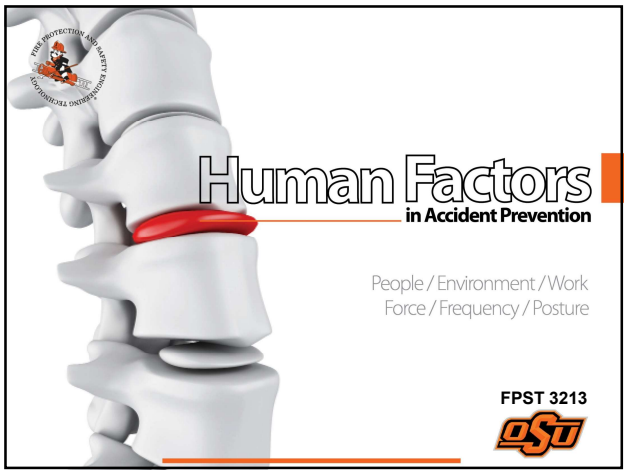

1

Environmental Stressors

Part 2

2

Environmental Stressors

- Lighting and color
- Noise
- Thermal conditions
- Vibration
- Ventilation

3

Thermal Stressors

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4

Thermal Stressors

- Human Factors is concerned with how thermal stressors impact productivity

Hot Danger Zone
Warm Discomfort Zone
Thermal Comfort Zone
Cold Discomfort Zone
Cold Danger Zone

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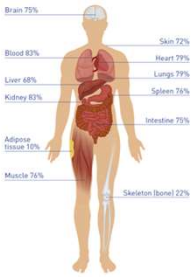
Thermal environments

- Principal concern is movement of heat to and from the person



Water composition of tissues and organs by weight. Adapted from Pivarnik and Palmer 1994

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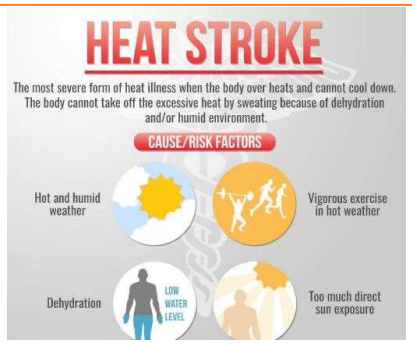
Heat Stress



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Heat Stress

- Can add to the cardiopulmonary burden thus increasing:
  - the likelihood of fatigue
  - frequency of accidents
  - overexertion injuries
  - decrease in quality
  - decrease in productivity

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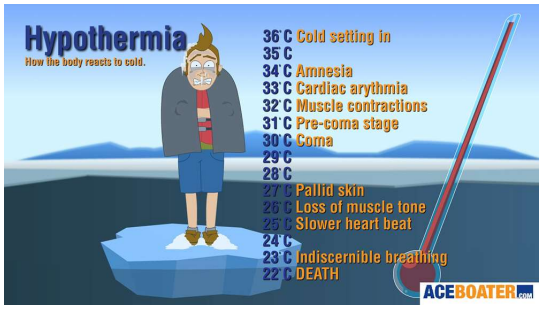
8

Cold Stress



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Cold Stress

- Cold stress is more associated with loss of cognitive function
  - e.g. reasoning, memory, attention

10

Thermal Stressors

- ASHRAE
  - American Society of Heating, Refrigerating and Air-Conditioning Engineers
  - Standard 55 – Thermal Environmental Conditions for Human Occupancy
  - Standard 62 - Ventilation for Acceptable Indoor Air Quality

11

Thermal Balance - Models

- The body as a whole
  - Heat exchange between the person and the environment
  - $S = M - E \pm R \pm C - W$

where

S is the heat gained or lost by the body
M is the metabolic energy production
E is the heat dissipated through evaporation (sweating)
R is the radiant heat to or from the environment
C is the convection to or from the environment
W is the work accomplished by the worker
S = 0 when the body is in thermal balance with the environment

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Thermal Balance

- Heat transfer on a local patch of skin
  - Considers heat gained or lost to the environment at a local patch of skin
  - Main pathways are conduction and convection

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Thermal Condition Assessment

- Environment
  - Minimum requirements for environmental assessment:
    - Air temperature
    - Humidity
    - Air speed

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Thermal Condition Assessment

- Air temperature or Dry bulb temperature

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Thermal Condition Assessment

- Humidity or the amount of water vapor in the air
  - Limits the rate of the evaporative cooling of sweat

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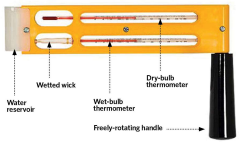
Thermal Condition Assessment

- To assess humidity measure dry bulb and psychrometric wet bulb temperatures and then find the humidity. (Air speed greater than 3 m/s)
- Natural wet bulb temperature. Similar to psychrometric wet bulb temperature except air motion is simply the ambient air movement



Wetted wick

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Thermal Condition Assessment

- Air speed or movement or air around a person.
  - Useful for cool discomfort and cool stress.

