

Project Koyash: Formal Design Document

I. Executive Summary

In the past, more than a quarter of Mongolia's three million citizens lived a nomadic lifestyle, raising livestock for subsistence. However, climate change has forced many people to leave their traditional way of living due to the depletion of suitable grazing pastures. According to a report conducted by the Japanese Ministry of Environment, desertification is impacting seventy percent of Mongolia's grasslands, which has made the maintenance of pastoral livestock economically infeasible for many families who once subsisted on the practice. As a result, many have moved into the nation's primate city and capital, Ulaanbaatar, which has seen its population double in the past eighteen years. In addition, facing a significant housing shortage, many of the formerly nomadic people of Ulaanbaatar have set up their mobile houses on the outskirts of the city. These dwellings, known as "Ger's," or in English as a yurt, have accumulated on the outskirts of the city forming Ger Districts.

According to the World Health Organization's report, sixty percent of the city's population (twenty seven percent of the nation's total population) lives in Ulaanbaatar's Ger Districts, numbering approximately 830,000 individuals. These residences, being disconnected from the city's gas utility system, are forced to burn raw coal to keep warm in the sub-Siberian winter, where the average winter high is -13 degrees Celsius (8.6 degrees Fahrenheit) [1]. The burning of raw coal emits Sulfur Dioxide at less than 2.5 micrometers in diameter, which, according to the EPA, poses significant health risk if inhaled. In fact, according to UNICEF, over the past eleven years, respiratory infections have increased by over 250% with the effects being especially severe on children. UNICEF found that children in Ulaanbaatar had lungs only 40% the function of their rural counterparts. With such egregious effects on the local community and the central Asian environment, the idea of addressing this issue as an EPICS project was developed [2].

As this is a student initiated project, it commenced without the support of a community partner. Having identified the need for information from the immediate area, it was a priority of the team to find a community partner who would be willing to correspond. In pursuit of such a correspondent, the team began by reaching out to local and international NGOs who have either had operations in Ulaanbaatar or may have contacts therein. In response, TFCF replied with interest in the project, as they have a concurrent project building Ger's for families in need. They have since been corresponding with the team and providing information to further the potential design solutions.

With analysis as the basis for the project, the team has gone forth to lay out the relevant questions that need to be answered in project identification. Going forward, the team will proceed with researching various topics to push our understanding of the situation and potential design solutions towards the goal of coming to a consensus of the most effective application of our skills and time to the issue. Upon coming to said consensus, the team's focus will shift to researching and implementing the chosen design solution.

A. Stakeholder Profile

Ulaanbaatar is divided into nine districts, or "Düüregs". Each düüreg is divided into sub-districts, or "Khoros", of which there are currently 132 in the city. Each khoroo is further divided into micro-districts, otherwise known as "Khesegs". Ger areas are located in all of the nine districts [3].

Mongolia itself is still in transition from decades of isolation and communism. The Ger districts have had rapid growth in the past few years (70% population growth in the last 20 years), but elected officials have been neglecting them by failing to provide essential infrastructure. Citizens living in the Ulaanbaatar Ger districts don't have access to sufficient power supply or grid connections to allow them to switch to electric heating rather than

burning coal. Additionally, most residents of the Ger districts have to walk about a quarter to half a mile to purchase water, which they carry back with them in plastic tanks.

Regarding the severe pollution in Ulaanbaatar, an area of extreme concern is the health of the children. Because young kids are especially vulnerable to the effects of air pollution, elementary schools have to be stocked with air purifiers. One mother in Ulaanbaatar said her boys get pneumonia “several times a year” and that “it’s normal in Mongolia” [4]. Newborns are at an increased risk of pneumonia or bronchitis with their very first breath. A physician in Ulaanbaatar even stated, “I no longer know what a healthy lung sounds like” [4]. It’s obvious that citizens in Ulaanbaatar need a solution quickly in order to turn around the health of their city.

Unemployment rates tend to be higher in the Ger districts (almost 60%), but those who are employed tend to perform more manual labor than residents living in apartment areas. Below are some graphs representing the demographics in Ulaanbaatar’s apartment areas vs the Ger districts.

