Title
Pandemic Cinema (Team 2)

Authors
Kang, Calvin
Sharma, Karan
Lin, Claire
et al.

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Team 2:
Pandemic Cinema

Team Members: Diego Alcalde, David Lopez Castro, Samuel Deans, Chad Hemmig, Ethan Higgins, Calvin Kang, Harnoor Lal, Claire Lin, Xuanyi Lin, Kristina McKee, Crystal Militante, TJ Morse, Jose Puyat, Karan Sharma, Nayeli Vallecillo, Lingyi Wu

Table of Contents

Design Prompt

With the sudden rise in COVID cases, there has been a sharp drop of people going to movie theatres to enjoy movies. Not only has this hurt the film industry, but has also taken a toll on the American public because of many businesses closing. The overall goal of this project is to design an integrated system to create a safe environment for people inside movie theatres during the pandemic, and to create a model for other businesses to follow so they can stay open. Our priorities include the **safety and health of the public**, and to help **save businesses and jobs**.

Overview

As we begin to return to normal daily life, movie theaters are a place of concern. Movie theatres will need **investment in infrastructure** to handle the effects of the COVID pandemic for **years to come**. The following designs describe possible engineering solutions to offer movie theaters and possibly other businesses guidance for re-opening.

Snac-Man:

Snac-Man is an **autonomous snack delivery system** for movie guests. This design can carry up to eight meals, where each meal can carry one large beverage, one large tub of popcorn, and several snacks. The utilization of modular shelves will allow concession stand workers to quickly swap out food compartments as soon as the device returns as well as to ease the process of sanitation and disinfection. A cylindrical design will help minimize any unwanted collisions with obstacles and corners.

Food compartments **isolate each meal** and **minimize the risk for contamination**. Automated sliding doors provide access to meal orders inside the bot in order to avoid hand-contact with Snac-Man. One of the design problems our team struggled with was to select the best wheel design. Our team came up with a total of three designs, all of which had their strengths and weaknesses. We learned to take advantage of commonly implemented designs known for their reliability and performance, and incorporate those into Snac Man's design.

MatControl:

Snac-Man is driven by an in-house system called **MatControl**. IR cameras in the theater room and various sensors on Snac-Man will track its position, destination, and each guest's seat. All computational work will be done on a local server that coordinates all the robots on site via Wi-Fi. The MatControl system is designed to locally compute and house information to guard guests' privacy. Minimal cameras and sensors are used to keep costs low and make installation easy. MatControl is not intended to fundamentally change the theater experience, but **to complement theaters** to adapt to COVID requirements and **be easily used by guests and employees**. One thing we learned from designing this system was the amount of prototype testing and data needed for algorithm design.

Covid Web:

The SARS-CoV-2 virus, commonly known as COVID-19, is a **respiratory disease**. Public health and government officials have requested people to wear a facial covering when interacting with others. This is done to **minimize the amount of airborne particles** and decrease the possibility of transmission. However, the transition to wearing a mask for everyday activities has been difficult for many due to the discomfort while wearing them, which poses a threat to others as it can result in the transmission of the virus. In order to combat this, many public health officials suggest **increasing ventilation and using fresh air**. COVID transmission significantly decreases outdoors and with the use of a **proper air**

filtration system ("COVID-19 and Map, Ventilation) . Therefore, in order to design a safer indoor movie experience without the use of masks, **this ventilation system** is designed to simulate an outdoor environment by increasing airflow and using a vacuum filtration system to capture and filter out COVID particles from the surrounding air.

The biggest challenge in creating this design is using a ventilation system that **would not disturb the viewer** while they are watching the movie. A proper ventilation system would require the use of fans and vacuums that produce sound while operating. Another design challenge is to have a reasonable cost because COVID cases will eventually decrease with the distribution of vaccines, so this type of system may only be used temporarily. While it is important for companies to invest in equipment that will protect the health of its customers, it's also important to recognize this form of ventilation **may not be necessary** in five years.

Biomimetic Theater:

This design implements a **radiatively cooled lobby** by placing open windows at the top of the building to allow air to escape. This works using a natural phenomenon known as the **stack effect**. Warm air is less dense, thus it will rise and escape through the windows. This creates an area of low pressure at the base which draws in fresh cool air and naturally cools the building with **zero energy expenditure**. This effect is exacerbated by **fluorescent roof panels** that absorb heat from the sun and create a temperature differential to encourage air to rise. In order to remove heat from theater rooms, a **mechanical ventilation system** is used to draw fresh air from the rear of the theater and guide it to the center of the building. Additionally, **geothermal cooling** is used to further draw out heat from the smaller, enclosed theaters. Water will be pumped from underground pipes through the floor to remove heat. Because soil has a larger heat capacity than air, it can absorb a larger amount of thermal energy for the same change in temperature.

We take advantage of both concepts to ensure a comfortable cinema experience with **minimal energy usage and no harmful byproducts**.

Goal

- Lower the risk of COVID-19 transmission by reducing human contact
- Design a stable, transportation device that will autonomously deliver food orders to movie guests
- Maintain hygiene in and around the theater
- Reduce people's movement to reduce the risk of spreading COVID-19. People can interact with the app to choose what they want. The information sent out to the robot after checkout. The robot will find the items from the storage and take them to their seats.
- Design filtration system or device that efficiently captures the SARS-CoV-2 particles
- Create ventilation system and directed airflow to simulates an outdoor environment to lower the transmission rates of covid
- Present the design proposal of a two-story movie theater that does not depend on air conditioners or coolers for the overall ventilation or cooling of the building
- Make use of the natural environment surrounding the building and to use natural cooling mechanisms such as passive and radiative cooling whilst being mindful of cost-effectiveness

Objectives

- Design an autonomous robot to safely and efficiently deliver food orders in such a way that human to human interaction is decreased to prevent the transmission of COVID-19 as well as isolate food orders so that the risk of contamination is minimized.
- Decrease the transmission of COVID-19 without requiring the customers to wear any protective gear using air filtration and directed airflow
- Create a controller system and navigation management tool for a network of food delivery robots that can be easily implemented into existing movie theater locations.
- Develop a cooling system that makes use of environmental features and passive cooling to naturally cool the theater while avoiding the use of higher energy usage options like air conditioners.

Project Outline

This team's robot has a cylindrical body with two levels of interior shelves which are capable of rotating and holding four orders on each level. The robot will be controlled by the theater's server, and will also be connected to a mobile application which customers would be able to order from. A removable lid would allow the robot to be refilled with orders easily. A hand sanitizer dispenser is also attached to the robot for easy hand sanitation for customers.

The high level system consists of different components including security cameras, private cloud network and storage, and robots with different sensors including wheel sensors and 4 distance sensors. We are using different algorithms to communicate between private cloud storage and the robot itself. This includes binary occupancy images(image processing algorithm), optimal path (shortest path algorithm), robot position and Ack and Err codes. The robot has QR code on it for position identification. The security camera detects the QR image (Visual ID code) on the robot and the visual data is sent from the security camera to the private cloud and network storage. The system also incorporates intelligent algorithms such as machine learning algorithm(supervised learning and unsupervised learning algorithm) for detecting the images sent from the robot to the camera and the robot to the network and data storage.

Airflow in this movie theater is directed similarly to how airflow is directed inside of a hospital room, where the air vents will be above the customer because the aerosol particles that are breathed out in a reclined position will travel upwards, unlike the downwards direction that particles travel in when indoors (Thatiparti). Fans and pumping in recycled, filtered air will be sufficient to simulate the outdoor airflow in an indoor environment.

The filtering system will consist of a 3M filter, and two main filter cells. The main filter cells contain filters with a MERV rating of 14 and a 95% ASHRAE efficiency. This will be sufficient to filter the aerosol particles that the COVID particles travel on.

- Spaces 1-8: potential spaces for medium-sized theaters. Smaller spaces = easier to cool.
- Natural cooling / heat transferral via six design principles:

1. Natural Ventilation - Crosswind cooling carries the heat out.
2. Passive Cooling - Chimney effect / stack ventilation. The rest of the heat that isn't carried out in the glass tower rises.
3. Radiative Cooling - Fluorescent panels on the roof absorb heat during the day and help to combat further heating. The difference in temperature between the roof and the ceiling creates air flow in the

space between the ceiling and the roof.

Strong thermal insulation will stop conductive heat transfer from occurring between the inside of the theater and the atmosphere. The walls, roof and floor will have high R values to reduce the variance of temperature within the theater. Therefore, the insulation material acts as a passive way to cool/heat the building by lowering the energy demand for temperature control. Theaters will also incorporate a Mechanical Ventilation system with heat recovery and geothermal heat pump. The heat recovery system is an efficient way to heat the inside of the building when the outside air is cold. The geothermal heat pump will cool incoming hot air in summer months by transferring heat with cold water from the ground. There will also be a summer bypass within the ventilation system to prevent overheating. Additionally, the ventilation system will be bringing in fresh filtered air to minimize CO_2 and VOC build up within the theater.

Design Breakdown

SnackBot Committee

Snac-Man has a cylindrical body to allow for the interior shelves to rotate and serve different people their orders without confusion. With two shelves, each split into four sections, the Snac-Man can hold up to eight orders. The top of the Snac-Man acts as a lid, giving easy access to whomever will be refilling the orders, and the removable shelves make for easy cleaning as well. The interior and exterior shapes of the lid were chosen in order to allow for more storage for hand sanitizer and give the robot a softer, and friendlier appearance. The robot is about 31 inches tall and 30 inches wide and is estimated to weigh about 138.57 pounds.

