Project 2 Design Notebook
Team 32
Kyle Heaton, Chris Hoppe,
Heather Mello, Shelby Palmer

Meeting 1: 3/25/2022 4:30-6:00
Total Meeting Minutes: 90
Attendance: Chris Hoppe, Kyle Heaton, Heather Mello, Shelby Palmer
Agenda: Project Management

- Engineering specifications table
- Gantt chart
- Functional block diagram
    - Input: power, particulate matter
    - Output: potential ozone, clean air
    - Functions
        - Absorb smoggy air
        - Purify air
        - Store particulate matter
        - Expel clean air
- Work breakdown structure

Engineering specification

Customer Needs	**Technical needs**	**Technical Requirements**
Power Requirements	Watts used per day	Watts used less than 100,000
Location of Towers	Distance between towers	Distance less than 10,000 meters
Efficiency	Amount of air purified	Efficiency greater than 60 percent
Sustainability	Time to replace towers Net positive change between smog intake and power output	Towers last longer than 5 years

Figure 1 Engineering Specification

Trying to figure out what this project is
- Is it better to have more towers or one big tower?
- Does an individual tower have a net positive environmental output?
- Do the smog towers actually purify the air? (11.1 Slide 12)
    - Might output more ozone than it purifies smog
- Need to show evidence that it is feasible to make larger towers or put them in more locations.
- Find data detailing how much smog is present in Hong Kong
    - Air Quality Index: https://www.iqair.com/us/hong-kong

- Video Explaining Tower: https://youtu.be/qHNA96IQlIw

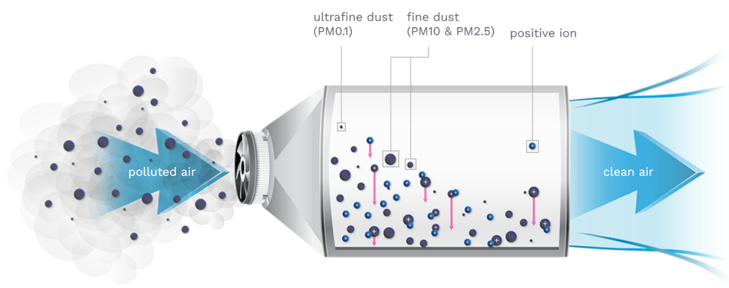


Figure 2 Technological analysis

From the smog we will determine how much will be removed per hour by one tower and then Physics behind smog tower. Figure two above shows a method of removing particles of air that may be represented in our model. This is a rudimentary model and our group knows that a lot more factors go into this model and method of removing smog.

Have it be on during the day because that is when the most smog is there. This is possibly an idea because smog is the worst during the day and thus we could make it more sustainable by having it turn on and off so that it is cleaning the air that is the most polluted the most often.

In figure 3 below we identify the main components of the project and how they interact with each other and their outside environments.

