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Print version

CEE 370 Environmental Engineering Principles

Lecture #10

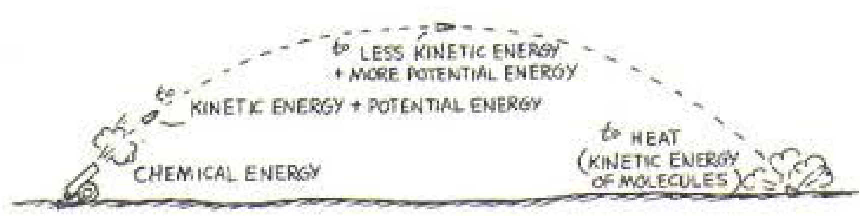
Energy Balances

Reading: Mihelcic & Zimmerman, Section 4.2 & 4.3

Davis & Masten, Chapter 4

CEE 370 L#10 1

Conservation of Energy



Energy Cannot Be Created or Destroyed

(It just changes forms)

Generic: $KNO_3 + C + S \rightarrow K^+ + \{S, SO_2, SO_4^{-2}\} + \{CO_2, CO_3^{-2}\} + N_2$

A specific example: $10KNO_3 + 8C + 3S \rightarrow 2K_2CO_3 + 3K_2SO_4 + 6CO_2 + 5N_2$

CEE 370 L#10 2

Energy Balance

- First law of thermodynamics
  - Energy can be neither created nor destroyed
    - But the form can certainly change
- Thermal Energy
  - Characterized by
    - Temperature (T) and
    - Specific heat capacity (c_p)

$$\Delta H = Mc_p \Delta T$$

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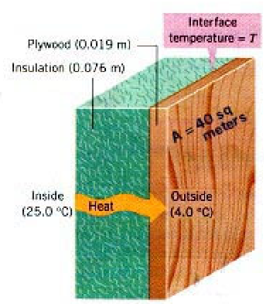
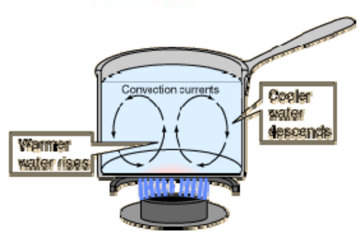
Heat Transfer

- Conduction
  - Transfer of energy without mass flux



- Convection
  - Energy is carried by molecules in bulk motion



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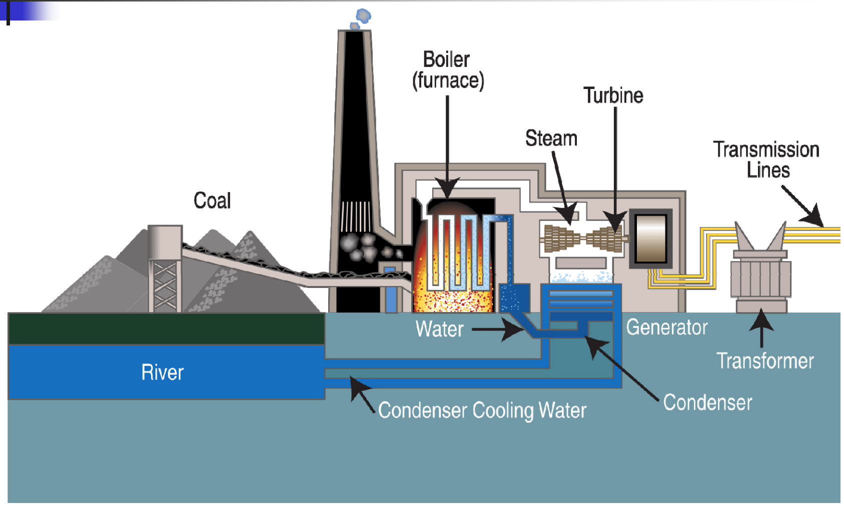
Energy Balances



Common Forms of Energy

Table / 4.4

Some Common Forms of Energy

	Representation for Energy or Change in Energy
Heat internal energy	$\Delta E = \text{mass} \times c \times \Delta T$
Chemical internal energy	$\Delta E = \Delta H_{rxn}$ at constant volume
Gravitational potential	$\Delta E = \text{mass} \times \Delta$ height
Kinetic energy	$E = \frac{\text{mass} \times (\text{velocity})^2}{2}$
Electromagnetic energy	$E =$ Planck's constant $\times$ photon frequency

SOURCE: Mihelcic (1999). Reprinted with permission of John Wiley & Sons, Inc.

