MANAGEMENT AND PREVENTION OF HEAT STRESS

GUIDELINE

Department of Industry and Resources

MOSHAB Approved

December 1997

Document No: ZMR002SX

CONTENTS

FOREWORD

This Department of Industry and Resources guideline offers a practical approach for mine managers and supervisors to assist with managing employees working in hot environments.

The acclimatisation and evaluation procedures listed in the body of this guideline are not regulations and compliance with them is not mandatory. However, adherence to the recommended procedures should ensure a high level of worker health protection. Acclimatisation and evaluation procedures different from those set out in the guideline may also be acceptable. In preventing heat strain, the importance of ensuring that employees appreciate the need for water intake, proper clothing and the need to be able to recognise early signs of distress cannot be over-emphasised.

Comments on, and suggestions for, improvements to the guideline are encouraged. The guideline will be revised as appropriate, to accommodate comments and to reflect legislature changes, new information on improvements in technology and operational experience. Comments should be sent to:

State Mining Engineer
Department of Industry and Resources
100 Plain Street
EAST PERTH WA 6004

TEL: (08) 9222 3333
FAX: (08) 9325 2280

REGULATORY FRAMEWORK

Provision in the Regulations for hot environments is covered in the Mines Safety and Inspection Regulations, 1995 as follows:

Air temperature in workplaces

9.15 (1) Each responsible person at a mine must cause all necessary measures and precautions to be taken to ensure that employees at the mine do not suffer harm to their health from the adverse effects of extremes of heat or cold.

(2) If conditions in any workplace are, or are likely to be, hot and humid, each responsible person at the mine must ensure that -

(a) all employees are provided with training on measures to be taken to avoid any harmful effects from those conditions; and

(b) appropriate workplace environmental controls (including ventilation) and monitoring are implemented; and

(c) if appropriate, a program for monitoring the health of employees in the workplace is implemented.

(3) In any workplace in an underground mine, and in any tunnel under a surge stockpile on the surface of a mine, each responsible person at the mine must ensure that -

(a) if the wet bulb temperature exceeds 25 degrees Celsius, an air velocity of not less than 0.5 metres per second is provided; and

(b) any appropriate action referred to in subregulation (2) is implemented.

1. INTRODUCTION

There are great variations in temperature found in Western Australia from the cool areas in the South West to the high summer temperatures in the North and inland areas. The effects of heat may be encountered during:

- work in confined workplaces without adequate ventilation;
- work where there is direct exposure to solar radiation;
- work in hot and humid conditions;
- work performed in the vicinity of hot sources such as furnaces, heaters and ovens;

- heavy physical work in moderately hot and humid conditions (e.g. such as in some underground mines);
- work situations where protective clothing has to be worn; and
- any situation where an employee has previously shown signs of heat related effects (e.g. dizziness, fainting and heat cramps).

Working in high heat environments can put workers at risk of impaired performance, heat illnesses and heat stroke. Impaired performance may result in unsafe acts and heat may also tend to promote accidents due to sweaty palms or impairment of vision through fogging of safety glasses.

By way of further introduction this guideline refers to:

- Heat Stress - which is the burden or load of heat that must be dissipated if the body is to remain in thermal equilibrium.
- Heat Strain - is the normal physiological or abnormal pathological change resulting from heat stress.

The physiological condition referred to as heat strain is characterised by increases in deep body temperature, heat rate, blood flow to the skin and water and salt loss due to sweating.

Most adverse effects arise from a failure of the body's cooling mechanisms or as a result of overloading of the system.

Normally, several physical and physiological mechanisms assure transfer of excess body heat to the environment. Even when the body is at rest, heat is generated by normal metabolism. With exercise, the heat produced by muscle activity rises rapidly.

This generated heat is moved to the skin by the blood with the aim of transferring body heat to the environment. Heat may then be lost through convection, evaporation of sweat, radiation and conduction.

To maintain the appropriate body temperature three issues are essential:

- ♦ The metabolic heat produced must be transferred to the skin via the circulation for dissipation;
- ♦ The sweat glands must be able to produce the necessary amount of sweat; and
- ♦ The sweat must be able to evaporate.

Failure in any of these mechanisms for heat transfer may cause the body core temperature to rise, leading to heat strain and subsequent heat illness.