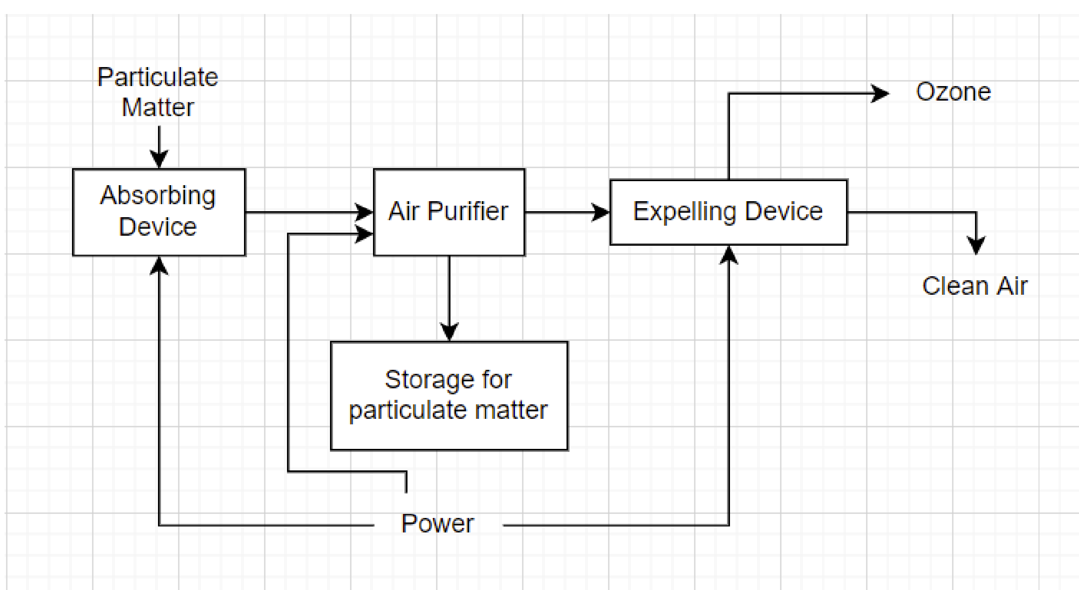


Figure 3 Functional Block Diagram

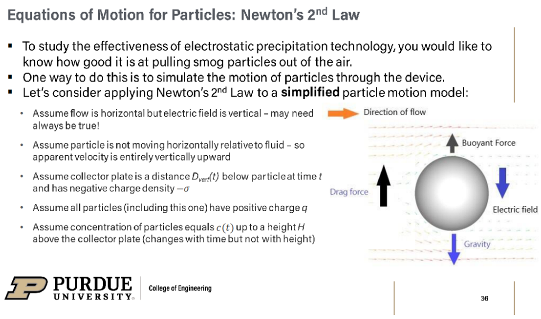


Figure 4.1 Newton's Laws

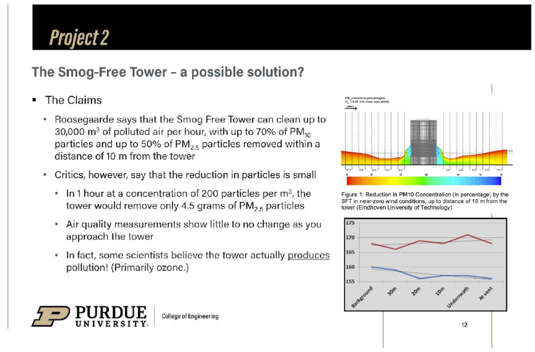


Figure 4.2 Smog Tower Claims

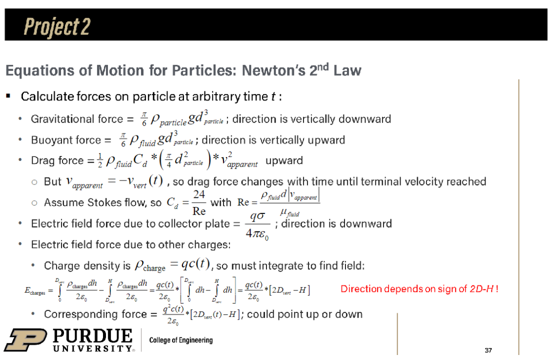


Figure 4.3 Forces

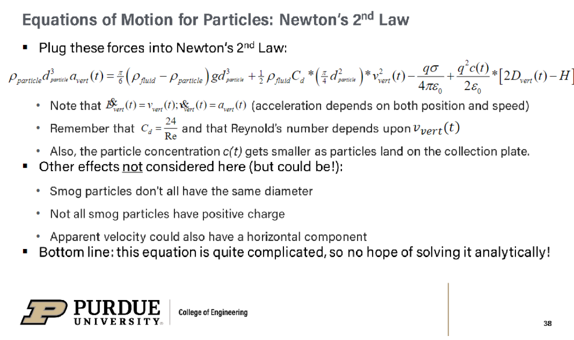


Figure 4.4 Fnet Equation

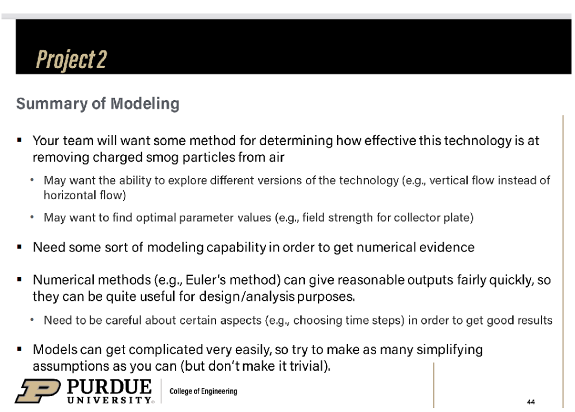


Figure 4.5 Modeling Summary

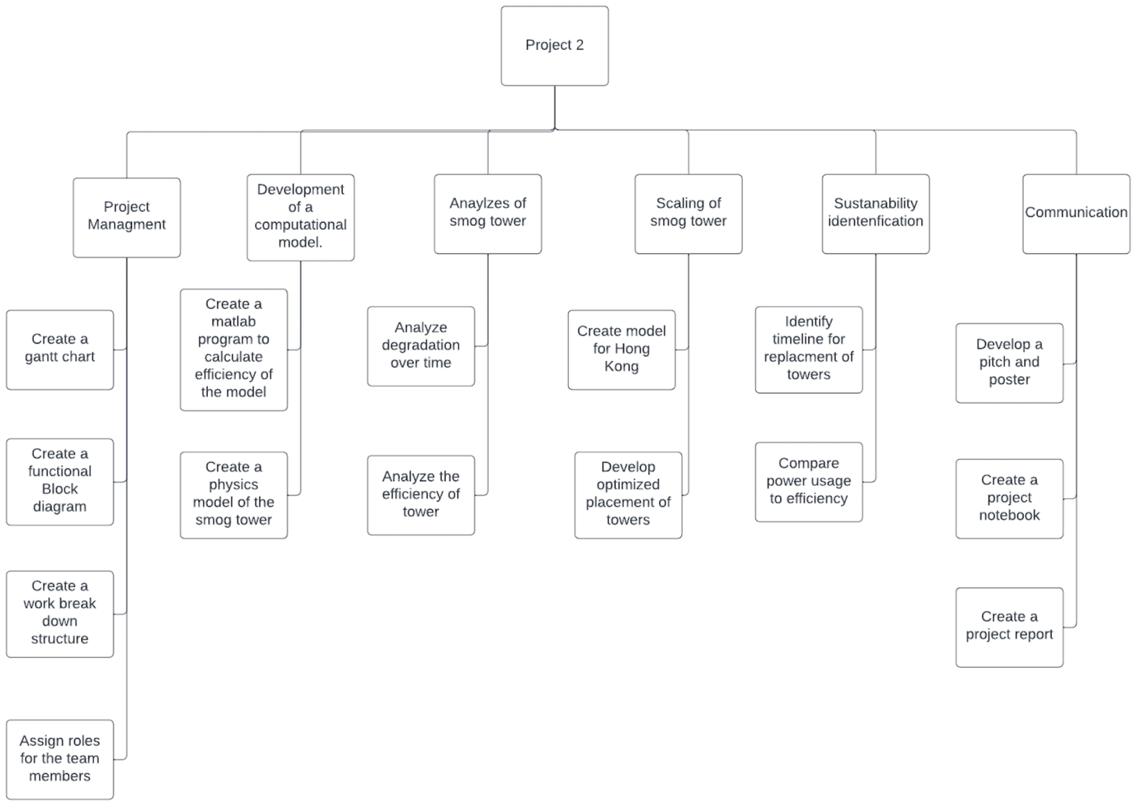


Figure 5 Work Breakdown Structure

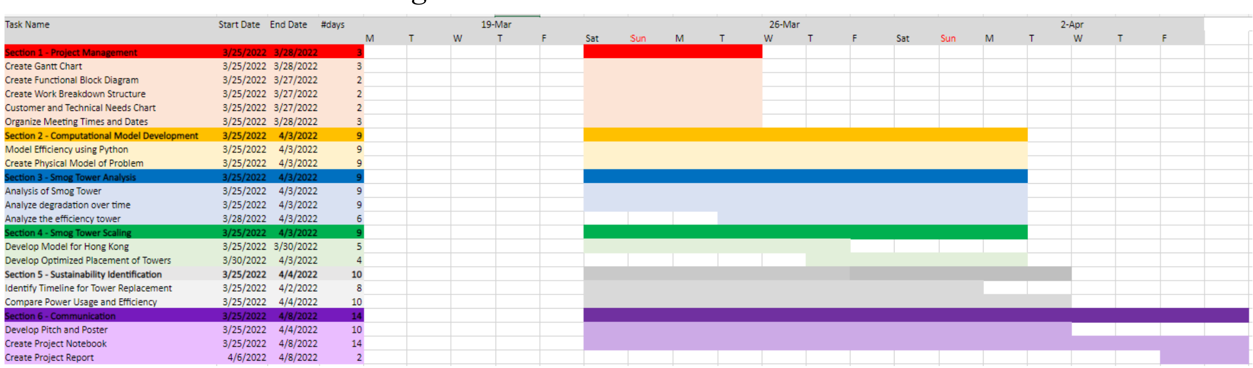


Figure 5.1 Gantt Chart

During this meeting we focused on the project management portion of the project and tried to begin to understand the task at hand. Each of the group members before hand read the project description and we came together to discuss that we found. We split the project into six categories that ranged from project management to communication to the scaling of the smog towers which can be seen above in figure five. The slides that can be seen above in figures 4.1 to 4.5. We attempted to develop and distribute roles during this meeting as well however we needed to understand the scope of the project a little more before we could determine where everyone would be able to contribute the most.

Next Meeting: Do our main research, assign roles, begin thinking about the computational model for the project, get any of our questions answered that we may have.

Meeting 2: 28 March 2022 (In Class)
Total Meeting Minutes: 210
Attendance: Kyle Heaton, Shelby Palmer, Heather Mello, Chris Hoppe
Goal: Research, develop a computational model, assign roles

Research:

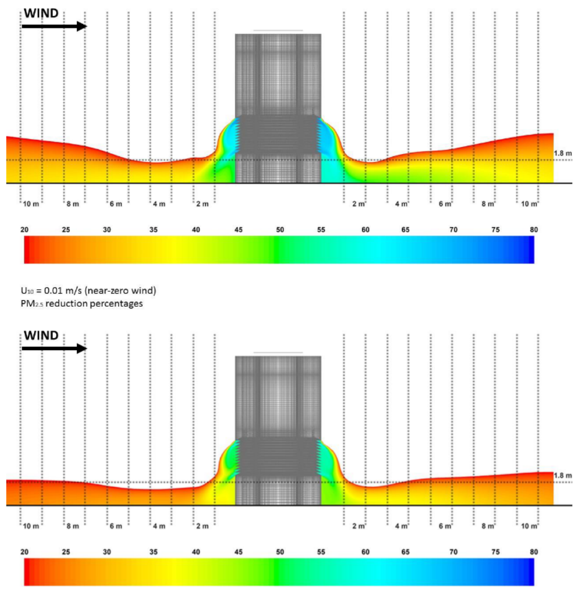


Figure 2. 3D representation of the CFD simulation depicting the reduction in PM10 (top panel) and PM2.5 (bottom panel) in the surroundings of the SFT, in near-zero wind conditions. The figure is slightly asymmetric due to the imposed 0.01 m/s wind speed.