Energy Balance

- Much like material balances

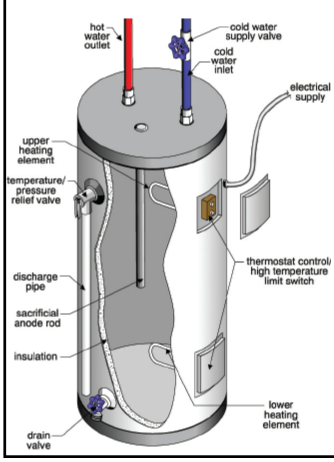
(Change in internal plus external energy per unit time) = (energy flux in) – (energy flux out)

$$\frac{dE}{dt} = E_{in} - E_{out}$$

CEE 370 L#10 7

Example 4.9

- Heating Water: Scenario 1
  - 40 gal capacity, cold water is 10C
  - 5 kW is max heating rate
  - Flow is 2 gal/min
  - Assume 100% efficiency & steady state



$$\frac{dE}{dt} = 0 = E_{in} - E_{out}$$

$$0 = \left(m_{H_2O} c T_{in} + 5kW\right) - \left(m_{H_2O} c T_{out}\right)$$

CEE 370 L#10 8

Example 4.9 cont

$$0 = \left(m_{H_2O} c T_{in} + 5kW\right) - \left(m_{H_2O} c T_{out}\right)$$

$$0 = m_{H_2O} c (T_{in} - T_{out}) + 5kW$$ Note error in book

- Note that c=4184J/kg°C and 1W=1J/s

$$0 = \frac{2\ gal\ H_2O}{min} x \frac{3.785\ L}{gal} x \frac{1.0\ kg}{L} x \frac{4184J}{kg°C}(T_{in} - T_{out}) + \frac{5000J}{s} x \frac{60s}{min}$$

$$0 = 3.16x10^4 \frac{J}{min°C}(T_{in} - T_{out}) + 3.00x10^5 \frac{J}{min}$$

$$(T_{in} - T_{out}) = \frac{3.00x10^5}{3.16x10^4} °C = 9.5°C$$

If T_{in} is 10°C, then T_{out} is 19.5°C

~67°F

CEE 370 L#10 9

Example 4.10

- How long should you wait to get a temperature of 54°C (~129°F)?

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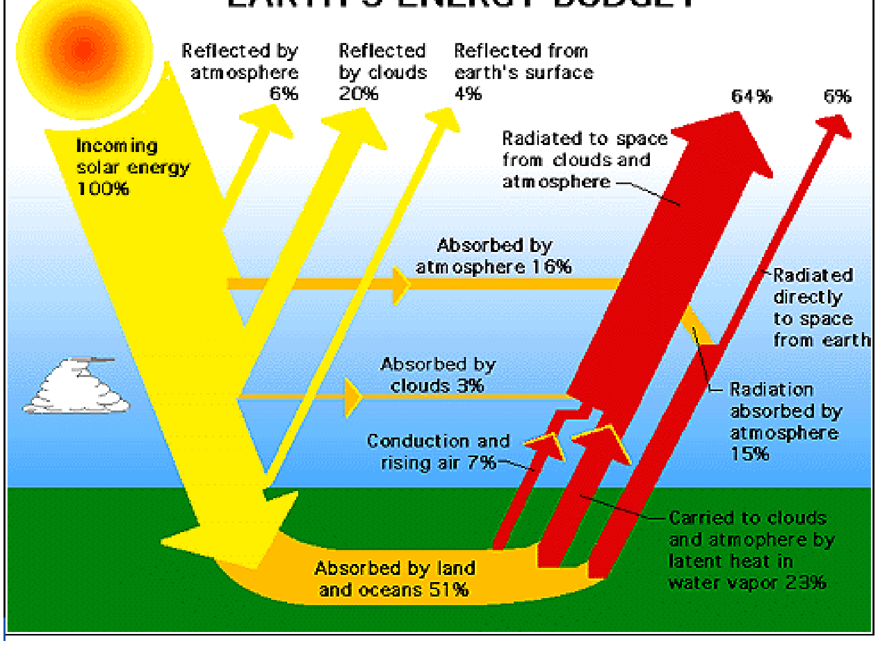
EARTH'S ENERGY BUDGET



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GHG Effect

- What are greenhouse gases?
- What are affects of GHGs?
- Are GHGs bad?

