Lecture 2 – Exercises Solutions

Exercise 1: Wind speed [L2, slides 6-7]

1. **Determine the predominant wind direction**

The predominant wind direction is the direction of the wind that occurred the most. Based on the wind rose diagram, it is North-East (NE).

2. **Determine the wind speed at the pedestrian height of 1.5 m above ground.**

The wind profile of the urban boundary layer is logarithmic per Eqn. (2-1): $u(z) = \left(\frac{z}{z_r}\right)^{\alpha} \cdot u(z_r)$

The reference height is $z_r = 20\ m$, and the wind speed $u(z_r) = 2\ m/s$

Thus, at the pedestrian height of 1.5 m above ground:

$$u(z) = \left(\frac{z}{z_r}\right)^{\alpha} \cdot u(z_r) = \left(\frac{1.5}{20}\right)^{0.27} \cdot 2.0 = \mathbf{0.994\ m/s}$$

Exercise 2: Temperature [L2, slides 14-16]

1. **On a clear summer afternoon (e.g., at 15-16 o'clock), would the surface temperature of the pavement be higher or lower than the air temperature? What would be the case in the early morning (e.g., at 6 o'clock)? Explain the physical processes involved.**

During the clear summer afternoon, the pavement temperature would be higher than the air temperature. This is because the pavement is exposed to *direct* and *diffuse* solar radiation (e.g., from warm surrounding buildings). Cobblestones absorb a significant part of the energy received and store it. Although conduction and convection also take place, the radiative processes are more profound.

In the early morning, with a clear sky, the pavement temperature would be lower than the air temperature as all the energy stored during the day slowly radiates from the surface of the pavement back to the sky at night. As cobblestone has high emissivity (ε=0.7), its efficiency in radiating thermal energy is relatively high. In addition, the pavement loses energy through conduction and convection at lower air temperatures at night.

The images (regular RGB and infrared IR) of cobblestone pavement on Av. Piccard at the EPFL campus taken on August 5, 2022, illustrates surface temperature at 9 AM and 4 PM. As the Sun intensity is already elevated at 9 AM, the pavement temperature ≈ 35°C already exceeds air temperature. Remarkably, the pavement temperature at 4 PM reaches ≈ 70°C.

2. **In the summer, would the deep ground temperature (~at 10m depth) be higher than the air temperature?**

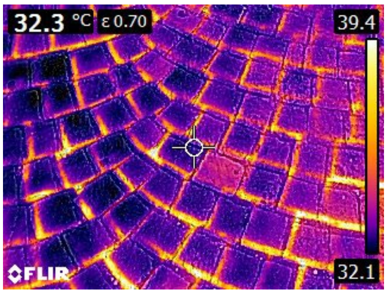
The deep ground temperature under the paved street is lower than the air temperature. As the deep ground temperature is constant, the surface temperature is higher.

RGB image of the pavement

IR image of the pavement

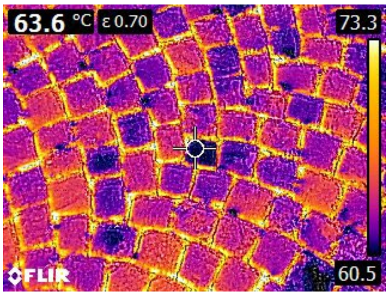
August 5, 2022

9 AM
T_a=27.2°C
I = 460 W/m^2



August 5, 2022

4 PM
T_a=34.6°C
I = 730 W/m^2



Exercise 3: Psychometrics [L2, slides 6, 21-23]

First of all, we need to determine psychometric properties at the outdoor state $\boldsymbol{t_a}$ = 35°C, $\boldsymbol{\varphi}$ = 20%:

- Water vapor saturation pressure using (Eqn. 2-6a)

$$p_{v,sat} = 611 \cdot e^{\frac{17.08 \cdot 35}{234.18+35}} = 5630\ Pa = 5.63\ kPa$$

- Partial water vapor pressure using (Eqn. 2-10b)

$$p_v = \frac{\varphi \cdot p_{v,sat}}{100} = \frac{0.2 \cdot 5630}{100} = 1126\ Pa = 1.126\ kPa$$

- Absolute humidity per Eqn (2-9b)

$$x = 0.622 \frac{p_v}{p_a - p_v} = 0.622 \frac{1.126}{101.3 - 1.126} = 0.00699\ kg/kg \approx 7\ g/kg$$

- Humidity by volume per Eqn. (2-11)

$$v = \frac{p_{v,sat} \cdot \varphi}{462 \cdot (t + 273.15)} = \frac{5630 \cdot 0.2}{462 \cdot (35 + 273.15)} = 0.000789\ kg/m^3 \approx 0.79\ g/m^3$$

- Wet bulb /condensation temperature from the psychometric chart: T_{wb} =18.5 °C
- Enthalpy $h = 53.1 \frac{KJ}{kg\ of\ dry\ air}$

Using the psychometric chart (shown below), by marking the given outdoor conditions, you can determine lines of constant enthalpy (co-inside with the lines of constant wet-bulb temperature). By following the constant enthalpy line, we can determine the resulting air condition at 24°C. Relative humidity at 24°C is 60%. It is relatively high but right at the comfort limit. This means that evaporative cooling could be used when outdoor air is dry, not to add too much water to the air while cooling it.