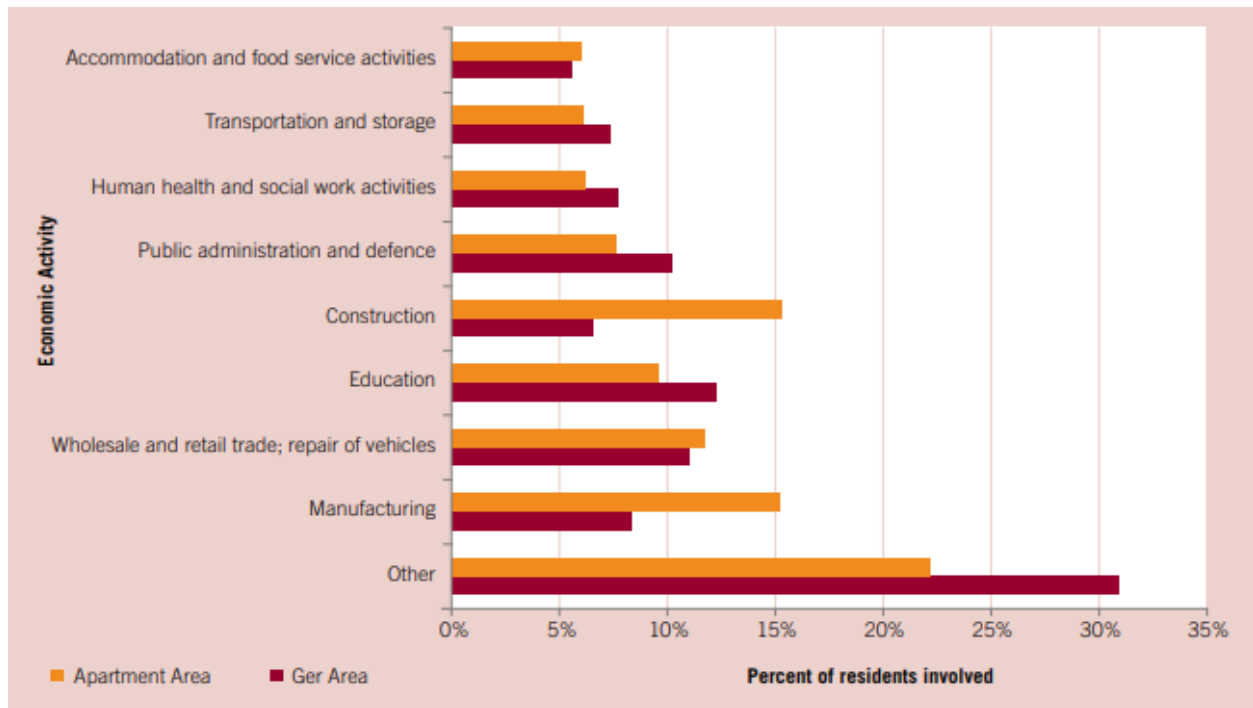


Figure 1 : Economic Activity of Ulaanbaatar Citizens: Apartment vs Ger District

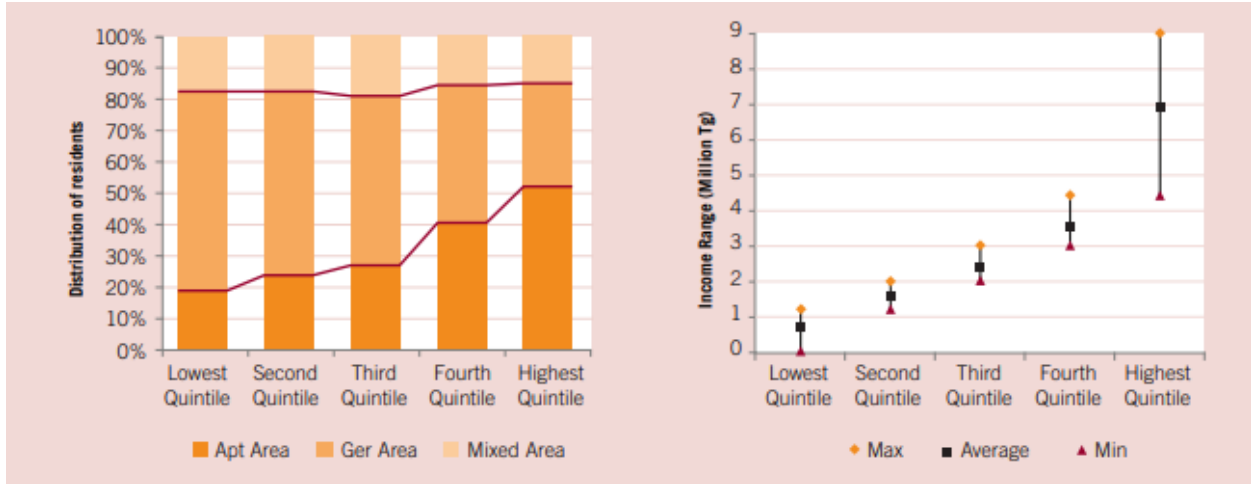


Figure 2: Household Income Distribution, Divided by Quintile

[3]

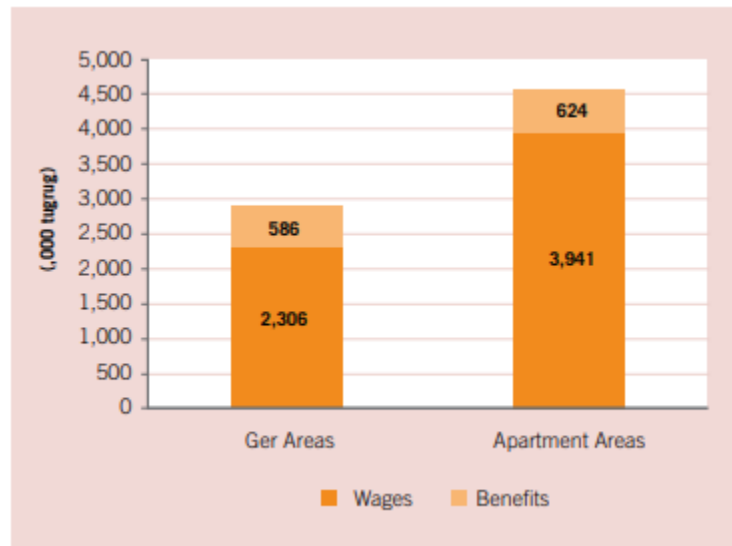


Figure 3: Average Incomes, Including wages and Benefits

[3]

II. Project Identification

There are two main methods the pollutant issues facing the Ger districts of Ulaanbaatar can be alleviated: substitution of fuel sources, and filtration. While the substitution of coal for an alternative, and cleaner, fuel source would be ideal, such a substance would also have to be sold to the Gher district residents. Not only would that involve creating a cheaper and more widely available substance than coal, but it would also mean convincing them to make the switch. In the conduction of research and communication with a professor studying coal clean up, Dr. Klaus Lackner, the team determined that while Dimethoxyethane (DME) is a much cleaner alternative, a solution ignoring the role that coal plays in Mongolia would be futile. Presently, Mongolia's largest export is coal, and the vast majority of its power is from coal power plants. The International Monetary Fund estimates that 71% of Mongolia's income is coming from mining. With coal providing the livelihood of many Mongolians, it is integrated

in their day to day lives. Any meaningful solution to the air pollution problem in Ulaanbaatar cannot ignore the widespread presence and reliance on coal.

On the other hand, air filtration can have a similar impact in improving air quality without the abrasion of competition with coal. Filtration can be considered at three levels: the entire city, the exterior of a yurt (chimney stacks), and the interior domestic environment. The team is currently researching each of these approaches.

There are a number of schemes employed across the world to intake pollutant matter on a city-wide scale including Xi'an's skyscraper sized filtration tower, the tree covered tower of "Bosco Verticale" in Milan, or Zürich's carbon intake factory. The team investigated such design solutions and their feasibility in Ulaanbaatar, and found them to be beyond the scope of this project.

The second option involves addressing the pollutant matter upon its release into the atmosphere; at the Ger chimney stack. Potential filtration units to be affixed to the end of a chimney stack were investigated, and found to be generally less efficient than those at the interior of the dwelling. In addition, such design can contribute to pollution build up without a sufficiently low pressure drop across the filter. Lastly, the effort to address the pollutant flow inside a Ger aims at relieving the negative health effects on its residents. Thus, the team has conceptualized a filtration unit optimized to the geometry of a Ger for maximum pollutant capture.

In order to optimize a filtration unit to the geometry of a Ger, should the research yield it as a positive next step, conducting a thermo-fluid (T-F) analysis of the pollutant flow through the structure has been conceptualized as a potential application of the team's efforts. This would involve taking the interior geometry as a control volume, measuring the properties of the pollutant matter including particulate density, velocity, and pressure, and applying conservation laws. Such a study would lead to a better understanding of the interaction of particulate matter in the domestic environment and help determine how best to design a filtration unit. The details of such a study, and those of the types of air filters the team is investigating are displayed in the specific development phase.

While filtration does alleviate the issue, a reduction in the combustion of biomass fuels is a necessity in addressing the root of this crisis. With Ger stoves being the primary source of heat for the dwelling, applying efficient insulation increases the heat retaining capacity of the dwelling, thus reducing the overall combusted biofuel mass. Thus the team aims to deploy a two pronged solution of air filtration and Ger insulation to alleviate the air pollution crisis facing Ulaanbaatar.

III. Specific Development

Two types of filters that the team is looking into currently include activated Carbon filtration and ionization. While the team is still researching the specifics of these filtration techniques, one concern brought upon by activated carbon was that of the pressure force of the pollutant matter. In order for an activated carbon filter to function, the contaminated air needs to pass through the filter, however, the team was unsure if the pressure force of the polluted air would be great enough to push through the filter. This concern was raised due to a lack of knowledge regarding the geometry of the Ger and how the stove was affixed to its roof. If the chimney of the stove (which was the source of the combusted coal pollutant) was flush with the roof, with no other area for exiting flow, then all the polluted air would have to pass through the filter inside the chimney, thereby required increased pressure force due to the reduction in area, as will be seen in the T-F analysis. However, with some pictures provided by TFCF, this concern was quelled.



