1 Summary: if organism in environment, must have solved problem of heat balance
   3 general strategies: (1) structural/anatomical, (2) physiological, (3) behavioral

2 Thermal Balance (Budgets)
   2.1 Inputs
      – Metabolic heat
      – Insolation
      – Diffuse radiation
      – Thermal radiation from environmental objects ($\propto T_{abs}^4$)
      (– Conduction from warm surfaces)
   2.2 Outputs
      – Conduction
      – Convection
      – Evaporation
      – Radiation ($\propto T_{abs}^4$)
   2.3 Thermal Balance Equation
      \[ H_s = H_m \pm H_{cd} \pm H_{cv} \pm H_r - H_e \]
      \( s = \) stored energy \( m = \) metabolic \( cd = \) conduction \( cv = \) convection \( r = \) radiation \( e = \) evaporation

3 Effects of Temperature on Metabolism
   3.1 Plants & ectotherms: exponential $\uparrow$ Metabolic rate w/ temperature
      – measured by \( Q_{10} = R_T / R_{T-10} \) (often, \( Q_{10} \sim 2 \))
   3.2 Thermal adaptation

4 Plant Responses to Temperature
   4.1 coping w/ heat stress: transpire water or reduce light exposure
   4.2 coping w/ cold stress: 3 strategies: avoidance, supercooling, freeze tolerance
      – Avoidance: • dropping leaves (deciduous)
        • persist under snow cover
      – Supercooling: pack cells w/ solutes: sugars, amino acids (prevent ice crystals)
      – Freeze Tolerance: 3 levels in plants
        1. pack cells w/ solutes (like supercooling)
        2. Alter membranes: H2O exported out of cell & replace w/ sugars
        3. poorly known mechanism: – far below natural temps (down to -80$^\circ$C)
   4.3 growth form
   4.4 thermogenesis
5 Animal Responses to Temperature

5.1 Poikilothermy

5.2 Homeothermy
   – thermal neutral zone (TNZ)

5.3 Heterothermy:
   – transient
   – prolonged: hibernation & torpor

5.4 Kinds of Temperature responses
   5.4.1 Behavioral responses
   5.4.2 Anatomical responses
   5.4.3 Physiological responses

6 Energy savings of Torpor & Hibernation

6.1 Winter energy stress primarily lack of food; cold temperatures secondary

6.2 Hibernating metabolic rate << non-hibernating metabolic rate
   – related to difference in body temperatures: hibernating vs. non-hibernating

6.3 Energy savings high: if integrate thru time difference in metabolic rates,

<table>
<thead>
<tr>
<th>Species</th>
<th>Body mass</th>
<th>T_\text{torpor}</th>
<th>% energy savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>European hedgehog</td>
<td>700g</td>
<td>5.2°C</td>
<td>96%</td>
</tr>
<tr>
<td>Little brown bat (Myotis lucifugus)</td>
<td>5-6g</td>
<td>2°C</td>
<td>98.5% !!</td>
</tr>
</tbody>
</table>

6.4 Low respiratory rate ⇒ lose little respiratory H2O

7 Extreme Adaptations to Cold: Supercooling & Freeze Tolerance

7.1 Most small mammalian hibernators maintain core body temperatures ≥ 2°C – 4°C
   – use burrows or nests with T_\text{ambient} just below T_\text{body}

   Some spp hibernate in colder places => must tolerate lower T_\text{body}
   – problem: risk of freezing (tissue damage, death)

7.2 Two alternatives: (1) Freeze avoidance by supercooling (T_\text{body} < Freezing pt of H_2O)
   (2) Freeze tolerance (let body freeze in controlled manner)

7.3 Examples: (1) Bats & Arctic Ground Squirrel: supercooling mammals
   (2) Goldenrod gall moth: supercooling insect
   (3) Wood frog: freeze tolerant amphibian
8 Conclusion: Temperature Relations

8.1 Thermal balance vital for survival; determines species distributions

8.2 Three general strategies:
  (1) structural/anatomical
  (2) physiological
  (3) behavioral

8.3 Three classes of temperature responses
  (1) Poikilothermy (invertebrates, fish, herps, “plants”)
  (2) Homeothermy (many mammals, most birds)
  (3) Heterothermy (hummingbirds, hibernating mammals, bees)

8.4 Can predict spatial distribution & temporal activity from:
  (1) type of temperature response
  (2) environmental energy available (thermal & food)

8.5 Check for yourself:
  (1) Poikilotherms active when adequate thermal energy in environment
  (2) Homeotherms: • exist where: food available year round, or can store food (as fat or caches)
      • lower limit to homeotherm body size (≈ shrew body size; > hummingbird)
  (3) Heterotherms: • when active, high food intake (alternate betw/ adding & burning fat)
      • exist where sheltered (temperature) hibernacula available
      – almost no arctic spp hibernate
      => loss of undisturbed caves an important factor in bat declines
      • exceptions require special adaptations (supercooling, freeze tolerance)