It will connect to a mobile app so people can order from their own seat. The app will assign which compartment to add the order to and send that information to the concessions computers. Once filled with snacks, when Snac-Man gets to the correct seat, it will rotate to have the correct compartment facing outwards, dispense hand sanitizer, and open the door, allowing the person to grab their food. The customer is expected to grab their own food so there is no extra cleanup required after the movie is over, like there would be if the trays were removable for the customer.

All CAD models were done on Solidworks.

Fig. 1 Snackbot Design Assembly

Mechanical CAD Breakdown

Overall, Snac-Man has a cylindrical shape so that if it were to bump into anyone, it would not hurt them with any sharp corners. The trays inside have cup holders and each section can hold one drink and one large popcorn with extra space for smaller snacks like candy. The domed lid allows for storage of hand sanitizer and will connect to a spout that is just to the side of the top door. The positioning of the spout was chosen so that it would be hard to miss before reaching to grab the snacks inside, while not accidentally sanitizing the food.

The use of six, small wheels was chosen from taking inspiration from the small robots that used to roam around campus, delivering food to students. Those robots are able to maneuver themselves around obstacles pretty well and balance isn't an issue at all. With this design, we were able to make the body lower to the ground than with the original idea of using three larger wheels, and reduce the risk of tipping over if it were to go over a bump or accidentally get kicked. The contact area to the ground is also larger this way, so overall stability is increased.

Having tall partitions makes for no confusion as to which order is yours! This way, nobody will accidentally be touching or taking other people's food. This allows for a safer, more COVID-friendly way of enjoying the movie theater. In addition, having very small gaps between each section will reduce the amount of airflow through the compartments as well.

The central rod down the center of the entire robot spins both trays using only one motor. It will be programmed to move the correct compartment facing outwards for a luxurious snacking experience.

Fig.2: Exploded View Assembly

Assembly Drawings

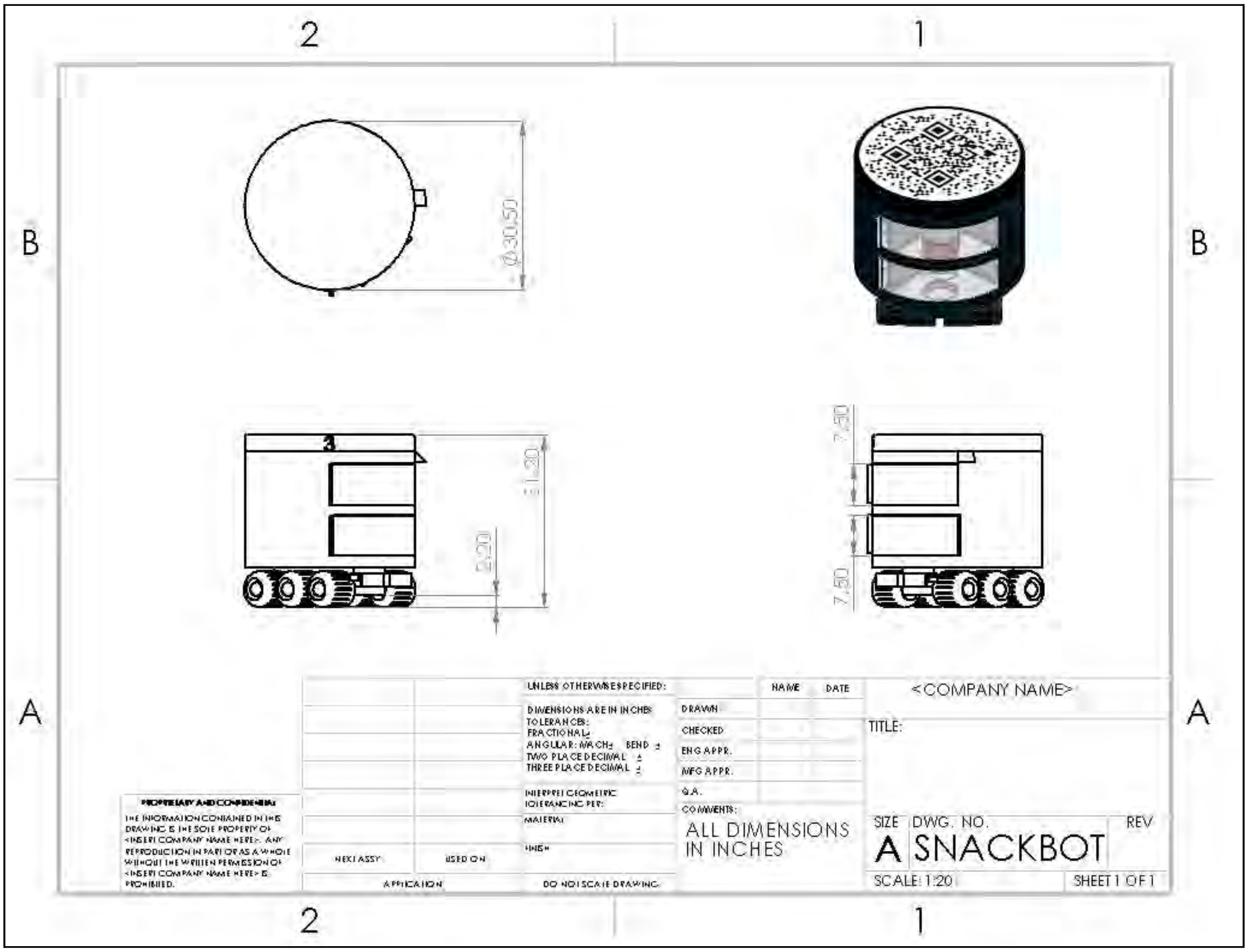
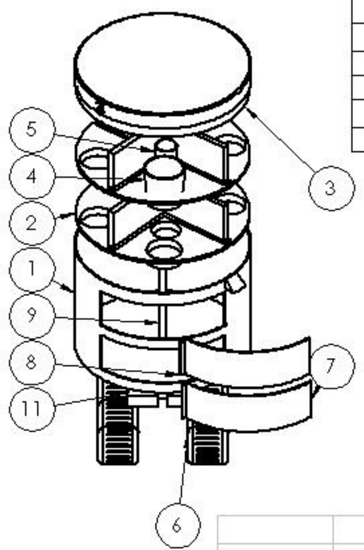


Fig. 3: Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Snackbot_Shell	Outer shell/main body of Snackbot	1
2	Removable_Tray		2
3	Snackbot_Lid	Lid with compartment for sanitizer	1
4	Popcorn_Tub	Model of large popcorn bucket	1
5	Soda_Cup	Model of large drink cup	1
6	zotbot.wheel		6
7	Snackbot_Door		2
8	Snackbot_Handle	Door Handles for manual opening	2
9	AxleRod		1

<COMPANY NAME>

TITLE:

SIZE A DWG. NO. SNACKBOT EXPLODED REV

SCALE: 1:50 SHEET 1 OF 1

Fig. 4: Exploded View Drawing

Material Selection

We selected materials based on how these objectives are prioritized per component :

Affordability
Safety
Stability
Durability
Modularity
Manufacturability

We determined that Affordability, Safety, and Manufacturability are prioritized for the outer shell and removable lid, since it will cover the meals and electrical equipment; therefore we chose to use ABS plastic. It is a cheap, scratch-resistant material, with a low melting point, making it easy to manufacture with injection-molding.

The automated sliding doors that open the compartments carrying each meal will be made of polycarbonate plastic. We determined for this component we will need to prioritize Stability and Safety, since it will be subject to stresses exerted by motors as it opens and closes.

The design of each shelf/tray storing meals will prioritize, like the outer shell, Affordability, Safety, and Manufacturability. Therefore we decided to use ABS plastic and easily shape the trays using injection molding.

The axle that rotates each level to select the correct meal for the consumer is a critical component to the Snac-Man's function. This axle will frequently experience high stresses because it will carry the weight of each meal compartment and experience high torque. Therefore the axle's design needs to prioritize Durability, Stability, and Safety. We determined the best material to use is Stainless Steel because of its durability and high strength. Additionally, Stainless Steel will be able to handle any moisture from the meals within the robot because of its resistance to corrosion.

Analysis

Stress Analysis on Tray made of lightweight plastic if it were to hold 4 medium sized drinks. Max displacement (red) is only 0.05 mm.