THE ROBINSON ANEMOMETER.

18

Thermal Condition Assessment

- Globe temperature is the internal temperature of a blackened hollow (thin-walled) copper sphere
  - Designed it to be responsive to radiant heat

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Thermal Condition Assessment

- Work demands
  - Metabolic rate reflects the amount of heat generated inside the body

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Thermal Condition Assessment

Category	Representative Metabolic Rate (W)	Representative Activities
Sedentary	110	Resting, sitting with no regular activity
Light	200	Sitting with light manual work such as writing, typing, using small tools, inspection, and driving Standing with light hand work such as minding a drilling or milling machine Intermittent walking at slow speed
Moderate	300	Sustained hand and arm work with little effort Walking Pushing and pulling lightweight carts
Heavy	400	Intense arm and truck work Carrying, lifting or pushing/pulling heavy materials Fast walking
Very heavy	500	Very intense activities such as shoveling or digging, which require frequent breaks.

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National Weather Service Wind Chill Chart

National Weather Service Wind Chill Chart

Air Speed		Temperature [°C]																
m/sec	mph	4	2	−1	−4	−7	−9	−12	−15	−18	−21	−23	−26	−29	−32	−34	−37	−40	−43
		Temperature [°F]																	
Calm	Calm	40	35	30	25	20	15	10	5	0	−5	−10	−15	−20	−25	−30	−35	−40	−45
2	5	2	−1	−4	−7	−11	−14	−17	−20	−24	−27	−30	−33	−37	−40	−43	−46	−50	−53
4	10	1	−3	−6	−9	−13	−16	−20	−23	−27	−30	−34	−37	−40	−44	−47	−51	−54	−58
7	15	0	−4	−7	−11	−14	−18	−21	−25	−29	−32	−36	−39	−43	−46	−50	−53	−57	−61
9	20	−1	−4	−8	−12	−15	−19	−23	−26	−30	−34	−37	−41	−45	−48	−52	−56	−59	−63
11	25	−1	−5	−9	−13	−16	−20	−24	−27	−31	−35	−39	−42	−46	−50	−53	−57	−61	−65
13	30	−2	−6	−10	−13	−17	−21	−25	−28	−32	−36	−40	−43	−47	−51	−55	−59	−62	−66
16	35	−2	−6	−10	−14	−18	−22	−25	−29	−33	−37	−41	−44	−48	−52	−56	−60	−64	−67
18	40	−3	−7	−11	−14	−18	−22	−26	−30	−34	−38	−41	−45	−49	−53	−57	−61	−65	−69
20	45	−3	−7	−11	−15	−19	−23	−27	−31	−34	−38	−42	−46	−50	−54	−58	−62	−66	−70
22	50	−3	−7	−11	−15	−19	−23	−27	−31	−35	−39	−43	−47	−51	−55	−59	−63	−67	−71
25	55	−4	−8	−12	−16	−20	−24	−28	−32	−36	−40	−44	−48	−52	−56	−60	−64	−67	−71
27	60	−4	−8	−12	−16	−20	−24	−28	−32	−36	−40	−44	−48	−52	−56	−60	−64	−68	−72
Time to Frostbite								30 min		10 min			5 min						

Special precautions must be taken when the wind chill is lower than −27°C (−17°F).

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Thermal Condition Assessment

- Clothing
  - Influences the rate of heat exchange by convection and radiation and modifies the rate of evaporative cooling
  - The Clo is the unit of thermal resistance used to quantity the insulation provided by clothing

$$1\ \text{Clo} = 0.155\ \text{K} \cdot \text{m}^2 \cdot \text{W}^{-1}$$

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Thermal Condition Assessment

Insulation Required (Clo Units) to Maintain Thermal Balance				
Temperature (°C)	Activity			
	Resting[a]	Slow Walking	Normal Walking	Fast Walking
21	1.5	0.7	0.4	0.3
10	3.1	1.5	0.9	0.7
−1	4.7	2.3	1.5	1.1
−18	7.2	3.5	2.3	1.

[a] When asleep, metabolic energy expenditure drops to 0.8 MET, so more insulation is required.