Figure 6 Model For Smog Tower

Need to consider or before research

- The average smog height is
- Because PM2.5 particles are smaller, penetrate deeper into the respiratory system, and thus more detrimental than PM10 particles, reduction of this particle should be prioritized.
- Smog Free Tower cleans approx. 30,000 m^3 of ambient air per hour (approx 263 million m^3 per year)
- Study performed between April 2-11, 2017 at Minyuan Stadium in Tianjin (China)
- To validate efficiency of air purification system in SFT, concentrations of fine dust (0.3-10 um aerodynamic diameter) were measured in the ingoing and outgoing streams of individual air purification systems
    - By calculating the difference between the finer dust concentration ingoing vs outgoing, the percentage reduction can be calculated (in table). During all measurements the systems were operating at full capacity (10,000 m^3 air per hr)

System	Orientation	PM2.5 reduction (%)	PM10 reduction (%)
Aufero-1	North	54	68
Aufero-2	South-East	53	71
Aufero-3	South-West	52	65

Figure 7.1 Reduction percentages

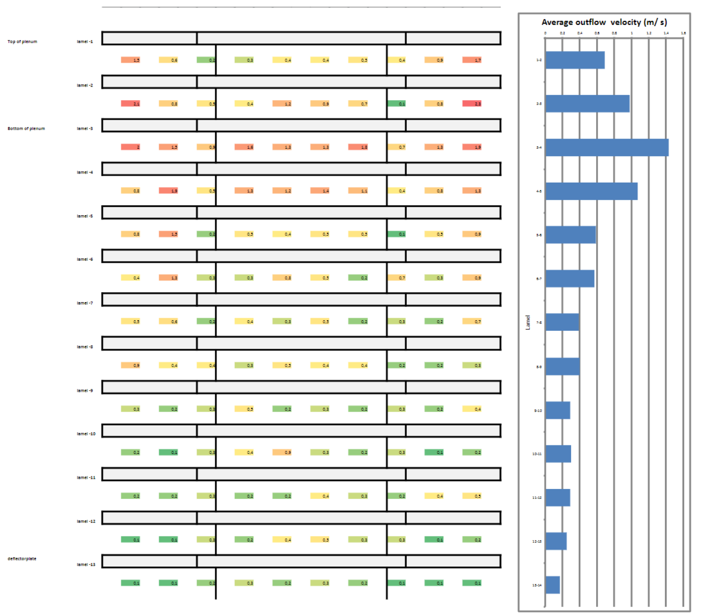


Figure 6a. Air velocity as measured at the outflow zone of the SFT. Left, schematic representation of the outflow zone (covering 120 degrees), and the measured outflow velocities between the lamellae (grey). Right, average outflow velocity between the lamellae in the outflow zone (in m/ s).

Figure 7.2 Velocity outputs

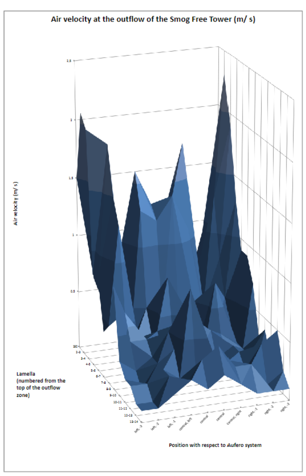


Figure 6b. Graphic representation of the air velocity as measured at the outflow zone of the SFT: Outflow velocities between the lamellae in the outflow zone (in m/ s).

Figure 7.3 Air velocity

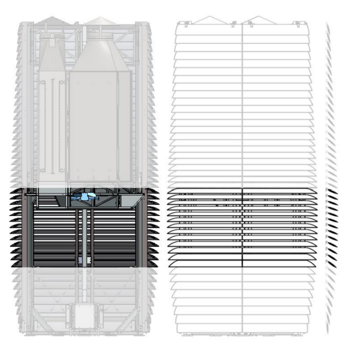


Figure 6c. Graphic representation of the SFT, indicating the outflow zone (left: cross section, visualizing the horizontal outflow of the Aufero air purification system (light-grey) and the central fan (blue), right: schematic view of the outside, indicating the lamellae in the outflow zone in black (numbered 1-13 from top to bottom) and their angle of inclination).

Figure 7.4 plate layout

In figure 7 above we gathered the research and analyzed the graphs and they helped us determine how the air velocity numbers changed and gave us some variability with that. Then more specifically in figure 7.1 it talks about the efficiency that particles are taken out of the air for the particle sizes of 2.5 and 10. From this and the plate layout in figure 7.4 we were able to get a better understanding of how the technology worked and the layout that we would have some control over.

Guidelines

- PM2.5 goal is 10ug/m^3 annual mean or 25ug/m^3 24 hour mean
- PM10 goal is 20ug/m^3 annual mean or 50ug/m^3 24 hour mean
- These guidelines apply to developed and developing countries
- 0.5 ratio is typical between the two particles in a lot of countries around the world.

Table 1

WHOair quality guidelines and interim targets for particulate matter: annual mean concentrations[a]

	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	Basis for the selected level
Iinterim target-1 (IT-1)	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [2–11%] relative to theIT-1 level.
Interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [2-11%] relative to the -IT-2 level.
Air quality guideline (AQG)	**20**	**10**	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$

Table 2

WHO air quality guidelines and interim targets for particulate matter: 24-hour concentrations[a]

	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	Basis for the selected level
Interim target-1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over the AQG value).
Interim target-2 (IT-2)	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over the AQG value).
Interim target-3 (IT-3)*	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase in short-term mortality over the AQG value).
Air quality guideline (AQG)	**50**	**25**	Based on relationship between 24-hour and annual PM levels.

Figure 8.1 & 8.2 Guidelines on Smog Particles

Electrostatic Precipitation

- 60% of airborne haze particles have a charge
- Positive and negative haze particles coexist
- Particle separator
    - Sampling frequencies of:
        - Space Charge Density (SCD): 1 Hz
        - Relative Ambient Humidity (RH): 1 Hz
        - Wind speed (U): 20 Hz
        - Ambient Temperature (T): 1 Hz
    - Plate dimensions
        - 8 pieces of anode plate, 9 pieces of cathode plate
        - Spacing between plates (L) =15 mm
        - Size of plate = 300 x 300 mm with 0.2 mm thickness
        - Time measured = 4 hrs
    - Assumptions
        - Horizontal electric field in haze events can be ignored.
        - The forces acting on the haze particles are balanced.
        - The vertical electric field in haze events is a function of particle concentration and altitude.

- Forces to consider (all vectors):
  - Electrostatic force (E)
  - Gravity (G)
  - Buoyancy (B)
  - Drag Force (D)
- Initially in equilibrium:
  - $F = B + E_{p0} + G + D = 0$ (Eq. 1)
  - B = ⅙(pi)(air density)(g)(particle diameter)^3
  - E_{p0} is the initial particle electric field
  - Initial drag force D = 0 because particle velocity is initially at 0
- External electric field is applied
  - $F_{applied} - G + B + D + E_p + E_{ext}$ (Eq. 2)
    - E_p is the particle electric field after applying external electric field
    - E_{ext} is external electric field force
- Subtract equations 1 and 2 to get:
  - $F = E_{ext} + F_d + (E_p - E_{p0})$
  - Drag force:
    - D = -½ C_d (rho)(A)(u)(vector u) (Eq. 3)
      - C_d = 24/R = 24v/ud = aerodynamic drag coefficient
      - $v = 1.39 \times 10^{-5}$ = air kinematic viscosity
      - R = particular Reynolds number
      - u (vector) is the relative velocity between the particle and the air
      - A = 1/4 (pi)d^2 is particle cross section in the u direction
    - Most haze events are $PM_{2.5}$ (particulate matter with aerodynamic diameter less than 2.5 micrometers)
      - Reynolds number R = ud/v = 0.18u << 1
        - Haze particles are mainly affected by viscous forces
- Newton's Second Law means Eq 3 can be rewritten as:
  - Ma = E_{ext} * q + (E_p - E_{p0}) * q - ½ C_d (rho)(A)(u)(vector u)
    - q = charge of haze particle
    - M = mass of haze particles
    - E_{ext} = (vector V)/h
      - V = voltage applied on the static electrode plate
      - h = height of the calculated point

