Human Factors Engineering

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Lecture - 37
Thermal Balance Equation and Heat Stress

So, during the second lecture session of this week I will be discussing the Thermal Environment Design and its issues - Thermal Balance Equation and the Heat Stress.

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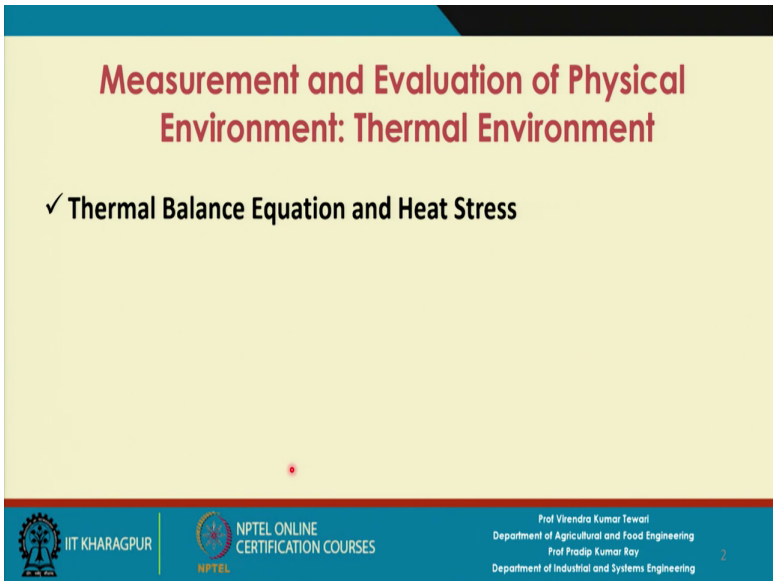

So, first I will discuss about thermal balance equation for human body and then I will also refer to the heat stress condition.

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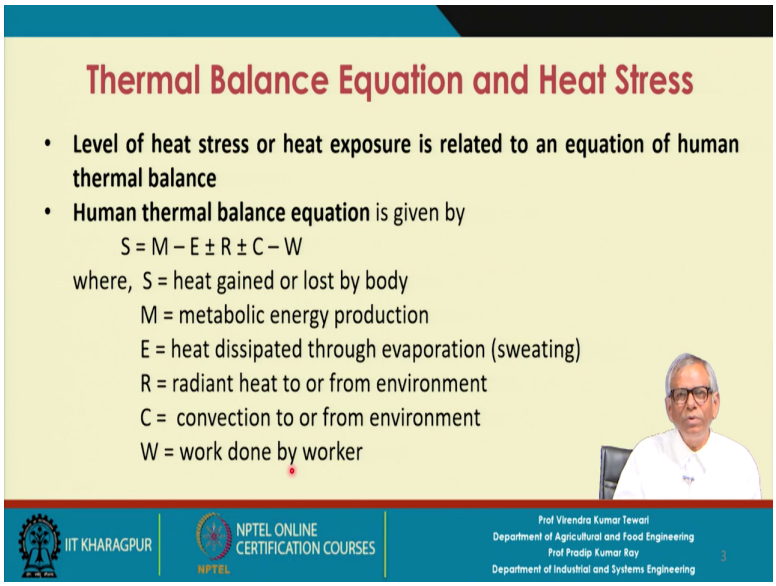

Level of heat stress or heat exposure is related to an equation of human thermal balance. Human thermal balance equation is given by

$S = M – E \pm R \pm C – W$

where, S = heat gained or lost by body

M = metabolic energy production

E = heat dissipated through evaporation (sweating)

