6	18.4	23.6	11.8	71.9	14.1	26.9	12.4
	B2	44.8	29.3	24.8	17.7	266.5	24.5	20.5	15.6	71.6	12.4	29.6	13.0	82.6	15.4	25.6	12.8
	C2	182.9	42.1	46.9	28.2	320.6	19.4	20.6	12.9	257.4	35.6	26.4	15.7	268.4	34.6	24.4	15.1
	C4	11.6	11.4	8.6	5.7	241.9	32.1	25.9	19.2	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	C5	67.3	36.7	32.3	22.5	279.5	20.5	23.5	15.3	118.6	15.4	30.6	11.7	131.1	18.9	30.1	12.4
Male - Unacc	A1	67.2	36.8	30.2	20.3	280.8	20.3	22.8	14.4	3.3	3.8	2.3	2.1	4.6	4.4	3.6	2.6
	B1	118.0	42.0	43.0	28.1	301.2	19.8	23.2	14.9	61.6	18.4	23.6	11.8	71.9	14.1	26.9	12.4
	B2	126.3	43.7	48.3	30.2	303.6	19.4	22.6	15.3	71.6	12.4	29.6	13.0	82.6	15.4	25.6	12.8
	C2	274.8	22.2	23.8	15.7	345.0	14.0	15.0	9.4	296.9	25.1	17.9	12.3	313.5	22.5	16.5	12.8
	C4	52.7	29.3	25.7	18.1	281.3	19.8	22.3	14.2	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	C5	163.5	42.5	50.5	29.5	314.6	18.4	23.6	14.3	118.6	15.4	30.6	11.7	131.1	18.9	30.1	12.4

TABLE 40. PORT HEDLAND 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside – Sun				Inside - Dbl Brk Slb Flr				Inside - Brk Ven Slb Flr			
		Average	Max Dev +	Max Dev -	Std Dev	Average	Max Dev +	Max Dev -	Std Dev	Average	Max Dev +	Max Dev -	Std Dev	Average	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	24.0	16.0	14.0	9.7	249.3	27.8	22.3	17.6	3.3	3.8	2.3	2.1	4.6	4.4	3.6	2.6
	B1	50.9	29.1	24.9	19.0	271.8	23.2	20.8	15.3	61.6	18.4	23.6	11.8	71.9	14.1	26.9	12.4
	B2	57.0	32.0	30.0	20.5	274.3	22.7	23.3	15.9	71.6	12.4	29.6	13.0	82.6	15.4	25.6	12.8
	C2	202.4	38.6	40.4	26.5	327.3	19.8	18.3	12.8	257.4	35.6	26.4	15.7	268.4	34.6	24.4	15.1
	C4	16.8	12.3	12.8	7.0	251.3	28.7	22.3	17.8	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	C5	82.0	43.0	39.0	25.6	286.8	18.2	22.8	14.1	118.6	15.4	30.6	11.7	131.1	18.9	30.1	12.4
Female - Unacc	A1	119.1	43.9	45.1	29.4	301.2	19.8	24.2	14.8	3.3	3.8	2.3	2.1	4.6	4.4	3.6	2.6
	B1	175.5	39.5	45.5	26.6	319.8	20.2	20.8	13.1	62.8	17.3	23.8	11.5	74.3	12.8	27.3	12.3
	B2	182.1	38.9	45.1	26.1	321.7	20.3	19.7	12.8	74.0	11.0	30.0	13.0	85.7	15.3	27.7	13.4
	C2	318.8	18.2	20.8	13.3	352.9	11.1	10.9	7.6	362.3	3.7	7.3	3.3	364.0	2.0	3.0	1.6
	C4	94.9	41.1	36.9	25.1	300.7	20.3	23.7	14.6	1.0	0.0	0.0		1.0	0.0	0.0	0.0
	C5	215.4	32.6	38.4	22.4	331.1	17.9	20.1	11.8	133.3	19.7	39.3	15.7	150.8	22.3	42.8	17.2

Obviously outdoors activity in Port Hedland will not be possible on very many days. Work in industrial buildings must similarly be impossible for considerable periods. Table 40 suggests that conditions indoor's even in the best types of housing will often be most uncomfortable should air conditioning or electrical supply fail, as can often happen on days of extreme heat.

Conditions in Port Hedland will be most extreme; it is probable that habitation of this and similarly located cities may not be economically viable for most of the time.

13.2.6 Sydney

Tables 41 and 42 show numbers of dangerous days that would be experienced for predicted 2070 conditions and for the period 1990 –2001 respectively. Table 43 gives days on which heat would be stored and core body temperature would rise uncontrollably for predicted 2070 conditions.

TABLE 41. SYDNEY 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside – Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male – Acc	A1	1.5	0.5	0.5	0.5	7.8	6.3	6.8	3.8								
	B1	1.3	0.7	0.3	0.5	13.3	9.7	10.3	6.2								
	B2	1.7	0.3	0.7	0.5	14.3	9.8	11.3	6.3					1.0	0.0	0.0	
	C2	11.3	21.7	9.3	10.2	35.4	12.6	11.4	8.5	37.4	14.6	15.4	8.3	64.8	18.3	21.8	11.9
	C4	2.0	0.0	0.0		6.7	5.3	5.7	3.2								
	C5	1.5	0.5	0.5	0.5	18.8	9.3	13.8	7.1					1.0	0.0	0.0	0.0
Male – Unacc	A1	1.4	0.6	0.4	0.5	18.3	11.7	13.3	6.8								
	B1	1.9	1.1	0.9	0.8	24.6	15.4	15.6	7.7								
	B2	2.0	2.0	1.0	1.0	25.6	14.4	16.6	8.0					1.0	0.0	0.0	
	C2	16.2	19.8	11.2	9.8	57.3	20.8	21.3	12.0	37.5	14.5	15.5	8.3	65.0	18.0	22.0	12.0
	C4	1.5	0.5	0.5	0.5	16.8	11.2	11.8	6.3								
	C5	2.9	2.1	1.9	1.2	31.2	14.8	18.2	8.9					1.0	0.0	0.0	0.0