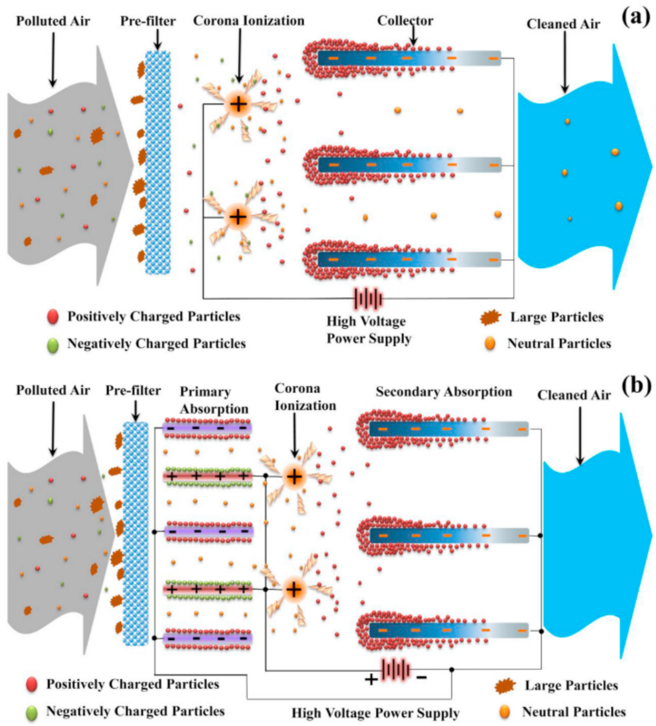


Figure 9.1 Electrostatic Precipitation

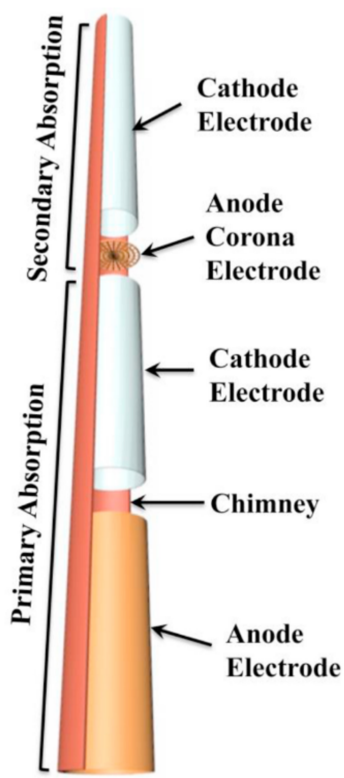


Figure 9.2 Electrostatic Precipitation Analysis

Figure 9 is the developmental model we are basing our research and computational model off of.

Computational Model

Things to get out of the computational model

- PM2.5-reduction: over 50%
- PM10-reduction: up to 71%
- In near-zero wind speed conditions
  - PM10 reductions up to 70% near tower outlets
  - PM10 reduction of almost 45% achieved up to a 10 m radius around tower
  - PM2.5 reductions of about 50% near tower outlets
  - PM2.5 reductions larger than 25% achieved more than 10m radius around tower
  - Fine dust (PM) concentrations varied between 140 and 45 ug/m3 (PM10) during the period of testing
  - PM10 reductions over 30%, PM2.5 reductions up to 20% are achieved in a circle of at 20m radius
- Since SFT is situated outdoors, the dispersion of cleaned air depends on local meteorological conditions with wind being the main driving force for diffusion. Due to mixing with ambient air, find dust reduction percentage will decreased with increasing distance from the tower. For strong wind, typical distribution pattern of cleaned air will be disturbed, resulting in a shift of the effect area to the leeward side of the tower. With higher wind speeds, the purified air is convected downstream, and reduction percentages exceeding 25% PM10 and PM2.5 are found at least 5m downstreams of the tower. Figure 10 below addresses so of the systems and projections that we will be dealing with while doing this project.

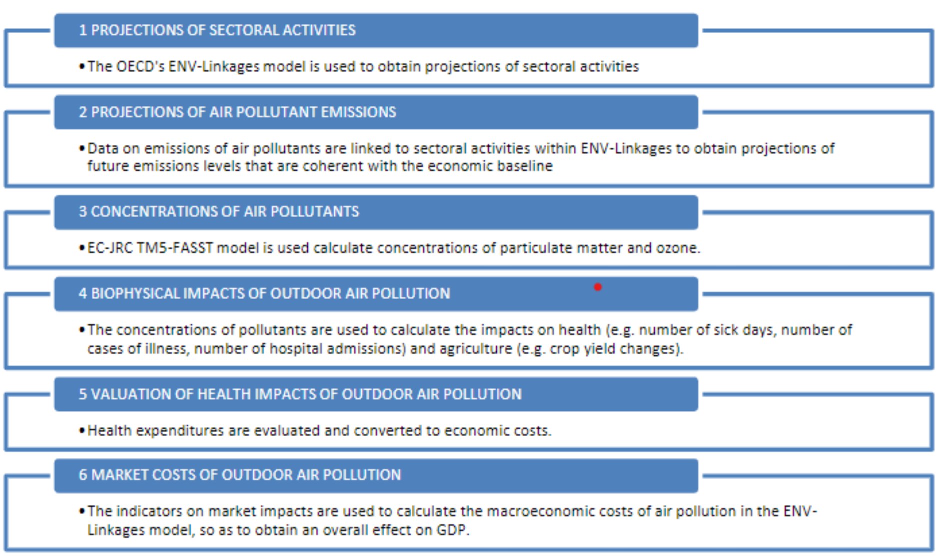


Figure 10 System Analysis

Consequences of Air pollution

- 2 million deaths due to air related issues
- Expensive to remove air pollution. Better to deal with the issue before it is produced however most companies are not willing to do this.
- Estimated monetary impact of outdoor air pollution (2010) -> China $1.4 trillion
- Health cost due to inaction in 2010
    - 1.7 trillion USD in OECD countries
    - 1.4 trillion USD in China
    - 0.5 trillion USD in India
- Labor affected

How Air Purification System Works

Positive Ionization Technology

- Positive ionization is a process in which an atom or a molecule acquires a positive charge by the removal of one or more electrons. When a high voltage is applied to an ionization electrode, this electrode ionizes the air it is direct vicinity, causing the air to become conductive (corona discharge(. HIgh-energy electrons are accelerated through the electric field surrounding the electrode collide with other atoms or molecules, knocking out an electron and thus creating further electron/positive ion pairs. Positive charge ions move toward the grounded (neutrally charged) collector plate, where they cluster to form large molecular aggregate. The net effect of this process is that airborne fine dust, chemicals, allergens, and biological agents are ionized, collected, and transformed into coarse dust, thus eliminating the risk of inhalation
- Capable of removing particulate matter from 60 nm upwards) and mist (conventional hepa filter-based equipment removes particulate matter from 350 nm upwards, and clogs when wet). Upon entrance into the aufero, airborne pollutants are captured on the collector plate inside the device and transformed into coarse dust. The airborne pollutants are thus immobilized, thereby eliminating the possibility for them to be emitted and inhaled. ONce captured the coarse dust remains fixed to the collector place surface, despite gravitational forces and shearing forces by the passing air stream.