R = radiant heat to or from environment

C = convection to or from environment

W = work done by worker

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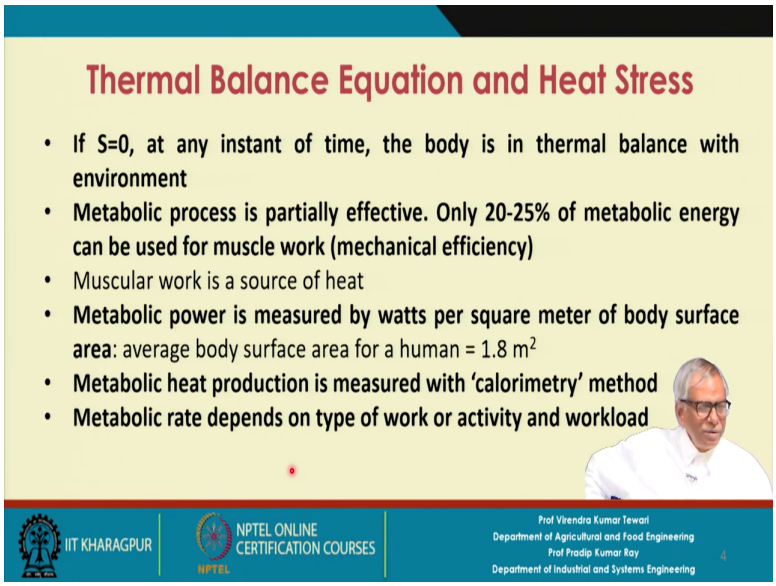

If S = 0, at any instant of time, the body is in thermal balance with environment. Metabolic process is partially effective. Only 20-25% of metabolic energy can be used for muscle work (mechanical efficiency). Muscular work is a source of heat. Metabolic power is measured by watts per square meter of body surface area: average body surface area for a human = 1.8 m^2. Metabolic heat production is measured with 'calorimetry' method. Metabolic rate depends on type of work or activity and workload.

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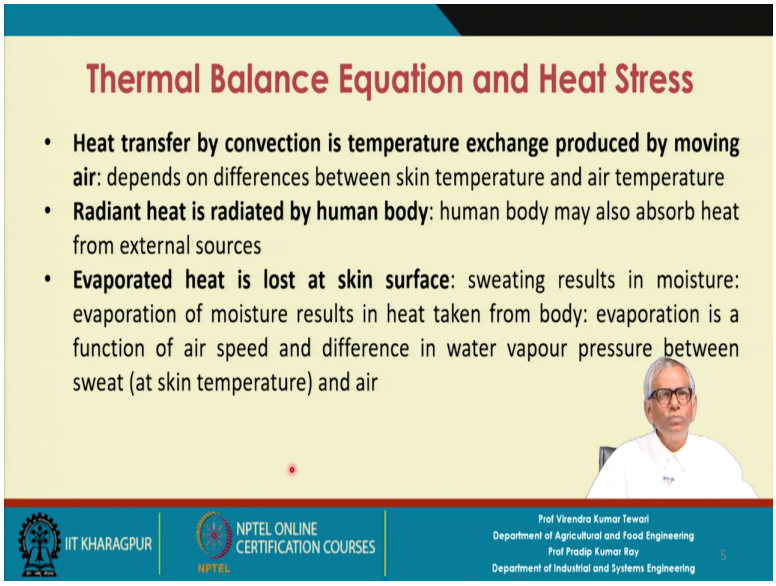

Now, the first one is the heat transfer by convection is temperature exchange ge produced by moving air. So, it depends on differences between the skin temperature and the air temperature or ambient temperature ambient air temperature.

Next one is the radiant heat is radiated by human body. So, human body may also absorb heat from external sources.

Evaporated heat is lost at skin surface; that means, sweating results in moisture: evaporation of moisture results in heat taken from body: evaporation is a function of air speed and difference in water vapour pressure between sweat (at skin temperature) and air.