TABLE 41. SYDNEY 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside – Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female – Acc	A1	1.5	0.5	0.5	0.5	10.2	7.8	7.2	5.0								
	B1	1.7	0.3	0.7	0.5	16.0	9.0	11.0	6.2								
	B2	1.5	0.5	0.5	0.5	16.8	9.3	11.8	6.3					1.0	0.0	0.0	
	C2	11.4	21.6	9.4	9.8	39.3	13.7	11.3	8.7	37.4	14.6	15.4	8.3	64.8	18.3	21.8	11.9
	C4	1.5	0.5	0.5	0.5	8.6	7.4	6.6	4.4								
	C5	1.4	0.6	0.4	0.5	21.3	11.7	16.3	7.4					1.0	0.0	0.0	0.0
Female - Unacc	A1	2.0	2.0	1.0	1.0	24.7	15.3	15.7	7.8								
	B1	3.4	1.6	1.4	1.3	31.8	16.2	18.8	8.3								
	B2	3.7	2.3	2.7	1.6	33.1	15.9	19.1	8.8					1.0	0.0	0.0	
	C2	23.7	18.3	13.7	9.4	72.9	21.1	17.9	12.3	46.0	17.0	14.0	8.9	95.8	15.2	18.8	12.3
	C4	1.8	1.2	0.8	0.7	22.8	17.2	14.8	7.6								
	C5	4.8	3.3	3.8	2.1	39.8	16.3	18.8	9.1					1.0	0.0	0.0	0.0

TABLE 42. SYDNEY 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1					1.5	0.5	0.5	0.5								
	B1					1.8	1.2	0.8	0.7								
	B2					1.8	1.2	0.8	0.7								
	C2	2.3	1.7	1.3	1.2	5.1	2.9	4.1	2.8	1.0	0.0	0.0		1.6	1.4	0.6	0.7
	C4					1.3	0.8	0.3	0.4								
	C5					2.6	1.4	1.6	1.2								
Male - Unacc	A1					2.8	1.3	1.8	1.1								
	B1					3.9	3.1	2.9	1.8								
	B2					4.1	2.9	3.1	1.9								
	C2	1.8	2.2	0.8	1.1	7.7	5.3	6.7	4.0	1.0	0.0	0.0		1.6	1.4	0.6	0.7
	C4					2.4	1.6	1.4	1.0								
	C5	1.0	0.0	0.0	0.0	4.5	3.5	3.5	2.6								

TABLE 42. SYDNEY 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1					1.4	0.6	0.4	0.5								
	B1					2.0	2.0	1.0	1.0								
	B2					2.1	1.9	1.1	1.1								
	C2	2.3	1.7	1.3	1.2	5.1	3.9	4.1	2.8	1.0	0.0	0.0		1.6	1.4	0.6	0.7
	C4					1.4	0.6	0.4	0.5								
	C5					3.3	2.8	2.3	1.6								
Female - Unacc	A1					4.0	2.0	3.0	1.8								
	B1	1.5	0.5	0.5	0.5	4.6	3.4	3.6	2.5								
	B2	1.5	0.5	0.5	0.5	4.8	3.2	3.8	2.4								
	C2	2.7	3.3	1.7	1.8	9.6	8.4	7.6	5.1	4.0	2.0	2.0	1.3	10.1	9.9	8.1	5.1
	C4					4.3	1.8	2.3	1.5								
	C5	1.3	0.8	0.3	0.4	5.1	2.9	4.1	2.4								

TABLE 43. SYDNEY 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside – Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	1.7	0.3	0.7	0.5	16.4	8.6	11.4	6.3					1.0	0.0	0.0	0.0
	B1	2.0	2.0	1.0	1.2	22.8	14.3	15.8	7.9	1.3	0.7	0.3	0.5	4.2	4.8	2.2	2.4
	B2	2.5	1.5	1.5	1.3	23.6	14.4	16.6	8.2	1.3	1.7	0.3	0.7	5.6	4.4	4.6	2.9
	C2	28.3	41.7	23.3	25.8	51.8	22.3	18.8	12.0	142.9	23.1	13.9	12.4	182.6	21.4	12.6	11.7
	C4	1.7	0.3	0.7	0.5	15.0	10.0	11.0	6.2					1.0	0.0	0.0	
	C5	4.5	10.5	3.5	4.3	29.3	12.8	13.3	8.6	7.3	6.8	6.3	3.8	20.9	10.1	11.9	6.3
Male - Unacc	A1	2.2	1.8	1.2	0.9	27.9	14.1	15.9	7.8					1.0	0.0	0.0	0.0
	B1	4.4	2.6	3.4	1.8	37.1	15.9	16.1	8.7	1.3	0.7	0.3	0.5	4.2	4.8	2.2	2.4
	B2	4.8	3.3	3.8	2.0	38.1	14.9	16.1	8.5	1.3	1.7	0.3	0.7	5.6	4.4	4.6	2.9
	C2	44.3	45.8	25.3	24.6	80.5	19.5	19.5	12.5	150.1	23.9	13.1	11.8	201.9	13.1	16.9	8.6
	C4	2.0	2.0	1.0	1.0	26.3	15.8	16.3	7.9					1.0	0.0	0.0	
	C5	7.5	8.5	5.5	4.0	46.6	17.4	19.6	10.6	7.3	6.8	6.3	3.8	20.9	10.1	11.9	6.3