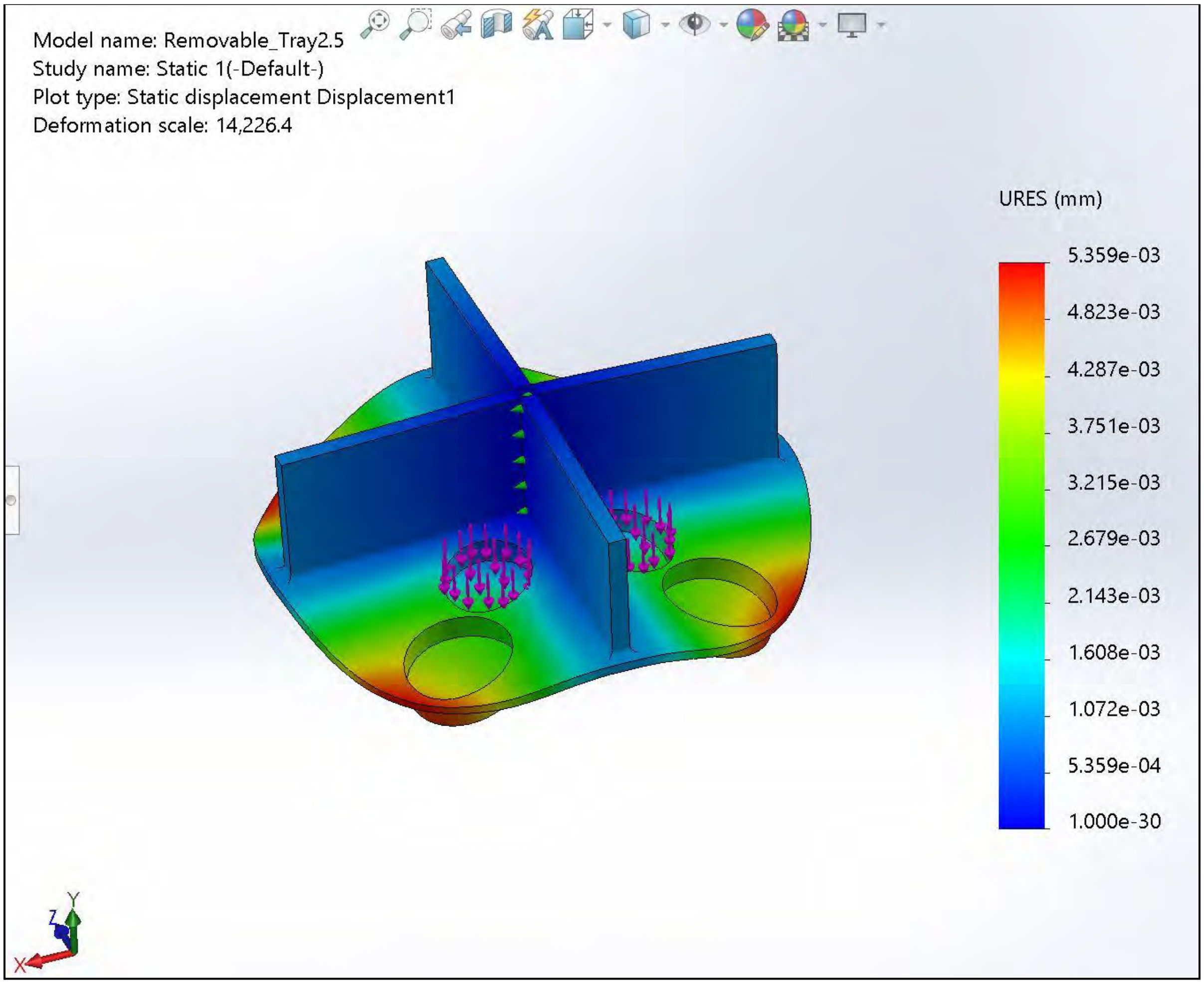
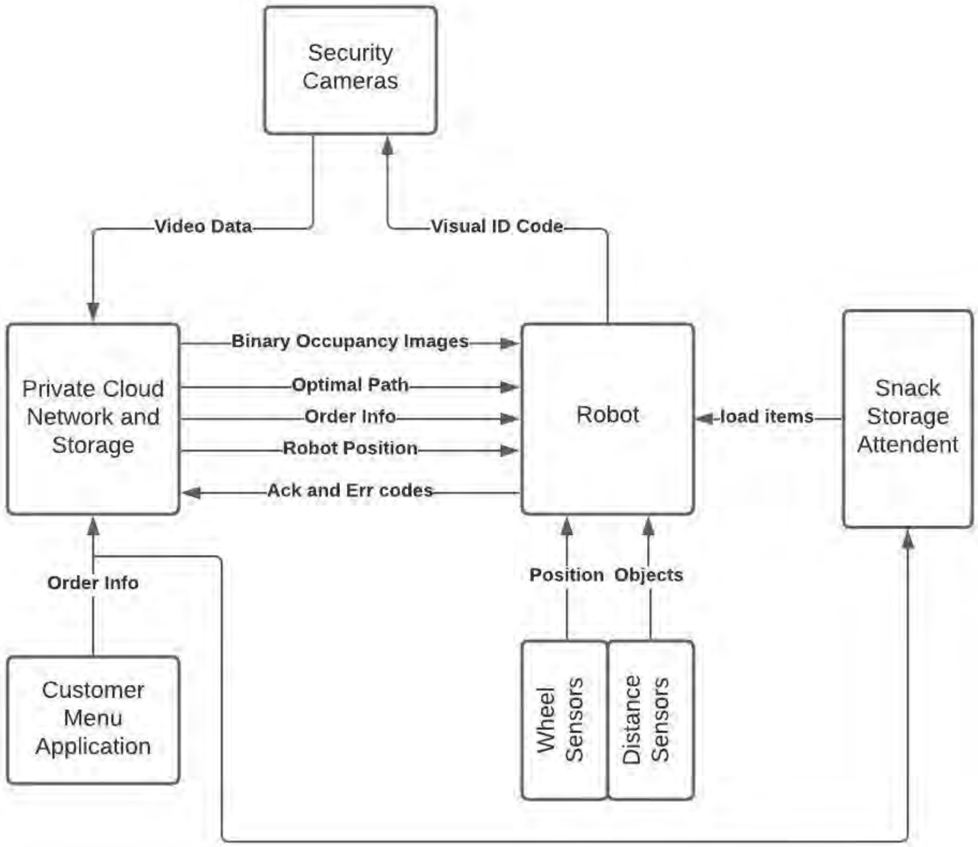
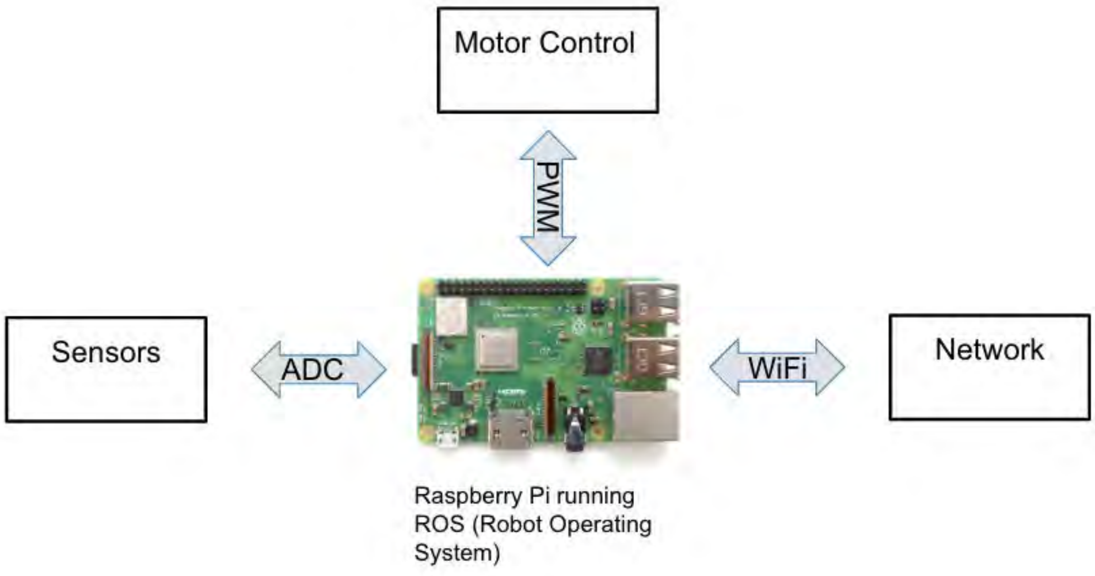


Fig. 5: Stress Analysis Showing Displacement

MatControl Committee





I/O Sensor Layer

Here is a list of sensors with descriptions.

1. Dome Security Camera - Multiple Dome Cameras mounted on the ceiling will take images from a birds-eye view. The Dome cameras send video data over to the network where the computer converts these images to binary to be used as Binary Occupancy Images (see below). It may be beneficial to use multiple cameras with the same field of view to implement stereo vision depth calculations. However, this will only be necessary as a redundant positioning method for the robot should it be needed.

2. Optical Wheel Sensor - An optical sensor on each robot wheel can track the robot's movement. Given an initial position and a coordinate map or wire-frame model of the environment, the robot can calculate its relative position. This initial position is given by the Binary Occupancy Image from the Dome Cameras. The robot is distinguishable in the binary occupancy image by a unique pattern (like a QR code)

stickered on top of the robot. The frequency of transmitted images may change depending on the data constraints of the network and possibly power constraints of the robot receiver, but 100ms/image is more than generous. Furthermore, the images being sent are not jpeg but binary occupancy images, requiring far less storage data.

3. Laser Range Sensor - We need an array of distance sensors to ensure the robot won't collide with people or objects. Three distance sensors are positioned on the front of the robot in the direction of movement. They are staggered across 90 degrees.

Peripherals

DC Motor for Wheels - High Torque DC motors will be controlled by PWM from the Raspberry PI. Feedback from optical sensors gives distance data.