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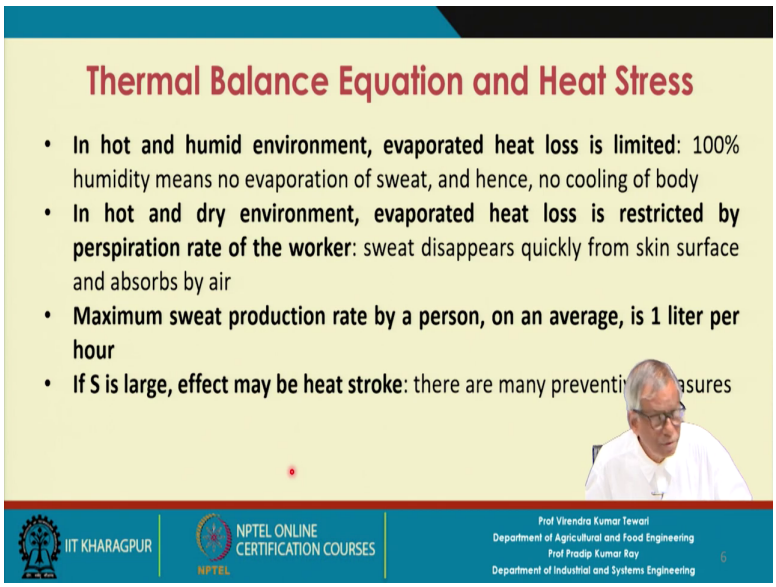

In hot and humid environment, evaporated heat loss is limited: 100% humidity means no evaporation of sweat, and hence, no cooling of body. In hot and dry environment, evaporated heat loss is restricted by perspiration rate of the worker: sweat disappears quickly from skin surface and absorbs by air. Maximum sweat production rate by a person, on an average, is 1 litre per hour.

If S is large, effect may be heat stroke: there are many preventive measures.

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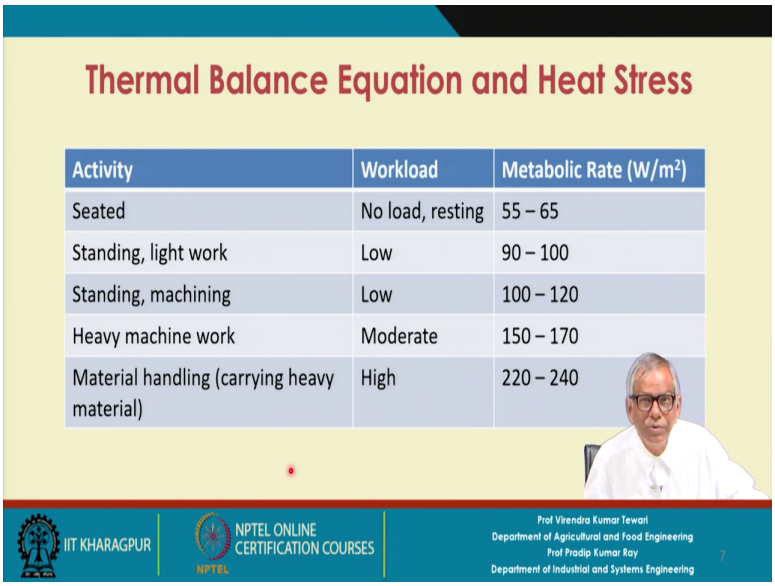

Workload is an important issue, there are activities, workload and metabolic rate give. In the typical seated activity- there is no workload and the metabolic rate is 55 to 65 watt per meter square. 2nd activity is standing, light work where workload is low and metabolic rate is 90-100 W/m^2.

3rd activity is standing, machining where workload is low and metabolic rate is 100-120 W/m^2.

4th activity is heavy machine work, where workload is moderate and metabolic rate is 150-170 W/m^2.

5th activity is material handling where workload is high and metabolic rate is 220-240 W/m^2.

We have noticed that metabolic rate increases when the workload increases.