TABLE 43. SYDNEY 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside – Sun				Inside - Brk Ven Tmb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Female - Acc	A1	1.4	0.6	0.4	0.5	18.4	10.6	13.4	6.9					1.0	0.0	0.0	0.0
	B1	2.1	2.9	1.1	1.2	25.2	14.8	15.2	8.1	1.3	0.7	0.3	0.5	4.2	4.8	2.2	2.4
	B2	2.4	2.6	1.4	1.4	26.1	13.9	15.1	8.1	1.3	1.7	0.3	0.7	5.6	4.4	4.6	2.9
	C2	30.4	42.6	24.4	25.6	56.3	21.7	19.3	11.8	142.9	23.1	13.9	12.4	182.6	21.4	12.6	11.7
	C4	1.7	0.3	0.7	0.5	17.1	9.9	12.1	6.2					1.0	0.0	0.0	
	C5	4.5	10.5	3.5	4.1	32.2	13.8	13.2	8.7	7.3	6.8	6.3	3.8	20.9	10.1	11.9	6.3
Female - Unacc	A1	4.3	2.7	3.3	1.8	36.4	16.6	17.4	8.6					1.0	0.0	0.0	0.0
	B1	6.1	4.9	5.1	2.6	48.8	17.2	24.8	11.8	1.3	0.8	0.3	0.4	4.6	4.4	1.6	2.2
	B2	6.9	5.1	5.9	3.2	49.9	16.1	24.9	11.6	1.4	1.6	0.4	0.7	5.6	4.4	4.6	2.9
	C2	69.3	45.7	36.3	30.4	99.3	25.7	21.3	14.8	244.5	10.5	13.5	7.6	341.0	9.0	11.0	6.8
	C4	3.7	2.3	1.7	1.3	33.8	16.2	19.8	8.9					1.0	0.0	0.0	
	C5	12.0	8.0	8.0	5.6	60.0	20.0	22.0	11.9	8.8	5.3	7.8	4.0	23.9	15.1	11.9	7.6

Results for Sydney and Liverpool indicate that extremely dangerous and difficult conditions will be experienced by large numbers of people on a quite regular basis if the C.S.I.R.O's predictions eventuate.

13.2.7 Townsville

Tables 44 and 45 list numbers of dangerous days that would be experienced for predicted 2070 conditions and for the period 1990 – 2001 respectively. Table 46 lists the numbers of days on which heat would be stored and core body temperature would rise uncontrollably for predicted 2070 conditions.

TABLE 44. TOWNSVILLE 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside – Sun				Inside - Brk Ven Slb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	1.0	0.0	0.0		30.1	17.9	19.1	11.2					1.0	0.0	0.0	
	B1	1.0	0.0	0.0	0.0	65.0	37.0	32.0	20.0					2.8	3.2	1.8	1.8
	B2	1.5	0.5	0.5	0.5	74.7	36.3	35.7	21.5	1.7	0.3	0.7	0.5	4.0	4.0	3.0	2.3
	C2	26.1	26.9	17.1	15.6	206.3	17.8	22.3	12.4	199.3	61.8	35.3	24.8	263.3	43.8	27.3	17.5
	C4	1.0	0.0	0.0		32.3	17.7	19.3	11.7								
	C5	2.7	4.3	1.7	2.4	123.0	27.0	45.0	23.3	5.7	7.3	4.7	3.9	27.0	16.0	19.0	11.9
Male - Unacc	A1	1.5	0.5	0.5	0.5	123.2	30.8	42.2	23.3					1.0	0.0	0.0	
	B1	2.0	1.0	1.0	0.8	160.8	30.3	29.8	18.0					2.8	3.2	1.8	1.8
	B2	2.0	1.0	1.0	0.7	165.9	31.1	26.9	16.7	1.7	0.3	0.7	0.5	4.0	4.0	3.0	2.3
	C2	57.1	39.9	29.1	20.3	265.8	25.3	22.8	15.7	199.3	61.8	35.3	24.8	263.4	43.6	27.4	17.6
	C4	1.0	0.0	0.0	0.0	126.0	30.0	38.0	22.8								
	C5	3.8	6.2	2.8	3.3	187.7	22.3	22.7	14.3	5.7	7.3	4.7	3.9	27.0	16.0	19.0	11.9

TABLE 44. TOWNSVILLE 2070 – DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside – Shade				Outside – Sun				Inside - Brk Ven Slb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1	1.0	0.0	0.0	0.0	37.0	20.0	20.0	12.4					1.0	0.0	0.0	
	B1	1.0	0.0	0.0	0.0	96.4	35.6	41.4	23.2					2.8	3.2	1.8	1.8
	B2	1.5	0.5	0.5	0.5	106.0	33.0	44.0	23.6	1.7	0.3	0.7	0.5	4.0	4.0	3.0	2.3
	C2	27.3	25.8	16.3	15.8	220.4	16.6	16.4	11.8	199.3	61.8	35.3	24.8	263.3	43.8	27.3	17.5
	C4	1.0	0.0	0.0		41.3	22.7	22.3	14.5								
	C5	2.8	4.2	1.8	2.3	137.3	27.8	40.3	22.4	5.7	7.3	4.7	3.9	27.0	16.0	19.0	11.9
Female - Unacc	A1	2.3	0.7	0.3	0.5	160.7	31.3	27.7	17.6					1.0	0.0	0.0	
	B1	3.7	4.3	2.7	2.6	195.1	22.9	21.1	13.7					2.8	3.2	1.8	1.8
	B2	2.7	5.3	1.7	2.3	199.8	23.2	20.8	14.3	1.7	0.3	0.7	0.5	4.0	4.0	3.0	2.3
	C2	137.8	23.2	48.8	23.7	294.8	26.3	27.8	16.7	202.4	59.6	35.4	24.2	317.8	21.2	29.8	15.6
	C4	2.0	0.0	0.0	0.0	163.5	31.5	25.5	16.7								
	C5	7.1	6.9	6.1	4.5	224.2	19.8	22.2	13.3	5.7	7.3	4.7	3.9	27.0	16.0	19.0	11.9