Stepper Motor for snack tray - A stepper motor with a 15 degree step size will rotate the snack tray with enough precision to rotate the 45 degrees needed for the 8 compartment snack tray. Using a stepper motor means we do not need a feedback controller.

Wifi Antenna - For communication to the robot from the Network. This is embedded in the Raspberry Pi

Microcontroller

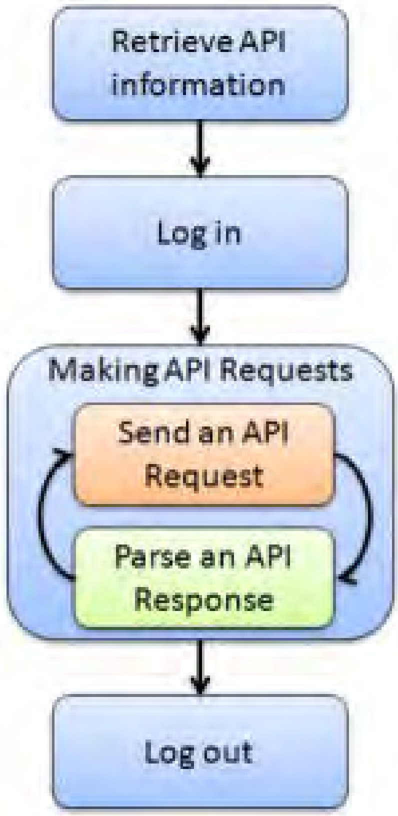
Raspberry Pi 4 - Raspberry Pi 4 has all of the required PWM, ADC and Wifi capabilities that we need for sensors and peripheral communication. Additionally, the Raspberry Pi 4 RTOS is capable of running ROS (Robot Operating System), which is a simple and fast method of sensor and motor control.

Data Storage Layer

The data received from apps and sent out to the apps are stored in the local network, since there is not a large number of people in the theatre at the same time. The system uses a Network Attached Storage (NAS) device called Synology DiskStation DS220j would be a good choice here to build a private cloud for storing and sharing the data. There is no need to care for the backup since it has the functionality. It provides convenience of apps on IOS or Android phones interacting with it anywhere and anytime in the theatre. The security is also ensured by many built in security tools.

Supervisory Layer

The Synology DiskStation DS220j comes with a supervisory UI and File Station APIs. Synology's DiskStation Manager OS (DSM) is a unified OS that makes managing data easy and intuitive. Here is a link to a demo. https://demo.synology.com/en-us/dsm m,o footage can also be viewed in real time for security surveillance. We can expand applications based on the APIs of File Station, which allows applications to interact with files in DSM via HTTP/HTTPS requests and responses.


Retrieve API information
Log in
Making API Requests
Send an API Request
Parse an API Response
Log out

COVID Web Committee

The following figure is an overview of the seating plan of the movie theater where there are four rows in which each group has four available seats. In between each row there is six feet of distance as recommended by the Center of Disease Control and Prevention agency. The spacing in between each group of people is twice the recommended amount to further assure moviegoers of their safety.

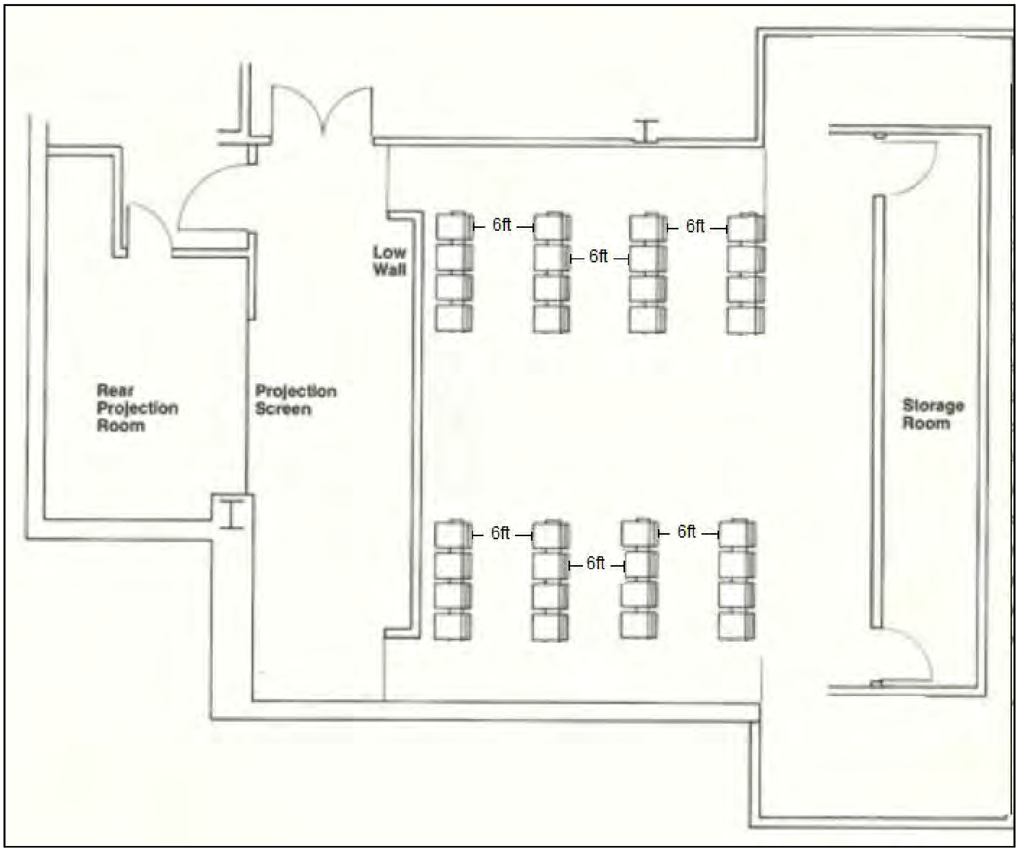


Figure 1: Seating Schematic of COVID-Free Movie Theater

Above each group a ventilation and filtration system will be installed that is composed of a duct fan and multiple filtration layers as seen in Figure 2 below. The filtration system entails three filters with the first being a pre-filter and the next two being more advanced filters.

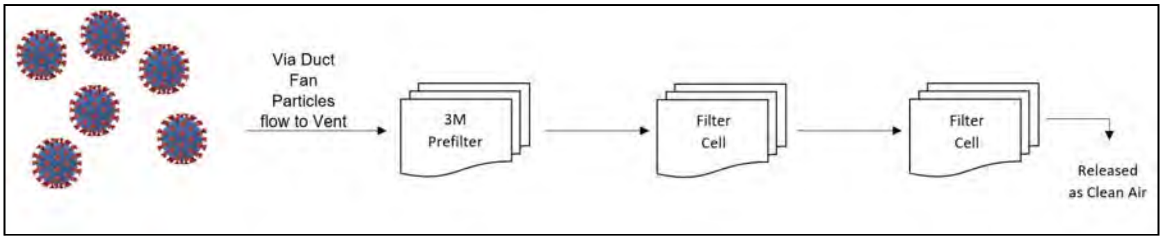


Figure 2: Overview of Filtration Device

The COVID particles are absorbed by Higher Power Supplies, Inc.'s Silent Mixed-Flow Turbo Duct Inline Fan which forces that air to travel to the filtration system. The air flows first into a 3M pre filter manufactured by Filtrete. The pre-filter has a MERV 14 rating and 81% efficiency of capturing bacteria thus will be the first point of contact against Covid particles. From there, the particles that make it through the pre-filter will encounter two layers of more advanced filters. These main filters are the SuperFlo Max and have a MERV rating of 14/15 as well as an ASHRAE rating of 95%.

Justification

This ventilation system implements ideas of ventilation and manipulation of air flows within hospital rooms, as well as external fans that would help increase airflow within the theater itself. Per personal observation of the group, it has been observed that a majority of moviegoers tilt their seat. Although it may seem trivial, this observation has played a key role in the design. A computational study done by the University of Cincinnati, revealed that at an angle of 30 degrees the majority of airborne particles expelled by a hospital patient travelled upwards (Thatiparti). Therefore the system was placed above each group. The Silent Mixed-Flow Turbo Duct Inline Fan was selected because it was noted by manufacturers as energy efficient and provided minimal noise that might disrupt the movie. A speed control is used to decrease the face velocity, or velocity at which the particles meet the filter. This is because literature has shown that increased face velocities decrease the efficiency of the filter (Leung). A 3 M pre-filter is used because it has the ability to capture large particles as well as some smaller ones. It has an 81% efficiency rating and an ASHRAE 52.2 rating. Standard ASHRAE rating 62.2 is acceptable for indoor air quality which is why addition filters are required. These additional filters come in the form of a SuperFlo Max filter cell which meets the aforementioned MERV and ASHRAE requirements of 14 and 95%. Two are used consecutively to ensure the air is COVID free.