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Now, our main concern is the heat stress and how to eliminate heat stress in a given condition and then only you say thermal involvement quality is excellent. In many workplaces the heat stress management is considered important and critical. It can be done in various way:

a) Reduce high relative humidity by using dehumidifiers.

b) Increase air movement/speed by using fans or air conditioners.

c) Decrease temperature by using air conditioners.

d) Remove heavy clothing, use loose-fitting overalls/wide-clothing.

e) Reduce work rate.

f) Increase frequency of rest pauses.

g) Introduce job rotation.

h) Carry out outdoor work at cooler times, say early morning.

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i) Select personnel who can tolerate extreme heat.

j) Allow two weeks for acclimatization.

k) Use cool, refrigerated vests (with cooling elements).

l) Install local cold spots (refrigerated room for rest breaks).

m) Provide shade to reduce radiant heat.

n) Maintain hydration by drinking water and taking salt tablets.

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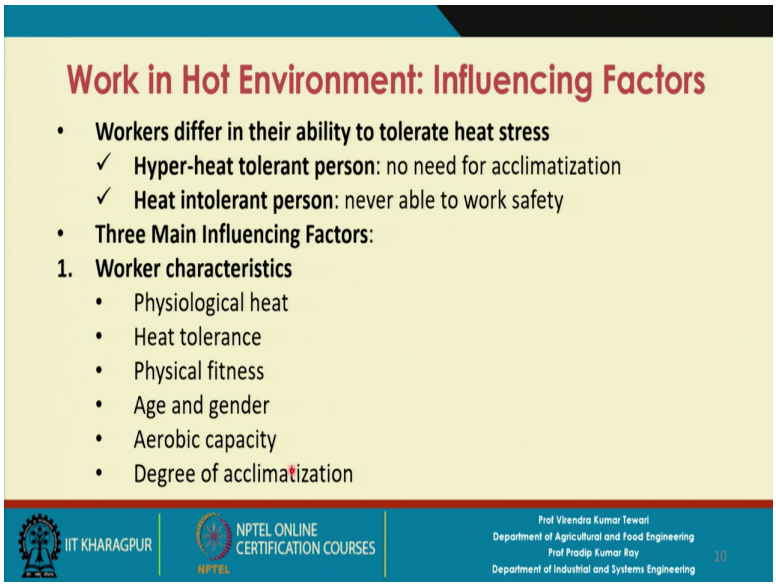

Work in hot environment is unavoidable. So, even in a cold country, hot environment you have to create a manufacturing plant so, there you have to work. It is an artificial workplace.

Workers differ in differ in their ability to tolerate heat stress, there will be individual difference. Now, there are two categories of persons you will come across, one type of person they are referred to as the hyper heat tolerant person and other one is heat intolerant person. There are three influencing factors which are as follow:

1. Worker characteristics

a) Physiological heat

b) Heat tolerance

c) Physical fitness

d) Age and gender

e) Aerobic capacity

f) Degree of acclimatization

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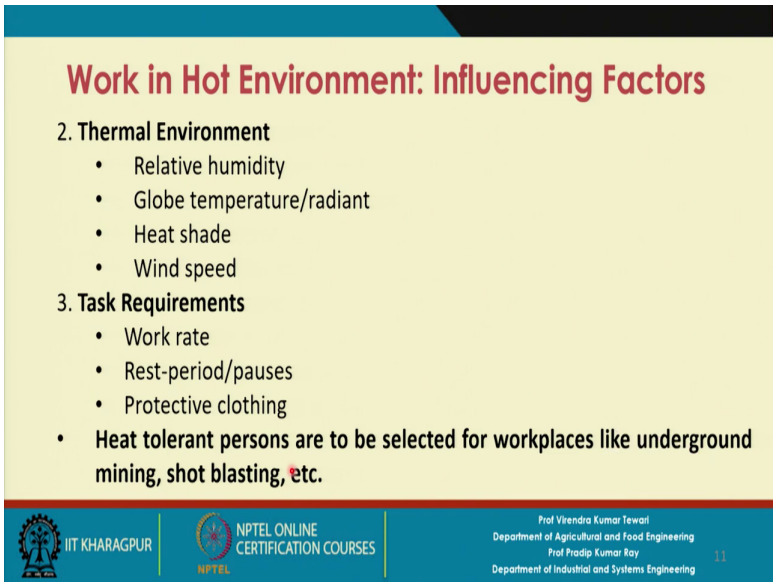

Next one is the, what kind of thermal environment and task requirement in which you have to work.

