Sample Application

Use the equations to find the heat index and humidex for an air temperature of 38°C and a relative humidity of 75% (which corresponds to a dew-point temperature of about 33°C).

Find the Answer

Given: $T = 38°C$, $RH = 75\%$, $T_d = 33°C$
Find: $T_{heat\ index} = ?\ °C$, $T_{humidex} = ?\ °C$

For heat index, use eqs. (3.65):

$T_R = 0.8841 \cdot (38) + 0.19 = 33.8°C$ (3.65b)
$p = 0.0196 \cdot (38) + 0.9031 = 1.65$ (3.65c)
$e_s = 0.611 \cdot \exp[5423 \cdot (\{1/273.15\} - \{1/(38+273.15)\})]$
$= 6.9$ kPa (3.65d)
$T_{heat\ index} = 33.8 + [38-33.8] \cdot (0.75 \cdot 6.9/1.6)^{1.65}$
$=$ **62.9°C** (3.65a)

For humidex, use eqs. (3.66):

$e = 0.611 \cdot \exp[5418 \cdot (\{1/273.16\} - \{1/(33+273.16)\})]$
$= 5.18$ kPa (3.66b)
$T_{humidex} = 38 + 5.555 \cdot (5.18-1) =$ **61.2°C** (3.66a)

Check: Units are reasonable. Values agree with extrapolation of Tables 3-4 and 3-5.

Exposition: These values are in the danger zone, meaning that people are likely to suffer heat stroke. The humidex and heat index values are nearly equal for this case.

Table 3-5. **Humidex** apparent temperature (°C)

T_d (°C)	Actual Air Temperature T (°C)						
	20	25	30	35	40	45	50
50							118
45						96	101
40					77	82	87
35				62	67	72	77
30			49	54	59	64	69
25		37	42	47	52	57	62
20	28	33	38	43	48	53	58
15	24	29	34	39	44	49	54
10	21	26	31	36	41	46	51
5	**19**	**24**	**29**	**34**	**39**	**44**	**49**
0	18	23	28	33	38	43	48
–5	17	22	27	32	37	42	47
–10	16	21	26	31	36	41	46

T_d is dew-point temperature, a humidity variable discussed in the Water Vapor chapter.

Humidex is also an indicator of summer discomfort due to heat and humidity (Table 3-3). Values above 40°C are uncomfortable, and values above 45°C are dangerous. **Heat stroke** is likely for humidex ≥ 54°C. This table also shows that for dry air ($T_d \le 5°C$) the air feels cooler than the actual air temperature.

3.8. TEMPERATURE SENSORS

Temperature sensors are generically called **thermometers**. Anything that changes with temperature can be used to measure temperature. Many materials expand when warm, so the size of the material can be calibrated into a temperature. Classical **liquid-in-glass thermometers** use either mercury or a dyed alcohol or glycol fluid that can expand from a reservoir or **bulb** up into a narrow tube.

House **thermostats** (temperature controls) often use a **bimetallic strip**, where two different metals are sandwiched together, and their different expansion rates with temperature causes the metal to bend as the temperature changes. Car thermostats use a wax that expands against a valve to redirect engine coolant to the radiator when hot. Some one-time use thermometers use wax that melts onto a piece of paper at a known temperature, changing its color.

Many electronic devices change with temperature, such as resistance of a wire, capacitance of a capacitor, or behavior of various transistors (**thermistors**). These changes can be measured electronically and displayed. **Thermocouples** (such as made by a junction between copper and constantan wires, where constantan is an alloy of roughly 60% copper and 40% nickel) generate a small amount of electricity that increases with temperature. **Liquid crystals** change their orientation with temperature, and can be designed to display temperature.

Sonic thermometers measure the speed of sound through air between closely placed transmitters and receivers of sound. Radio Acoustic Sounder Systems (**RASS**) transmit a loud pulse of sound upward from the ground, and then infer temperature vs. height via the speed that the sound wave propagates upward, as measured by a radio or microwave profiler.