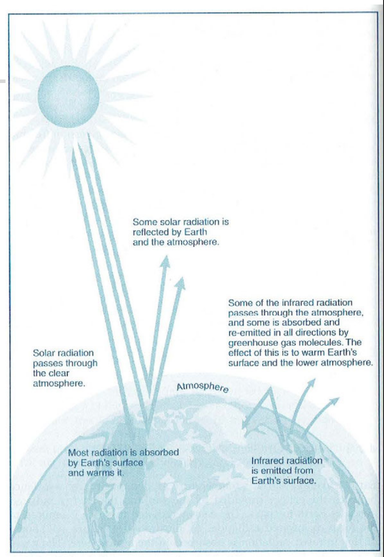


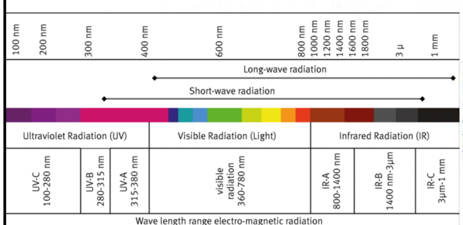
Figure / 4.12 The Greenhouse Effect

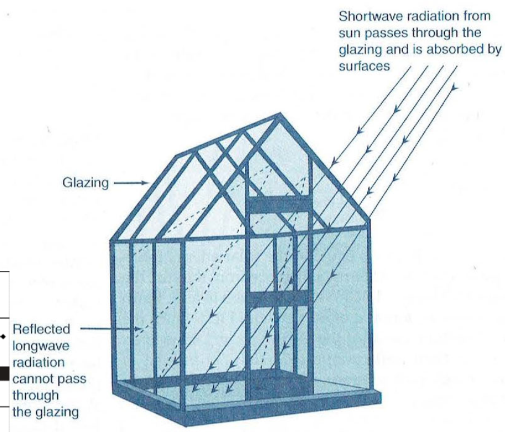
(Redrawn from *Our Changing Planet: The FY 1996 U.S. Global Change Research Program*, Report by the Subcommittee on Global Change Research, Committee on Environment and Natural Resources Research of the National Science and Technology Council (supplement to the President's fiscal year 1996 Budget)).

CEE 370 L#10 12

Solar Radiation & Climate Change

Figure / 4.13 Function of Glazing Materials Glazing materials allow shortwave radiation from the sun to pass through the glazing, but reflected longwave radiation cannot pass through the glazing. This is similar to the greenhouse gases that trap solar radiation and lead to climate change.





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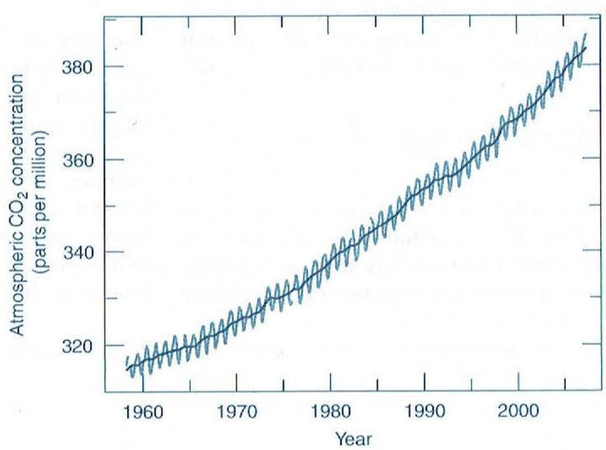
Global Average CO2 Concentration Trend



Why?

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Climate Change Scenarios

Table / 4.5

Temperature Change and Sea Level Rise Resulting from Various Future Scenarios Scenarios include economic and population growth, material and energy efficiency technology development, and consumption patterns for 2090–2099.

