Solved Example

Given the following measurements from an instrumented tower, find the sensible and latent heat fluxes. Also, $\Im^* = -500\ W \cdot m^{-2}$.

index	z (m)	T (°C)	r (g_{vapor}/kg_{air})
2	10	15	8
1	2	18	10

Solution

Given: the table above.

Find: $\Im_H$ and $\Im_E$ = ? $W \cdot m^{-2}$

First step is to find $\Delta\theta$:

$$\Delta\theta = T_2 - T_1 + (0.0098\ K/m) \cdot (z_2 - z_1)$$
$$= 15\ K - 18\ K + (0.0098\ K/m) \cdot (10m - 2m)$$
$$= -3\ K + 0.0784\ K = -2.92\ K$$

Use eq. (3.39a)

$$\Im_H = \frac{-0.9 \cdot (-500\ W \cdot m^{-2})}{\dfrac{(-2\ g_{vap}/kg_{air})}{[0.4\ (g_{vap}/kg_{air}) \cdot K^{-1}] \cdot (-2.92\ K)} + 1}$$

$\Im_H = \underline{165.91}\ W \cdot m^{-2}$

Next, use eq. (3.41a):

$$\Im_E = -0.9 \cdot \Im^* - \Im_H$$
$$= -0.9 \cdot (-500\ W \cdot m^{-2}) - 165.91\ W \cdot m^{-2}$$
$$= \underline{284.09}\ W \cdot m^{-2}$$

Check: Units OK. Physics OK.

Discussion: Sensible heat flux is roughly 50% of the latent heat flux (i.e., $B = 0.5$). Thus, we can guess that these observations were made over grassland.

APPARENT TEMPERATURES

Humans and livestock are warm blooded. Our metabolism generates heat, while our perspiration evaporates to keep us cool. Our bodies attempt to regulate our metabolism and perspiration to maintain a relatively constant internal temperature.

Whether we feel warm or cool depends not only on air temperature, but on wind speed and humidity. During winter, faster wind makes the air feel colder, because it removes heat from our bodies faster. Wind chill is a measure of this effect.

During summer, higher humidity makes the air feel hotter, because it reduces evaporation of our perspiration. The heat index measures this effect. Both of these indices are given as **apparent temperatures**; namely, how warm or cold it feels.

Wind Chill

Wind chill is the hypothetical air temperature in calm conditions ($M = 0$) that would cause the same heat flux from the skin as occurs for the true winds and true air temperature. The heat transfer equation (3.21) for flux across a surface can be slightly modified to give one version of the wind-chill equation:

$$T_{wind\ chill} = T_{skin} - \left(\frac{M + M_o}{M_o}\right)^{0.21} \cdot (T_{skin} - T_{air}) \tag{3.42}$$

where $T_{skin} = 33°C$, and $M_o = 2$ m/s is the average speed that people walk. It is assumed that even in calm weather, there is an effective wind due to a person's movement.

Thus, the weather seems colder with colder air temperatures and with stronger winds. Table 3-1 shows wind chills computed using this equation on a computer spreadsheet, with the results plotted in Fig 3.10.

Table 3-1. Wind-chill temperatures (°C).

Wind Speed		Air Temperature (°C)					
km/h	m/s	10	0	-10	-20	-30	-40
0	0.0	10	0	-10	-20	-30	-40
10	2.8	5	-7	-19	-31	-43	-55
20	5.6	3	-11	-24	-37	-50	-64
30	8.3	1	-14	-28	-42	-56	-70
40	11.1	-1	-16	-31	-46	-61	-75
50	13.9	-3	-18	-33	-49	-64	-80
60	16.7	-4	-20	-36	-52	-68	-84

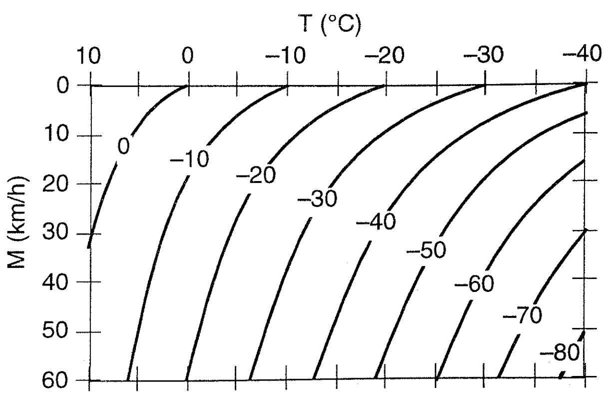

Figure 3.10

Curves are wind chill equivalent temperature (°C), as a function of air temperature (T) and wind speed (M).