In order to solve for the force of pollutant matter flowing through a filtration system, the T-F analysis can be performed by taking the Ger as a control volume and applying conservation laws.

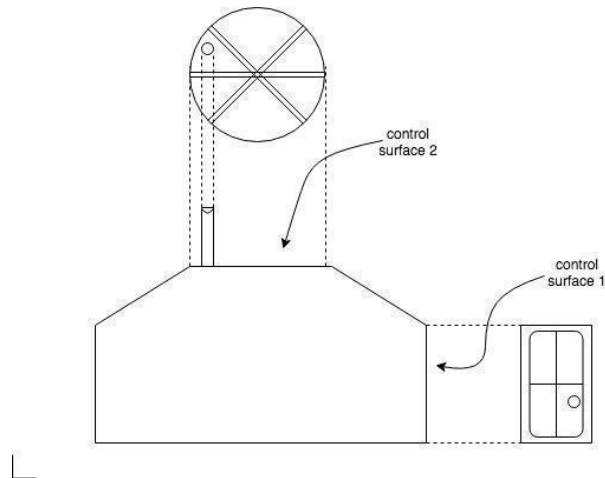


Figure 4: Control Volume of Ger geometry

$$\text{Conservation of mass: } \frac{d}{dt} \int_{cv} \rho \, dv + \int_{cs} \rho v \, dA = 0$$

$$\text{Conservation of Momentum: } \frac{d}{dt} \int \rho v \, dv + \int \rho v (v \cdot \hat{n}) \, dA = - \int P \hat{n} \, dA + \int \tau_u \, dA + \int \rho g \, dv + F_{ext}$$

$$\text{Bernoulli's Equation (Derived from prior two): } P_1 + \frac{1}{2} \rho_1 v_1^2 + \rho_1 g h_1 = P_2 + \frac{1}{2} \rho_2 v_2^2 + \rho_2 g h_2$$

$$\text{Conservation of Energy (dependent on enthalpy, heat flow) : } h_{t2} - h_{t1} = q - w$$

ρ : density

v : velocity

dv : differential volume

dA : Differential Area

τ : Shear stress

g : gravitational acceleration

F_{ext} : external force used to model pollutant pressure force

h : height

h_t : enthalpy

q : heat flow rate

w : work

The goal of the T-F analysis is to solve for the external force in the conservation of momentum, which will represent the pressure force of the pollutant matter. The conservation of energy equation is unlikely to aid in solving for the pressure force as it is dependent on heat flow, the terms of which do not appear in the conservation of momentum equation. Thus, the system has to be assumed as that of three equations with three unknowns. Luckily, the shear stress term can largely be disregarded as it is dependent on the horizontal air speed derivative, which can be assumed as negligible. In addition, the body force term is also equivalent across the whole system, because gravity is constant, thus the term can be disregarded. The last simplification to be named is the neglect of the unsteady terms in the conservation of mass and momentum, assuming air density is constant with respect to time. Ultimately, this yields a system of three equations dependent on air density, air velocity, air pressure, and the Ger geometry, in order to solve for the external pollutant pressure force. During testing, should the air filter fail to achieve its second testing parameter (see page 8), this system will have to be solved in order to establish a design parameter for the minimum pressure drop in our chosen air filter model. In accordance, a sample of local coal, to be lab combusted to determine aerated density, would need to be obtained.

In order to determine the specifications of the filtration unit to be used, significant research needed to be conducted. This research needed to keep in mind the requirement that any filtration units will require autonomous power systems, as the Ger district's electricity has been confirmed as highly unreliable by TFCF. It was determined that the shape this autonomous power system would take on should draw on renewables. Commencing this research was an investigation into the function of Air Ionizing filtration. As previously discussed, the ionizing air filter works by passing charged particles through the air thus allowing them to bond to pollutant ions, the heavy particles then being captured. How exactly the particles were captured was the question of importance. According to Green Builder Media, "Once the particles pass through the field, there are either positively or negatively charged plates that attract the particles" [5]. So not only can a single unit deal with both negatively and positively charged ions, but it can also filter said particles on a magnetic collector.

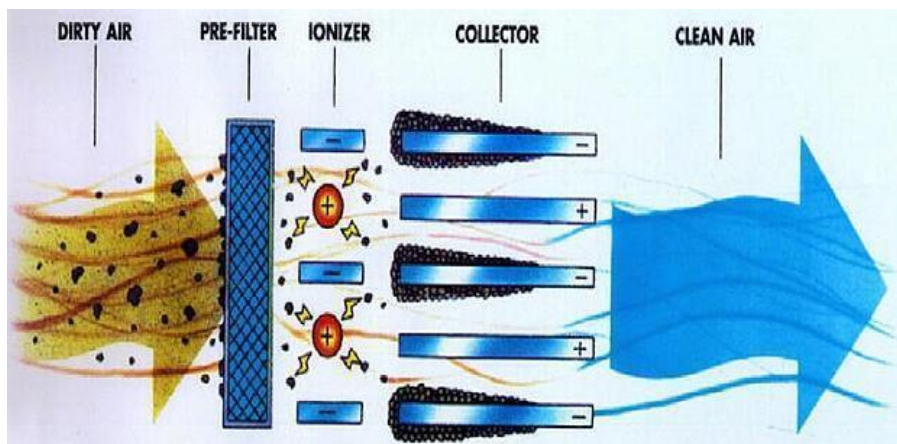


Figure 5: Ionizing Air Cleaners

This seems to support the case for an Air Ionizer being a legitimate solution to domestic air filtration for Ulaanbaatar Ger's. Since the system can deal with both anions and cations, it is likely to be effective on most particles released by combusted coal. However the system overall efficiency needed to be accounted for. To answer this question the team looked to the article "Ionizer Assisted Air Filtration for Collection of Submicron and Ultrafine Particles Evaluation of Long-Term Performance and Influencing Factors," which made a comprehensive study thereof. The study used "class M5-F9 according to EN779:2012 (European standard for air filters)" which designated it as appropriate for filtering fly ash, oil fumes and agglomerated soot among others [6]. The outcome of the study stated that "Results showed that ionization enhanced the filtration efficiency by 40%-units during most of the operation time. When the ionization system was managed by periodically switching the ionizer polarity, the filtration efficiency against PM0.3-0.5 was maintained above 50% during half a year". The usage of the system also simplifies the Thermo-Fluid analysis as its results state that "The pressure drop of the ionizer-assisted M6 filter was 25-30% lower than that of a filter of class F7" [6].