Properties of moist air at 24°C (60%) are the following:

- Water vapor saturation pressure using (Eqn. 2-6a)

$$p_{v,sat} = 611 \cdot e^{\frac{17.08 \cdot 24}{234.18+24}} = 2989\ Pa = 2.989\ kPa$$

- Partial water vapor pressure using (Eqn. 2-10b)

$$p_v = \frac{\varphi \cdot p_{v,sat}}{100} = \frac{0.6 \cdot 2989}{100} = 1793\ Pa \approx 1.793\ kPa$$

- Absolute humidity per Eqn (2-9b)

$$x = 0.622 \frac{p_v}{p_a - p_v} = 0.622 \frac{1.793}{101.3 - 1.793} = 0.01121\ kg/kg = 11.21\ g/kg$$

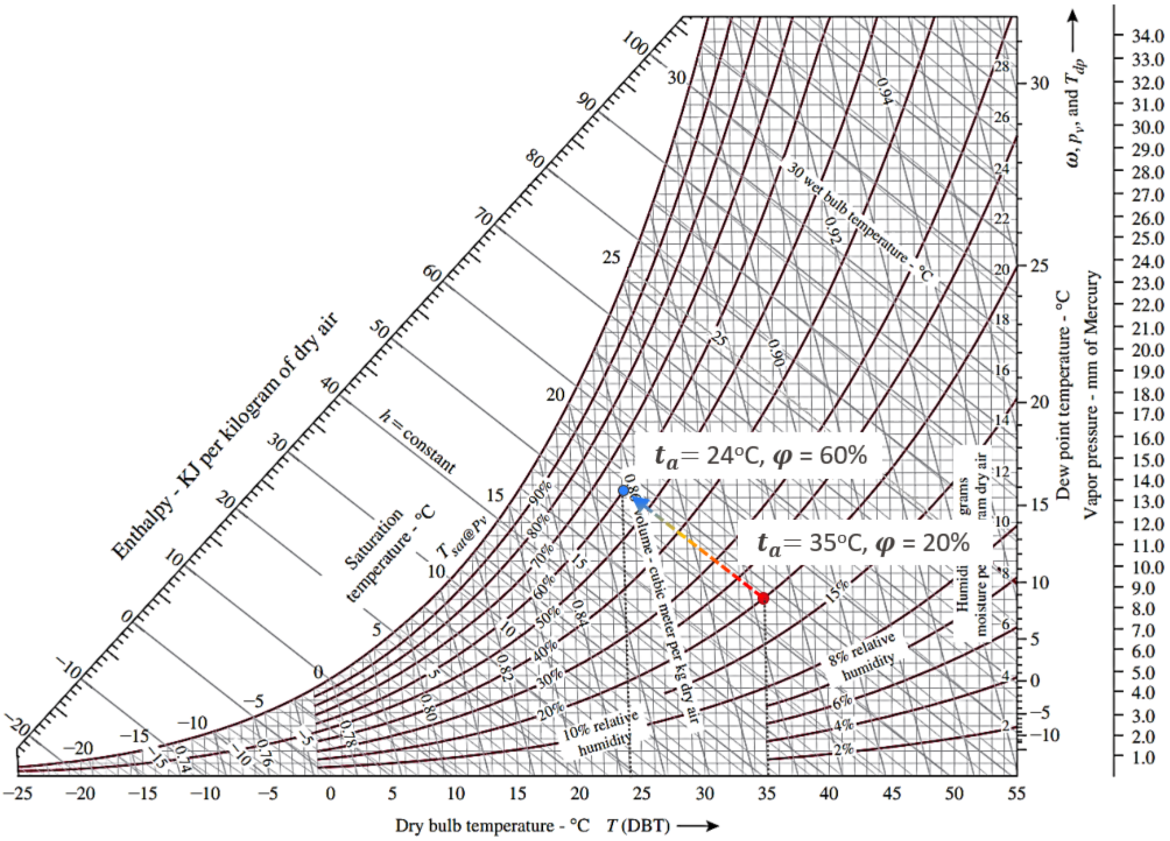
- Humidity by volume per Eqn. (2-11)

$$v = \frac{p_{v,sat} \cdot \varphi}{462 \cdot (t + 273.15)} = \frac{2989 \cdot 0.6}{462 \cdot (24 + 273.15)} = 0.0013\ kg/m^3 = 1.3\ g/m^3$$

To cool air from 35°C (20% RH) to 24 °C (60 % RH) using evaporative cooling process, the following amount of water needs to be added:

$$\Delta x = 11.21 - 7 = \mathbf{4.21} \frac{g}{kg\ of\ dry\ air}$$

$$\Delta v = 1.3 - \mathbf{0.79} = 0.51\ g/m^3$$



The psychometric chart is drawn for standard atmospheric conditions (101.3 kPa); thus, its use for other atmospheric conditions would lead to imprecise results. Relationships such as in Eqn. 2-8…2-11 need to be used instead.