Scenario	Temperature Change (°C at 2090–2099 relative to 1980–1999)		Sea Level Rise (m at 2090–2099 relative to 1980–1999)
	Best Estimate	*Likely Range*	*Model-Based Range**
B1: rapid economic growth toward a service and information economy; population peaks in midcentury and then declines; reductions in material intensity; clean/resource-efficient technologies; global solutions to sustainability, including improved equity	1.8	1.1–2.9	0.18–0.38
A1T: rapid economic growth; population peaks in midcentury and then declines; rapid introduction of new and efficient technologies; convergence among regions; nonfossil-fuel energy sources	2.4	1.4–3.8	0.20–0.45
B2: local solutions to sustainability; continuously increasing population; intermediate levels of economic development; less rapid and more diverse technological change	2.4	1.4–3.8	0.20–0.43
A1B: same as A1T except balance between fossil and nonfossil-fuel energy sources	2.8	1.7–4.4	0.21–0.48
A2: self-reliance and preservation of local identities; continuously increasing population; economic development that is primarily regionally oriented; slow and fragmented per capita economic growth and technological change	3.4	2.0–5.4	0.23–0.51
A1FI: same as A1T except fossil-intensive energy sources	4.0	2.4–6.4	0.26–0.59

*Excluding future rapid dynamic changes in ice flow in the large glacial regions of Greenland and Antarctica. Based on IPCC (2007a).

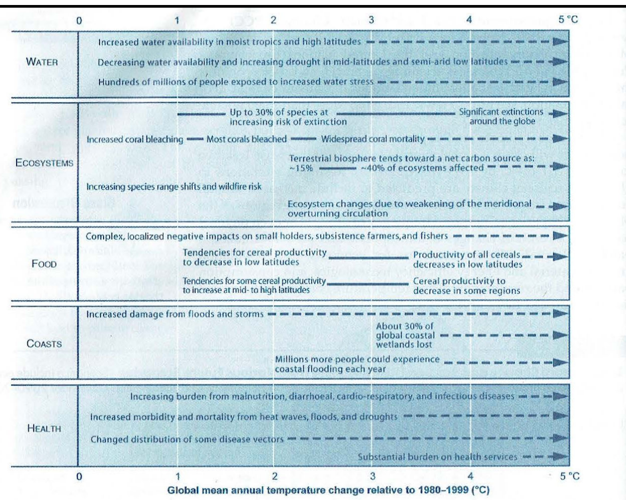
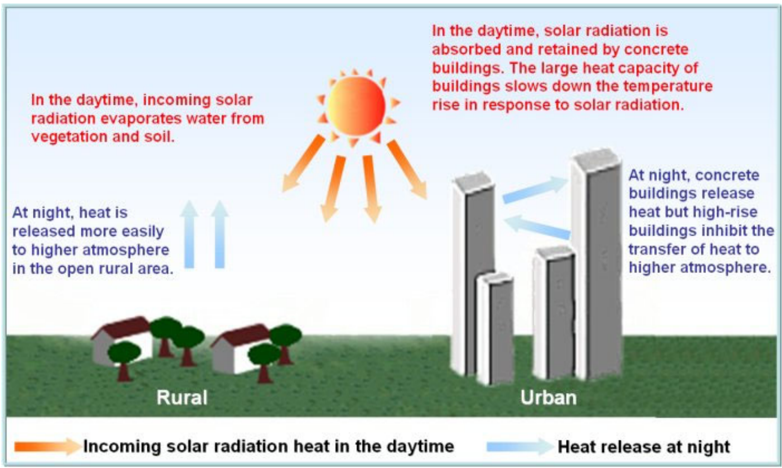


Figure / 4.15 **Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century.** The black lines link impacts and dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of the text indicates the approximate onset of a given impact. Quantitative entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of Special Report on Emissions Scenarios (SRES) scenarios A1FI, A2, B1, and B2 (see Endbox 3).