Additionally, for the successful maintenance of the thermoregulatory system, adequate fluids must be consumed to prevent dehydration. When the air temperature is above skin temperature (around 36°C), evaporation of sweat is the main mechanism for the body to lose heat.

2. HEAT STRESS FACTORS

There are six factors influencing a persons capacity for heat exchange with the environment:

- ♦ **Air temperature (dry bulb)**. Above 36°C the body can gain heat from the environment.
- ♦ **Absolute humidity (wet bulb temperature)**. When the absolute humidity is high, evaporation of sweat is reduced, thereby reducing the body's opportunity to lose its heat.
- ♦ **Radiant heat** from objects such as the sun, furnaces, and other hot surroundings. The direction of heat transfer depends on the absolute temperature difference between the body and the surrounding surfaces. It is not affected by the air temperature or humidity.
- ♦ **Air movement**. This can influence both convection and evaporation and can have a marked effect on heat exchange at the exposed skin surfaces (face, arms, legs). Convective heating or cooling does depend on the air temperature. Air movement assists with the evaporation of sweat from the skin and hence cooling capacity.
- ♦ **Muscular activity**. This is the most significant as it imposes a variable heat load. Work rates may increase heat production up to ten times the resting level and can cause a rapid body heat rise if this cannot be lost to the surroundings.

- **Clothing.** This can have a major effect on the amount of heat transfer from the body. Clothing may limit convective exchange and may interfere with the body's capacity to lose heat through evaporation of sweat. However clothing can reduce the radiant heat to the body from surrounding surfaces (firefighters, furnace operators, underground motors and machinery).

3. EFFECTS OF THERMAL STRESS ON THE BODY

The body core temperature is significantly affected by body activities and by the ability of the body to lose this core heat. The extent of any rise is related to the physical work level. Skin temperature on the other hand depends on several environmental conditions.

Increased blood flow through the skin allows body core heat to be dissipated at the body surface. Evaporation of sweat cools the skin and in conjunction with increased skin blood flow assists in achieving thermal balance.

The body uses its own water reserves to generate sweat, so maintaining body temperatures within safe limits. Sweat loss if not replaced leads to dehydration which in turn puts a strain on the circulation causing the heart to beat at a higher rate additionally sweat rate is reduced, so affecting thermoregulatory capacity and adaptation.

Repeated exposure to heat over a period (usually not less than 7 days) produces physiological changes enabling a person to respond more efficiently to the heat demands - this is acclimatisation. This increases water requirement, reduces strain, improves performance and comfort. There are reductions in core temperature and heart rate reached at the same rate of work as before, there is an increase in blood volume, the body sweats more readily and the salt content of sweat is decreased.

A description of the symptoms of the various effects is tabulated below.

Adverse Effect	Description
Skin problems (e.g. prickly heat)	Caused by blockage of sweat ducts and associated inflammation of the skin.
Heat strain	This is the change in pulse, body temperature and sweating. It may lead to heat illness if the heat load continues.
Heat illness	This is a feeling of weakness, dizziness and nausea. The person loses concentration. Safety awareness and performance may deteriorate.
Heat exhaustion	If there is insufficient replacement of water loss from sweating, progressive dehydration occurs. These can be pallor, profuse sweating, hypotension, rapid heart rate, alteration of consciousness, thirst and increase in body temperature. Blood pooling may cause fainting. Salt deficiency, especially following long periods of sweating may also produce a form of heat exhaustion and can cause muscle cramps.
Heat stroke	This is more severe and may be life threatening. A person may become irritable, confused and apathetic before a life threatening stage is reached. The person may also have fits. The body temperature is high (over 40°C) and the skin may be hot and dry. Heat stroke can occur if treatment is not given immediately. Any increase in body core temperature beyond that point is life threatening and must be treated accordingly.
Chronic heat disorders	These are not well documented and there is little available information.

4. METHODS FOR REDUCING HEAT STRESS (LOAD)

Excessive heat load can be due to radiation, convection, unsuitable clothing or, body metabolism.

Consistent with the hierarchy of control measures generally applied to health and safety hazards, the employer should ensure that exposure to heat is limited by:

- ♦ not exposing employees to heat so far as is practicable;
- ♦ isolating sources of heat, so far as is practicable, through shielding, containment and remote handling techniques, if applicable;

- providing engineering controls, such as ventilation, to reduce heat loads;
- adopting safe work practices and appropriate administrative procedures such as job rotation, and
- if other means of controlling exposure are not practicable or adequate, by providing personal protection equipment.