Integration Designs

Biomimetic Cinema

In order for the geothermal heat pumps to properly regulate the temperatures in a theater, the COVID Web committee and the Biomimetic Cinema committee decided to keep the theaters at around 1000 square feet and 30 feet high. This is to allow enough space for groups of chairs to be spread out, while also ensuring that the heat pump does not consume too much energy regulating the temperatures for each theater. The COVID Web filters would be used on the geothermal heat pump for the ventilating air into the theater in order to remove any pollutants from the outdoor air. As a result, the filters used on the geothermal heat pumps will be replaced every three to six months

The Biomimetic Cinema Committee

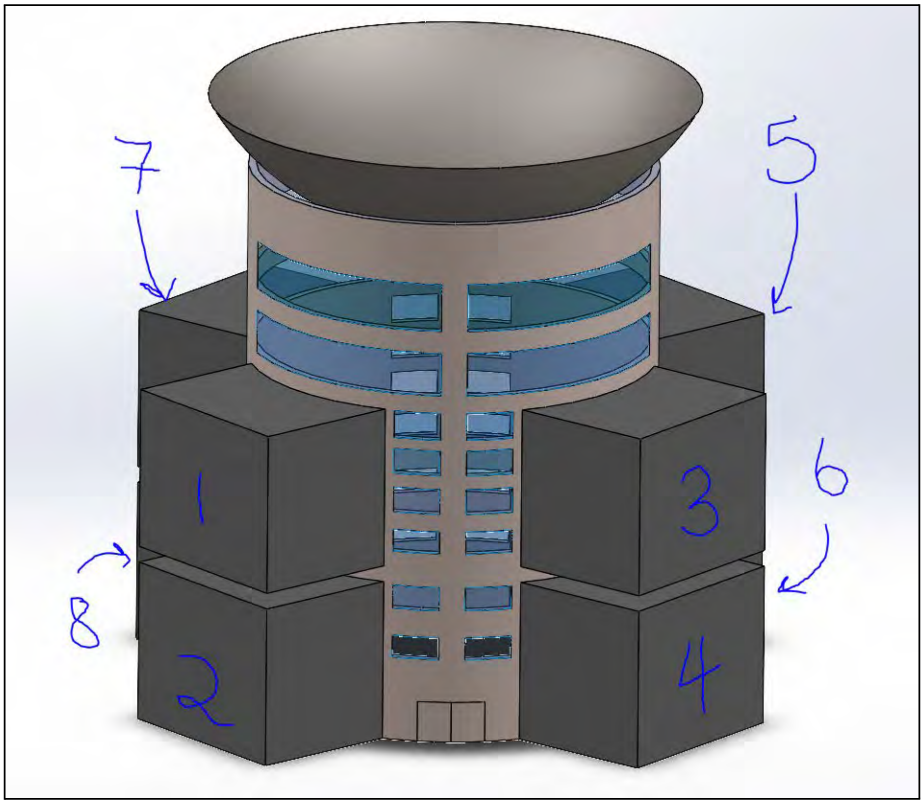


Figure 1: Full CAD Model with 1-8 labeled theatres

Each design is systematically inspired by natural occurrences or pre-existing building types, combined into one overall inclusive building design. All of these designs seek to provide energy-efficient methods of heat management without the use of air conditioning.

The first natural occurrence design that saves on both energy and space is the natural ventilation cross-wind phenomenon. This occurs when air moves across large spaces and pulls hotter air with it as the wind moves across a particular space. Additionally, this works more efficiently when there are open windows and spaces allowing for further airflow, ensuring that there is never stale air in the main system (the glass tower). The flow will, in general, follow the air from the hotter side, carried by the wind towards the inside of the building, and then out the other side. The spaces between the glass paneling on the tower will facilitate this airflow. This works especially well with moderate speed winds traveling in a single cardinal direction, which the glass tower building should be faced to accommodate this. Overall, this design is captured in Figure 2 (cross ventilation).

The second natural passive cooling design, also an inherent feature of the building, is the stack ventilation method. Between the shaped roof and the ceiling, there are spaces (escapements) to allow airflow. This air will flow in an upward direction towards the roof due to a temperature gradient with the roof being hot and the ceiling being cool. The air will continue flowing in this convective pattern because of the thermal buoyancy effect with the hot airlifting up to the top of the glass tower, out the escapements, and traveling towards the hotter radiative portion on the roof, which is then carried away by wind or the rising of the hot air. Following the principle of thermal buoyancy, there will always be airflow upwards in the glass tower regardless of actual wind flow perpendicular to the length of the tower. This overall design is captured in Figure 2 (stack ventilation) when airflows have considerably low velocity and the crosswind phenomenon does not dominate the design.

In addition to these two primary methods of natural ventilation, the tempered glass panes are also movable and coated to resist thermal conductivity and weather. During humid or rainy days, the glass windows can be sufficiently moved to reduce airflow by closing the gaps between the windows. Normally, however, this is not a major concern in buildings with spaced windows. The tempered glass will avoid any possible damages due to wind speed, and the coating will further support the inside of the glass tower remaining cool in the summer and warm in the winter. Thus, with moveable windows, the construction may be customized to fit the aspects of any environmental airflow model.

The third part of the inclusive design is radiative cooling fluorescent roofing panels. The fluorescent panels will absorb heat for a small period of time, and then emit an electromagnetic wavelength as it reaches an equilibrium temperature. The wavelength it emits will be engineered (based on the fluorescent material) to be within the infrared atmospheric window, which will selectively radiate the absorbed energy back out to the atmosphere. The effective heat transmission can be observed in Figure 3, where the heat is absorbed with a 70% radiation absorption ratio, and then at equilibrium temperature (during the emission stage) is emitted with a radiation absorption of only 15%. The temperature difference will cause a consistent airflow between the escapements on the sides of the ceiling towards the roof using the air that rises in the stack ventilation method. This method will therefore facilitate continued airflow while also dealing with direct thermal radiation from the sun on the roof of the building.

The fourth part of our design is to aid heat transfer within the theaters themselves. To do this, we propose running water piping beneath cool concrete on the base of the glass tower and up to the floors of the theaters, exchanging heat to the water and carrying the heat away to a heat sink under the cool concrete base floor of the glass tower.

COVID-19 decays the quickest in a warm and mildly humid environment. It is essential that the building considers these factors into the design while maintaining a low carbon footprint. To achieve optimal temperatures, the theaters will have an uninterrupted thermal envelope (R-value 40-80). Heat transfer in buildings occurs primarily through conduction between materials of the construction. Selecting materials with low thermal conductivity will significantly reduce the demand for heating and cooling. According to the Passive House Institute, high performance insulation can decrease the cooling/heating energy consumption by 90% (Feist). Since the variance in temperature within the theater is small, this will lower the risk of any condensation and mold in the building. Low variance in temperature will flatten the heating and cooling loads. Additionally, this solution is applicable to all climates. In winter heat will remain in the building. In summer the insulation will prevent the outside from heating up the building, thus increasing the demand for active cooling.

Mechanical Ventilation with heat recovery(MVHR) in conjunction with a geothermal heat pump will control the temperature and humidity in the building. Mechanical ventilation demands far less energy than typical air conditioning. The MVHR system will introduce fresh air and extract stale air. According to the EPA, a building needs 0.3-0.35 airchanges/h to reduce the risk of adverse health effects (EPA). Around 11.7 cfm/person of new supply air is optimal (Fesit). A recycle feed with a COVID Web will help increase the efficiency of keeping the air free of pollutants and viruses. In colder conditions, cold supply air and hot extracted air will pass through a heat exchange, thus heating the incoming air. In hotter climates there will be a summer bypass to prevent heating of incoming air. The incoming air will be cooled through a geothermal heat pump. This design is natural gas free and will only run off of small amounts of electricity. The MVHR system will reside in the storage room of the theater to provide easy filtration maintenance. A humidity recovery system can be implemented in dry/humid conditions. This will allow the building to control humidity around 40-60% relative humidity. Customers will enjoy a comfortable fresh, COVID-free air, as well as a comfortable temperature and humidity.

U-value benchmarks to reduce the heating/cooling demand 90%

- $U_{floor} \leq 35.2$ kBtu/(h ft^2 ℉)
- $U_{Wall\ Warm\ Climate} \leq 88$ kBtu/(h ft^2 ℉)
- $U_{Wall\ Hot/Cool\ Temperate} \leq 26.5$ kBtu/(h ft^2 ℉)
- $U_{Roof} \leq 17.6$ kBtu/(h ft^2 ℉)

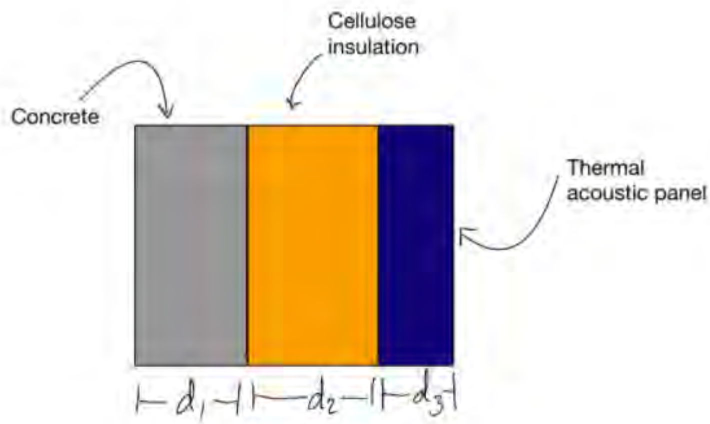


Figure 2: Thermal Envelope Materials

Insulation thickness calculation:

$$U = \frac{1}{R_T} = \frac{1}{R_{se} + \frac{d1}{\lambda_1} + \frac{d2}{\lambda_2} + \cdots + R_{si}}$$