(Adaptation to climate change is not included in these estimations. Confidence levels for all statements are high with permission of Intergovernmental Panel on Climate Change: Impacts, Adaptation, and Vulnerability, Summary for Policymakers, Table SPM.2, 2007)

Rural vs. Urban Temperatures



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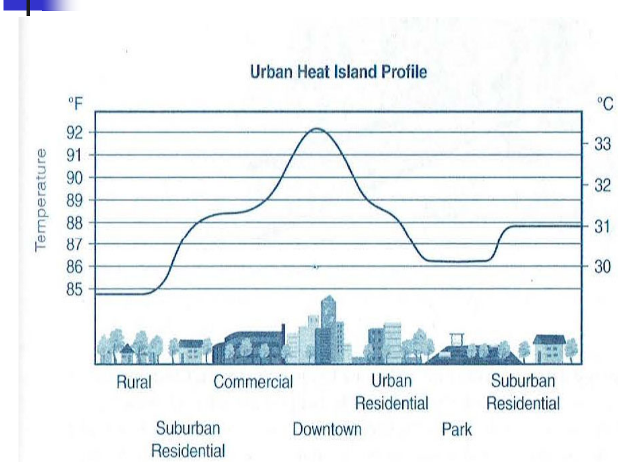
Heat Distribution in Different Areas



Why?

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Urban Shallow Layer Energy Balance

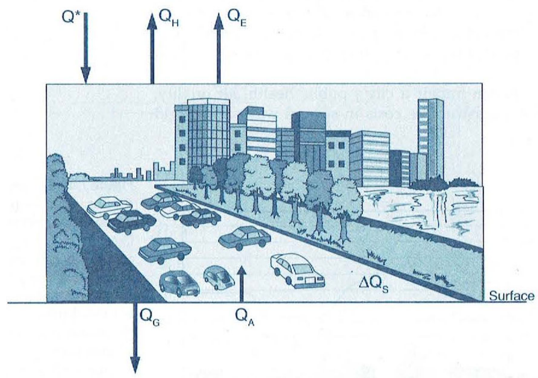


Figure / 4.18 Energy Balance Written for a Shallow Layer at the Urban Land Surface This layer contains air and surface elements that make up the built environment. Q^* is the net radiation, Q_H is the sensible heat flux, Q_E is the latent heat flux, Q_G is the ground heat flux, Q_A is the anthropogenic heat discharge, and ΔQ_S is the energy stored or withdrawn from the layer.

Table / 4.6

Features of Urban Environment Related to Terms in the Heat Island Energy Balance Designing and modifying an urban environment to modify climate processes requires an understanding of this balance.

Energy Balance Term	Feature of an Urban Environment That Alters the Energy Balance Term	Engineering Modifications That Reduce Intensity of Urban Heat Island
Net shortwave and longwave radiation, Q^*	Canyon geometry of the street and building	Canyon geometry influences the way shortwave radiation enters and is absorbed by the built environment and the way longwave radiation is reflected out of the urban canopy.
Heat added by humans (Q_{human})	Emission of waste heat from buildings, factories, and vehicles	Though this is a small term in the overall energy balance, buildings can be designed to reduce the need for mechanical cooling. Cities can be planned so they are dependent on mechanical engines to move people and goods.
Sensible heat flux, Q_H	Types of engineering materials	Increasing the surface albedo of paints and roofing materials will limit the surface–air sensible heat flux. Albedo is a measure of the amount of solar energy reflected by the surface. Narrow canyon geometry can result in reduced air flow, which decreases the effect of Q_H.
Latent heat flux, Q_E	Types of engineering materials and storm water management	The latent heat flux out of the system is the result of water evaporation. The energy is carried out in the form of water vapor (in the form of the higher energy in the water molecules in the vapor form). The heat is taken from the vegetation or water. This is the same process as sweat, where one's body is cooled with the heat going away in the form of latent heat. Impervious and nonvegetated surfaces hinder evaporative cooling (unless water is sprinkled on them). Low-impact development recognizes that leaving some standing water on the surface is not bad and vegetation such as green roofs and trees is an important feature of the urban built environment.
Increased storage of heat	Different abilities to store heat in different types of construction materials	The thermal conductivity of asphalt and concrete are similar (1.94 versus 2.11 $J/m^3 - K$, respectively). The thermal admittance of asphalt and concrete results in increased storage of heat. Urban surfaces heat up faster than natural and impervious surfaces that retain water. Built-environment materials have a high ability to store and release heat. Paved surfaces are thick and in contact with an underlying ground surface. Buildings, though, have a thinner skin that separates indoor and outdoor air. Surfaces with higher albedo will reduce the stored heat.

