1. Suppose a clothed person can be represented as a cylinder 170 cm tall with a radius of 15 cm, with a skin temperature of 30 **°**C. Assume the person radiates as a blackbody.  
   1. Calculate the radiative power of the person in Watts.

Stefan Boltzmann equation

I =  σ T4

 = 1

 = 5.67 x 10-8 W m-2 K-4

T = 30°C = 303.15 K

A = 2(*pi* r 2) + (2 *pi* r)\* h

1 x 5.67 x 10-8 W m-2 K-4 x (303.15 K4)

=478 W/m2

Find the area 2 π r2 + h (2 π r)

2 π (225) + 170 (2 π 15)

450 π + 5100 π

5550 π

= 17436 cm2 convert to m2 =1.7 m2

Area x radiative power of the person

1.7 m2 x 478 W/m2**= 812.6 W**

* 1. Imagine that this person is standing alone in the middle of a room in which all the walls, ceiling, and floor have a constant temperature of 22 **°**C.  
       
     Calculate the net rate of energy gain or loss by the person in Watts.  
       
     I =   T4

22°C + 273.15 = 295 K  
5.67 x 10-8 W m-2 K-4 (295 K) 4 = 430 W/m2

430 W/m2 x 1.7 m2 **= 731 W**

812.6 W (heat loss) minus 731 W (heat gained) = **81.6 W net loss**

* 1. Comment on how this gain or loss by thermal radiation can be maintained.   
       
     **The thermal radiation is maintained by the food we eat.**

81.6 W = 81.6 Joules/second = (81.6 J s-1) (60 s min-1) (60 min hr-1) (24 hr day-1)

= 7.05 x 106 J day-1

1 dietary calorie (= 1 kcal) = 4187 Joules

so this person would have to eat (7.05 x 106 J day-1) / (4187 J kcal-1) = 1684 dietary calories per day to “stay warm” (i.e., to “stay alive”)

1. Nighttime surface temperature in Fort Collins in July is about 15 **°**C.
   1. Using this temperature and assuming the surface emits thermal radiation as a blackbody, calculate the rate of radiative cooling of the surface in Watts per square meter.

Emission of blackbody at 15°C = 288 K

I =   T4 =5.67 x 10-8 W m-2 K-4 (288 K) 4 = 390 W/m2

* 1. The volumetric heat capacity soil is about 1.5 x 106 J K-1 m-3. This means it take 1.5 million Joules of heat to heat or cool a cubic meter of soil by 1 degree Kelvin (same as Centigrade).   
       
     Assuming that the rate of cooling of the surface you found in (a) is the only energy transfer, and that the top 10 cm (0.1 m) of soil cools at night, calculate how many degrees would the soil cool during an 8-hour July night in Fort Collins?

390 Joules/ sec m-2 (8hr) (3600sec/hr)

(1.5 x 106 Joules K-1m-3) (0.1) m

**= 75 K  
  
So by morning the soil would be 15 °C – 75 C = -60 °C = -78 °F  
Brrrr!**

* 1. In reality, the soil only cools at night by about 10 C, so there has to be another source of energy besides the one we calculated in part (a). A tiny amount comes from the air and from deep underground, but not even close to enough to keep the surface warm. Where does the extra energy come from?

Greenhouse effect -radiation emitted downward by CO2, H20, and clouds absorbed by the soil. Typically around 300 W m-2

1. Use the toy model called “Two-layer graybody atmosphere” found on the web at <http://bit.ly/1KAK3pa> to answer the following questions. The model lets you vary the absorptivity (also called emissivity) of the layers of air, and also the amount of convective mixing of heat from the surface into the atmosphere. You will probably need the “Diagram” tab for this problem.
   1. Increase the emissivity of the lower layer to 0.75 and the upper layer to 0.65. What are the temperatures of the surface, lower atmosphere, and upper atmosphere? How does the simulated surface temperature compare to the actual global mean surface temperature of the Earth?  
        
      Surface T = 306 K; Lower Atm T = 271 K; Upper Atm T = 237 K  
      This is too hot! (306 K = 33 C). Actual mean sfc T ~ 288 K (15 C)
   2. Is it reasonable that the emissivity (absorptivity) of the lower atmosphere is greater than the upper atmosphere? Why or why not?  
        
      Very reasonable, because there’s way more water vapor in the warmer lower atmosphere than the much colder upper atmosphere.
   3. Add convective mixing of heat: 100 W m-2 from the surface to the lower atmosphere and 50 W m-2 from the lower to upper atmosphere. What is the effect on the temperature of each layer? Is this arrangement more or less realistic than the situation you simulated in part (a)?

Surface T = 288 K; Lower Atm T = 268 K; Upper Atm T = 243 K  
Much more realistic! Sfc T is correct, plus temp doesn’t drop with height as steeply, thanks to convective mixing of the atmosphere.

* 1. Turn down the brightness of the Sun by 10%. Can you bring the surface temperature back up to the Earth’s average surface temperature by adjusting the emissivity of the atmospheric layers? What values for the emissivity did you use?

Reducing solar constant to from 1368 W m-2 to 1230 W m-2 makes the surface much colder (279 K with previous values for emissivity and mixing).

By setting emissivity of lower atmosphere to 0.88 and emissivity of upper atmosphere to 0.75, I can restore the observed mean surface temperature of 288 K even with convective mixing as in part c above.