Clothing, Insulation, and Climate

Turn off all electronic devices

Observations about Clothing, Insulation, and Climate

- Clothing keeps you warm in cold places
- Clothing can keep you cool in very hot places
- Insulation controls heat flow in various objects
- Insulation can be obvious, as in foam cups
- Insulation can be subtle, as in special windows
- Greenhouse gases trap heat and warm the earth

4 Questions about Clothing, Insulation, and Climate

1. How does clothing control thermal conduction?
2. How does clothing control thermal convection?
3. How does insulation control thermal radiation?
4. Why do greenhouse gases warm the earth?

Question 1

- How does clothing control thermal conduction?

Thermal Conductivity

- Heat naturally flows from hot to cold
- If one end of a material is hotter than the other
  - it will conduct heat from its hot end to its cold end
  - at a rate equal to the material's area
  - times the temperature difference
  - times the material's thermal conductivity
  - divided by the material's thickness.

$$\text{heat flow} = \frac{\text{conductivity} \cdot \text{temperature difference} \cdot \text{area}}{\text{thickness}}$$

Limiting Thermal Conduction

- Clothing is often intended to reduce heat flow
  - so it should use low-thermal conductivity materials
    - electrical insulators, not metals
    - materials that trap air—air is a very poor thermal conductor
  - and it should use relatively thick materials
    - wool sweaters, down coats, heavy blankets
- Reducing exposed area is helpful when possible
- Reducing the temperature difference always helps

Question 2

- How does clothing control thermal convection?

Natural Convection

- Heat naturally flows from hot to cold
- If one region of a fluid is hotter than the other
  - those regions will also have different densities
  - and buoyancy may cause the fluid to circulate.
- The rate of heat flow depends on
  - the heat capacity and mobility of the fluid
  - how quickly heat flows into or out of the fluid
  - how well buoyancy circulates fluid from hot to cold

Forced Convection

- Buoyancy isn't always effective at moving fluids
  - It fails when the hotter fluid is above the colder fluid
  - It fails when fluids experience large drag forces
  - It fails in certain awkward geometries
- Stirring the fluid enhances heat flow
  - Wind leads to faster heat transfer (wind chill)
  - Moving through air or water speeds heat transfer

Limiting Thermal Convection

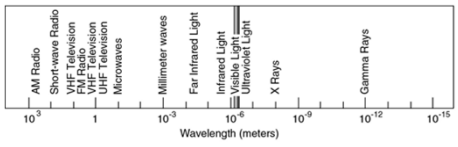
- Clothing can reduce convective heat flow by
  - preventing fluids from circulating
  - reducing temperature differences in the fluid
- The most effective clothing is thick and fluffy
  - The fluffiness traps air so that it can't convect
  - The thickness allows the surface temperature to drop to that of your surroundings so that there is no external convection
- A wind breaker minimizes forced convection

Question 3

- How does insulation control thermal radiation?

Thermal Radiation

- Materials all emit thermal radiation because
  - they contain electric charges
  - and thermal energy causes those charges accelerate.
  - Accelerating charges emit electromagnetic waves
- Hotter temperatures yield shorter wavelengths

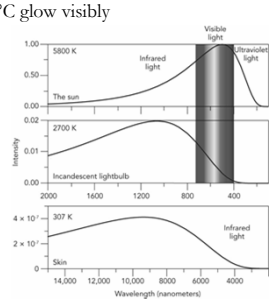


Black Body Spectrum (Part 1)

- A surface's efficiency at absorbing and emitting thermal radiation is measured by its emissivity
  - 1 for a perfect emitter-absorber (black)
  - 0 for a nonemitter-nonabsorber (white, clear, shiny)
- The spectrum and intensity of a black surface's thermal radiation depend only on its temperature

Black Body Spectrum (Part 2)

- The black body spectrum of the sun is white light
- Objects hotter than about 500 °C glow visibly
- But even your skin emits invisible thermal radiation



Radiative Heat Transfer

- Your skin radiates heat at a rate given by the Stefan-Boltzmann law:

$$\text{power} = \text{emissivity} \cdot \text{Stefan-Boltzmann constant} \cdot \text{temperature}^4 \cdot \text{surface area}$$

  where temperature is an absolute temperature.
- Because of the 4th power, thermal radiation is extremely sensitive to temperature.
- Black or gray objects with different temperatures can exchange heat via thermal radiation

Limiting Thermal Radiation (Part 1)

- Insulation can reduce radiative heat flow by
  - having surfaces with low emissivities
  - reducing temperature differences between surfaces
- Emissivity depends on temperature
  - You can see high-temperature emissivity
    - black surfaces have high-temperature emissivities near 1
    - white, clear, shiny surfaces values near 0
  - You can't see low-temperature emissivity
    - most materials have low-temperature emissivities near 1
    - conducting (metallic) surfaces can have values near 0

Limiting Thermal Radiation (Part 2)

- To reduce radiative heat flow
  - use conducting, low-emissivity surfaces
  - allow exterior surfaces to reach ambient temperature

Question 4

Q: Why do greenhouse gases warm the earth?

A: By increasing altitude of earth's radiating surface

- Earth receives thermal radiation from the sun
- Earth emits thermal radiation into space
  - The atmosphere contributes to that thermal radiation
  - Effective radiating surface is 5 km above sea level
- Balance requires Earth's radiating surface is -18 °C
- Greenhouse gases increase altitude of that surface

Effects of the Atmosphere

- Atmosphere has a temperature gradient
  - air expands and cools is its altitude increases
  - air temperature decreases 6.6 °C per km of altitude
- Atmosphere's average temperature
  - at 5 km is -18 °C
  - at sea level is 15 °C

Effects of Greenhouse Gases

- Greenhouse gases "darken" the atmosphere
  - Low-temperature emissivity of atmosphere increases
  - Effective radiating surface moves to higher altitude
  - Average temperature at sea level increases
- Increasing greenhouse gases cause global warming
- Greenhouse gases include
  - water, carbon dioxide, nitrogen oxides, and methane
  - but not nitrogen or oxygen; they're transparent to IR
- Limiting greenhouse gases is critical to our future

Summary about Clothing, Insulation, and Climate

- Clothing and insulation limit heat transfer
- They use materials with low thermal conductivities
- They introduce drag to impede convection
- They use low emissivities to reduce radiation
- Greenhouse gases affect Earth's thermal radiation
- Those gases raise Earth's surface temperature