SOURCE: Based on Mills (2004).

Comparison of the American Home

Table 4.7

Then and Now: Increasing Size of the American Home

	Then	Now
Average number of occupants	3.67 in 1940	2.62 in 2002
Average size of home	100 m^2 (1,100 ft^2) in the 1940s and 1950s	217 m^2 (2,340 ft^2) in 2002
Garage	48% of single-family homes had a garage for 2 or more cars in 1967	82% of homes had a garage for 2 or more cars in 2002
Air-conditioning	46% of new homes had central air-conditioning in 1975	87% of new homes had air-conditioning in 2002

Energy Use for Small vs. Large Homes

Table 4.9

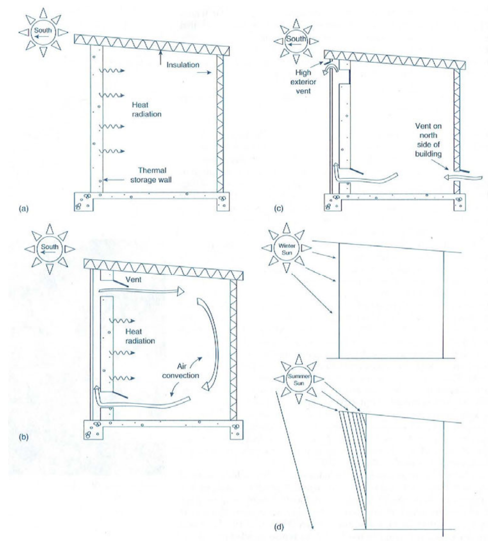
Comparative Annual Energy Use for Small versus Large Houses *R* factor is a measure of resistance to heat flow. R-19 is comparable to RSI-3.3 in the metric system.

House	Location	Relative Energy Standard[a]	Heating (million Btu)	Cooling (million Btu)	Heating Cost ($)[b]	Cooling Cost ($)[c]
3,000 ft^2	Boston, MA	Good	73	19	445	190
3,000 sq. ft^2	St. Louis, MO	Good	61	29	378	294
1,500 ft^2	Boston, MA	Good	35	13	217	131
1,500 ft^2	St. Louis, MO	Good	29	20	181	198
1,500 ft^2	Boston, MA	Poor	48	12	297	124
1,500 ft^2	St. Louis, MO	Poor	40	21	247	206
1,500 ft^2	Northern U.S.	High	27[d]	0[e]	240	0

[a] "Good" means a moderately insulated home with R-19 walls, R-30 ceilings, double-low-e vinyl windows, R-4.4 doors, R-6 insulation in air ducts, and infiltration of 0.50 air change per hour for heating and 0.25 air change per hour for cooling.
"Poor" means a poorly insulated home with R-13 walls, R-19 attic, insulated glass vinyl windows, R-2.1 doors, and infiltration of 0.50 air change per hour for heating and 0.25 air change per hour for cooling. Air ducts are not insulated.
"High" means the home is carefully designed and constructed to be airtight. It has R-25 walls, R-50 in the attic, double-low-e vinyl windows, R-14 doors, and infiltration of 0.20 air change per hour for heating.
[b] Heating costs assume natural gas costs $0.50 cents per 100,000 Btu.
[c] Cooling costs assumed to be $0.10 per kWh.
[d] Heating consumes two cords of hardwood and assumes 17 million usable Btu per cord.
[e] No air-conditioning is installed. Building insulation stores cool air obtained during the night, and strategic placement of windows, tree shading, and use of porch contribute to no need for mechanical cooling.
SOURCE: Adapted from Wilson and Boehland (2005). With permission of Wiley-Blackwell.

Sustainable Design for Temperature Regulation

a) Thermal walls for heat transfer and dissipation
b) Ventilation systems for natural heating
c) Ventilation systems for natural cooling
d) Overhangs to regulate effects from sun



CEE 370 L#10 23

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CEE 370 L#10 24