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Thermal Condition Assessment

Work Demands	Air Temperature					
	10ºC 50ºF	12ºC 54ºF	14ºC 57ºF	16ºC 61ºF	18ºC 64ºF	20ºC 68ºF
Sedentary	2.4–3.9	2.2–3.5	2.0–3.2	1.8–2.9	1.6–2.5	1.4–2.2
Light	1.3–2.7	1.2–2.5	1.1–2.2	1.0–2.0	0.9–1.7	0.7–1.5
Moderate	0.9–2.0	0.8–1.8	0.7–1.6	0.7–1.5	0.6–1.3	0.5–1.1
Heavy	0.7–1.6	0.6–1.4	0.5–1.3	0.5–1.1	0.4–1.0	0.4–0.9

The higher level of insulation helps maintain minimum discomfort, and the lower value is the least required to avoid extreme discomfort based on the equations provided in the text. While the cold stress threshold is 10C (see section on cold stress), caution must be exercised in allowing extreme discomfort.

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Thermal Condition Assessment

Clothing	clo
Sleeveless blouse, light cotton skirt, sandals	0.3
Shorts, open-neck shirt with short sleeves, light socks, sandals	0.3–0.4
Long lightweight trousers, open-neck shirt with short sleeves	0.5
Long lightweight trousers, open-neck shirt with long sleeves	0.6
Cotton fatigues, lightweight underwear, cotton shirt and trousers, cushion-sole socks and boots	0.7
Typical business suit; pant suit (with full jacket)	1.0
Typical business suit and cotton coat (lab coat)	1.5
Heavy traditional European business suit, long cotton underwear, long-sleeved shirt, woolen socks, shoes; suit includes trousers, jacket, and vest	1.5–2.0

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Thermal Comfort Zone

- Temperature
  - Ankles and head should not change by more than 3ºC (5ºF)
- Humidity
  - Below 55% or preferable in the summer months
  - Where feasible, values above 25% shall be used for extended exposure (more than two hours)
- Airspeed
  - Local draft can make a workplace feel very cool even when it is well within the comfort guidelines for dry bulb temperature
  - Allowing fans and worker discretion can increase the level of comfort for those who may feel unacceptably warm

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Thermal Comfort Zone

- Workload
- Clothing
- Radiant heat
  - The difference between dry bulb and globe temperature defines the amount of radiant heat present in the workplace

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Warm Discomfort and Heat Stress

- The exposure limits are based on an index for the environment called WBGT

Wet bulb glob temperature WBGT

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Heat Stress

- Heat stress
- Controls
  - Individual
  - Engineering
  - Administrative

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Heat Stress Controls

- Personal protection

Circulating air systems

Circulating water systems

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Heat Stress Controls

Passive cooling systems

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Cold Stress Controls

- Individual
- Engineering controls
- Administrative controls

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Cold Stress Controls

- Personal protection
  - Adequate insulated clothing
  - Hydration
  - Balanced diet

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Screening for Heat Stress

Screening for Heat Stress—Checklist*

Job	Analyst
	Date
Description of Climate, Work Demands, Clothing	Special Conditions

Complete the following checklist for each potential heat stress situation.

Job Factor	Yes	No
Obvious sweating		
Environment perceived to be warm		
Work requires a break at least every 2 hours		
Wearing regular work clothes would be more comfortable		
Reports of fatigue, weakness, loss of coordination, dizziness, headaches, nausea, heat exhaustion, cramps		
Absenteeism, employee irritability, or worsening employee relations can be associated with these work conditions		
Increases in accidents and injuries and/or decreases in production and quality indices can be associated with these work conditions		

A yes to the presence of any of these job factors would indicate that a further investigation and controls are appropriate.

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Screening for Heat Stress

Screening for Thermal Stress—Observational Analysis*

Job	Analyst
	Date
Description of Climate, Work Demands, Clothing	Special Conditions

Complete the following matrix by consensus of observers very familiar with the workplace and possible exposure situations. Table of scores and qualitative descriptors for each of the categories follows on the next page.

Scores	−3	−2	−1	0	+1	+2	+3
			Ideal Zone				
Air temperature							
Humidity							
Thermal radiation							
Air movement							
Workload							
Clothing							
Worker opinion							

Actions should be taken to bring scores outside of the ±1 range into this range.

* This observational method is adapted from J. Malchaire, H. J. Gebhardt, and A. Piette, "Strategy for evaluation and prevention of risk due to work in thermal environments." *Annals of Occupational Hygiene* 43:367–376, 1999.

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Summary

1. Operators should remain in thermal balance with the environment while carrying out critical and generic tasks
2. Work must be designed so that skin temperatures remain in a range defined as comfortable
3. Fluid should be readily at hand to prevent dehydration
4. Ventilation should be sufficient to support human health and performance
5. Workers should be protected from high radiant heat and ultraviolet radiation

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Vibration

Do you think we are expose to any vibration right now?