2. Thermal Environment

a) Relative humidity

b) Globe temperature/radiant

c) Heat shade

d) Wind speed

3. Task Requirements

a) Work rate

b) Rest-period/pauses

c) Protective clothing

d) Heat tolerant persons are to be selected for workplaces like underground mining, shot blasting, etc.

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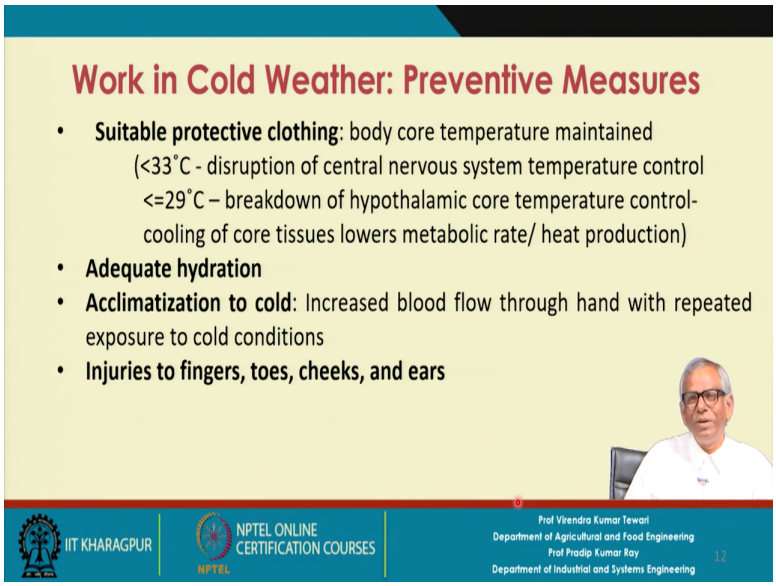

Suitable protective clothing for maintaining body core temperature:

(<33˚C - disruption of central nervous system temperature control <=29˚C – breakdown of hypothalamic core temperature control- cooling of core tissues lowers metabolic rate/ heat production). Adequate hydration. Acclimatization to cold: Increased blood flow through hand with repeated exposure to cold conditions. Injuries to fingers, toes, cheeks, and ears.

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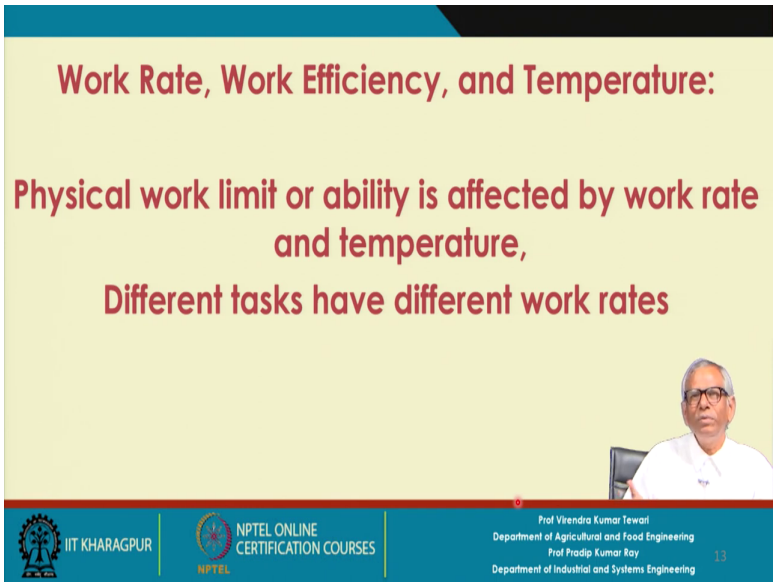

Now, work rate, work efficiency and the temperature these are interrelated. And as you come across different task or the jobs and they have different work rates. You cannot avoid this as this condition is imposed on the system.

