

# Thermal Stress

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# Introduction

- Information take from the *2006 TLVs<sup>®</sup> and BEIs<sup>®</sup> by the ACGIH* (ACGIH '06) and

Fundamentals of Industrial Hygiene, 4<sup>th</sup> edition, 1996. (FIH)

Will address both cold stress and heat stress

# Introduction

- Thermal Balance

$$S = (M + W) + R + C + K + (C_{resp} + E_{resp}) + E$$

Units in watts or kcal/min or Btu/hr

- (FIH)

# Introduction

$S$  = heat storage rate – zero means equilibrium

$M$  = metabolic rate – always positive

$W$  = external work rate - always positive (usually 10% of  $M$ )

$R$  = radiant heat exchange rate (can be +/-)

$C$  = convective heat exchange rate (can be +/-)

$K$  = conductive heat exchange rate (can be +/-)

$C_{resp}$  = rate of convective heat exchange by respiration

$E_{resp}$  = rate of evaporative heat loss by respiration

$E$  = rate of evaporative loss

(FIH)

# Introduction

- $W$ ,  $K$ ,  $C_{resp}$  and  $E_{resp}$  are small compared to other routes of heat exchange and can be ignored for simplicity sake, therefore:
- $S = M + R + C + E$

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# Introduction

- M can be 10-100X (R+C)
- 3 important characteristics of clothing
  1. Insulation –resistance to heat flow
  2. Permeability- resistance to water movement
  3. Ventilation- air movement

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# Cold Stress

- Generally less of an issue than heat stress, especially in this part of the country
- Goals
  - Prevent hypothermia
  - Prevent injuries to the extremities

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# Cold Stress – Overall Goal

- How are these goals achieved
  1. Prevent Hypothermia
    - Keep deep body core temperature above 96.8 degrees F (TLV)
    - Single exposure to body core temperature of 95 degrees F (akin to STEL or Ceiling value – although not called this per se) is acceptable.

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# Cold Stress- Overall Goal

2. Prevent injury to body – extremities mostly = hands, feet, head

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# Cold Stress- Fatalities

- Fatalities due to cold have generally happened when a person is trapped (e.g. on a mountain top) or immersed in cold water (e.g. commercial fisherman falls overboard in North Atlantic)

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# Cold Stress Related Disorders

- Raynauld's Syndrome - symptoms and causes
  - blanching of the fingers
  - vibration and cold
  - smoking is often a factor
  - neuro-vascular implications

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# Cold Stress Related Disorders

- Chilblain - symptoms and causes
  - recurrent, localized itching
  - swelling and spasms
  - exposure to cold and dampness
  - inadequate clothing
  - vascular disease

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# Cold Stress Related Disorders

- Trench Foot – symptoms and causes
  - prolonged exposure to dampness and cold
  - above freezing temperatures
  - pain, tingling and itching
  - edema and blisters

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# Cold Stress

- Insulated dry clothing necessary for workers in an environment less than 40 degrees F
- Equivalent chill temperature (ECT)– relates wind speed and temperature to give an equivalent temperature under calm conditions

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# Cold Stress- Skin Exposure

- No continuous exposure to exposed skin when the equivalent chill temperature (ECT) reaches -25.6 degrees F.
- Superficial or deep local tissue freezing starts when temperatures dip below 30 degrees F

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# Cold Stress – Hand Protection

- Controls

- Detailed bare handed work below 61 degrees F, provide a source to warm hands
- Insulate metals handles
- Gloves recommended for temperature below:
  - Sedentary work = 61 degrees F
  - Light work = 39 degrees F
  - Moderate work = 19 degrees F

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# Cold Stress – Hand Protection

- Mittens recommended for hand work below 0 degrees F

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# Cold Stress – Whole Body Protection

- Whole body protection required when temperature falls below 39 degrees F...in still air
- If clothing becomes wet, change it, especially if air movement is present

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# Cold Stress- Warming Shelters

- Continuous work below 19 degrees F, provide a warming shelter, hut, or similar structure
- Remove outer layers of clothing upon entering hut – to aid in evaporation

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# Cold Stress – Warming Shelter

- Warm, sweet drinks are recommended – for calories and fluid volume
- Coffee not recommended – diuretic

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# Cold Stress-ECT

- ECT temperature less than 10 degrees F
  - Supervision of workers (can be buddy system)
  - Work rate below the level of sweating

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# Work/Warm-up Schedule

- 4-hour shift
- Limits length of work shift based on temperature and wind speed
- Work periods vary from 30-75 minutes
- 10-minute warm-up period  
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# Work/Warm-up Schedule

- Contains an end point below which non-emergency work should not be performed
- Examples
  - 25 to -29 degrees F with a 20 mph wind
  - 45 degrees F with zero wind

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# Prevention of Cold Stress

- Avoid work where employee must stand or be in contact with bare metal objects
- Acclimate new employees
- Consider weight and bulkiness of clothing for work

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# Prevention of Cold Stress

- Train workers
  - Signs and symptoms of hypothermia and frost bite
  - Eating and drinking habits
  - Clothing
  - Rewarming
  - 1<sup>st</sup> aid

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# Cold Stress- Prevention

- Refrigerated rooms – keep air below 200 fpm for workers
- Consider vibration – Hand/arm vibration syndrome
- Eye protection for UV and glare

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# Cold Stress - Prevention

- Thermometry when temperatures are less than 61 degrees F relative to TLV
- Air speed included when outdoor air temps fall below 30 degrees F

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# Cold Stress - Prevention

- ECT measured and recorded when temp is less than 19 degrees F (ACGIH '06)
- Medical surveillance when temperature falls below -11 degrees F. (FIH)

# Heat Stress

- TLV based upon
  - Nearly all workers
  - Healthy
  - Unmedicated
  - Hydrated worker

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# Heat Stress and Strain

- Work levels
  - Resting
  - Light
  - Moderate
  - Heavy
  - Very Heavy

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# Heat Stress- Definitions

- Definitions:
  - **Heat Stress** is the net heat load to which a worker may be exposed from the combined contribution of metabolic cost of work, environmental factors, and clothing.
  - **Heat Strain** is the overall physiological response resulting from heat stress.