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Vibration's definition

Periodic back-and-forth motion of the particles of an elastic body or medium, commonly resulting when almost any physical system is displaced from its equilibrium condition and allowed to respond to the forces that tend to restore equilibrium.

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Vibration

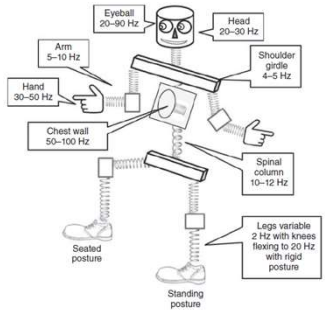

Figure 10.1 Resonance frequencies of the human body

Frequency (F) – The frequency of a vibration, measured in hertz (Hz), is simply the number of to and for movements made in each second.

Resonance – Every object tends to vibrate at one particular frequency called the natural frequency.

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Vibration

- ACGIH TLVs (ISO 5349, ANSI S3.34) for
  - Hand-Arm Vibration
  - Upper Limb
  - Whole Body Vibration

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Vibration Injuries

- Hand-Arm Vibration (HAVS)
  - Hand and arm vibration syndrome, white finger, raynaud's phenomenon.
  - Some evidence supports exposure to hand and arm vibration contributing to carpal tunnel and ulnar nerve entrapment
- Whole Body Vibration (WBV)
  - Headaches, nausea, motion sickness, insomnia, shakiness, back problems

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Hand Arm Vibration Syndrome (HAVS)

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Whole Body Vibration (WBV)

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TABLE 10.1 Sources of Vibration

Industry	Type of Vibration	Common Source of Vibration
Agriculture	Whole body	Tractors
Military, commercial, and general aviation	Whole body	Aircraft
Military and others	Whole body and hand-arm	Boats
Boiler making	Hand-arm	Pneumatic tools
Construction	Whole body	Heavy equipment vehicles
	Hand-arm	Pneumatic tools, jackhammers
Diamond cutting	Hand-arm	Vibrating hand tools
Forestry	Whole body	Tractors
	Hand-arm	Chain saws
Foundries	Hand-arm	Vibrating cleavers
Furniture manufacture	Hand-arm	Pneumatic chisels
Iron and steel	Hand-arm	Vibrating hand tools
Lumber	Hand-arm	Chain saws
Machine tools	Hand-arm	Vibrating hand tools
Mining	Whole body	Vehicle operation
	Hand-arm	Rock drills
Riveting	Hand-arm	Hand tools
Rubber	Hand-arm	Pneumatic stripping tools
Sheet metal	Hand-arm	Stamping equipment
Shipyards	Hand-arm	Pneumatic hand tools
Shoe-making	Hand-arm	Pounding machine
Stone dressing	Hand-arm	Pneumatic hand tools
Textile	Hand-arm	Sewing machines, looms
Transportation	Whole body	Vehicles

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Hand Arm Vibration Syndrome (HAVS)

- Hand Arm Vibration Syndrome (HAVS)

The Stockholm Workshop Scale for the classification of Cold-Induced Raynaud's Phenomenon in the Hand-arm Vibration Syndrome *

STAGE	GRADE	DESCRIPTION
0		No attacks.
1	Mild	Occasional attacks affecting only the tips of one or more fingers
2	Moderate	Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers.
3	Severe	Frequent attacks affecting all phalanges of the most fingers.
4	Very Severe	As in stage 3, with trophic skin changes in the finger tips.

* The staging is made separately for each hand. In the evaluation of the subject, the grade of the disorder is indicated by the stages of both hands and the number of affected fingers on each hand; example "2L(2) / 1R(1)", "- / 3R(4)", etc.

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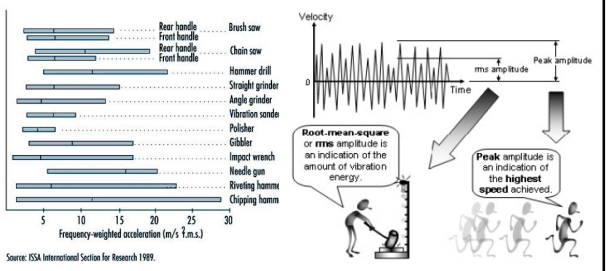
Hand and Arm Vibration



https://reliabilityweb.com/articles/entry/how_is_machine_vibration_described/

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Vibration Measurement

- Vibration measurement
  - Magnitude of acceleration RMS
  - Frequency (Cycles per second or hertz (Hz))
  - Direction
  - Exposure time
  - Point of application
  - Clothing
  - Body size
  - Body posture
  - Body tension