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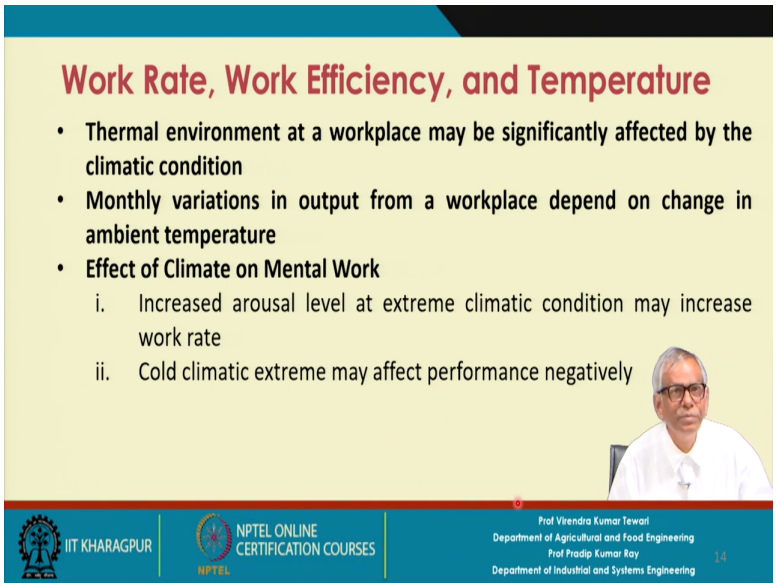

So, the thermal environment at a workplace may be significantly affected by the climatic condition and Monthly variations in output from a workplace depend on change in ambient temperature.

Effect of Climate on Mental Work

1. Increased arousal level at extreme climatic condition may increase work rate
2. Cold climatic extreme may affect performance negatively

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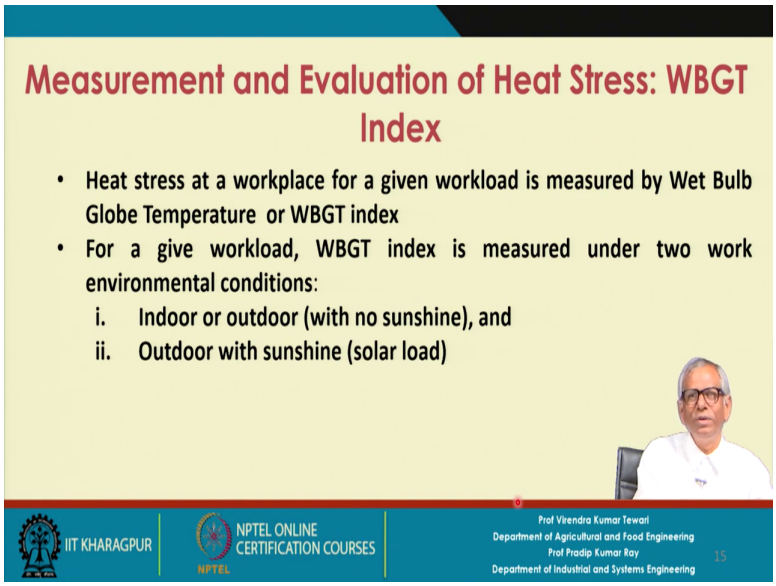

So, there is one the condition you have to maintain for different kinds of conditions. When you refer to the thermal balance equation, sometimes you work outside, sometimes you work inside, the indoor or outdoor so you should know how to measure these heat stress. Heat stress at a workplace for a given workload is measured by Wet Bulb Globe Temperature or WBGT index. For a give workload, WBGT index is measured under two work environmental conditions: Indoor or outdoor (with no sunshine), and Outdoor with sunshine (solar load).