TABLE 45. TOWNSVILLE 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Slb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Male - Acc	A1					2.2	1.8	1.2	1.1								
	B1					2.9	2.1	1.9	1.6								
	B2					3.1	3.9	2.1	2.1								
	C2	6.4	10.6	5.4	5.0	8.8	15.3	7.8	7.2	15.4	14.6	14.4	8.8	53.6	34.4	33.6	15.3
	C4																
	C5																
Male - Unacc	A1	1.0	0.0	0.0		3.9	5.1	2.9	2.7								
	B1	1.0	0.0	0.0		4.2	4.8	3.2	3.0								
	B2	1.0	0.0	0.0		5.3	4.7	4.3	3.6								
	C2	6.8	11.2	5.8	5.4	19.5	17.5	15.5	10.2	15.4	14.6	14.4	8.8	53.6	34.4	33.6	15.3
	C4																
	C5																

TABLE 45. TOWNSVILLE 1990 - 2001 - DAYS WHEN TC REACHES 40°C WITHIN 2 HOURS

Activity & Gender		Outside - Shade				Outside - Sun				Inside - Brk Ven Slb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev	Aver-age	Max Dev +	Max Dev -	Std Dev
Female - Acc	A1					2.5	2.5	1.5	1.4								
	B1					3.1	3.9	2.1	2.1								
	B2	1.0	0.0	0.0		3.9	6.1	2.9	3.1								
	C2	6.4	10.6	5.4	5.0	10.0	14.0	9.0	7.3	15.4	14.6	14.4	8.8	53.6	34.4	33.6	15.3
	C4																
	C5																
Female - Unacc	A1	1.0	0.0	0.0		4.8	5.2	3.8	3.2								
	B1	1.0	0.0	0.0	0.0	6.3	7.7	5.3	4.1								
	B2	1.0	0.0	0.0	0.0	6.7	7.3	5.7	4.4								
	C2	7.8	15.3	6.8	6.8	36.8	35.2	24.8	16.5	16.1	13.9	10.1	8.5	77.8	24.3	37.8	18.9
	C4																
	C5																

TABLE 46. TOWNSVILLE 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Slb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Male - Acc	A1	2.2	2.8	1.2	1.7	100.3	32.8	40.3	22.5	3.3	0.8	2.3	1.3	9.4	8.6	7.4	5.5
	B1	6.4	10.6	5.4	5.0	150.5	26.5	34.5	19.7	40.6	27.4	23.6	13.3	99.6	43.4	27.6	17.9
	B2	6.9	12.1	5.9	5.5	154.8	25.3	33.8	19.0	50.3	40.8	33.3	17.7	117.9	53.1	25.9	21.1
	C2	58.2	47.8	33.2	25.4	253.5	23.5	19.5	13.3	315.0	23.0	18.0	11.8	342.8	14.2	14.8	8.0
	C4	1.0	0.0	0.0	0.0	110.9	35.1	47.9	24.8	1.3	0.7	0.3	0.5	3.2	2.8	2.2	1.9
	C5	12.5	16.5	9.5	8.6	180.3	25.8	25.3	15.3	116.4	61.6	29.4	24.4	189.3	55.7	32.3	23.0
Male - Unacc	A1	2.6	3.4	1.6	1.7	179.0	27.0	25.0	15.6	3.3	0.8	2.3	1.3	9.4	8.6	7.4	5.5
	B1	9.1	13.9	7.1	6.9	213.7	18.3	20.7	12.1	40.6	27.4	23.6	13.3	99.6	43.4	27.6	17.9
	B2	10.3	13.7	8.3	7.3	218.7	19.3	18.7	12.2	50.3	40.8	33.3	17.7	117.9	53.1	25.9	21.1
	C2	183.3	32.8	39.3	24.7	306.6	29.4	27.6	17.1	318.8	20.3	15.8	10.7	360.5	4.5	12.5	4.5
	C4	2.3	0.7	0.3	0.5	179.3	28.8	25.3	16.1	1.3	0.7	0.3	0.5	3.2	2.8	2.2	1.9
	C5	21.1	21.9	15.1	11.4	241.3	19.8	20.3	12.5	116.4	61.6	29.4	24.4	189.3	55.7	32.3	23.0