Warmer objects emit more radiation, particularly in the infrared wavelengths. An **infrared thermometer** measures the intensity of these emissions to infer the temperature. Satellite remote sensors also detect emissions from the air upward into space, from which temperature profiles can be calculated (see the Satellites & Radar chapter).

Even thick layers of the atmosphere expand when they become warmer, allowing the **thickness** between two different atmospheric pressure levels to indicate average temperature in the layer.

3.9. REVIEW

Three types of heat budgets were covered in this chapter. All depend on the flow rate of energy per unit area (J m^{-2} s^{-1}) into or out of a region. This energy flow is called a flux, where the units above are usually rewritten in their equivalent form (W m^{-2}).

1) One type is a heat balance at the surface of the Earth. The surface has zero thickness — hence no air volume and no mass that can store or release heat. Thus, the input fluxes must exactly balance the output fluxes. Sunlight and IR radiation (see the Radiation chapter) must be balanced by the sum of conduction to/from the ground and effective turbulent fluxes of sensible and latent heat between the surface and the air.

2) Another type is an Eulerian budget for a fixed volume of air. If more heat enters than leaves, then the air temperature must increase (i.e., heat is stored in the volume). Processes that can move heat are advection, turbulence, and radiation. At the Earth's surface, an effective turbulent flux is defined that includes both the turbulent and conductive contributions. Also, heat can be released within the volume if water vapor condenses or radionuclides decay.

3) The third type is a Lagrangian budget that follows a mass of air (called an air parcel) as it rises or sinks through the surrounding environment. This is trickier because the parcel temperature can change even without moving heat into it via fluxes, and even without having water vapor evaporate or condense within it. This adiabatic temperature change is caused by work done on or by the parcel as it responds to the changing pressure as it moves vertically in the atmosphere. For unsaturated (non-cloudy) air, temperature of a rising air parcel decreases at the adiabatic lapse rate of 9.8°C km^{-1}. This process is critical for understanding turbulence, clouds, and storms, as we will cover in later chapters.

The actual air temperature can be measured by various thermometers. Humans feel the combined effects of actual air temperature, wind, and humidity as an apparent air temperature.

3.10. HOMEWORK EXERCISES

3.10.1. Broaden Knowledge & Comprehension

B1(§). For an upper-air weather station near you (or for a site specified by your instructor), get recent observation data of *T* vs. *z* or *T* vs. *P* from the internet, and plot the result on a copy of the thermodynamic diagram from this chapter.

B2. For an upper-air weather station near you (or for a site specified by your instructor), get an already-plotted recent sounding from the internet. Find the background isotherm and isobar lines, and compare their arrangement to the diagram (Fig. 3.4) in this chapter. We will learn more about other thermo-diagram formats in the Atmospheric Stability chapter.

B3. Use the internet to acquire temperatures at your town and also at a town about 100 km downwind of you. Also get the wind speeds in both towns and take an average. Use this average speed to calculate the contribution of advection to the local heating in the air between those two towns.

B4. Use the internet to acquire a weather map or other weather report that shows the observed near-surface air temperature just before sunrise at your location (or at another location specified by your instructor). For the same location, find a map or report of the temperature in mid afternoon. From these two observations, calculate the rate of temperature change over that time period. Also, qualitatively describe which terms in the Eulerian heat budget might be largest. (Hint: if windy, then perhaps advection is important. If clear skies, then heat transfer from the solar-heated ground might be important. Access other weather maps as needed to determine which physical process is most important for the temperature change.)

B5. Use the internet to acquire a local weather map of apparent temperature, such as wind-chill in winter or heat index (or humidex) in summer. If the map covers your location, compare how the air feels to you vs. the apparent temperature on the map.

B6. Use the internet to acquire images of 4 different types of temperature sensors (not 4 models of the same type of sensor).