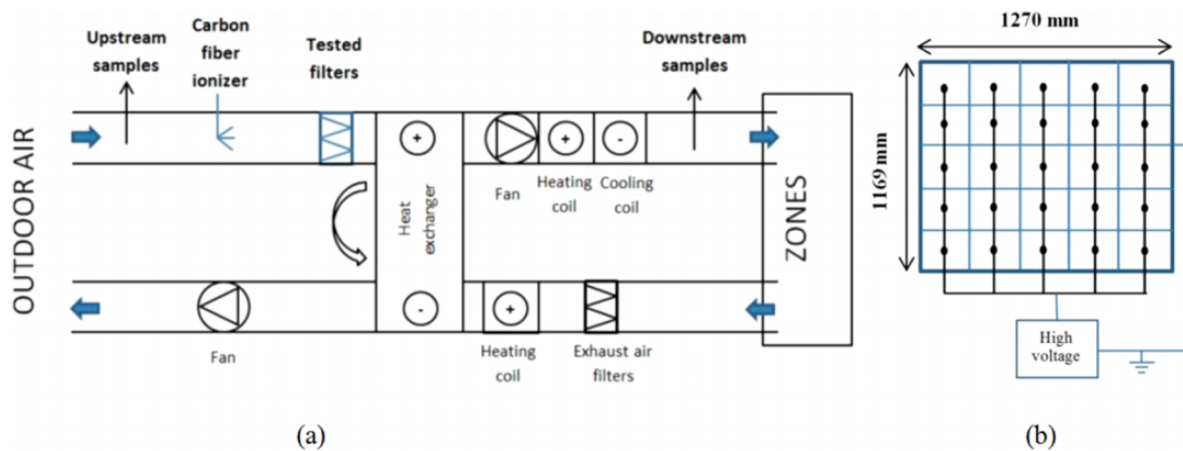


Figure 6: Specifications of Filter Media Tested in the DCV System

[6]

As the above information indicates the utility of such an air filtration device to the design, the remaining piece of the puzzle would be the connection to an autonomous and sustainable power source. In an effort to understand how best this can be achieved, the team cited the patent for "Air Ionizer and Method" [7]. The information regarding the specific power source and the connection to be made therein will have to be surmised from separate research.

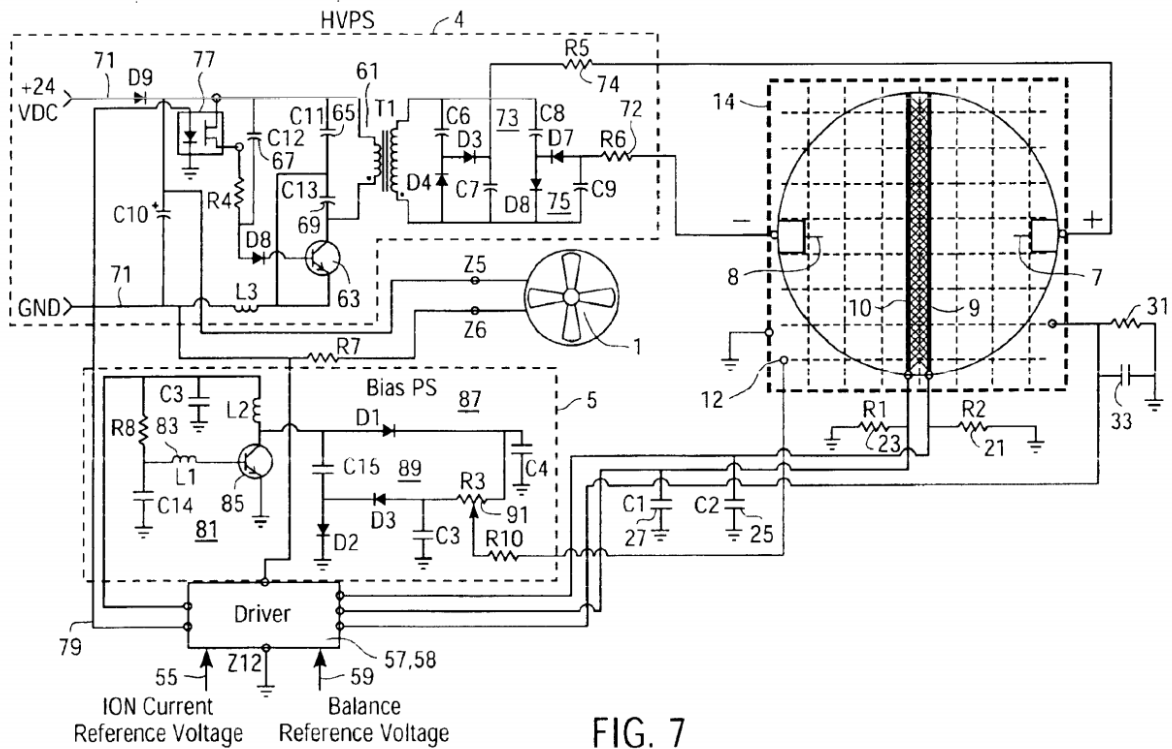


Figure 7: Schematic diagram of the closed-loop circuitry for automatically controlling bipolar ionizing Voltages

[7]

With this determination of, and some deliberation on, a series connection of an activated carbon and ionizing filter, the prior of those fixtures deserves some specification of its own. Thus far the basic understanding of activated carbon filtration is that it is some sort of air filter that features a bed of “activated carbon,” through which air must be passed, which traps gaseous pollutants. The team’s first concern regarding this apparatus is the nature of activated carbon itself, what is it and how is it different from normal carbon. According to Molekule, an air purifier manufacturer, “Activated carbon is carbon that has undergone some additional processing to make it better at trapping gas molecules. First, it is injected with hot air, carbon dioxide, or steam, which creates a lattice of tiny pores in the carbon, vastly increasing its surface area” [8]. The larger surface area of the activated carbon molecule allows for more pollutant particles to adhere to its surface. For activated carbon does not trap pollutant matter in it, but rather adheres to it. For reference, the terms “Activated Carbon” and “Activated Charcoal” are often used interchangeably.

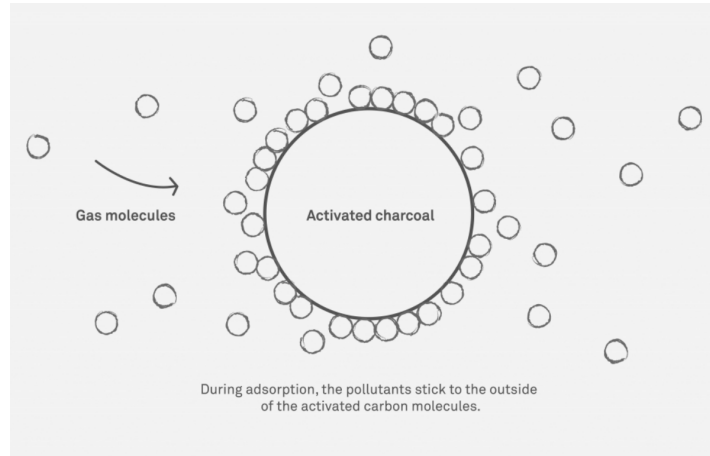


Figure 8: Activated Carbon Illustration

[8]

According to ArchrNews, activated carbon is known as a universal absorbent, and is used widely in the HVAC (Heating, Ventilation, and Air-Conditioning) industry [9]. Thus, with the series connection of an activated carbon and air ionizing filter showing significant promise, the next goals of the team will include further investigation into power sourcing, and fabrication. In regards to power sourcing, to facilitate air filtration in yurts in Ulaanbaatar, our system needs to be able to operate without reliance on the local electric grid, and needs to be able to treat local air to healthy standards. Thus, in testing our system, there are two fundamental questions to be answered:

1. Does the system utilize a functional autonomous power system?
2. Does the system yield a healthy air quality?

In the case of question one, our system will be running off modular solar panels. The solar panels will then be connected to a charge controller, from which the voltage can be read. The charge controller will be connected to batteries, which will store the power, which can then be utilized from an inverter, to which the air filter will be hooked up. Thus, test question #1 can be answered by reading the voltage change displayed on the charge controller, and by hooking up the air filter and running it. The process will commence with the setup of the system, neglecting the air filter, for the battery will need to charge before the filter can be tested. The initial confirmation of test #1 will be to check the voltage read out from the charge controller, which will indicate that current is flowing, and our system has been properly set up. After the battery has charged, plugging in the air filter and running it will affirm that our autonomous power system is functional.