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Vibration Measurement

- Accelerometers
  - Specialized devices for home-body vibration
    - Impact
    - No impact
  - Device directly mounted to vibrating object

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Vibration Measurement

- Evaluation of human vibration RMS acceleration compared against reference levels
- ACGIH has established TLV's
  - Whole body
  - Hand and arm

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Vibration Hand and Arm

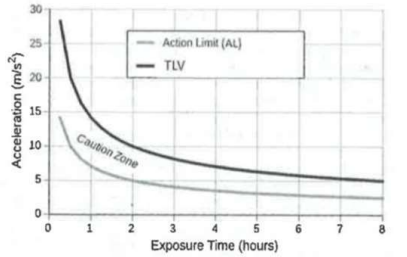

FIGURE 1. Relationship between exposure time [hours] and *A*(8) acceleration [m/s²].

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Example

- String trimmers are around 20 m/s^2 rms
- What is the daily operating limit?

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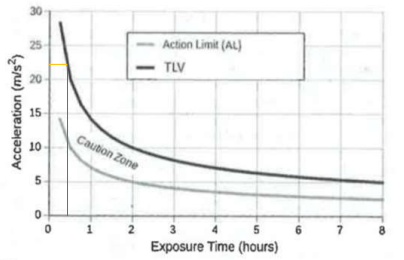
Vibration Hand and Arm



The daily limit for operating a string trimmer is around 30 minutes

FIGURE 1. Relationship between exposure time [hours] and *A*(8) acceleration [m/s^2].

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Vibration

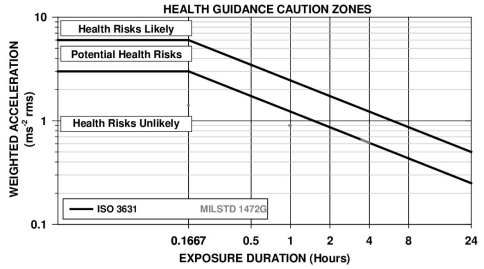

Figure 16. ISO 2631-1 Health Guidance Caution Zones
Plot includes more conservative lower boundary defined in MIL STD 1472G exposures at 3.5 hours and below [2, 3]

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Vibration Controls

- Source control
- Receiver control

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Vibration Controls

- Path control
  - Gloves are more common
    - More effective for high frequencies
  - Reduce the weight of the object held
  - Use larger gripping surfaces to better distribute forces in the hand

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Ventilation

Carbon Dioxide or CO_2 is a greenhouse gas that is natural and harmless in small quantities, but as levels rise it can affect productivity and sleep.

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Ventilation

As buildings and homes become more energy-efficient and airtight, this means we have less fresh air.

- Recycle air to conserve energy

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What do my CO_2 levels mean?

250-400ppm	Normal background concentration in outdoor ambient air
400-1,000ppm	Concentrations typical of occupied indoor spaces with good air exchange.
1,000-2,000ppm	Complaints of drowsiness and poor air
2,000-5,000ppm	Headaches, sleepiness and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate and slight nausea.
>40,000ppm	Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma and even death.

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Ventilation

$$N = \frac{60Q}{Vol}$$

Where:

- N = number of air changes per hour
- Q = Volumetric flow rate of air in cubic feet per minute (cfm)
  Area*speed
- Vol = Space volume $L \times W \times H$, in cubic feet

$$Rp = \frac{N * D * h}{60}$$

Where:

- R_p = ventilation rate per person (CFM per person, L/s per person)
- N = Air changes per hour
- D = Occupant density (occupants per square foot, occupants per square meter)
- h = Ceiling height (ft, meters)

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Ventilation rate

- Range *15 - 60 cfm per person*
- Most common range *15 - 35 cfm per person*
- Average range *15 - 20 cfm per person*

Cubic feet per minute (cfm)

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What are the effects of CO_2?

High levels are directly correlated to low productivity and high sick leave making this a crucial concern in offices, schools and home environments.


Restlessness


Drowsiness


Increased heart rate and blood pressure


Sweating


Headache

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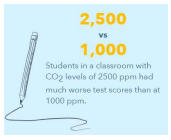
What are the effects of CO_2?

At home

Fresh air will help you get a better night's sleep.

At school



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Measuring CO_2

- CO_2 Monitor

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Reducing CO_2

- Ventilation
- Amount of people
- Length of time in an enclosed space
- Regularly replace air filters in indoor fan systems

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Reducing CO_2

- Plants:

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To do list

- Read chapter 6,15
- I will post HW 3.
- Next week
  - Tuesday – Bring computers.

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