*U-value for homogeneous construction

Surface Resistance	Direction of heat flow		
(m^2K / W)	Upwards	Horizontal	Downwards
Rsi	0.10	0.13	0.17
Rse	0.04	0.04	0.04

Assume:

Material	Thermal Conductivity λ	Distance d_i in meters
Reinforced concrete$_1$	2.3	0.0254
Insulation - Cellulose/Foam Glass$_2$	0.04	d_2
Thermal Accoustic$_3$	0.063	0.032

$$d_2 = \lambda_2[\frac{1}{U} - (R_{se} + R_{si} + \frac{d_1}{\lambda_1} + \frac{d_3}{\lambda_3})]$$

Wall Very hot/ Cool Temperate d_2 = **239 mm**

Wall Warm Climate d_2 = **52.44 mm**

Roof d_2 = **368 mm**

Floor d_2 = **149 mm**

Optimal Air supply flow: 11.7 cfm / person for a 36 person theater

11.7 cfm / person * 36 = **421.2 cfm**

Performance of MVHR = 0.01218 Wh/ft^3 ; Volume of 2 story theater = 10,000 ft

Energy required for MVHR= 121.8 Wh

Operation Cost of MVHR (running 24/7 at 19 cents an hour): $202.86 / year

According to the department of Energy, 40% of energy consumption in Commercial spaces go into heating and cooling. Average cost on utilities $2.10 sf/year (IOTA) which comes out to be $4,200 for a 2,000 sf building. With this design, the owner is paying 20 times less on utilities every year than the average 2,000 sf commercial property.

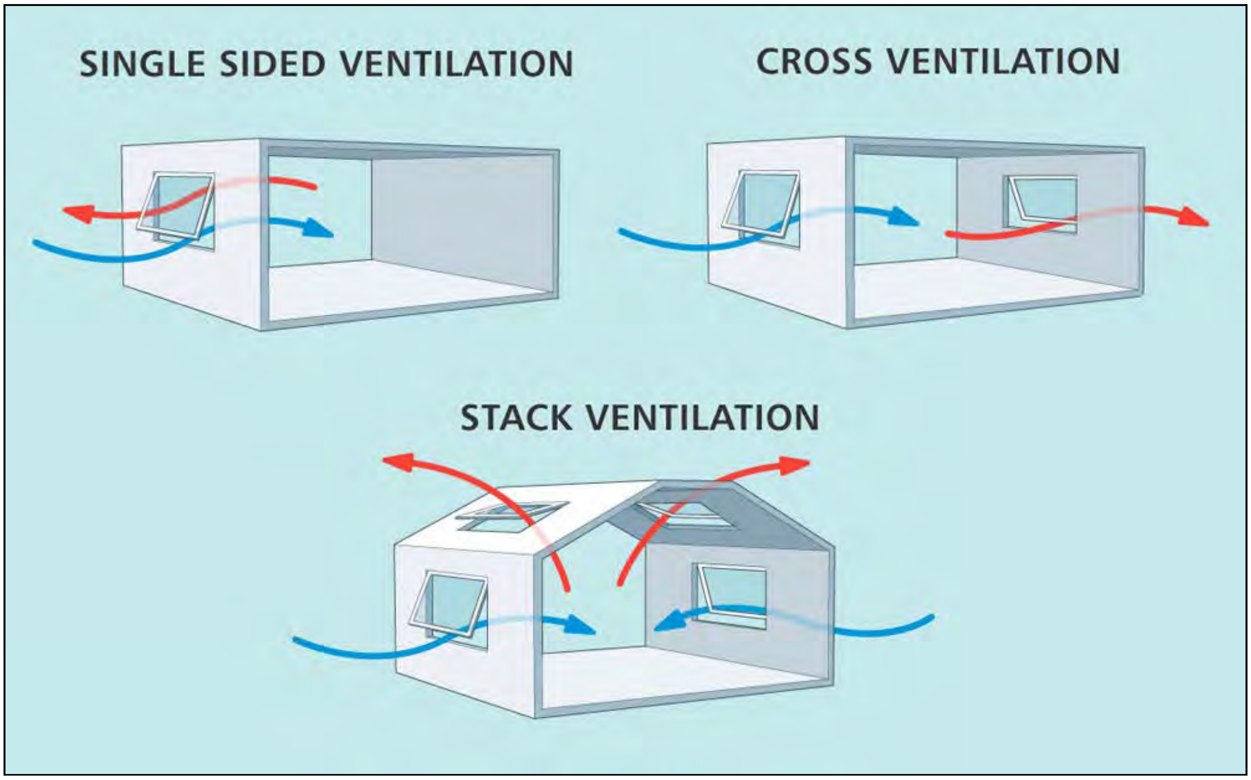


Figure 3: Ventilation Methods (*RODFORCT*)

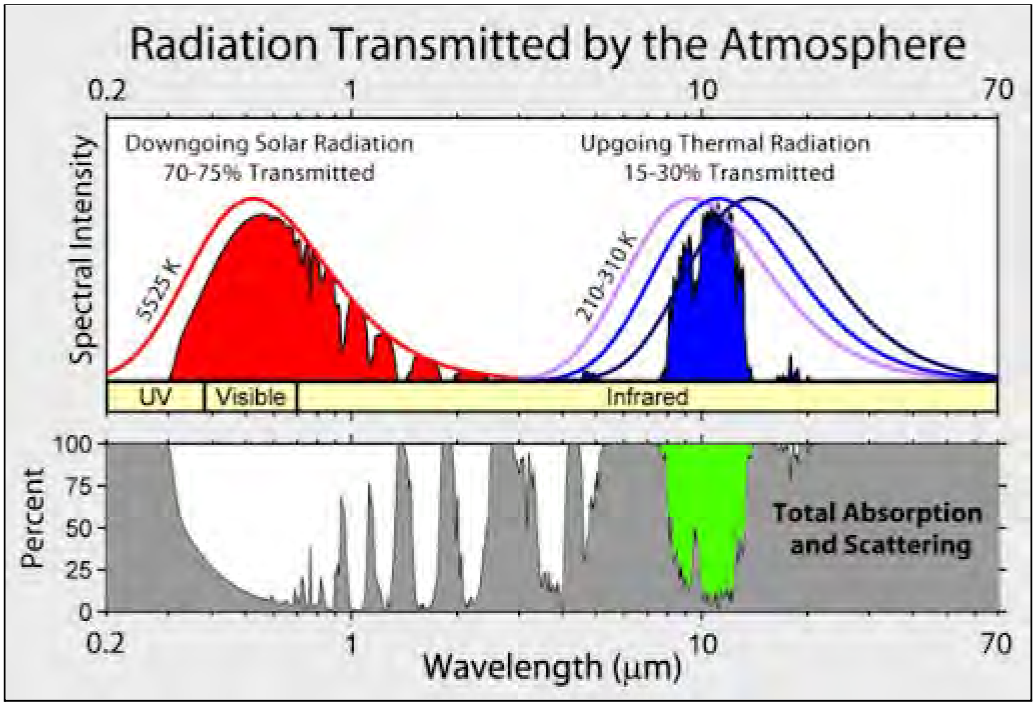


Figure 4: Radiative Cooling Wavelength Ranges (*Passive Radiative Cooling*)

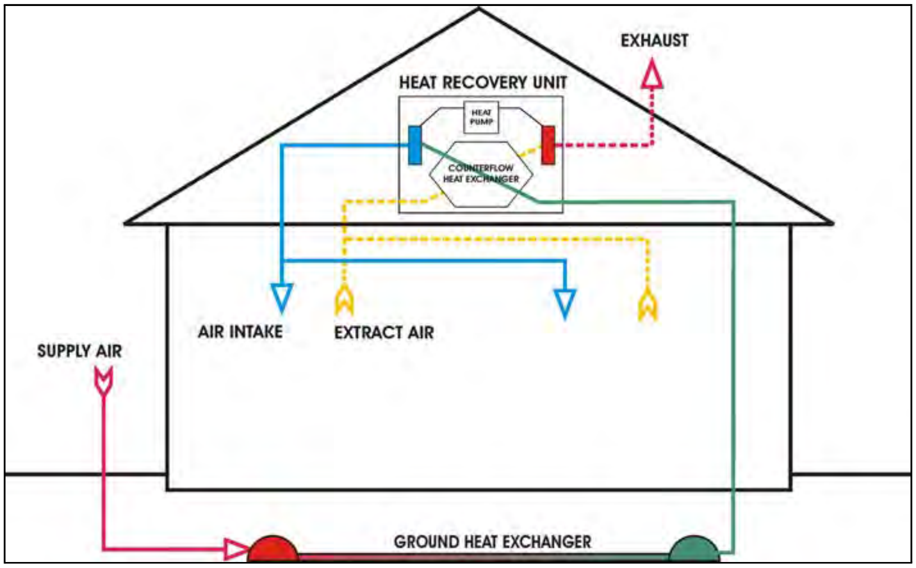


Figure 5: Mechanical Ventilation and Heat Recovery System

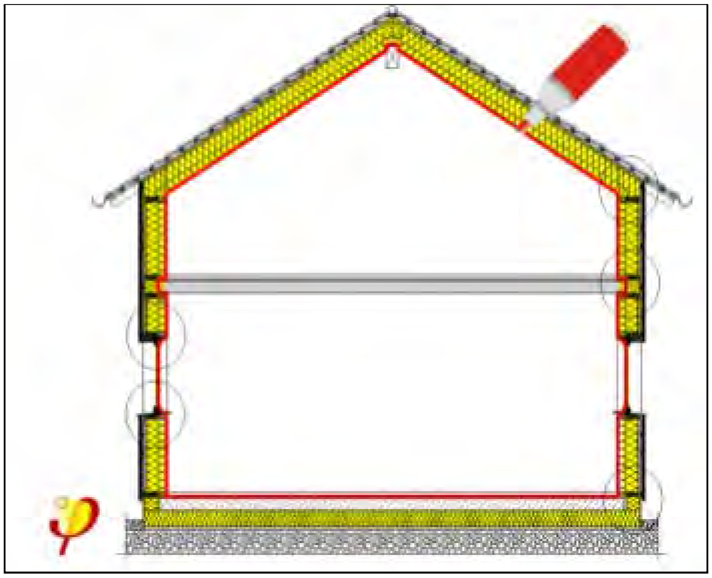


Figure 6: Continuous Thermal Envelope: Passive House Concept Developed by Wolfgang Feist