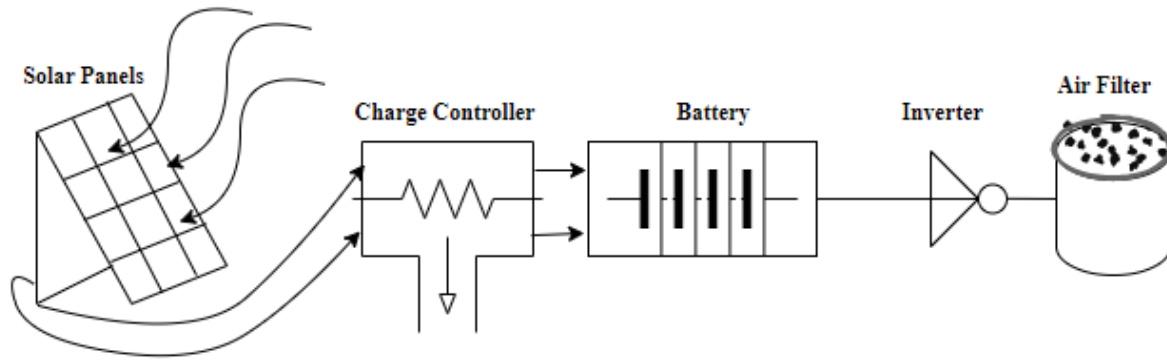


Figure 9: Rough diagram indicating autonomous power system design

[10]

The second test question is in regards to the performance of the selected filter, will it clean the air, from the pollution levels experienced in yurts in Ulaanbaatar, to healthy levels. For this test we will have to simulate the air quality we expect to experience in Ulaanbaatar, and see if the filter can function properly. We will use the Air Quality Index (AQI) to determine the unitless pollution at a given time in Ulaanbaatar, and match that air quality here. In order to determine when we have reached said air quality, we will need an air quality sensor, which has been included in our prototyping order. In discussion with our academic associate, it was determined that incense can function as a close approximation to coal, as the main driver of air pollution in Ulaanbaatar. Thus we will have to burn large quantities of incense to raise the AQI to match that of Ulaanbaatar, and when our sensor indicates that we match our target level, we will switch on the filter and see if it can bring the levels back down. Specifically, the AQI data from Ulaanbaatar city districts of Songinokhairkhan (SK) and Bayanzurkh (BZ) will be used, as, with the help of TFCF, they have been identified as the areas most representative of the Ger districts.

Per the autonomous power system design mentioned above, after the team set a prototype system to TFCF, an issue was identified regarding its interfacing. Namely, that for the system to be switched from charging to discharging modes, the wires need to be manually changed. The battery cannot connect to the charge control, and thus be charging, while it is connected to the inverter, and thus powering the system or discharging. It is inconvenient and dangerous for this wire switching to be frequently conducted by the user. Thus, a goal of the team in the fall semester of 2021 was to develop an autonomous switching system. Such a system aims to reduce the interfacing with current flowing wiring that the user must undertake, by regulating the system with an Arduino. Power regulation run by the arduino will autonomously switch the system from charging to discharging modes. In order to conduct this function, certain sensors and associated PCB design will be required. These technical details are given in Figure 11.

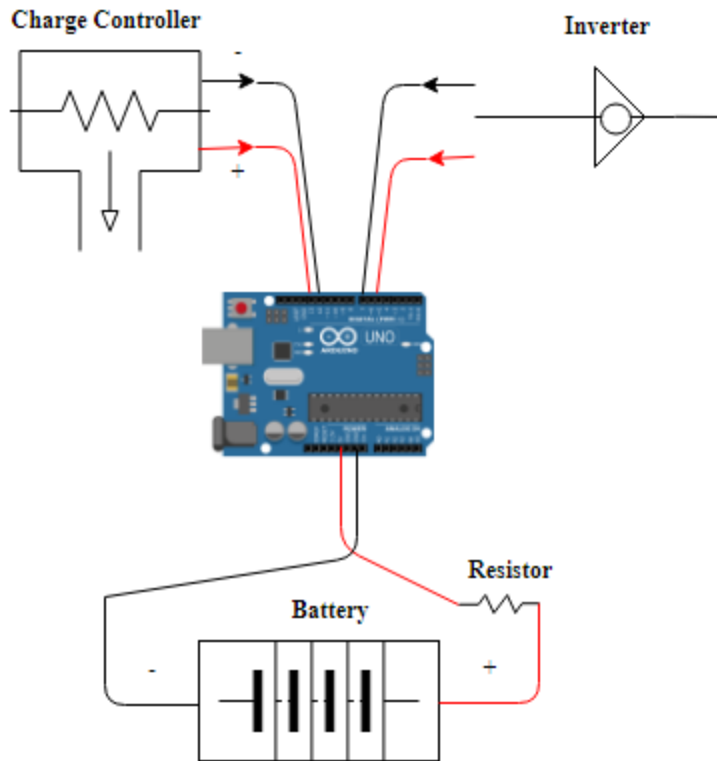


Figure 10: Overall diagram of power switching set up

[11]

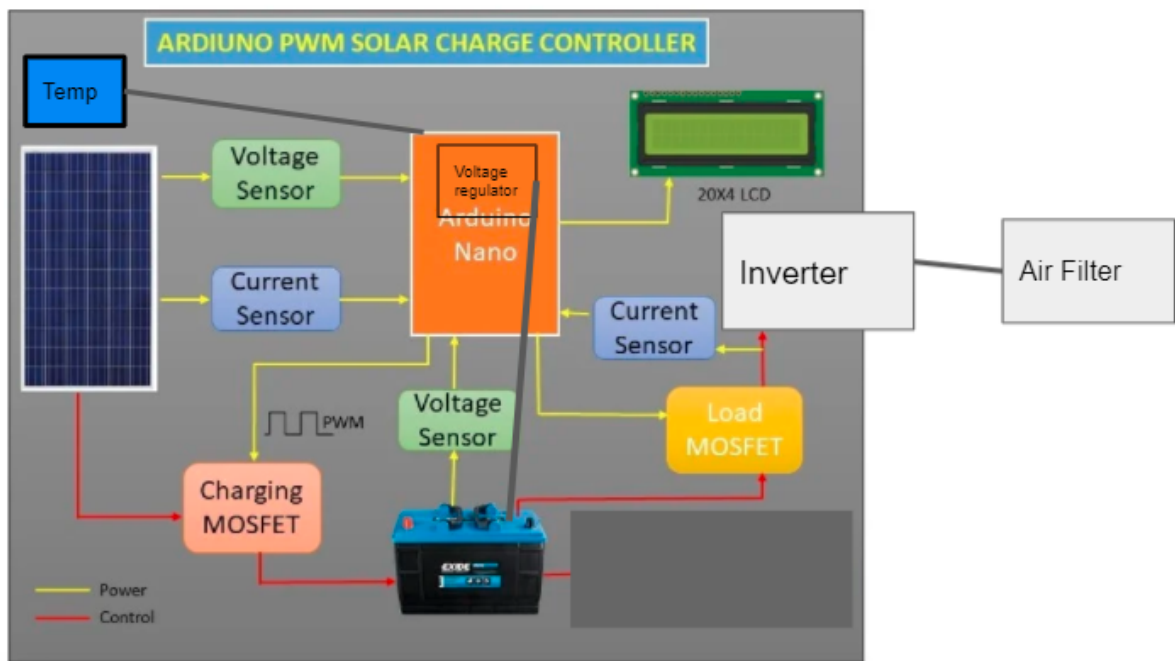


Figure 11: Detailed diagram of sensor and PCB interaction with Arduino and power system