TABLE 46. TOWNSVILLE 2070 – DAYS ON WHICH HEAT WOULD BE STORED

Activity & Gender		Outside – Shade				Outside - Sun				Inside - Brk Ven Slb Flr				Inside - Tmb&Fbr Tmb Flr			
		Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev	Aver-age	Max Dev		Std Dev
			+	-			+	-			+	-			+	-	
Female - Acc	A1	2.2	2.8	1.2	1.7	125.1	28.9	43.1	23.2	3.3	0.8	2.3	1.3	9.4	8.6	7.4	5.5
	B1	6.6	11.4	5.6	5.3	163.9	26.1	26.9	16.7	40.6	27.4	23.6	13.3	99.6	43.4	27.6	17.9
	B2	7.1	11.9	6.1	5.8	168.4	25.6	29.4	16.5	50.3	40.8	33.3	17.7	117.9	53.1	25.9	21.1
	C2	71.0	54.0	34.0	26.7	264.6	25.4	19.6	14.8	315.0	23.0	18.0	11.8	342.8	14.2	14.8	8.0
	C4	1.0	0.0	0.0	0.0	128.4	27.6	45.4	23.3	1.3	0.7	0.3	0.5	3.2	2.8	2.2	1.9
	C5	12.9	20.1	9.9	9.3	191.6	22.4	22.6	14.1	116.4	61.6	29.4	24.4	189.3	55.7	32.3	23.0
Female - Unacc	A1	4.6	6.4	3.6	3.2	212.7	19.3	19.7	12.8	3.3	0.8	2.3	1.3	9.4	8.6	7.4	5.5
	B1	20.3	21.8	14.3	10.1	248.1	23.9	19.1	14.3	40.6	27.4	23.6	13.3	99.9	43.1	27.9	18.2
	B2	24.4	21.6	16.4	11.3	252.3	25.8	18.3	14.4	50.3	40.8	33.3	17.7	118.5	52.5	26.5	21.0
	C2	259.9	24.1	21.9	17.3	331.4	18.6	24.4	13.1	362.2	3.8	11.2	4.1	364.6	1.4	6.6	2.1
	C4	3.0	5.0	2.0	2.5	211.7	20.3	19.7	13.0	1.3	0.7	0.3	0.5	3.2	2.8	2.2	1.9
	C5	61.5	40.5	36.5	22.9	272.8	24.2	24.8	17.0	116.9	61.1	29.9	24.4	191.9	54.1	31.9	22.5

Conditions for Townsville do not appear to be as extreme as those obtaining at Port Hedland even though at similar latitudes, even so they may be extremely difficult; many of the comments made for Port Hedland are applicable to Townsville. The lower numbers of dangerous days found for Townsville could also be partially due to the missing and incomplete data as well as the different climate regime.

14 EXTREME EVENTS

Initially records for periods of about 50 years (see table 18) were examined before it was decided to examine in detail only the period 1990- 2001. Some of the most severe days in the extended record did not occur in the 1990-2001 period, some of these in the records for Katherine, Perth, Port Hedland, Sydney and Townsville, after being adjusted to 2070 conditions, were examined for their effect on the subjects of our previous analysis, semi clothed, with the following results: -

14.1 Katherine

18/11/59 – Acclimated men and women standing in the shade would store heat. An unacclimated man standing in the shade would reach a core body temperature of 42°C in one hour 19 minutes.

14,16/11/62 – Subjects would reach a core body temperature of 42°C in 1 hour 45 minutes if standing in the shade. These were humid days when sweat rates are unimportant.

15/11/62– An acclimated man would store heat if standing in the shade. An unacclimated man standing in the shade would reach a core body temperature of 42º C in one hour 45 minutes.

14.2 Perth

18/01/61 – An acclimated man sitting in the shade would reach a core body temperature of 42°C in one hour and 5 minutes.

24/01/61 – An acclimated man sitting in the shade would have reached a core body temperature of 42°C in one hour 53 minutes.

14.3 Port Hedland

27/12/54 – An acclimated man sitting in the shade would reach a core body temperature of 42ºC in 26 minutes and 44ºC in 32 minutes.

22/12/81 - An acclimated man sitting in the shade would reach a core body temperature of 42ºC in 29 minutes and 44ºC in 36 minutes.

24/01/85 – An acclimated man sitting in the shade would reach a core body temperature of 42ºC in one hour and 10 minutes, and 44ºC in one hour 26 minutes.

14.4 Sydney

21/12/53 – An acclimated man sitting in the shade would have reached a core body temperature of 42ºC in one hour 16 minutes.

25/11/82 – An acclimated man sitting in the shade would reach a core body temperature of 42ºC in 61 minutes.

14.5 Townsville

13/02/69 – An acclimated man sitting in the shade would store heat and an unacclimated man sitting in the shade would reach a core body temperature of 42ºC in one hour 16 minutes.

30/12/84 – An **acclimated** man standing in the shade would reach a core body temperature of 42º C in one hour 40 minutes. An unacclimated man would reach a core body temperature of 42ºC in one hour 5 minutes.

Statistics would suggest that if longer return periods were contemplated conditions of greater severity might be experienced. In the case of Sydney the highest maximum temperature ever recorded at the Bureau's regional office was 45.3ºC on 14/11/1939, a day well remembered by the author. This would translate to a temperature of 51.3ºC when adjusted; if this were to occur accompanied with 30 kph winds the results could be devastating.

15 SUMMARY AND CONCLUSIONS

The work described in this paper was aimed at answering the question, will global warming as projected by the CSIRO [1] for Australia in 2070, cause conditions such that, locally and episodically human life will be difficult if not impossible?

In order to obtain an answer it was necessary to adjust the climate record in the study period. This was done by adjustment of recorded ambient temperatures to predicted 2070 conditions. All other climate variables were adopted unchanged. Available methods of assessing the rates of heat exchange between the environment and a human subject, both outside in shade and sun, in and out of the wind and inside in various house types were examined and methods selected and developed that were considered to be the most appropriate for the available data sets.

In order to assess the effect of extreme dry hot conditions a method had to be selected to assign evaporated sweat rates to persons experiencing those conditions. Adjustment factors for the available climate data [2] were developed to enable conditions, of temperature and humidity to be predicted inside four different house types.

Experimental data were obtained and a correlation developed to enable fully exposed unventilated wet bulb temperatures to be calculated from the available data for use in calculating environmental cooling/warming powers.

Using these methods, applied to suitable data, environmental cooling or indeed, warming powers, for both humid and dry heat were calculated. These were applied to male and female subjects (with Caucasian type skin characteristics), in several clothing states, with known rates of metabolic heat production and acclimation status, to determine their rate of change of heat storage (+ or -) and from this the length of exposure to those conditions for certain core body temperatures to be reached.