The radiant heat load may be reduced by insulation (shielding) or relocation of heat sources, use of barriers or reflective screens with aprons and covering exposed parts of the body.

The convective heat load may be reduced by lowering the air temperature and increasing the air velocity (e.g. fans).

For extreme conditions, (e.g. during certain confined space maintenance activities) air or ice cooled clothing may be used. In general, clothing is chosen to allow ready evaporation of sweat.

Reducing the effect of metabolism can be accomplished by reducing the physical demands of the work (e.g. mechanisation, automation), sharing the work load (particularly during peak heat periods) and increasing rest time.

5. EVALUATION OF HEAT STRESS (LOAD)

This can be complex because of the numerous indices in use with each one providing a differing assessment of heat stress. Thermal load and the body's response to it is influenced by seven important factor:

- radiant heat;
- air temperature;
- air movement;
- humidity;
- intensity of physical work;
- clothing worn; and
- individual acclimatisation.

There are several heat stress indices in use, incorporating these seven factors to varying degrees (for additional information see Appendix C).

One index used currently in Western Australia for measuring environmental factors is the Wet Bulb Globe Temperature (WBGT). This is the most universally applied heat stress index. The American Conference of Government Industrial Hygienists (ACGIH) has recommended Threshold Limit Values (TLVs) for differing workloads using this index. Additionally, the ACGIH recommends accommodation to be made for unacclimatised workers and suggests a correction factor for clothing (Appendix D).

A hand held instrument for assessing WBGT is available. It is emphasised that the WBGT index was developed for workers in temperate climates and that interpretation is required when attempting to adapt it to hotter climates.

However, as stated earlier, the degree of activity or workload (metabolic rate) heavily influences body heat load. Therefore, an index that recognises this work activity may be considered more appropriate. An example of such an index is the Air Cooling Power (ACP) which accounts for the degree of work activity and the clothing worn. A small computer programme can be generated to run this index, as it is based on quantified data such as dry bulb, wet bulb and air velocity. ACP calculates the energy balance of metabolic heat production for comparison with the mechanical work done.

The environmental indices are best used as "screening tools" to assist in defining the magnitude of the problem and to determine whether further investigations are needed.

The Mines Safety and Inspection Regulations 1995, Regulation *213(3)(a)* requires that the air velocity must not be less than 0.5 m/sec when the wet bulb exceeds 25°C. This will increase the evaporation of sweat and hence the cooling power.

Appendix C lists some of the more commonly used indices.

6. MINIMISING THE POTENTIAL FOR HEAT STRAIN

1. **Ensure appropriate water consumption**. Sweat rates can be as high as 2 litres/hour for those performing heavy physical labour in the heat. Therefore water must be readily available and should be consumed before the shift, and then subsequently at regular intervals thereafter (such as half hourly). Thirst indicates that moderate dehydration is already established.

The water must be palatable by being cool (6-15°C) and can be flavoured for example, with weak cordial.

Proprietary carbohydrate/electrolyte beverages are not required if the diet contains the normal amount of salt.

A simple spot urine test (Fantus Test) can be undertaken which assesses the specific gravity and total urinary chloride level (see Appendix A). The result determines whether a person is well hydrated, partially dehydrated or unacceptably dehydrated. Simply put, dark yellow urine could indicate already established dehydration, urine should be the colour of water.

2. **Heat acclimatisation**. Through acclimatisation, employees have the ability to increase tolerance to work in heat. Full acclimatisation takes 7-14 days with 3 hours activity per day. Acclimatisation usually increases water requirements as acclimatisation increases sweating, but reduces salt loss. Additional information on acclimatisation is provided in Appendix B.

3. **Good physical condition** will reduce the likelihood of heat strain. Those that are more than 20% overweight are more prone to developing heat illness symptoms. Those that are fit will most readily acclimatise and have some 'protection'.

4. **Clothing** that is both loose fitting and made from cloth that "breathes" may be appropriate. Artificial fibre cloth such as nylon is not recommended in heat stress situations. It is important not to obstruct evaporation from the skin.

Protective covering such as hats, long sleeved shirts and shoes is recommended in situations where radiant heat is likely to be a problem, such as outdoors.

5. **Scheduling of physical activity.** Where practicable, adjustment of work schedules and hot jobs may need to be made. Activities in the earlier part of the day (before 10 am) and later in the day (after 3 pm) should be considered to avoid the maximum heat conditions found in the middle of the day.