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# Heat Stress- Definitions

- **Heat Stoke** – also known as hyperthermia
  - medical emergency
  - thermoregulatory activity not functioning
  - skin may be hot and dry (no sweating)
  - with body core temp  $>104$  degrees F
  - behavioral changes or unconscious
  - relatively rare

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# Heat Stress - Definitions

- **Heat Syncope** – loss of consciousness due to pooling of blood in the lower extremities from prolonged standing during hot weather
- **Heat Cramps** – prolonged sweating causing an electrolyte imbalance (FIH)
- **Heat Exhaustion** – dehydration, high pulse rate, profuse sweating, body temperature is normal to high. Relatively common, but not life threatening

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# Heat Stress & Strain – Reproductive Hazard

- Temporary infertility in both males and females
- Sustained core temp  $>39$  degrees C during the first trimester may endanger the fetus

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# Heat Stress

- All bets are off with encapsulated suits
- Evaporation is the primary method by which the body cools itself

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# Heat Stress and Strain

- WBGT – Wet Bulb, Globe Thermometer
- An index of the environment contribution to heat stress
- Does not take into account all conditions for heating

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# WBGT

- Adjusted WBGT to take into account:
  - clothing
  - work load
  - acclimatization of worker

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# WBGT

- Clothing Adjustment to the WBGT
  - Summer work uniform – no adjustment
  - Cloth (woven material) overalls - add 3.5 degrees C to measurement
  - Double-cloth overalls - add 5 degrees C to measurement

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# WBGT

- In direct sunlight:

$$\text{WBGT}_{\text{out}} = 0.7T_{\text{nwb}} + 0.2 T_{\text{g}} + 0.1 T_{\text{db}}$$

- Without direct sunlight:

$$\text{WBGT}_{\text{in}} = 0.7T_{\text{nwb}} + 0.3T_{\text{g}}$$

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# Heat Stress and Strain

- 3 Ways to Transfer Heat
  1. Radiation- Infrared radiation, can move through a vacuum
  2. Conduction – direct contact
  3. Convection- heat

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# WBGT

$T_{nwb}$  - Natural Wet Bulb Temperature

$T_g$  - Globe Temperature

$T_{db}$  - Dry Bulb (air temperature)

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# Heat Stress

- Do not use WBGT if clothing:
  1. Acts as a barrier to air or water movement
  2. Encapsulated
  3. Multiple layers

Instead – use physiological and behavioral monitoring

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# Heat Stress- Physiology Monitoring

- Physiology
  - Heart rate – beats per minute (bpm)
    - >180 bpm-worker's age for several minutes
    - >100 bpm

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# Heat Stress – Physiology Monitoring

- Body Core Temperature:
  - >101.3 degrees F for acclimated individuals
  - >100.4 degrees F for unacclimated individuals
- Other Signs and Symptoms:
  - Severe fatigue
  - Nausea
  - Dizziness
  - Lightheadedness

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# Heat Stress – Physiology Monitoring

- Other Symptoms:
  - Excess sweating
  - Wt. loss  $> 1.5\%$  of body wt over work shift
  - Behavioral changes

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# Heat Stress

- Primary goal – prevent heat stroke, which is a life threatening condition that necessitates immediate medical attention

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# Heat Stress and Strain - Controls

- Proper hydration – look out for diuretics - is 1 cup of cool water per 20 minutes
- Shield workers from radiant heat sources
- Air movement – fan, for temps below 95 degrees F. Limit air movement if temperature is above 95 degrees F

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# Heat Stress and Strain- Control

- Work/rest regiment
- Monitor for heat stress- behavioral, body temp, heart rate
- Train workers
- Acclimate workers  
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# Heat Stress and Strain- Control

- Support healthy diet and exercise
- Consider pre-placement medical screening for those at risk
- Mechanical means to accomplish heavy tasks

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# Heat Stress and Strain - Controls

- Personal Protective Equipment
  - Ice vests or circulating ice water vests
  - Vortex tubes, connect to compressed air supply, reduce the air temperature by up to 18 degrees F. Tubes allows compressed air stream to expand and separate into 2 air streams (warm and cool) (FIH)

# Heat Stress and Strain - Controls

- Personal Protective Equipment
  - Reflective suits for radiant heat

# Thermal Comfort

- Factors include:
  - a. Air temp
  - b. Humidity
  - c. Air velocity
  - d. Metabolic rate
  - e. Clothing
  - f. Age
  - g. Sex
  - h. Season
  - i. Cultural background

# Thermal Comfort

- ASHRAE – American Society of Heating Refrigeration and Air Conditioning Engineers
- Under ideal conditions 95% of the occupants of an area will be happy
- 80% happy is considered successful