Skyscraper Theory Lab

PHYS 253
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Abstract

The Willis Tower is the tallest building in the city of Chicago, the second tallest in the United States and Western Hemisphere, and the 16^{th} tallest in the world. In this lab, you will be estimating the amount of people that work in the tower and the amount of water used in the building based on the limited amount of information provided. This is an exercise in forcing oneself to make sure that their answers make sense and looking for possible errors in their process.

1 Theory

This lab focuses mostly on one major skill: unit conversion. You will be provided with an area and you will need to use that area to calculate how many people work in the Willis Tower. So let's do a couple of examples to ensure the understanding of how unit conversions work.

Let us start with converting a speed in meters per second (a unit commonly found in problems in PHYS 253) to the same speed in miles per hour. Doing so does not change the speed at which the object is moving, it only changes the way that we understand the result. So, let us start with a ball traveling at 30 $\frac{m}{s}$. The first thing that we will want to do is to convert seconds into hours, and so we multiply our speed by the amount of seconds in a minute and then the amount of minutes in an hour. This will cancel out one unit and put our speed in terms of the other unit.

$$\begin{aligned} 30\,\frac{\text{meters}}{\cancel{\text{second}}}\left(\frac{60\,\cancel{\text{second}}}{1\,\text{minute}}\right) &= 180\,\frac{\text{meters}}{\text{minute}} \\ 180\,\frac{\text{m}}{\cancel{\text{minute}}}\left(\frac{60\,\cancel{\text{minute}}}{1\,\text{hour}}\right) &= 108,000\,\frac{\text{m}}{\text{hour}} \end{aligned} \tag{1}$$

Now that we have converted the dimension of time from seconds to hours, we can do the same thing with the distance. Instead of doing one calculation at a time, however, we can chain the different conversions together and plug the values into our calculator at the end.

$$108,000\,\frac{\cancel{\text{meters}}}{\text{hour}}\left(\frac{100\,\cancel{\text{cm}}}{1\,\cancel{\text{m}}}\right)\left(\frac{1\,\cancel{\text{inch}}}{2.54\,\cancel{\text{cm}}}\right)\left(\frac{1\,\cancel{\text{foot}}}{12\,\cancel{\text{inches}}}\right)\left(\frac{1\,\text{mile}}{5,280\,\cancel{\text{feet}}}\right) = 67.1\,\frac{\text{miles}}{\text{hour}} \tag{2}$$

There are a couple of other rules that we need to be aware of when converting units, however. If we look to equations (1) and (2), we see that these describe a quantity that has a dimensionality of length. But what about area or volume? As we know, the area of a square (for example) is given as

$$\text{Area} = \text{Length} \times \text{Width}$$

which means that the surface of a table will have units of m^2, or $m \times m$. Therefore, we need to use the "conversion factor" for length twice when converting area (or three times when converting volume). For example, let us take the surface area of a dart board. A dart board typically has a radius of 225 millimeters, and therefore the surface area would be 1.59×10^5 mm^2. Let's convert this into square inches.

$$1.59 \times 10^5 \,\cancel{\text{mm}^2}\left[\left(\frac{1\,\text{cm}}{10\,\cancel{\text{mm}}}\right)\left(\frac{1\,\text{cm}}{10\,\cancel{\text{mm}}}\right)\right]\left(\frac{1\,\text{in}}{2.54\,\cancel{\text{cm}}}\right)^2 = 246\,\text{in}^2 \tag{3}$$

1.1 Given Information for Experiment

Below is the list of information provided to calculate everything you are told to find, as well as a couple of pictures to help your estimations.

1. The Willis Tower has 110 stories (or floors) and sits on one city block (about 450 feet by 450 feet).
2. City planners assume that each person uses about 100 gallons of water per day.
3. Length Conversions:
   1 mile = 5280 feet
   1 foot = 12 inches
   1 inch = 2.54 cm
   1 meter = 100 centimeters
4. Volume Conversions:
   1 m^3 = 1000 liters
   1 m^3 = 264 gallons
5. The typical floor plan for the tower on one of the lower:

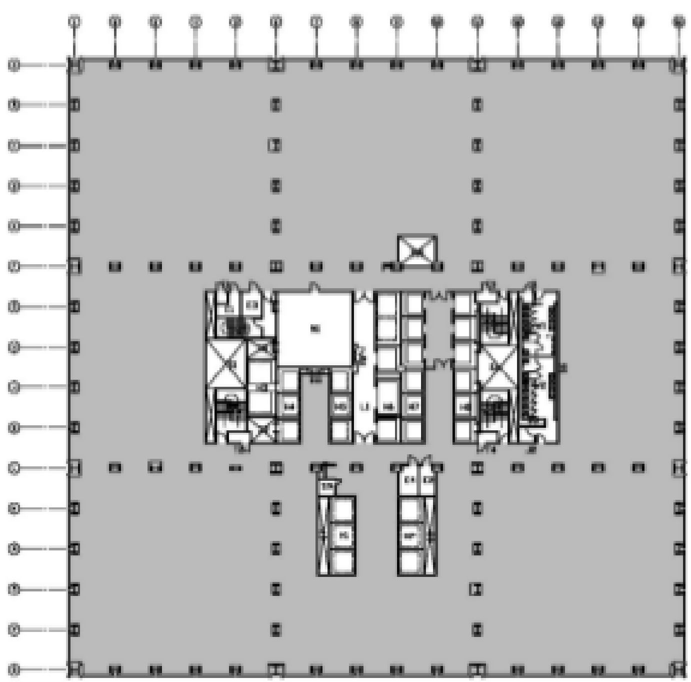


Figure 1: The typical floor plan; the white areas seen in the middle of the figure are where all of the staircases, elevators, rest rooms, etc.

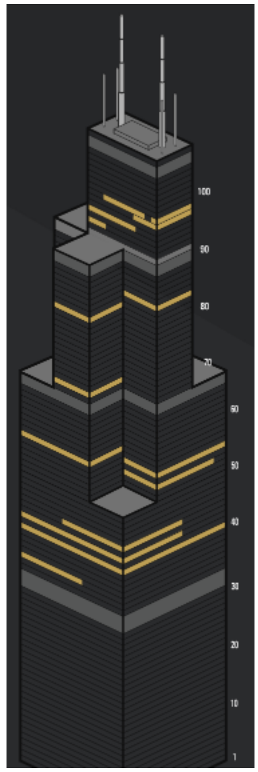
6. 

Figure 2: The Willis Tower every tenth floor provided.
Source: https://www.willistower.com/Office-Leasing

2 Experimental Procedure

The items below should all be done in Colab! Put your constants at the top of a Colab cell and then do any necessary arithmetic in the cell. Take a screen shot of your notebook and include it in your lab report

2.1 Estimating How Many People Work in the Willis Tower

1. Starting with the length and width of the ground floor provided, calculate the total area in meters.

2. Use Figure 1 to estimate how much of the space that you calculated is actually usable. (Hint: not only do you have to consider the space used up by the white space, but also the amount of room used for storage, conference rooms, walkways, and so on. It may behoove you find the area of the boxes and then consider the number of boxes being taken up by the aforementioned areas).

3. Use Figure 2 to estimate the amount of floors in each section of the building and calculate the total available surface area in the building. (Hint: notice that each section, as the height increases, becomes thinner, which means more "unusable space".)

4. Estimate the size of a cubicle that a person would need to work comfortably and efficiently.

5. Using your estimation from Step 4, calculate the total number of workers in the Willis Tower.

2.2 Calculating the Water Usage

Use Colab as above!

1. Using the given that city planners assume that each person uses 100 gallons of water per day and your results from Part 1, calculate the total water usage per day in the Willis Tower.

2. Convert your result in Step 1 from gallons per day to liters per minute.

Once you are complete with your calculations, your TA will have put a table on the board as the one shown below. Fill out one of the rows with your group's data.

Group	Total Area Calculated	Total Workers	Water Usage ($\frac{\text{L}}{\text{min}}$)
1			
2			
3			
4			

3 Data Analysis

For the report, there is no theory with which to compare the "data" to. For your data section of the report, simply take the table with every groups' data and type it up neatly in your document. The Calculations/Results section needs to be focused on your group's process and how you got to your results. Lastly, the discussion portion of the report should answer questions such as "Do the answers that my group and I calculated make sense? Why or why not?" Additionally, comment on the dispersion of all the results that are seen in the table. Are there any results that make more sense than others?