From the literature survey the effects of both abnormally high core body temperature and dehydration have been established and are reported, together with the upper limits, which would in all likelihood result in death.

Persons most at risk are the very young and the very old. They have either impaired or undeveloped body temperature sensing mechanisms, which means, in the case of the elderly they very often don't activate cooling systems or take evasive action appropriately, and the very young cannot adequately communicate cause of distress and appropriate adult intervention can come too late. Others at greater risk are people with certain diseases and those using certain medicines, drugs or alcohol, some information about which is included in the report.

In order to answer the question raised at the beginning, data for the twelve-year period 1990-2001, for seven Australian cities, Alice Springs, Liverpool, Melbourne, Perth, Port Hedland Sydney and Townsville, were adjusted for 2070 conditions to create a synthetic data set and the effect of these synthetic data on four subjects determined for three clothing states, outside in shade and sun, in and out of the wind and indoors in four different types of houses. These subjects were tested for six different activity levels over a range of metabolic rates from 147 - 997 kJ/m^2 hr. Results are for daylight hours only and are certainly an under estimate, especially for northern cities and even Sydney, Liverpool and possibly even Perth.

Full results are shown in appendices 4-35. Selected results are shown as an illustration at tables 26 to 45.

Results were obtained for dangerous days resulting from exposure to both the adjusted data and the base - as recorded – data, for comparison. Also the number of days on which subjects would store body heat for both 2070 and 1990-2001 conditions were obtained and a statistical summary of all results prepared.

No attempt has been made to estimate numbers of deaths, as has been done in other studies, [41,44] the reason being that on a day when a given level of activity, would result in a Tc of 42° C in any time period, possibly all people engaged in such activity would die. However, unless circumstances prohibit such, most people would desist from high levels of activity at such times. It should be mentioned that studies that make estimates of probable numbers of deaths by linear extrapolation from known increases in death rate per degree rise in temperature must become unreliable as core body temperatures exceed certain limits.

The methods developed here enables a subject's core body temperature to be estimated for any environmental condition, any rate of metabolic heat production and degree of exposure. The effect of that temperature on an individual will be different for each individual as suggested above. Except there is a core body temperature above which no one can survive regardless of fitness, age, or degree of acclimation.

Returning to the original question, **Yes!** In all cities studied, the climate conditions predicted for 2070 will result in episodes when human life will be most difficult and indeed often impossible to sustain.

The least affected city will be Melbourne, where an acclimated male would experience a rise in core body temperature to 40°C, within one hour, only if working in the shade at a metabolic rate of approximately 997 Kj/m^2.hr.

Indoors he would be safe, except if working at this rate in all studied housing types and also if exercising at the lesser rate of 587 $Kj/m^2.hr$, in a timber house with timber floor. These rates relate to the specific activities studied, the lower limits for danger could be slightly lower. Work at higher rates would result in many more dangerous days. Even for Melbourne on many days exposure to sun would result in elevation of Tc to 40°C within one hour when engaged in all the activities tested. Furthermore because they would be acclimated to a less stressful environment, a severe heat wave could have a devastating effect on Melbournians, similar to that experienced by inhabitants of Europe during summer[62] 2003.

In all the other cities there are very many days when outdoors activity will be quite impossible. This is especially so in the northern cities, but Sydney, Liverpool and Perth will experience many dangerous days both outdoors in shade or sun and indoors.

Study of the results shows that dangerous days have also occurred in the actual 1990 – 2001 period. People who cope with these conditions do so by reducing their metabolic rates i.e. by either ceasing to work altogether, or by taking frequent rest breaks. Or by removing themselves from the dangerous environment either by going indoors or altering the conditions using mechanical means. These can often fail on days of high demand as exemplified in Melbourne and Adelaide last year and Perth this year (2004). Also of course at present, many susceptible people die prematurely during heat waves as described above.

The results also list numbers of days when heat would be stored. These results include both the dangerous days and days on which body temperature would merely rise, perhaps for a limited period without reaching a dangerous level. These are days when the activity would have to cease and respite sought, with major disruption to social and economic activity.

This study shows, that should CSIRO's projections eventuate, in the period post 2070 both the numbers and severity of dangerous conditions will escalate. This could result in very considerable loss of life, disruption to economic and social activity and extremely uncomfortable conditions for lengthy periods each summer. In fact existence in our tropical areas could become economically and practically impossible during summer.

Harmful effects will not be restricted to the human population as indicated in the paper, economic plants and animals can be seriously affected, similarly the native vegetation and animals can also be adversely affected.

The importance of acclimation and appropriate housing in helping to protect human populations from heat stress is well illustrated in the Appendices 4 – 35 and tables 26 – 46.

People who live and work in air-conditioned houses and offices may not achieve an adequate degree of acclimation and would be at risk if electric power fails as a result of overload, or if engaged intermittently in outdoors activity.

This work will have achieved its objective if it leads us to have a more realistic understanding of how seriously life may be affected by global warming, and to devise and implement appropriate strategies to limit the disaster we may be facing and how to best survive. It is hoped that the concepts used here will be of help and that they will be further refined and improved by other workers.

Additional work needs to be done to determine evaporated sweat rates for a wider range of subjects, clothing state, activity, and environmental conditions. So the effect of dry heat can be more accurately assessed.

16 ACKNOWLEDGEMENTS

I have received help from very many people who are largely responsible for any merit this work may have. The faults are all mine. I have tried to acknowledge all sources from which I have drawn information, data, ideas etc, in the reference list. However, there are a number of people to whom I am particularly grateful, these include, Karen Fairbrass who formatted the report, John Relf for help with data, my son Robert Forbes for help with the vagaries of 'Excel', my son in law Greg Defina for help with computing methods and for developing the computer programme and calculating the results appendices, Dr Shane Maloney for encouragement, enlightening discussion and help in many areas, Mr John Cramb for help and for putting me right on several occasions, Professor Bernard and Mrs Catchpole for thermal house response data, and my internet mentors Professor Ken R Koehler, Dr David L Costill and Dr Angelo Delsante.