Figure 7: Strong vs Weak Thermal Envelope (Passivhaus Institut)

Snackbot Bill of Materials

Item	***Link***	***Manufacturer***	***Price per unit***	***Quantity***	***Total price***
ABS	ABS	OTS	**$2.00**	**70**	**$140**
Polycarbonate Plastic Sheet	Polycarb	OTS	**$129**	**1**	**$129.00**
Wheels	Wheels	OTS	**$16.67**	**6**	**$100**
Lithium Battery	Battery	OTS	**$99**	**1**	**$99**
Axles	Axles	OTS	**$24.17**	**4**	**$96.68**
Servo Motors	Continuous Servo	OTS	**$7.485**	**4**	**$29.94**
Hands Free Soap Dispenser	Soap Dispenser	OTS	**$24.99**	**1**	**$24.99**
High Torque Motor	Motor	OTS	**$17.09**	**3**	**$51.27**
LED Bulbs	LED Bulbs	OTS	**$0.0655**	**4**	**$0.26**
Wire Spools	Wire Spools	OTS	**$4.95**	**4**	**$19.80**
Rubber Gaskets	Rubber Gaskets	OTS	**$9.98**	**1**	**$9.98**
Grand Total:	**$ 700.92**				

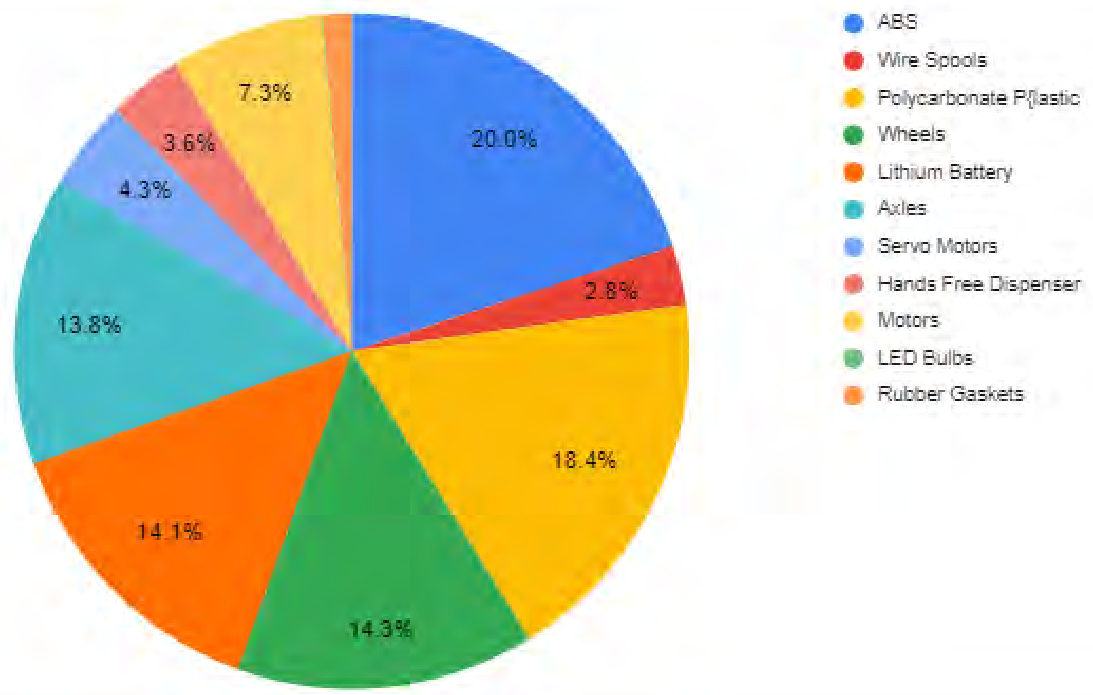
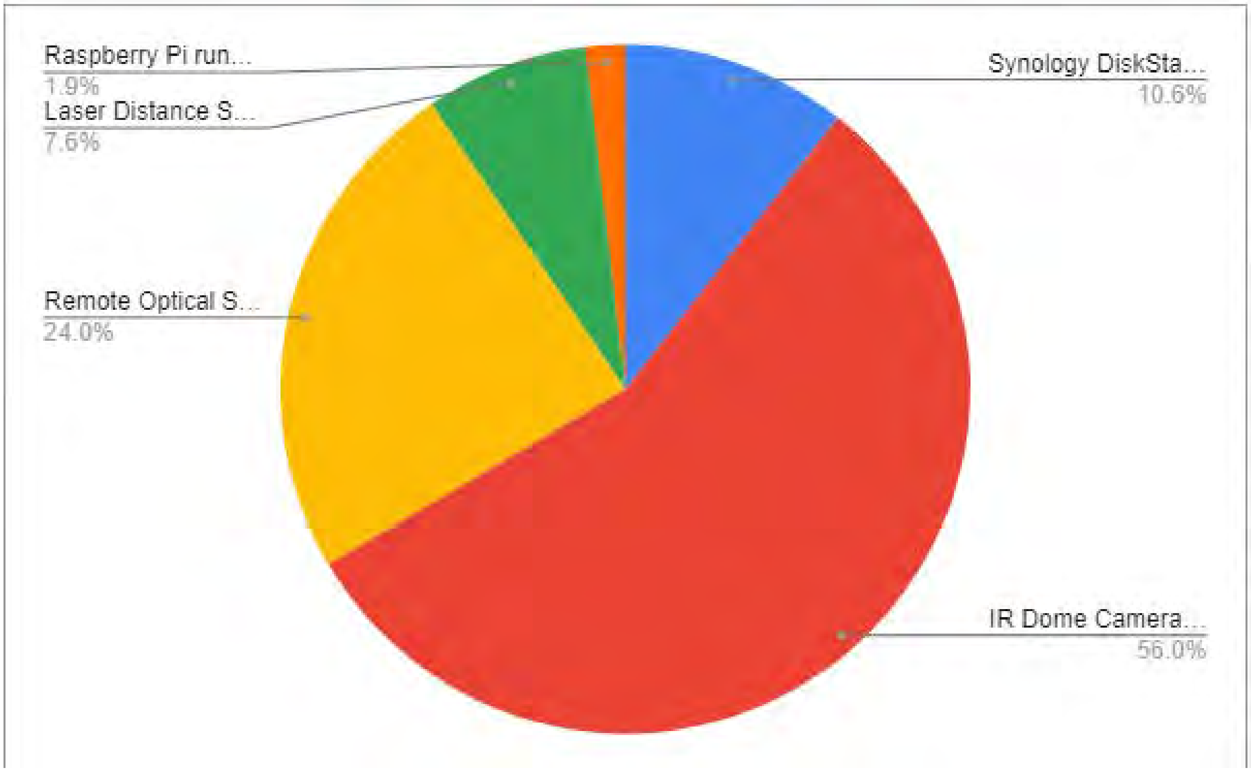