Drawbacks of positive ionization technology

- Positive ionization technology produces only a negligible amount of ozone (well below legal limits)

Case Study: Smog Free Tower

Materials used for measurement:

- Optical Particle Sizer Model 3330
    - Measures number of particles, size and mass with +-10% accuracy
    - Uses optical and gravimetric analysis
        - Gravimetric: a method of quantitative chemical analysis in which the constituent (in our case, PM) is converted into a substance of known composition that can be separated from the sample and weighed
- Cup-anemometer DS
    - Measures wind speed (in m/s) with less than 0.1 m/s error
    - Uses the hall effect (magnets)
- Wind Pennant DD (Potentiometer)
    - Measures wind direction in degrees using the rotation angle of the potentiometer

Air Purification in big cities:

- World's largest air purification tower is 100 meters tall and located in Xi'an China
    - According to researchers from the Institute of Earth Environment at the Chinese Academy of Sciences, the tower is capable of producing 10 million cubic meters of clean air per day

Next Meeting: Continue conduction research and develop a computational model that we can use to model the system and produce results where we can make recommendations to the engineering program

Meeting 3: 28 March 2022 (8:45 - 10:15)
Total Meeting Minutes: 300
Attendance: Heather Mello, Kyle Heaton, Chris Hoppe, Shelby Palmer
Goal: Start the computational model

Worked on white boards:

- Initial Assumptions
  - Smog is evenly distributed
  - Smog is at a height of 100m and lower https://smartairfilters.com/en/blog/less-pm25-pollution-higher-floors/ (This link is the source for this data)
  - All buildings are full of smog OR there are no buildings. The entire volume of air in Hong Kong contains smog/particulate matter
  - Radius of smog collection from towers is infinite
- Volume of air in hong kong calculation
  - 2.755*10^11 m^3
- Average pm density in hong kong at any given moment https://www.aqhi.gov.hk/en/annual-aqi/latest-annual-aqi.html (This link is the source for this data)
  - PM10: 28.39 ug/m^3
  - PM2.5: 16.28 ug/m^3
- Variables we are going to test:
  - Height
  - Voltage
  - Windspeed (velocity)
  - Density

This meeting we looked a lot at the numbers that we found in research and tried to find standards that we would have to reach for the model to be deemed successful. In figure 11 below we averaged some data to get smog height and volume of air in Hong Kong. Then after that we wrote down some of our initial assumptions that might impact our model later on and help us solve the system.

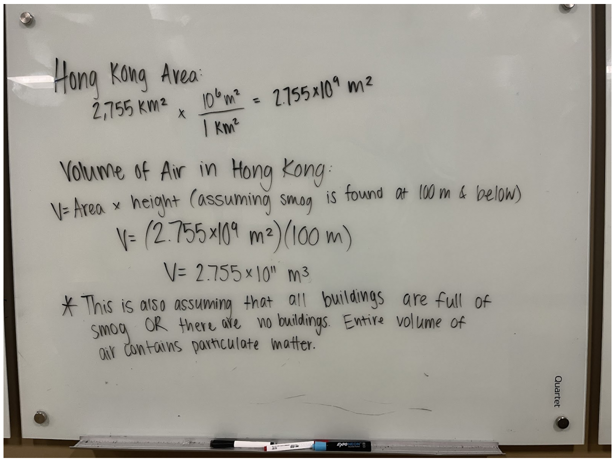


Figure 11.1 Volume of Air Calculations

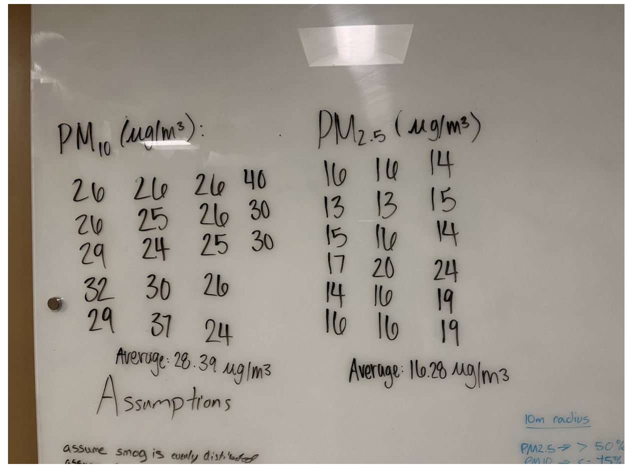


Figure 11.2 Average of PM Calculations

Meeting 4: 30 March 2022 (In Class)
Total Meeting Minutes: 420
Attendance: Heather Mello, Kyle Heaton, Shelby Palmer, Chris Hoppe
Goal: Start the computational model

- We decided that we will use Cotter's method to determine the factor that changes the efficiency (and power) of the towers the most
  - Height
  - Distance Between Towers
  - Height of the Plates

$$\frac{\pi}{6}\rho_{particle}d^3_{particle}a_{vert}(t)=\frac{\pi}{6}\left(\rho_{fluid}-\rho_{particle}\right)gd^3_{particle}+\frac{1}{2}\rho_{fluid}C_d*\left(\frac{\pi}{4}d^2_{particle}\right)*v^2_{vert}(t)-\frac{q\sigma}{2\pi\varepsilon_0}+\frac{q^2c(t)}{2\varepsilon_0}*\left[2D_{vert}(t)-H\right]$$

- p*d^3*a (first part of equation) = Fnet
  - The value that the code outputs
- p_{fluid} = density of the air
  - 1.29kg/m^3
- $p_{particle}$ = density of the particle
  - 2.8x10^{-8} kg/m^3
- g = gravitational constant
  - 9.81 m/s^2
- d = diameter of particle
  - 2.5 or 10
- C_d = drag friction coefficient
  - 24/(Reynolds Number)
- Epsilon naught = 8.85 * 10^{-12} C^2/N*m^2
- v_{vert} = vertical velocity of the particle
- q = charge
  - 1.61*10^{-19}
- sigma = charge per unit area
  - 1.98x10^{-13}kg/m^3
- **h = height of plate**
  - **1m 2m**
- **D_{vert} = height**
  - **7 m 100m**

Scipi Animation: https://scipython.com/blog/the-forest-fire-model/

Meeting 5: 31 March 2022 (5:30 - 7:00)
Total Meeting Minutes: 510
Attendance: Heather Mello, Shelby Palmer, Kyle Heaton, Chris Hoppe
Goal: Continue working on the numerical model, determine values of variables

- Continued working on numerical model (SHELBY)
- Determined values of variable that we still had to find
- Fine-tuned the equation we're using

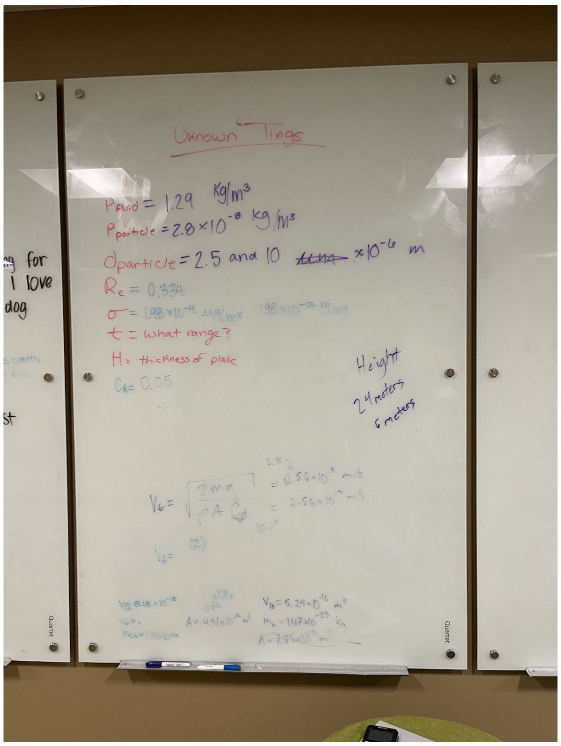


Figure 12 Unknown Data

During this meeting we went through the computational model that was being developed based on the fnet physics equation and identified variables and other information that we did not know. We worked on the white boards and looked through our research and preformed a few calculations to find the missing information. This took us most of the time for this meeting as this was the missing portion of our project that we would need to calculate what would be the most impactfully on the efficiency of our model.