Jon Morris, Carol J Skinner, and Glen E Van Knowe for help with understanding the urban heat island effect and Albert Stocklein of the Building Research Association of New Zealand, there are many others.

17 REFERENCES

1. Climate Change Projections for Australia – CSIRO 2001.
2. Climate Records for Alice Springs, Liverpool, Melbourne, Perth Airport, Port Hedland, Sydney Airport and Townsville – Commonwealth Bureau of Meteorology.
3. Climate Atlas of Australia – Rainfall. Cmwlth.Bureau of Meteorology.2000.
4. The Physics Fact Book – Glenn Elert. elert@hypertextbook.com 1997.
5. Body Heat and Temperature Regulation – http://siu.edu/~tw3a/331temp.htm Revised 11/10.1996.
6. Hot Weather Management of Poultry – Kenneth E. Anderson and Thomas A. Carter. North Carolina State University. Revised 11/02/ 98 – http://www.ces.ncsu.edu/depts/poulsci/techinfo/4Pst30.htm
7. Heat Stress in Aviation. – Graham Bates – Aviation Medical Society of Australia and New Zealand – Vol 24 No. 2 – Broome 2000.
8. Heat Related Illnesses During Extreme Weather Emergencies – American Medical Association (Medical Science) Report 10 of the Council on Scientific Affairs (A-97) – http://www.ama-assn.org/ama/pub/article/2036-2522.html
9. Body Temperature Regulation – Kenneth R Koehler – 27/05/01 – http://www.rwc.uc.edu/koehler/biophysics/8d.html
10. Virtual Naval Hospital: Manual of Naval Preventive Medicine: Chapter 3 (3-12) - Assessment of Heat Stress. – http://www.vnh.org/PreventiveMedicine/Chapter3/3.12.html
11. Tables of Half-Hour Global Exposure (Tens of Kilo –Joules per square metre) – Comm. Bureau of Meteorology. Various years – Perth, Port Hedland and Sydney.
12. Global Solar Irradiance – Comm. Dept of Health – Radiation Unit Melbourne. Alice Springs and Townsville – for year 1999.

13. W. H. Terjung and Stella S-F Louie - Potential Solar Radiation Climates of Man. – Ann. Ass. American Geographers: 1971 - 61-3: 481-500.

14. Metabolism 2 – Exercise and Body Heat. - M. Maskrey, September 1999 – University of Tasmania – Faculty of Health Science – Lee.Weller@utas.edu.au

15. Energy Balance and Temperature Regulation – M.W.Stannier, L.E.Mount & J.Bligh. – Cambridge University Press – 1984.

16. DEA350: Ambient Environment: Thermal Regulation. – CUErgo (Cornell University Ergonomics Web)

17. Gases Dust and Heat in Mines. – K. Neville Moss. Charles Griffin and Company Ltd. – 1927.

18. Influence of Exercise Mode and Selected Ambient Conditions on Skin Temperature. – William C. Adams. – Ann. N.Y. Acad.Sci. 301: 110-127,1977

19. Physiological Defences Against Hyperthermia of Exercise – Ethan R. Nadel, C. Bruce Wenger, Michael F. Roberts, Jan A. J. Stolwijk, and Enzio Caferelli. – Ann. N.Y. Acad. Sciences 1977: 301 – 98 –109.

20. Acclimatization in a Hot, Humid Environment: Energy Exchange, Body Temperature, and Sweating. – D. Mitchell, L. C. Senay, C. H. Wyndham, A. J. van Rensburg, G. G. Rogers, and N. B. Strydom. – Journal of Applied Physiology Vol. 40 No. 5 – 1976.

21. Physiologic Limits to Work in the Heat and Evaporative Coefficient for Women. – E. Kamon and B. Avellini. Journal of Applied Physiology: Vol 41 No 1 July 1976.

22. Physiological and Biophysical Limits to Work in the Heat for Clothed Men and Women. – E. Kamon, B. Avellini and J. Krajewski. – Journal of Applied Physiology: Vol. 44:918 – 925: 1978.

23. Psychrometric Limits and Critical Evaporative Coefficients for Unacclimated Men and Women. – W. L. Kenney and M. J. Zeman – Journal of Applied Physiology 92: 2256 – 2263: 2002.

24. Frank SM, Raja SN, Bulcao CF & Goldstein DS 1999 Relative contribution of core and cutaneous temperatures to thermal comfort and autonomic responses in humans. Journal of Applied Physiology **86** 1588-1593.

25. Sweating: its Composition and Effects on Body Fluids. – D. L. Costill. – Ann. N. Y. Acad. Sciences. 1977, 301: 160 – 174.

26. Virtual Naval Hospital. Manual of Naval Preventive Medicine: chapter 3: Ventilation and Thermal Stress Ashore and Afloat: Section III. Physiological Principles. – 3-9 Effects of Heat. Modified June 2001 http://www.vnh.org/PreventiveMedicine/Chapter3/3.09html

27. Understanding Heat Stress. – www.uq.net.au/~zzsraffe/Articles_Papers/understanding_heat_stress.htm

28. Virtual Naval Hospital – Prevention of Heat Illness. http://www.vnh.org/HeatIllness/prevenhi.html

29. Gastric Emptying During Exercise: Effects of Heat Stress and Hypohydration – P. D. Neufer, A. J. Young and M. N. Sawka. – Eur. J. Appl. Physiol: (1989) 58: 433 – 439.