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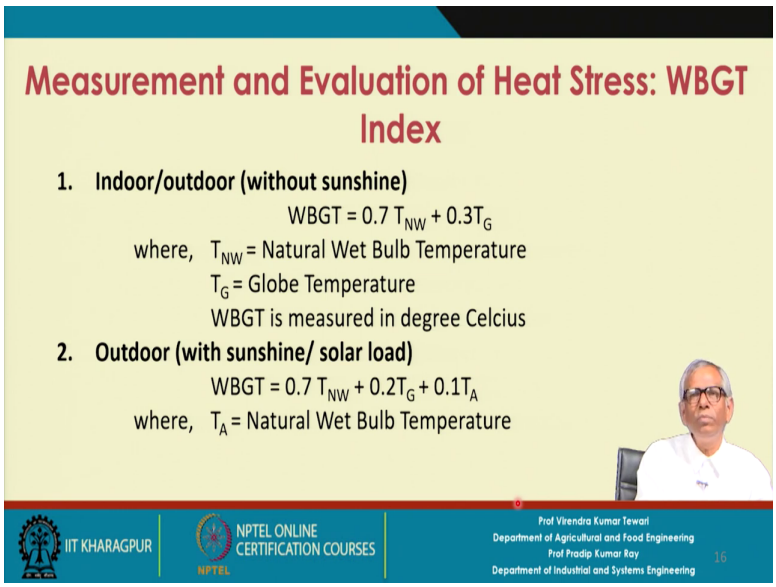

So, these two equations we have one is an indoor/outdoor without sunshine and outdoor with sunshine or the solar load.

1. Indoor/outdoor (without sunshine)

WBGT = 0.7 TNW + 0.3TG

where, TNW = Natural Wet Bulb Temperature

TG = Globe Temperature

WBGT is measured in degree Celsius

2. Outdoor (with sunshine/ solar load)

WBGT = 0.7 TNW + 0.2TG + 0.1TA

where, TA = Natural Wet Bulb Temperature

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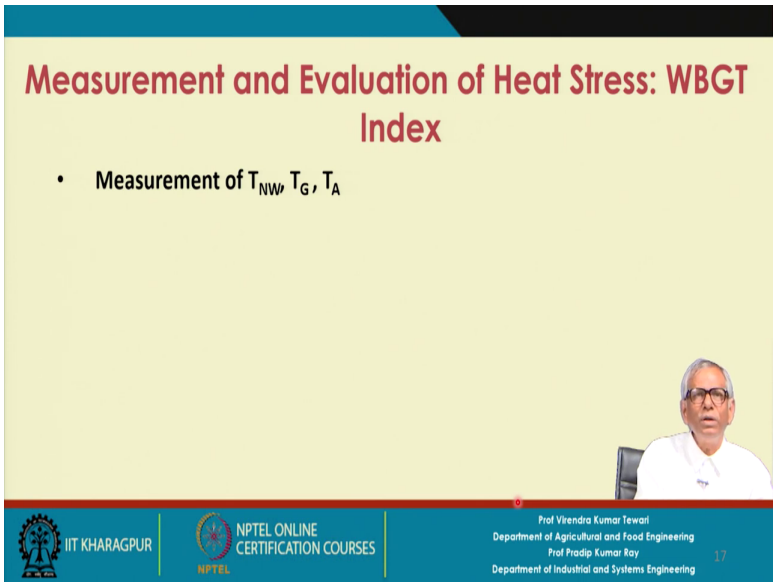

Measurement of T_{NW}, TG , TA.