Solved Example

What is the wind chill temperature in °F for an air temperature of –10°F and a wind of 20 mph.

Solution

Given: $T_{air} = -10°F$, $M = 20$ mph

Find: $T_{wind\ chill} = ?$ °F.

First, convert the units of the parameters:

$T_{skin} = 33°C = 91.4°F$

$M_o = 2$ m/s ≈ 4 mph

Use eq. (3.42):

$$T_{wind\ chill} = 91.4°F - \left(\frac{20+4}{4}\right)^{0.21} \cdot [91.4 - (-10)°F]$$

$$= \underline{-56°F}$$

Check: Units OK. Physics OK.

Discussion: This is close to the tabulated value.

Heat Index

More humid air feels warmer and more uncomfortable than the actual temperature. **Heat index** (or **apparent temperature** (AT) or **temperature-humidity index**) is one measure of heat discomfort and heat-stress danger.

The equation for heat index below is an inelegant regression to human-perceived apparent temperatures, but it works nicely. It gives heat index (HI) values in Fahrenheit, and is written in the form of a spreadsheet formula[1].

```
HI or AT = 16.923 +((1.85212*10^-1)*T)
        +(5.37941*RH)                          (3.43)
        -((1.00254*10^-1)*T*RH)
        +((9.41695*10^-3)*T^2)
        +((7.28898*10^-3)*RH^2)
        +((3.45372*10^-4)*T^2*RH)
        -((8.14971*10^-4)*T*RH^2)
        +((1.02102*10^-5)*T^2*RH^2)
        -((3.8646*10^-5)*T^3)
        +((2.91583*10^-5)*RH^3)
        +((1.42721*10^-6)*T^3*RH)
        +((1.97483*10^-7)*T*RH^3)
        -((2.18429*10^-8)*T^3*RH^2)
        +((8.43296*10^-10)*T^2*RH^3)
        -((4.81975*10^-11)*T^3*RH^3) .
```

where T is dry bulb temperature (°F), RH is relative humidity percentage (values of 0 to 100), and "^" means "raised to the power of". This equation works for $T > 70°F$.

[1] From web site http://www.zunis.org/16element_heat_index_equation.htm

Table 3-2 shows the solution to this equation. For low relative humidities, the air feels cooler than the actual air temperature because perspiration evaporates effectively, keeping humans cool. However, above 30% relative humidity, the apparent temperature is warmer than the actual air temperature.

Table 3-2. Heat Index Apparent Temperature °C

RH	Actual Air Temperature (°C)						
(%)	20	25	30	35	40	45	50
0	16	21	26	30	35	39	43
10	19	23	27	31	37	43	49
20	21	24	28	33	40	48	57
30	23	25	29	35	44	55	
40	24	25	30	38	49	63	
50	24	26	31	41	55		
60	25	26	33	45	62		
70	24	27	35	49			
80	24	27	37	55			
90	24	28	40	61			
100	24	29	43				

SUMMARY

Air parcels that move through the atmosphere while conserving heat are said to be adiabatic. When parcels rise adiabatically, they cool due to the change of pressure with height. The change of temperature with height is called the adiabatic lapse rate, and indicates a physical process. The ambient air through which the parcel moves might have a different lapse rate. Thermodynamic diagrams are convenient for determining how the temperature varies with height or pressure, and for comparing different lapse rates.

Once heat from the sun is in the earth-atmospheric system, it is redistributed by advection, radiation, turbulence, and conduction. Some of the sensible heat is converted between latent heat by water phase change. Eventually, heat is lost from the system as infrared radiation to space.

The net radiation is balanced by turbulent fluxes into the atmosphere and conduction into the ground. Turbulent fluxes consist of sensible heat flux, and latent heat flux associated with evaporation of water. The ratio of sensible to latent heat flux is the Bowen ratio. All of these fluxes vary with the diurnal cycle.

Warm blooded animals and humans feel heat loss rather than temperature. On cold, windy days, the heat loss is quantified as a wind chill temperature. During humid hot days, the apparent temperature is warmer than actual.