30. Gastric Emptying During Walking and Running: Effects of Various Exercise Intensity. – Eur. J. Appl. Physiol: (1989) 58: 440 – 445.

31. Savage, M.V. and G.L. Brengleman – Control of Skin Blood Flow in the Neutral Zone of Human Body Temperature Regulation. – Journal of Applied Physiology. 80:1249-1257, 1996

32. Basal Metabolism, Radiation, Convection and Vaporization at Temperatures of 22 to 35°C. Hardy, J.D. and E.F. Dubois. - Journal of Nutrition. 15:477-497, 1938

33. Environmental Factors and Exercise. – http://jan.ucc.nau.edu/~kkt/EXS300/Environmental_Factors.html

34. Near-Fatal Heat Stroke During the 1995 Heat Wave in Chicago. - Jane E Dematte, MD. Etal – Annals of Internal Medicine, August 1998. 129:173-181.

35. Hyperthermia and Hypothermia. – R. W. Besdine. – Chapter 67: Merck Manual of Geriatrics.

36. Hot Weather Response Plan – City of Toronto Council and Committees. – clerk@city.torontp.on.ca

37. The Hot Brain – C. V. Gisolfi and F. Mora. – The MIT Press Cambridge, Massachusetts London England. 2000.

38. Heat – Related Illnesses – M.W. Barrow, M.D., and K. A. Clark. D. O. – American Family Physician. – September 1, 1998.

39. Heat – Related Illnesses and Deaths – United States, 1994-1995. – MMWR Weekly June 30, 1995 / 44(25); 465-468. mmwrq@cdc.gov

40. A Climate Change Mammalian Population Collapse Mechanism. – Dewey M. McLean. – http://filebox.vt.edu/artsci/geology/mclean/Dinosaur_Volcano_Extinction/pages/grhskill.html

41. Daily Mortality in Relation to weather and Air Pollution in Christchurch New Zealand. – S. Hales, C. Salmond, T. Kjellstrom, and A. Woodward. Aust. And New Zealand Journal of Public Health 1999:Vol. 24 No. 1.

42. Fatalities Due to Weather Hazards. – B. Geerts and E. Linacre. – www.das.uwyo.edu/~geerts/cwx/notes/chap3/nat_hazard.htmml

43. Heatwave Hazard. – Kylie Andrews, - Natural Hazards Quarterly, December 1995, Vol. 1 Issue 2. NHRC@ocs1.ocs.mq.edu.au.

44. Human Health and Climate Change in Oceania: A Risk Assessment 2002. – A. McMichael and R. Woodruff. – National Centre for Epidemiology and Population Health. – A.N.U. Canberra. – 2003.

45. Impacts of Global Warming on Human Health: Heat Stress Related Mortality. – L. S. Kalkstein. – 1992. – in, Global Climate Change: Implications Challenges and Mitigation Measures, ed. S. K. Majumdar, L. S. Kalkstein, B. Yarnal, E. W. Miller, and L. M. Rosenfeld, 371-83. Easton, P.A.: The Pennsylvania Academy of Science.

46. John Cramb – Regional Manager: Climate and Consultancy. Western Australia – Bureau of Meteorology.

47. The Assessment of the Thermal Environment A Review. – R. K. McPherson. – British Journal of Industrial Medicine, 1962, 19:151.

48. Assessment of Thermal Stress – the essentials. – G. M. Budd. – Journal of Thermal Biology, (2001) – 371-374.

49. Wet Bulb Globe Temperature Index and Performance in Competitive Distance Runners. – D. J. McCann and W. C. Adams – Journal American College of Sports Medicine – 1997.

50. Heat Wave: Heat Index. – Allan Darling - National Weather Service Internet Weather Source. – http://weather.noaa.gov/weather/hwave.html

51. Management and Prevention of Heat Stress. – W.A. Dept. of Minerals and Energy.

52. The Influence of Radiant Heat and Air Movement on the Cooling of the Kata Thermometer. – T. Bedford and C. G. Warner. – (1933) J. Hyg. (Lond.), 33:330-348.

53. Specific Heat Capacities – Gamma Tau Associates Inc. 1998. – http://yesican.yorku.ca/home/sh_table.html

54. Lecture 41: Body Metabolism: Thermogenesis. – www.biology.iastate.edu/courses/zool%20355/lecture%2041

55. Energy Efficient Australian Housing 2nd Edition. – J.A.Ballinger. D. K. Prasad, D. Rudder. – National Solar architectural Research Unit. – Australian Government Publishing Service Canberra. 1997.

56. A Comparison of the Thermal Performance of Heavyweight and Lightweight Construction in Australian Dwellings. – P. J. Walsh, T. A. Gurr and E. R. Ballantyne. – Division of Building Research Technical Paper (Second Series) No. 44 – CSIRO, Australia 1982.

57. The Wise House. – T. Jenkins and J. James. – Rigby 1978.

58. Personal Communication. – Albert Stocklein. – Building Research Association New Zealand.

59. Associations Between Varying Magnitudes of the Urban Heat Island and the Synoptic Climatology in Melbourne, Australia. C. J. G. Morris and I. Simmonds. International Journal of Climatology 20: 1931-1954 (2000).

60. Dr. G. E. Van Knowe c/o Meso Inc. Personal Communication. – glenn@meso.com

61. Mr Greg Defina, Prop. Humanifest Software. – gregd@humanifest.com.au

62. Associate Press Report – 26/09/2003. – http://www.news.com.au/common /story_page/0,4057,7379368%5E1702, 00.html

63. Typhoon Maemi claims 58 lives in South Korea –ABC News Report.- http://www.abc.net.au/news/newsitems/s945361.htm

APPENDICES