1.020 Ecology II: Engineering for Sustainability
Spring 2008

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Civil and Environmental Engineering

1.020 Ecology II: Engineering for Sustainability

Problem Set 3 – Thermal analysis for a small house
**Due: 5PM Friday March 21, 2008**

A. Introduction
In this problem set you will be evaluating the energy performance of a house using a MATLAB model you construct. Your model will include heat gains and losses from heat conduction, convection, and radiation as well as heat gains from a thermostatically controlled furnace. You will be examining the effect of changing windows, and other structural components.

B. House Description
The house consists of a single room and an attic with a roof. It is located in Harvard, MA.

1. House dimensions: 8m by 8m in plan, walls 4m high (see diagram)

2. Window dimensions: 3 windows each 2m by 1m

3. Door dimensions: 2.5m by 1m

4. Roof: Surface area 80m^2, maximum height above room ceiling 3m.
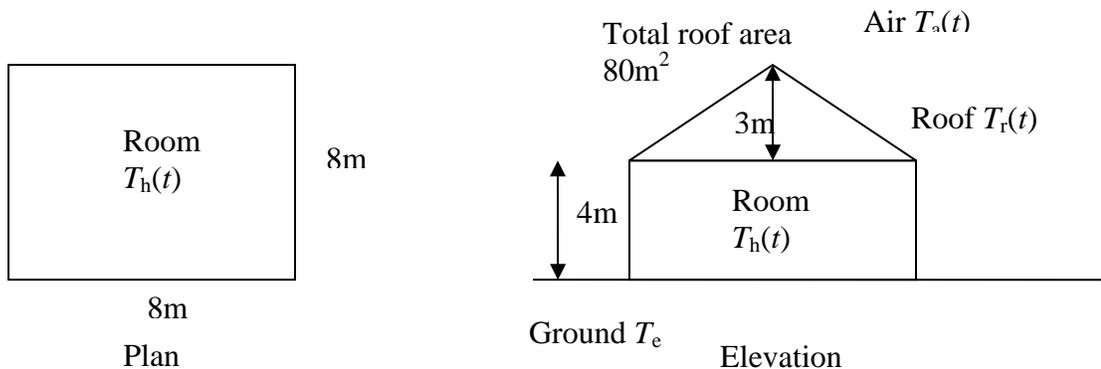
5. Furnace: Supplies heat to the main room (but not the attic), generates 26 kW of heat when switched on.

6. Thermostat: Set to 18 °C (switches furnace on when interior temperature is below 18 °C, otherwise switches furnace off).

7. Meterological data for Harvard MA:

Data are given for every 6 hours during a typical year (1999) in the data file `harvardmet.txt`
found in the PS3 section of the 1.020 Stellar site.

The file contains four columns:

Column 1: Time in days
Column 2: Global (total incident shortwave) solar radiation in Wm^{-2}
Column 3: Outside air temperature in °C
Column 4: Sky temperature for computing incoming longwave radiation in °C
Column 5: Ground temperature below floor in °C

Use `dlmread` to import the data into the MATLAB code.

8. Nominal house construction details and conductive heat transfer coefficients (R-values quantify resistance only to *conductive* heat transfer, R - values in SI units).

Walls:

Wood frame as viewed
from within roon

Section through wall
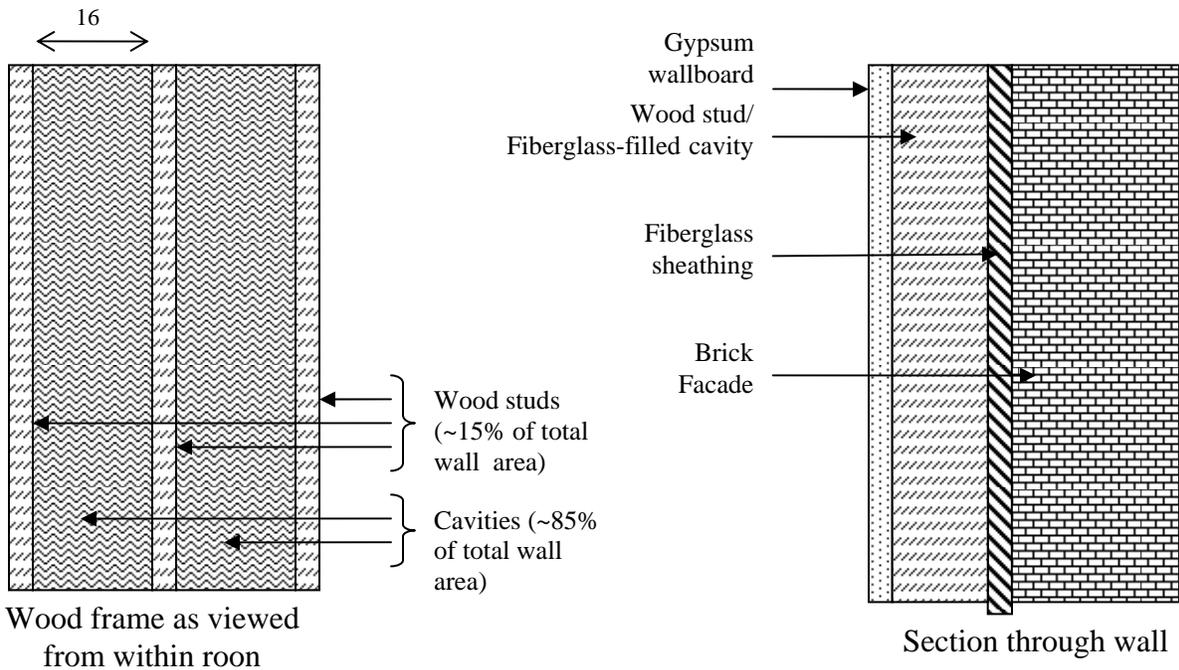
	Material				
	gypsum wallboard	wood stud	cavity-fiberglass insulation	fiberglass sheathing	brick façade
R[m^2 K/w]	0.10	0.55	1.38	0.70	0.08
% of layer area	100%	15%	85%	100%	100%

Room ceiling:

Blown fiberglass
insulation

Wood stud/
Fiberglass-filled cavity

Gypsum
wallboard

Ceiling Section
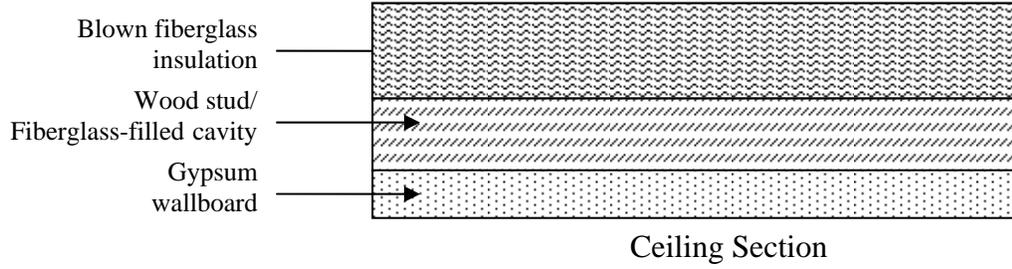
	Material			
	gypsum wallboard	wood stud	cavity-fiberglass insulation	blown fiberglass insulation
R[m² k/w]	0.10	0.55	1.38	2.32
% of layer area	100%	15%	85%	100%

Roof:

Asphalt
shingles

Plywood
sheathing

Wood stud/
air cavity

Roof Section
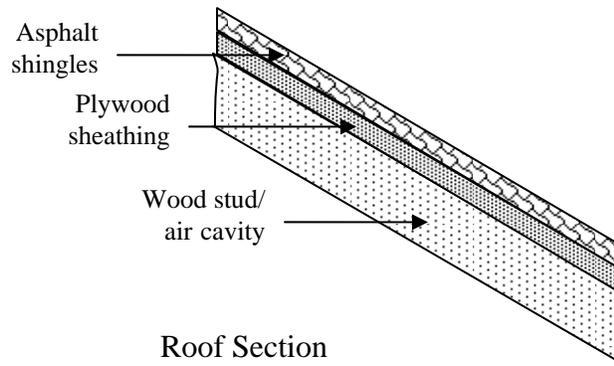
	Material			
	wood stud	cavity- air	plywood sheathing	asphalt shingles
R[m² k/w]	0.55	0.18	0.17	0.08
% of layer area	15%	85%	100%	100%

Floor:

	Material	
	carpet	poured concrete
R[m² k/w]	0.37	0.34
% of layer area	100%	100%

Windows in walls:

	Material
	single pane
R[m^2 k/w]	0.16
% of layer area	100%

Door in wall:

	Material
	wood, hollow core
R[m^2 K/w]	0.67
% of layer area	100%

9. Convection Coefficients

	outdoor	indoor
h [W/(m^{2}K)]	33	8

10. Heat Capacities

C_{pr} Attic/Roof	8×10^7 J °K^{-1}
C_{ph} Room	8×10^9 J °K^{-1}

11. Roof radiation emissivity: 1.0 (unitless)

12. Roof radiative transfer coefficient: $h_{rad} = \varepsilon\sigma 4T_{sky}^3$, T_{sky} from `harvardmet.txt`

C. Model Formulation:
The MATLAB model you need for this problem set can be constructed by modifying the MATLAB code Lecture08_8.m on the 1.020 Stellar site.

1. Use SI (metric) units throughout

2. Your model should solve for the following unknowns in your model:
Temperature in the main room °C
Temperature in the attic °C

3. You should account for the fact that the outside roof temperature that controls conduction and convection between the attic and outdoors is different than the air temperature. This requires you to include the effects of shortwave and net longwave radiation incident to the roof (See Lecture08_8through10 notes).

4. Include the following heat transfer processes in your model:

Into the attic:
- Conductive and convective heat transfer entering attic through room ceiling.
- Effective conductive and convective heat transfer entering attic through roof (account for the effects of net longwave radiation).
- Effective radiative heat transfer into attic (account for the effects of shortwave radiation incident to roof).

Into the room:
- Conductive convective heat transfer into room through room ceiling.
- Conductive and convective heat transfer into room through walls, windows, and door.
- Conductive and convective heat transfer into room through floor.
- Do not include the effects of long wave or short wave radiation to or from the room walls.

4. Total simulation time: 1 year (same as the year of data in `harvardmet.txt`). Your simulation times should be the same as the times given in this file..

D. Problem Set Tasks

*** All of the information requested below should be compiled in a single MS Word (or equivalent) file with all your team member names clearly identified in the file name and submitted via the 1.020 Stellar site ***

Nominal Case

1. Plot following temperatures vs. time on one set of labeled axes (one figure) every 6 hours for the entire year:
- **Outside air temperature (from** `harvardmet.txt`**)**
- **Room temperature**
- **Attic temperature**

Use model inputs obtained from the "House Description" section above.

2. Compute total Heating Degree Days (HDD) for Harvard MA, in °C days

Note that $HDD = -\int (\Delta T) dt$

ΔT is the difference between the mean daily temperature and 18°C.
Compute the time integral from days 1-90 and days 275-365 (a total of 180 winter days).
Note that an average temperature must be computed for each day, and *dt* is in days.
You can use the MATLAB function `trapz` to compute integrals (see MATLAB help)

3. Compute total energy generated by the furnace to heat the house over the year (in Joules) (see the Lecture08_8.m code on the 1.020 Stellar site).

4. Compute the cost of using home heating oil to generate the furnace energy derived in 4.
Assume that one gallon of home heating oil produces 140,000 kJ.
Use current prices for home heating oil.

5. Provide a copy of the MATLAB code you used to generate results for the nominal case.

Energy Conservation Case

1. Decide upon new designs for the windows and floor that will reduce the amount of home heating oil required to heat the house. Illustrate your designs with sketches similar to those provided above for the ceiling and walls.

2. Specify the R-values for each material used in your new window and floor designs. Derive new inputs for your simulation model from these R-values.

3. Plot following temperatures vs. time on one set of labeled axes (one figure) every 6 hours for the entire year of data supplied in:
   - **Outside air temperature (from** `harvardmet.txt`**)**
   - **Room temperature**
   - **Attic temperature**
Revise the nominal model inputs as required by the design you described in 1. above.

4. Compute total energy produced by the furnace over the year (in Joules) (see the Lecture08_8.m on the 1.020 Stellar site).

5. Compute the cost of using home heating oil to produce the furnace energy derived in 4.
Assume that one gallon of home heating oil produces 140,000 kJ.
Use current prices for home heating oil

6. Compute the difference in yearly fuel oil cost between the nominal and energy conservation cases.

7. Provide a copy of the MATLAB code you used to generate results for the energy conservation case.