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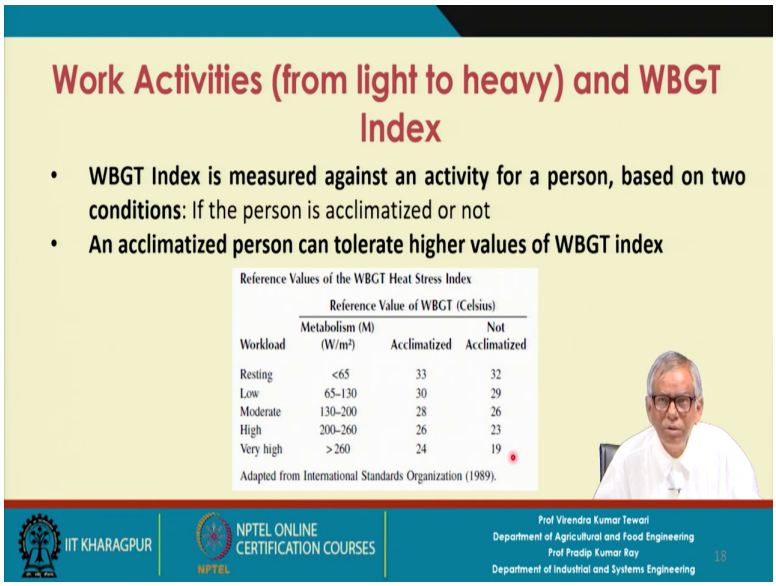

WBGT Index is measured against an activity for a person, based on two conditions: If the person is acclimatized or not.

An acclimatized person can tolerate higher values of WBGT index.

Refer to table: So, here under different workload like resting, low, moderate, high, very heavy- these are the five categories we have.

So, metabolism rate is mentioned and acclimatized and non-acclimatized condition are also there.

After analysing we can conclude that work rate is dependent on the metabolism rate as well as the acclimatized condition or non-acclimatized condition.

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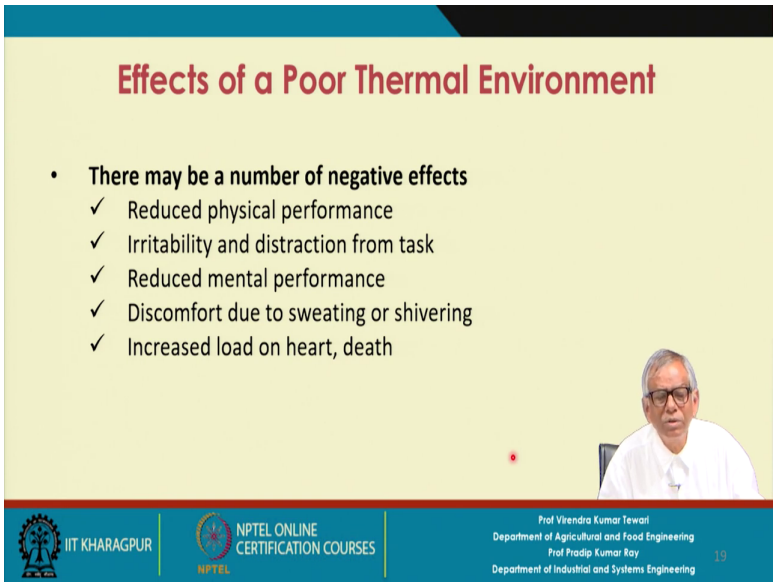

There may be a number of negative effects:

1. Reduced physical performance.
2. Irritability and distraction from task.
3. Reduced mental performance.
4. Discomfort due to sweating or shivering.
5. Increased load on heart, death.

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List of Reference Textbooks

1. Sanders, M. S. and McCormick, E. J., Human Factors in Engineering and Design, McGraw-Hill, Sixth Edition

2. Bridger, R. S., Introduction to Ergonomics, Taylor and Francis Group, Third Edition

3. Helander M, A Guide to Human factors and Ergonomics, Taylor and Francis Group, Second Edition