Meeting 6: 31 March 2022 (10:00 - 11:00)
Total Meeting Minutes: 570
Attendance: Shelby Palmer, Heather Mello, Chris Hoppe, Kyle Heaton
Goal: Finalize numerical model

https://www.apimages.com/metadata/Index/CHINA-BEIJING-SMOG-FREE-TOWER/18ade09d680b4132b85e8ae6ea27b8ce#:~:text=As%20smog%20season%20starts%20to%20hit%20China%2C%20Studio,air%20purifier%20in%20the%20world%2C%20and%20it%27s%20mobile%21

- Worked on the numerical model

At the start of this meeting we took a second to see where we were and plan out the rest of the things that we would have to accomplish for this project. We planned out what everyone needed to do and began to finalize our design specifications. We got the comuptational model to begin to work and finalized a lot of details of discussion.

We made a few calculations and tried to deal with the initial issues that the model gave us. This was a late meeting and therefore we were not the most productive. After this meeting we determined that we needed a small break and therefore the rest of the project would be completed in future meetings.

Meeting 7: 01 April 2022 (In class)
Total Meeting Minutes: 630
Attendance: Heather Mello, Shelby Palmer, Kyle Heaton, Chris Hoppe
Goal: Finalize numerical model and work on presentation poster

- Finished cotters method
- Selected variety values to test
- Determined which is the most sensity
- Devised a way to calculate the total number of towers and the amount of air that is cleaned

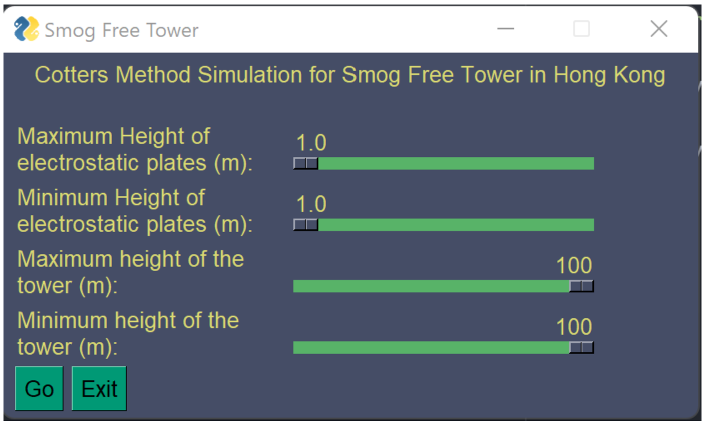


Figure 13 User Interface

The program used the Fnet equation and cotter's method to calculate the sensitivity of the tower height and the height of the plate. Four input values were used: the maximum and minimum height of electrostatic plates and the tower. The range of values were represented by a slider where the value is printed as the user determines the input.

<u>Ranges</u>

- Height of electrostatic plates (m) : 1.0-2.0
- Maximum height of the tower (m) 7-100

<u>Lines of Output Meaning</u>

- Fnet results for:
    a. Maximum Electrostatic Plate Height
    b. Minimum Electrostatic Plate Height
    c. Maximum Tower Height
    d. Minimum Tower Height
- Codd
- Sensitivity
    a. Tower Height
    b. Electrostatic Plate Height

```
[1.0354303107224831e-16, 1.0354303108337824e-16, 1.0354303107224824e-16, 1.0354303108337817e-16]
[-8.347445683648844e-27, 5.546678239835239e-32]
S is:
0.9999933552830483
6.644716951669651e-06
The tower height has a sensitivity of 99.99933552830484% and is most impactful
The plate thickness has a sensitivity of 0.0006644716951669651% and is least impactful
[Finished in 27.081s]
```

Figure 14 Outputs from the Code

We also looked up different cost values for the smog-free tower. It was determined that the rate at which smog particles were absorbed by the tower would be a key factor in the cost of each tower. This will help determine how cost efficient different smog towers are.

Next meeting: Talk about sustainability, focus on the poster, split up speaking roles, and finalize calculations and analysis.

First, the height of 24 meters per tower was decided upon because it is the average height of smog towers. Then using that information we calculated the amount of air that a one meter tower can take in. We then set up a ratio to calculate the total amount of air that a 24 meter tower could clean, assuming that the same amount of air would be cleaned by every tower. Therefore, it is assumed that the smog is evenly distributed around the city of Hong Kong. We used the values 100 meters, the tallest, and 7 meters because that was the size of the one that Rosengarde designed for this project. The reason for choosing the taller towers was because the taller the tower the greater the force on the smog particles which will allow the smog towers to be able to calculate higher amounts of smog particles and essentially be better at removing the two different smog particles from the air. However, the 100 meter value which was the largest smog tower ever created is not feasible because it is so expensive to construct a 100 meter tower and for it to be able to go through all of the air around it in a reasonable amount of time will take a while. Which presented the problem of the city and surrounding area producing more smog then the machine can take out.

After deciding on the height of 24 meters we attempt to map out how many of the smog free towers we would need to place over the city in order to go through the correct amount of air in a reasonable amount of time. In the figure 15 below we initially took the amount of air that a tower of 7 meters, roosengardes tower, was able to go through and clean in an hour and used a ratio to calculate the amount that a 24 meter tower would be able to go through in that same amount of time. It was determined that a 24 meter tower could go through 102,857m^3 per hour. After determining this value we wanted to compare how the number of towers in the city will affect how long it will take for the towers to go through all of the air in the city that could be smog covered. Based on the level that smog can sit at 100meters (determined through research) and the total area of Hong Kong we found the volume of air to be 2.755×10^{11} m^3, for this we assumed that the volume of smog omitted the buildings that would inevitably make up a small portion of the city. This allowed us to calculate its area.For the next portion of our calculations we had to come up with a few assumptions that would make this model feasible. The first being that the smog particles are evenly distributed throughout the city thus that the smog density will be the same throughout the city. Then one of our most important assumptions in our model is that once air has gone through one of the smog towers and has been cleaned, it will not enter the same smog tower or any other subsequent smog tower until all of the air has traveled through the towers. This assumption is necessary to calculate the amount of time that would be needed for any number of towers to clean the air. This assumption is the least practical in practice primarily because air travels in no uniform pattern and the smog and air will interact with objects around it to produce a not uniform path. Using the above stated assumptions we were able to calculate the amount of air that would be able to go through a predetermined set of air and how long it will take to clean the entire volume of air.

We began the calculations by having one tower. It was calculated that for one tower it would clean approximately 102,857 m^3 per hour. Then based on our total volume it would take approximately 30 years to clean the total volume of air. Then we used 100 towers and it would clean approximately 10,285,700 m^3 per hour over a 2678 hours period which would take about 111 days. Using 1000 towers it would clean 102,857,000 m^3 per hour over a 267.8 hour period and would take about 11.1 days to clean the total volume of air. Using these values we say the different ranges and the feasibility of cleaning this huge amount of air. We then determined that a reasonable metric of cleaning air is to go through the total volume of air in 10 days and determined the total amount of towers needed to clean the smog in that time period. 10 days was determined as an appropriate amount of time because it will allow the total volume of air to be cleaned and filtered about 36 times per year and using the data gathered on the amount of air pollution produced per day it would be feasible for the smog towers to clean more smog then smog is produced so it will be unlikely to ever go above the WHO's recommended guidelines of PM10: 30 ug/m^3, PM2.5: 10 ug/m^3.