[11]

Insulation is another aspect of the design that was considered for the long term. Insulation here refers to using a radiant barrier similar to reflective foil in order to trap heat inside the Yurt. Utilizing radiant barriers allows for 96% of the heat to be contained or reflected. Here heat rays move across air spaces from a warmer object to a cooler object. The mechanics of radiant barriers in a Yurt work by creating a dead airspace between two barriers, allowing heat to be trapped and minimal escape of any radiant heat. This air space is critical to bar any radiant heat from escaping, which would otherwise render it ineffective. A Yurt would have the radiant barriers be the covering that will trap heat within the space, with some form of insulation between the barriers. This allows for less burning of coal to keep the warmth inside, or even use a different source of heating entirely such as an electric stove thereby reducing harmful emissions produced by the raw coal.



Figure 12: EcoFoil Radiant Barrier

[12]

According to a study by World Bank, which surveyed the 6 Ger Districts of Ulaanbaatar, 96% of that population was able to identify the burning of coal as the #1 source of pollution and harmful health trends throughout the city. In addition, 85% of those people were more willing to transition out of coal to more sustainable options that will reduce the harm to their health and were more willing to consider alternate heat sources such as electric heating [11].

In Fall 2021, the team began the conduction of insulation testing in order to understand how the EcoFoil radiant barrier insulation, and traditional insulations of wool compare and interact. In order to minimize the manual labor of installation, it was identified that the EcoFoil should be deployed as a single continuous sheet. Thus, a geometric analysis was done to determine the shape and application of such a continuous sheet of insulation, the result of which showed that the insulation should be deployed on the Ger wall. With the traditional insulation already being used to some extent on Ger walls, the question arises of how the two insulations work constructively with each other. With heat reflectivity “R” value used as the parameter to describe the efficiency of an insulation, the goal of insulation testing is to determine the cumulative R value of the layered insulation, as well as the difference from usage of an individual insulation that said layering provides.

To this end, a testing parameter was determined, in which a control volume would be heated up to a sufficiently high temperature, and then would be allowed to transfer the heat to the exterior ambient conditions. Thereafter, each insulation condition would be applied to the interior of the control volume, and the time taken for heat transfer would be recorded. This timing parameter would be used to compare the heat retaining capacity of each insulation condition. Firstly, to conduct this testing, a control volume needed to be identified, and the testing temperature, that which the control volume would need to be raised to, also needed to be determined. With a digital thermometer being used as a temperature probe, the final setup requirement would be the physical installation of the insulation.

It had also been a goal of the team to conduct insulation testing during the Fall semester of 2021, however after an initial test set up failure, this initiative has been pushed into a subsequent semester. Referring to the insulation testing parameter, the same shed (see Conceptual Design section) was used as a control volume as in the

filtration testing. The testing temperature identified had to equate to the difference between desired room temperature and ambient conditions in Ulaanbaatar. On the day of testing, the ambient air temperature in Ulaanbaatar was $-4^{\circ}C$, where room temperature is taken to be $20^{\circ}C$. Thus our desired change in temperature $\Delta T = 26^{\circ}C$. In order to replicate this ΔT , the control volume needed to be heated up above ambient conditions in Tempe AZ. On the day of testing, the ambient temperature in Tempe was $20^{\circ}C$, thus the desired testing temperature $T_t = 20 + 26 = 46^{\circ}C$. It should be noted that the control volume used already had some insulation from its structural design, thus requiring further corresponding increase in T_t .

However, it was quickly realized that achieving such a high temperature in the control volume would be unrealistic. An attempt was made to determine the maximum achievable T_t for the test setup, using three electric heaters. Unfortunately, these heaters managed to trip the power supply they were operating on. Thus the setup was scaled down, functioning only under a single heater, which did not manage to achieve any significant heat addition. After this failure, the team determined that the similarity parameter that was required for filtration testing was not required for insulation, for while pollution concentration and flow needs to be modeled per geometric constraints, temperature, as an intensive property, does not. Thus, moving forward, the team plans to develop a unit cube control volume, and associated power requirements for heat addition.

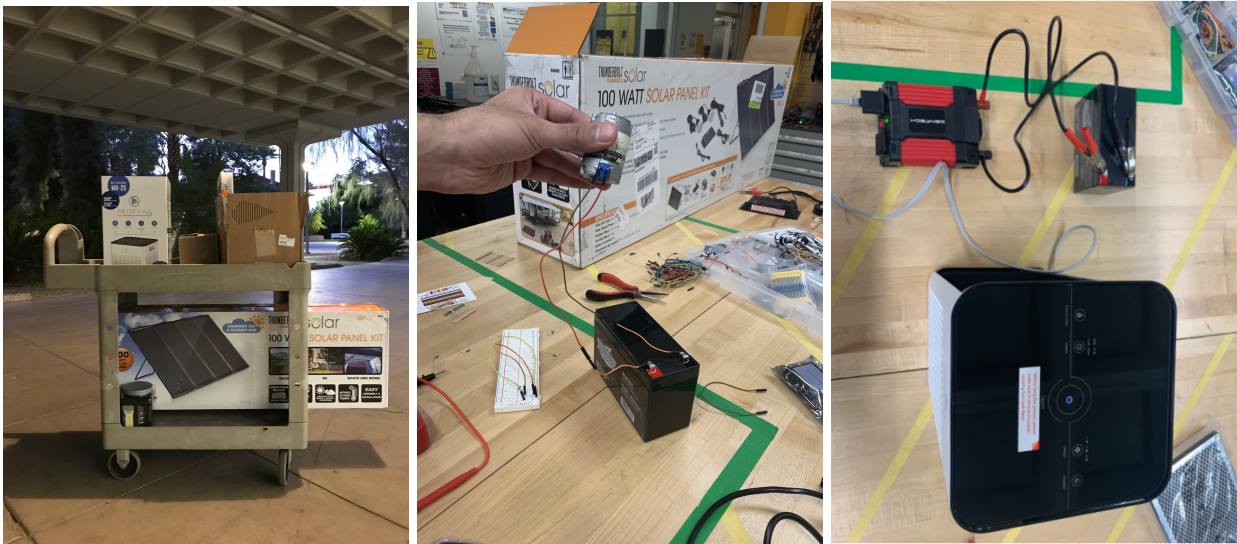
IV. Conceptual Design

The team began prototyping, to the end of answering the filtration test questions listed above, during the fall semester of 2020, after having the following budget items approved. This budget was submitted on Sept. 24th 2020, and after a month of waiting for necessary items to arrive, the team convened for a rapid prototyping session on November 4th. Unfortunately, the AQI sensor requested in the budget was never received, thus hindering prototyping. It had been the team's goal to complete testing before the end of the year, and, ideally, sent the first prototype to TFCF in Ulaanbaatar. While this did set back plans to address the second test question, by the date of the team's prototyping session, all necessary components had arrived to address the first test question, that of the autonomous power system.