Consideration may need to be made to re-scheduling work according to weather conditions. In hot conditions relative humidity over 75% contributes a substantial risk to heat injury.

6. **Work rates and physical activity.** Sustained physical activity can cause a rapid rise in body core temperature which may exceed the body's capacity to dissipate this heat to the environment. It may be necessary to provide adequate and regular rest periods to minimise heat production, or to provide for self paced work. The provision of air conditioned retreats and cooled fluids may also assist in maintaining appropriate body temperature. Resting or performing other tasks in cool (<25°C), low to moderate humidity surroundings reduces considerably the effects of hot work. Rest areas should be located close to the hot work areas in order to encourage their use.

7. **Other factors**. Other issues that need to be considered include:

- Age. The older a person is, the less capacity they have for coping in heat stress.
- Obesity. This is a factor in a persons ability to reduce body core temperature.
- Physical Fitness. The fitter a person the better they manage in heat stress conditions.
- Medical conditions and medications. These influences a persons ability to acclimatise and cope in hot conditions.

Medical conditions for consideration include, heart disease, high blood pressure on medication, asthma on medication, kidney disease. Medications for concern include the use of steroid (cortisone, prednisolone) tablets, blood pressure tablets and diuretics.

REFERENCES

1. Bates, G.; Heat Stresses at Work and their Management. Thesis, Curtin University of Technology.

2. Chesson, B.J.; Heat Stress Control, Evaluation of Personal Cooling Systems. Masters Thesis 1984. Curtin University of Technology.

3. Howes, M.J.; Application of Refrigeration in Mines. Trans. Instn. Min. Metall., 92 April 1983.

4. Keilblock, A.J., Schutte PC; Human Heat Stress: Basic Principles, Consequences and its Management. Minesafe 1993. Proceedings p119-134.

5. Stewart, J.; Fundamentals of Human Heat Stress. Environmental Engineering in South African Mines. The Mine Ventilation Society of South Africa 1982. Ch. 20 p495-533.

6. Commonwealth Department of Science and Technology. Thermal Comfort at Work. Working Environment Series No. 14 Australian Government Publishing Service Canberra 1987.

7. Threshold Limit Values for Chemical Substances and Physical Agents; 1994-1995. American Conference of Governmental Industrial Hygienists.

8. World Health Organisation. Health factors involved in working under conditions of heat stress. Tech. Rep. Series No. 412 Geneva.

APPENDIX A

Assessment of Urinary Chloride (Fantus Test)[1]

The Fantus Test is used to determine the chloride content of the urine. In order to identify those employees who may be pre-disposed to heat illness, the test should be performed at the beginning of the shift before work activity starts. The chloride content of the urine is an important sign in the early diagnosis of heat exhaustion.

The test requires the collection of a spot sample of urine, assessing the specific gravity, titrating for total chloride level and reading the result from a graph.

The result will indicate whether an individual has salt depletion and, by inference water depletion. This result should only be used as a guideline to confirm the suspicion of dehydration.

Group I - appropriately hydrated, no additional salt required. Re-enforce the importance of keeping fluid intake at recommended levels.

Group II - additional salt and water is needed. If symptoms of heat illness are obvious suggest working in cooler conditions.

Group III - Salt and water definitely needed, consider sending home for the rest of the shift. Must have a repeat Fantus test before the commencement of the next shift.

Details of the Fantus test protocol and method is available from the State Mining Engineer.

[1] Cross R. B.; Galton-Fenzi B, Jordan L. A simple field test for assessing salt balance in heat stressed miners. Journal of occupational medicine, Vol 31. No. 8 August 1989 p668-673.

APPENDIX B

Acclimatisation Procedures

Some of the characteristics of acclimatisation to heat can be summarised as follows:

- Acclimatisation begins with the first exposure, progresses rapidly and may be well developed in about one week for some.
- Acclimatisation can be induced by short, intermittent work periods in the heat for two hours daily. Resting or inactivity in the heat produces only slight acclimatisation.
- Subjects in good physical condition acclimatise more rapidly and are capable of doing more work in the heat. Good physical condition, however, does not in itself confer acclimatisation. Also, individuals differ widely in their ability to acclimatise.
- Acclimatisation to high heat loads will enhance performance at less severe conditions, but will only provide partial benefits for more severe conditions.
- Acclimatisation to heat is well retained during periods of no exposure for about one week; thereafter, acclimatisation is lost at a rate that varies among individuals. Within about three weeks to a month, acclimatisation effects are lost and hardly any traces are to be found after a few months. Staying in good physical condition helps retain acclimatisation.