Using the 10 days we calculated the number of towers needed to be 1,117. From this we then needed to determine the spacing needed for the towers and we used Hong Kong as the boundaries for that. We calculated the area of Hong Kong using the assumption that its land mass was in the shape of a rectangle in order for use to space out the towers evenly. Then using the earlier assumption that the smog is evenly distributed we are able to space them out evenly without having to place them in the most densely populated.

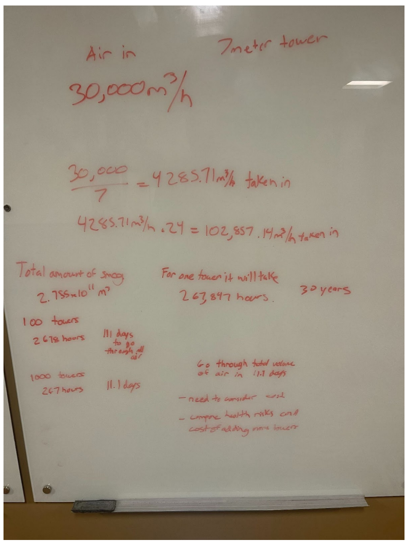


Figure 15.1 Calculations

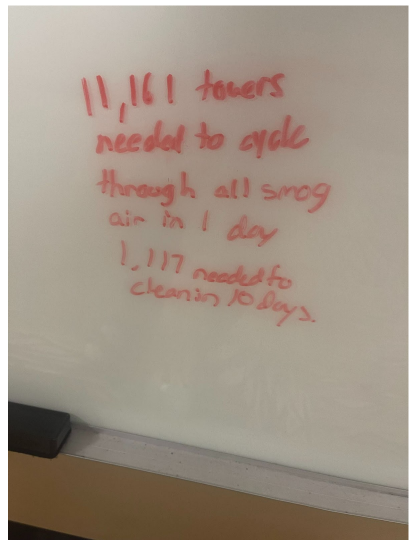


Figure 15.2 UpScale Info

After determining the number of towers, the price, and the placement of the towers, we had to reconsider some of the sustainability issues that we had identified earlier in the project. The first of which was the claim that the towers did omit some ozone which could deplete and produce holes in the ozone layer. This is an issue that we are not able to get concrete evidence for because there are a variety of factors that affect the ozone layer but this could be an issue for future cities and areas that may have to deal with some of the issues that may arise from a depleting ozone layer later on. Another issue is how long the smog towers will last before they are required to be replaced because that could have a huge impact on the number of towers that are feasible and the total cost that this project will require. The average smog tower costs anywhere from $54,000 for a 7 meter tower to $771,428 to construct a 100 meter tower. These values are omitting the labor costs and other building and zoning fees that may appear when constructing these towers. The building cost only one thing to consider because the maintenance costs and operation costs amount to a lot over the lifetime of the towers. The operation costs can range from $6,400 to $74,000 per sm3/sec. From this the smog towers according to the EPA have a cost effectiveness of $38 to $260 per metric ton ($35 to $236 per short ton). These are some of the cost effects to consider when constructing these smog free towers. The technology for these are relatively new and therefore there is not a lot of data on how long the towers are able to last and therefore we analyzed the yearly costs mainly when discussing the effectiveness of the towers and the feasibility of implementing a little over 1000 of them across a city. The cost of these was then compared to the hospital and health costs due to bad air quality in the city. 1.4 trillion USD is spent every year in China due to air pollution issues. Comparing this to the cost of the towers it can be seen that the amount of money that will be saved in the long term from implementing these towers outweighs the upfront cost that it will take to build and operate these smog free towers.

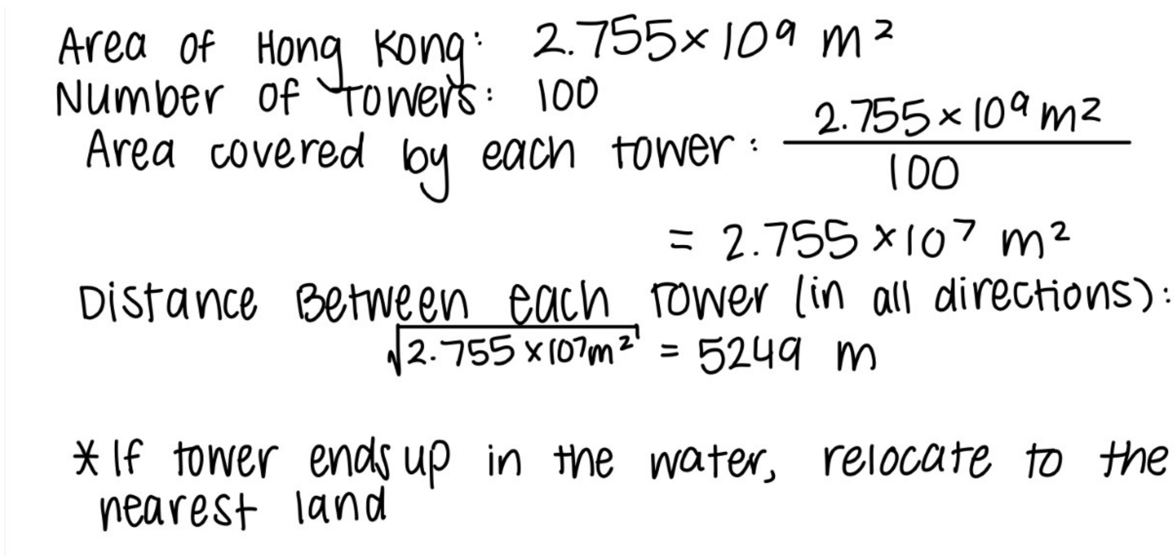
Another issue is the amount of power that it will require for the towers to be run consistently or at periodic times. We were considering the last part of this sustainability issue a lot because smog is more prevalent during certain seasons and weather patterns which could affect the efficiency of the towers. This is a scaling up issue mainly because the weather is unpredictable and thus is an issue that would need to be considered. However the amount of power that it will need to run is 20,000 to 100,000 volts according to the EPA. This is a value that will not take a huge swath of energy at a time. For example times square takes 161MW of power and it is nowhere near that value however it is much larger than teslas which typically take a little over 100 volts to charge. From this the power requirement is not a huge sustainability issue but it does still contribute to the issue of needing a good amount of power to operate. Rossengarde developed an idea to combat this and offset some of the operating costs and that was to introduce a wind catching mechanism which would be able to convert wind energy into 20 to 100 kW of energy that could be used to power each of the machines and create energy to put back into the system if possible.

Another thing to consider about this project is that this project will work most efficiently only in largely urban or densely populated areas therefore it could not be implemented on a grand world wide scale because some areas will not have as much of an issue with smog and it would then not be reasonable to use resources time and money to put it in those places. This technology in practicality will be less effective then what we have modeled primarily because there is a lot of variability that can never be accounted for like natural disasters and air patterns. With this in mind we believe that our method for modeling the product and discussion of the findings and sustainability issues are good representations of the project and what would occur in actuality.

After the discussion of sustainability and finalizing the features of our design and model we were able to begin looking at the method that we were going to communicate our results to the group of individuals that we are making recommendations to. It was determined for us that we would develop a 12 minute pitch that would highlight our findings and other issues and things to consider when finalizing this project. We determined that we would tackle the rest of this process during the next meeting and divide the speaking roles. We discussed that each of the members would discuss the topics that they were subjectively most familiar with and knowledgeable about.