Item	Quantity	Price per unit	Total price
Modify MA-25 W1 Medical Grade Filtration H13 True HEPA for 500 Sq. Ft. Air Purifier Dual Air Intake Two '3-in-1' Filters 99.9% Removal in a Modern Design - White	1	\$160.00	\$160.00
Interstate Batteries 12V SLA1075 General Purpose Battery	2	\$24.99	\$49.98
400 Watt Continuous/800 Watt Peak Modified Sine Wave Power Inverter	2	\$32.99	\$65.98
6 Ft. Inverter Cable Set - #2 AWG	1	\$34.99	\$34.99
100 Watt Solar Panel Kit	2	\$189.99	\$379.98

PM1.0 PM2.5 PM10 Detector Module Air Quality Dust Sensor	1	\$29.99	\$29.99
Total			\$755.08 (720.92 + 34.16 Tax)

In order to address the first test question, the various components of the system first needed to be proven to run off standard power sourcing, as a control. If the components were faulty to begin with, the first test question would yield a false negative result. After the fidelity of each component was established, the plan was to hook up the air filter to the battery, via the inverter, to ensure the system ran on battery power alone. This too was completed fairly quickly. The final step to be taken during the prototyping session was to discharge the battery, for the battery arrived fully charged. In order to affirm the batteries' ability to power the system purely on solar energy, the initial charge of the battery needed to be expended, and then recharged off the solar system. This was achieved by attaching a motor to the battery and affixing a long and heavy object therein. The idea was to draw maximal torque by stalling the motor. Despite this, the set up took several hours to drain the battery, and so was conducted the following day.



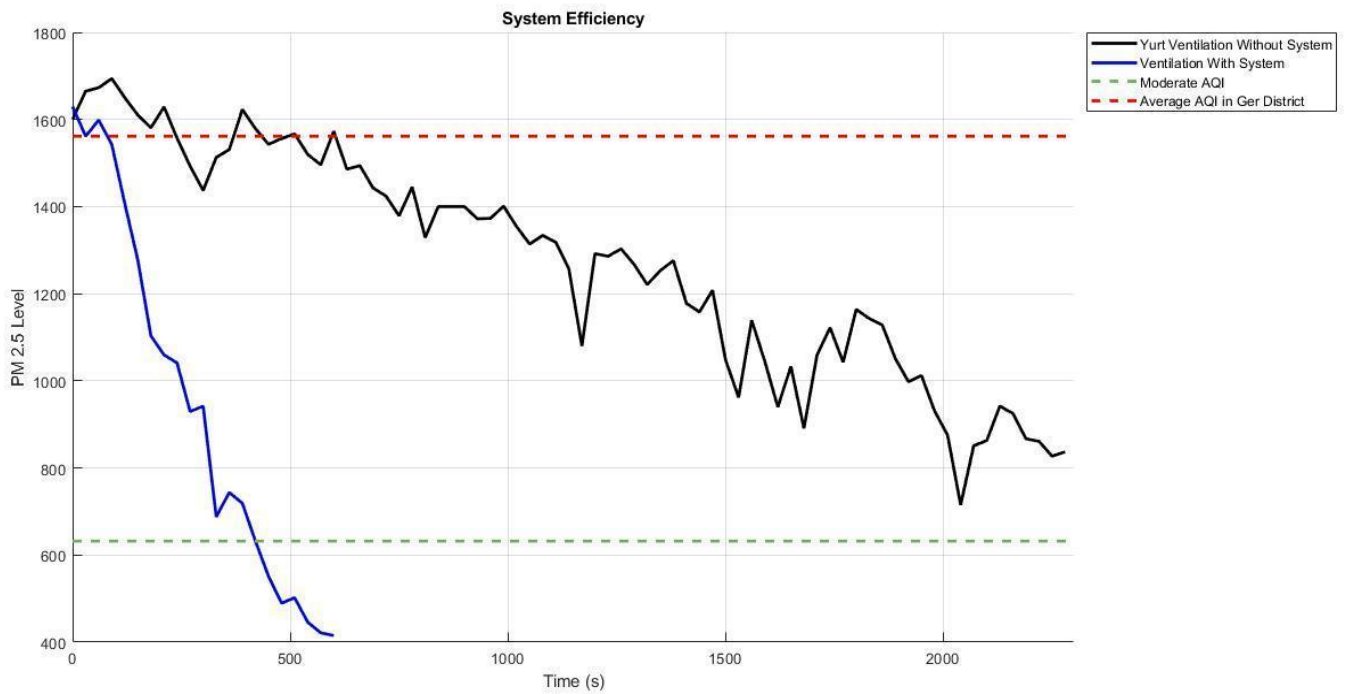
Thus, the last step in answering the first test question was to recharge the battery using the solar panels. As this needed to be done over a long period of sunshine, the recharging was done leading up to the team meeting following the prototyping session. The recharging process was conducted with a solar panel connected to the battery, via the charge controller, and monitored with a digital multimeter. So, it was seen that the solar panel successfully recharged the battery, thus positively answering testing question #1.