By way of example, the American National Institute of Occupational Safety and Health (NIOSH) recommends the following acclimatisation routine:

(1) Unacclimatised employees should be acclimatised over a period of 6 days. The acclimatisation schedule should begin with 50 percent of the anticipated total work load and time exposure of the first day, followed by daily 10 percent increments building up 100 percent total exposure on the sixth day.

(2) Regular acclimatised employees who return from nine or more consecutive calendar days of leave, should undergo a four-day acclimatisation period. The acclimatisation schedule begins with 50 percent of the anticipated total exposure on the first day, followed by daily 20 percent increments building up to 100 percent total exposure on the fourth day.

(3) Regular acclimatised employees who return from four consecutive days of illness should have medical permission to return to the job, and should undergo a four-day re-acclimatisation period as in (2) above.

* It should be recognised that the above acclimatisation routine was developed for typical climatic conditions experienced in the USA and its adoption may not be practicable at many mine sites in Western Australia. It is provided here to highlight the need to consider suitable acclimatisation procedures for employees who are subject to heat stress. Such procedures should be developed in consultation with employees and consider the particular shift roster schedules used and also the differences in climatic conditions between the site and the employees off-work site location The need for a suitable acclimatisation routine may be particularly critical in situation where employees have an extended absence from site in climatic conditions which are substantially cooler than those experienced on site.

APPENDIX C

Commonly used Heat Stress Indices

1. **Wet Bulb Globe Temperature (WBGT).** Considered the simplest of indices to use (hence its continued recommended use by NIOSH, NH&MRC, ACTU). The index was devised for use in US military field operations. The index is sensitive to dry bulb, radiant and natural wet bulb temperatures, and air velocity. It can be adjusted to take into account clothing, work rate or duration of exposure (see next page).

2. **Effective Temperature (ET) and Corrected Effective Temperature (CET)** were devised originally as a comfort scale. This index combines the effects of globe temperature (radiant and dry bulb), wet bulb and air velocity, though not under hot, humid conditions.

3. **Heat Stress Index (HSI)** of Belding and Hatch is based on the physical analysis of heat exchange. The index equates the amounts of heat required to be dissipated by evaporation of sweat with the maximum possible evaporative capacity. This index tends to overestimate the environmental heat load, and is too complex for daily use.

4. **Predicted Four Hour Sweat Rate (P4SR).** This is the quantity of sweat, in litres, likely to be produced under specific thermal conditions. It takes into account the metabolic rate and to a lesser extent the clothing worn, along with dry bulb, radiant temperature, wet bulb and air velocity. This index is also complex and requires a nomogram to obtain corrected figures.

5. **The Wet-Kata Thermometer**. This is the measure of the cooling power of the environment. This index correlates well with body responses in hot, humid conditions, but is less meaningful in hot dry conditions and with unacclimatised people.

6. **The Air Cooling Power**. This index is used in South African underground mines and recognises workload, and clothing additionally to the environmental factors of wet and dry bulb temperatures, radiant temperature and wind velocity. This index is complex and requires a short computer programme.

APPENDIX D

Examples of Permissible Heat Exposure Threshold Limit Values
[Values are given in ^{o}C WBGT]*

Work-Rest Regimen	Work Load		
	Light	Moderate	Heavy
Continuous work	30.0	26.7	25.0
75% Work / 25% Rest, each hour	30.6	28.0	25.9
50% Work / 50% Rest, each hour	31.4	29.4	27.9
25% Work / 75% Rest, each hour	32.2	31.1	30.0

* Not to be confused with normal day bulb temperature readings.

* As workload increases, the heat stress impact on an unacclimatised worker is exacerbated. For unacclimatised workers performing a moderate level of work, the permissible heat exposure TLV should be reduced by approximately 2.5°C.