Meeting 8: 02 April 2022 (2:00 - 3:00)
Total Meeting Minutes: 690
Attendance: Heather Mello, Kyle Heaton
Goal: Finalize all data

At today's meeting we discussed the number of towers that Hong Kong will need to have to solve the smog problem. We decided to base the number of towers off of the severity of the situation, and concluded that clearing 100% of the smog in 10 days would be an estimate for a minimum amount of time. 1,117 towers would have to be constructed for this to be possible. However, if the situation was even more dire and the smog had to be cleared in 1 day, 11,000 towers would have to be constructed. On the other hand, if the situation is deemed less dire, we would only use 100 towers to clear the smog in 111 days. We decided to go with 100 towers since 111 days is a more reasonable timeframe.


Area of Hong Kong: $2.755 \times 10^9 \text{ m}^2$
Number of Towers: 100
Area covered by each tower: $\frac{2.755 \times 10^9 \text{ m}^2}{100} = 2.755 \times 10^7 \text{ m}^2$
Distance Between each tower (in all directions): $\sqrt{2.755 \times 10^7 \text{ m}^2} = 5249 \text{ m}$

*If tower ends up in the water, relocate to the nearest land

Figure 16: Calculations for Tower Distance

Meeting 9: 02 April 2022 (7:15 - 8:15)
Total Meeting Minutes: 750
Attendance: Heather Mello, Shelby Palmer, Chris Hoppe
Goal: Work on slide

All we did at this meeting was divide up work for the slide for the presentation on monday. We decided that Heather would take the start of the presentation and discuss the goals of the project and our approach, Chris would discuss the physics behind the electrostatic precipitators as well as scaling up, Shelby will discuss our computational model, and Kyle will close the presentation by talking about sustainability.

Meeting 10: 03 April 2022 (12:00 - 2:00)
Total Meeting Minutes:
Attendance: Heather Mello, Shelby Palmer, Chris Hoppe, Kyle Heaton
Goal: Work on slide

Kyle's Talking Points

Now as the implementation of the smog free towers for this project on a large scale site like Hong Kong there are some sustainability issues to address. Firstly the creating and building of the smog free towers yielded a considerable cost. Each of the towers cost, at our determined height of 24 meters, is $185,142.86. The need to replace these towers in a short amount of time was a concern that we found because of the high price tag that previously mentioned. We looked at an analysis for the EPA of the tower's performance costs and normal maintenance and operation costs. This was then compared to the health costs that neighboring china utilizes to deal with health related issues due to air pollution which amounts to 1.4 trillion US dollars. When finally calculating the total cost of implementation, maintenance and replacement costs it will be much less compared to the amount of money that governments spends on health cost.

Another issue is the amount of power that it will require for the towers to be run consistently or at periodic times. We were considering the last part of this sustainability issue a lot because smog is more prevalent during certain seasons and weather patterns which could affect the efficiency of the towers. This is a scaling up issue mainly because the weather is unpredictable and thus is an issue that would need to be considered. However the amount of power that it will need to run is 20,000 to 100,000 volts according to the EPA. This is a value that will not take a huge swath of energy at a time. From this the power requirement is not a huge sustainability issue but it does still contribute to the issue of needing a good amount of power to operate. Roosegaarde developed an idea to combat this and offset some of the operating costs and that was to introduce a wind catching mechanism which would be able to convert wind energy into 20 to 100 kW of energy that could be used to power each of the machines and create energy to put back into the system if possible.

Used the volume of air that one tower could clean and scaled it up to cover the full city

Another thing to consider about this project is that this project will work most efficiently only in largely urban or densely populated areas therefore it could not be implemented on a grand world wide scale because some areas will not have as much of an issue with smog and it would then not be reasonable to use resources time and money to put it in those places. This technology in practicality will be less effective then what we have modeled primarily because there is a lot of variability that can never be accounted for like natural disasters and air patterns. With this in mind we believe that our method for modeling the product and discussion of the findings and sustainability issues are good representations of the project and what would occur in actuality.

Heather's Talking Points:

Hi, we're Team 32. I'm Heather, and this is Chris, Shelby, and Kyle. Today, we're going to discuss our analysis of air quality improvement strategies.

Hong Kong's air pollution is considered a serious issue due to the fact that significant smog problems in the area have been linked to many health and economic issues, with almost 2 million deaths worldwide due to air pollution, and a total of 1.4 trillion USD of monetary impact from outdoor pollution in China. Although Hong Kong has started to implement measures to reduce air pollution, they are looking to further reduce the effects using what is known as a "Smog Free Tower". A "Smog Free Tower" was designed by a Dutch artist Daan Roosegaarde and uses electrostatic precipitation to purify the air around it. However, Roosegaarde claims that the tower must be scaled up for significant impact in large cities, either by making the tower taller or by creating multiple towers. As a team, we were tasked with evaluating the implementation, feasibility, scaling, and sustainability of these smog towers. To assist us during this process, we were also expected to create a computational model that supports our conclusions about the Smog Free Tower.

Our initial approach to the problem I just outlined was to research smog free towers, the physics behind them, and the values that we would need for our computational model to ensure that we had a thorough understanding of the system before we began our analysis. After we completed our research, we created a computational model using python that is able to solve for force with varying values of tower height and electrostatic plate height. Once the computational model solved for force on the smog particles, it then used Cotter's method to determine which factor, tower height or electrostatic plate height, affects the system the most. After this was determined, we made decisions on the structure and location of the towers necessary to clear the smog in Hong Kong over a specified period of time.

I'm going to pass it over to Chris now, who is going to talk about the physics behind the Smog Free Tower.

Meeting 11: 03 April 2022 (8:00 - 9:30)
Total Meeting Minutes: 840
Attendance: Kyle Heaton, Shelby Palmer, Heather Mello, Chris Hoppe
Goal: finish scripts, practice presenting, submit poster

We finished writing our scripts and going over what we are going to say. We also practiced presenting and submitted the code and the poster around 9:30. The slides were reviewed and we practiced our talking points after the poster was turned in. This was our final meeting and we talked about how the project went and things that we could consider once we focused on project three. We discussed the plan for the following day presentation and what we were going to wear. Then called it a night.

Refrences

https://www.ens-cleanair.com/en/technology/#:~:text=Our%20air%20purification%20technology%20works,negative%20surface%3A%20the%20collector%20plate.
This is used in the first meeting to help us understand how the technology works and gives us more information on the topic. Used in meeting one

https://www.wired.co.uk/article/daan-roosegaarde-smog-free-project
This is used to find a lot of metrics that rossegaarde's tower dealt with and other information regarding the system that we are analysising. Used in meeting six

https://www.aqhi.gov.hk/en/annual-aqi/latest-annual-aqi.html
This is used for the annual amount of smog data and calculations of density. Used in meeting three

https://www.tandfonline.com/doi/pdf/10.1080/00022470.1978.10470733b
This is used for data gathering that we will use for calculations. Used primarily in meeting three.

https://www.moneycontrol.com/news/trends/health-trends/air-pollution-how-well-do-delhis-giant-smog-towers-combat-bad-air-7676951.html
This is used for the average height of smog towers that we determined for the height of our smog tower. This was used after meeting 7.

https://www.apimages.com/metadata/Index/CHINA-BEIJING-SMOG-FREE-TOWER/18ade09d680b4132b85e8ae6ea27b8ce#:~:text=As%20smog%20season%20starts%20to%20hit%20China%2C%20Studio,air%20purifier%20in%20the%20world%2C%20and%20it%27s%20mobile%21
Used for research on smog towers

https://weatherspark.com/y/127942/Average-Weather-in-Hong-Kong-Hong-Kong-SAR-China-Year-Round#:~:text=The%20windier%20part%20of%20the,of%2013.0%20miles%20per%20hour
Used to find weather and wind speed in Hong Kong. Used in meeting 6

https://scipython.com/blog/the-forest-fire-model/
Used as an inspiration for development of Cotter's method code.