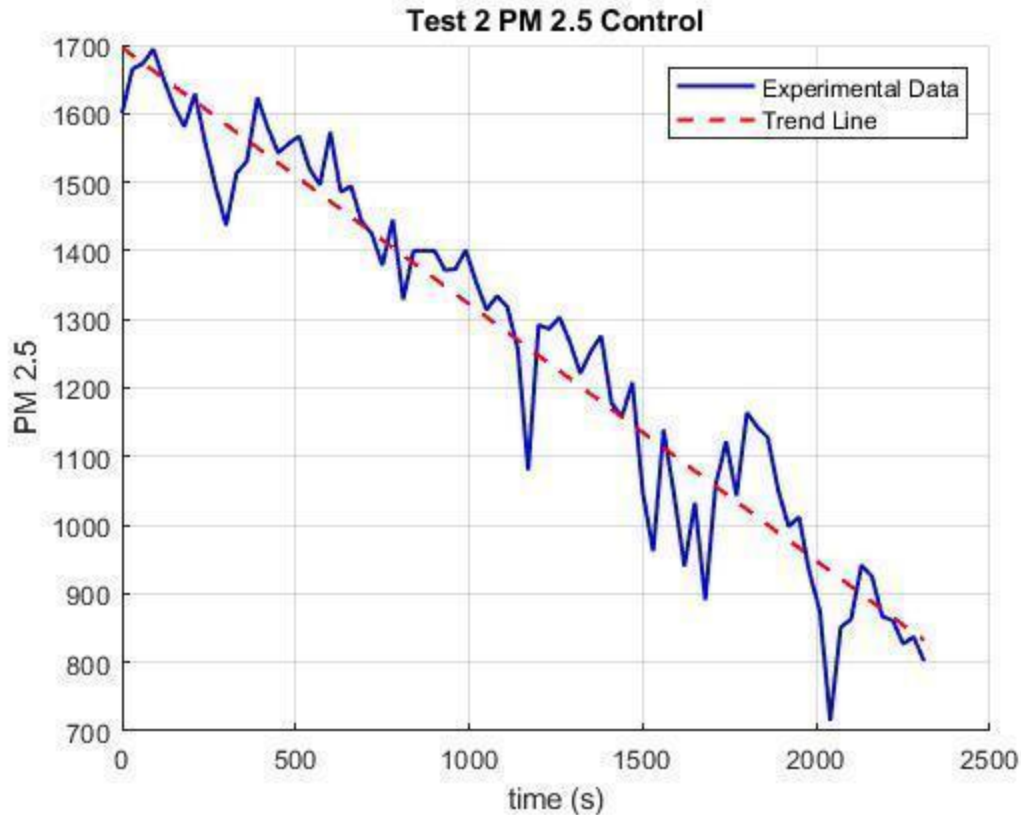
In order to test research question #2, a control volume which the team would be allowed to intentionally pollute would need to be found. The shed in the backyard of one team member was determined to be an adequate analog. The shed was prepared for the test by blocking all the ventilation of the system except for a single outlet, as reflected in the crown of the Ger. In using the shed as a control volume, the concern of accuracy as a model was raised. Research yielded no meaningful results for testing parameter equating, other than that used for standard flows, namely Reynolds number. In equating the Reynolds numbers of the two systems, the velocity of the pollutant flow had to be assumed to be negligible, given the inverse relation between subsonic flows and cross sectional area; at the scale of a dwelling, the Reynolds number equation yields a factor in the form of the ratio of the volumes of the shed and ger.

The testing done to initially address the filtration 2nd testing parameter was conducted throughout the spring semester of 2021, using the items listed in the above budget, in addition to a subsequent purchase of the same model of AQI sensor, purchased, and received, from a separate vendor. The pollutant used for testing emanated from a meat smoker. The first test was conducted with the smoker sealed in the shed and ran for twenty minutes. Thereafter, the AQI sensor reading was taken, the smoker was turned off and the autonomously powered air filter was switched on. The change in AQI was recorded at 30 second intervals, ultimately returning to below 50. The second test was conducted in the same manner, but while keeping the smoker and air filter on simultaneously. The PM 2.5 count was recorded every 30 seconds during test #2. The third test was used as a control, in which the smoker was run, to an AQI of 500 and a PM 2.5 count of 1600, and then the system was observed without the filter. Data points of PM 2.5 and AQI were taken every 30 seconds

In result, the first test revealed that as the filter stayed on in the shed, it reduced the air quality to normal levels within 20 minutes. This is great for the case in which the people of Ulaanbaatar may decide to turn down the heat, the air filter works perfectly in terms of bringing the air quality to a normal state.



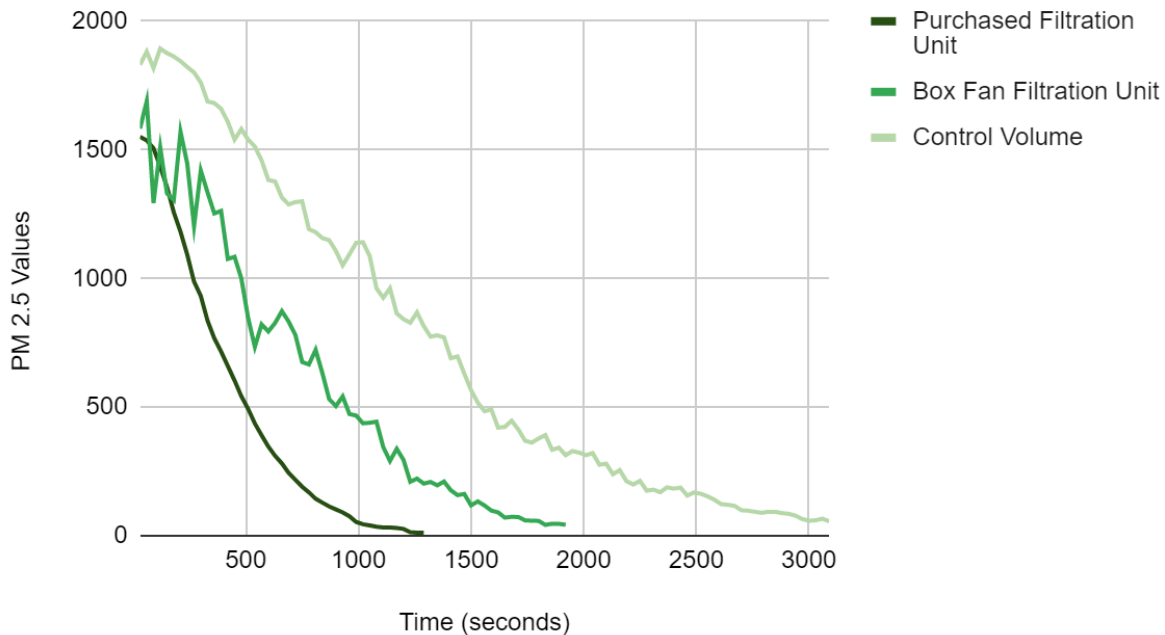
In the second test however, through the 20 minute time frame, air quality did not decrease to a healthy state. This meant that there might be an error with the quality of material we are burning, to the comparison of how much this air is actually being let out compared to the coal furnaces in the yurts. In the third test, this showed that over the span of 20 minutes, the shed kept the air quality at a high, meaning that the control of the shed, the smoker, and the air quality sensor functioned properly and could not cause any outliers within our data. While the team was not able to find an analytical relation between PM 2.5 and AQI, by recording both values as decreasing functions of time, a conversion factor was numerically determined. Using this factor, it was revealed that the use of the system improved air quality six times faster than without it.



Note that the above figure is representative of the control test, above referred to as test #3

Concern was raised regarding the usage of a prefabricated air filtration unit, due to its complexity and its lack of local support. For this reason, prototyping was continued into the fall semester of 2021, with the aim of testing a simpler, team designed filtration unit, validating the testing results from the spring semester, and starting the insulation testing. The team began by conducting the validation testing on the MA-25 air filter, by reconducting the testing done in the spring semester several times. The result of this exercise, as depicted below, verifies the fidelity of the system. Thereafter, the team constructed a simplified filtration unit using activated carbon filter sheets attached to a box fan. The plot listed below shows the performance of the team-built filtration unit. This data will advise further deployment decisions.

Testing Comparison



The team sent their initial prototype to the TFCF office in Ulaanbaatar at the end of the spring semester of 2021. Due to shipping delays caused by Covid, the shipment took an exorbitant amount of time to arrive. In addition, due to differences in policy additional fees were levied on the packages upon their arrival. As a result of all these delays, TFCF only got the product in hand in September of 2021. Directly thereafter, the team's contact at TFCF contracted Covid, and the team lead also separately contracted Covid, further delaying the deployment of the initial prototype. On November 17th 2021, the team had a zoom call with TFCF where data collection and system deployment were discussed. The team is currently awaiting initial results from this system deployment.

V. Appendix

A. References

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