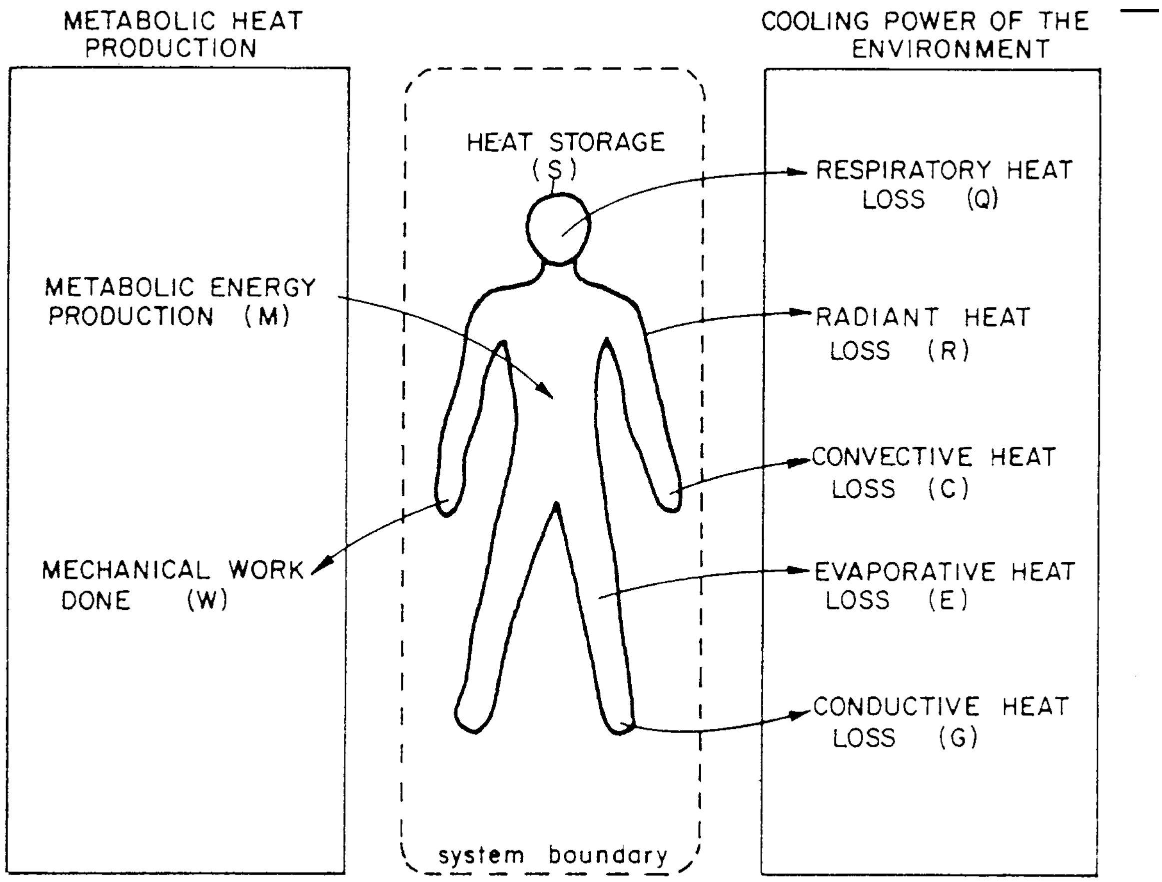
TLV WBGT Correction Factors in ^{o}C for Clothing

Clothing Type	Clo Value*	WBGT Correction
Summer work uniform	0.6	0
Cotton coveralls	1.0	-2
Winter work uniform	1.4	-4
Water barrier, permeable	1.2	-6

* Clo: Insulation value of clothing. One clo unit = 5.55 kcal/m^2/hr of heat exchange by radiation and convection for each ^{o}C of temperature difference between the skin and adjusted dry-bulb temperature.

APPENDIX E

The Heat Balance of a Working Person[2]



Schematic representation of an energy balance on the human body.

To understand human heat strain the use of the heat balance equation is important:

$$M - W - Q - S = R + C + E + G$$

This equation provides the basis for quantifying heat stress and relating human physiological response to the heat stress causing it.

The thermodynamic and psychrometric equation, need in a computer programme for ACP, are based on atmospheric pressure, wet bulb, dry bulb, and air velocity. Variables include skin surface area, clothing and workload.

Radiant, convective and conductive transfer of temperature can be positive or negative. Only evaporative transfer goes in one direction.

2 Stewart, J.; Fundamental of Human Heat Stress. Environmental Engineering in South Africa Mines. The Mine Ventilation Society of South Africa 1982. Ch 20 p495-567.