Fig. 6: Materials Cost Distribution

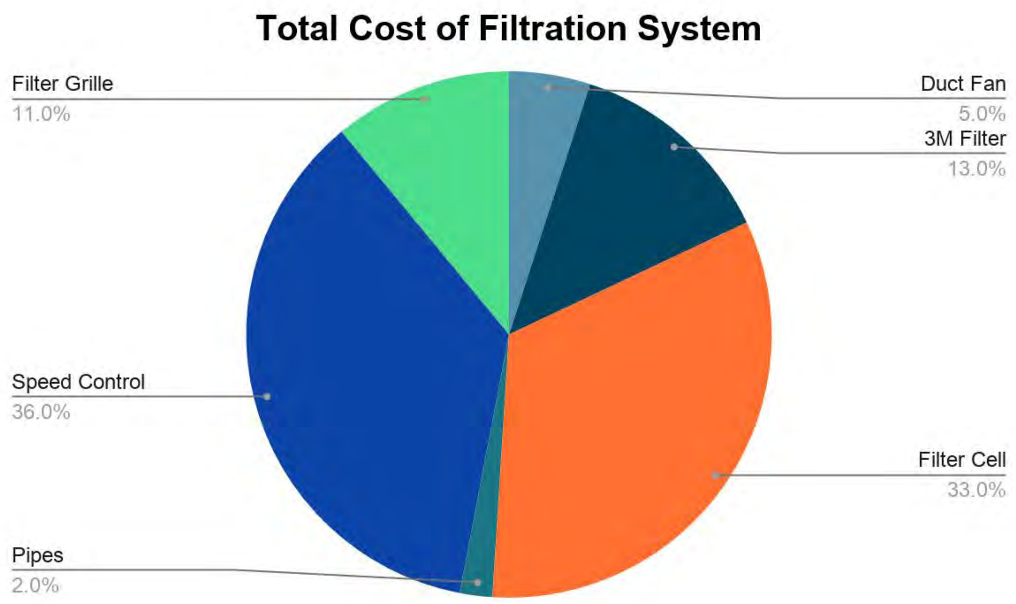
MatControl Bill of Materials

item	Description	Link	Manufacturer	Price per unit	Quantity	Total price
Synology DiskStation DS220j	*private cloud*	*link*	*Synology*	*169.99*	*1*	*169.99*
IR Dome Camera 1080p	*Dome Camera*	*link*	*Monoprice*	*29.99*	*30*	*900.00*
Remote Optical Sensors	*optical sensors measure robot wheels movement*	*link*	*Monarch*	*192.78*	*2*	*385.56*
Laser Distance Sensors	*Laser distance sensor*	*link*	*AutomationDirect*	*41.00*	*3*	*123.00*
Raspberry Pi running ROS	*Robot Operating System*	*link*	*Raspberry*	*30*	*1*	*30.00*
DC Step Motor	*Tray Controller*	*link*	*DigiKey*	*1*	*1*	*26.25*
Grand Total:	1634.80					


Raspberry Pi run...
1.9%
Laser Distance S...
7.6%
Remote Optical S...
24.0%
Synology DiskSta...
10.6%
IR Dome Camera...
56.0%

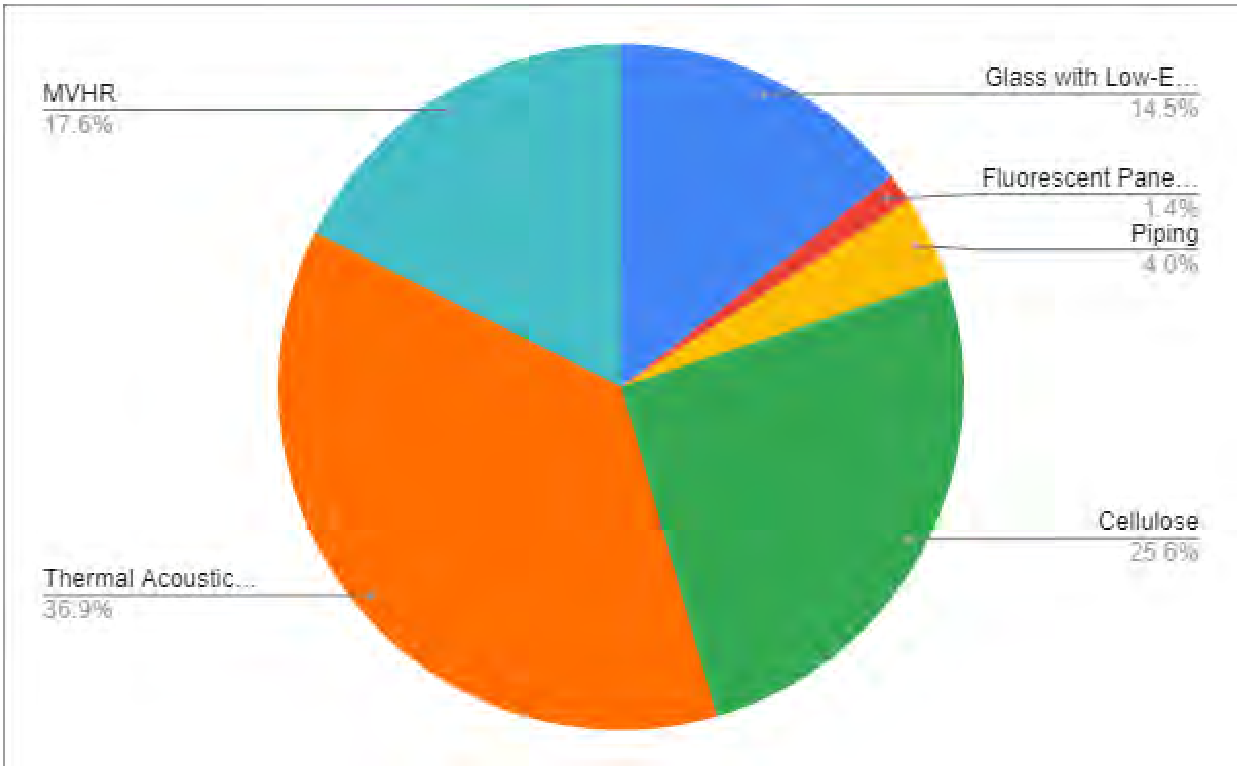
COVID Web Bill of Materials

Item	*Description*	*Link*	*Manufacturer*	*Price per unit*	*Quantity*	*Total price*
TT Silent Mixed-Flow 2 Speed Turbo Duct Inline Fan 4 inch 146 CFM TT Silent 100	Particle Absorption	Link	Higher Power Supplies, Inc.	$98.30	8	$786.40
2 Speed Manual Control 4Switch 115V TS-15	Control Speed on particle intake	Link	Canarm	$25.50	4	$102.00
Filtrete 14x20x1, Air Filter, 2-Pack	Particle reduction, 14 MERV Prefilter	Link	Filtrete	$54.01	5	$270.05
20x20x1, Metal cell mini pleat	95% Ashrae, 14 Merv	Link	SuperFlo Max	$44.47	16	$711.52
FASTPIPE 7ft 6in Aluminum Pipe	Airflow pipes	Link	RapidAir Products	$18.89	2	$37.78
Ferguson 20x20 White steel filter grille	Filter Grille	Link	Ferguson	$28.16	8	$225.28
Grand Total:	$2,133.03					


Total Cost of Filtration System
Filter Grille
11.0%
Duct Fan
5.0%
3M Filter
13.0%
Speed Control
36.0%
Filter Cell
33.0%
Pipes
2.0%

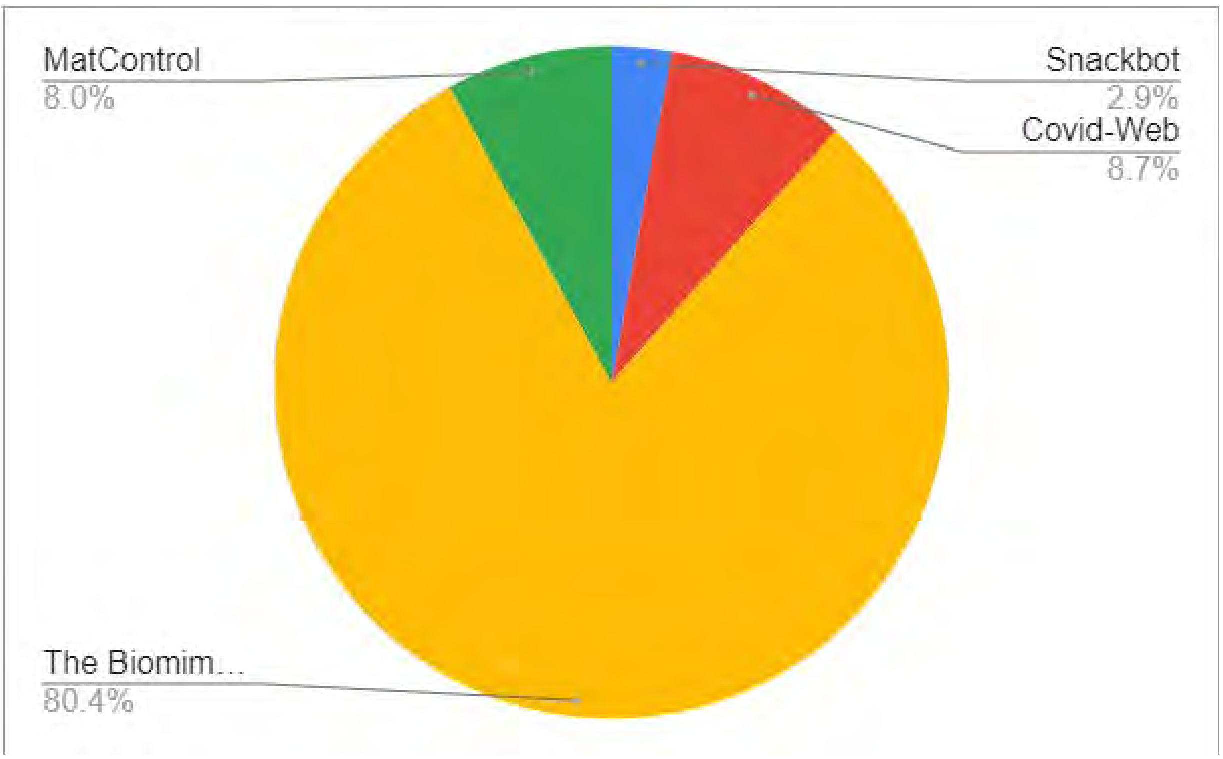
Biomimetic Cinema Bill of Materials

Item	*Description*	*Link*	*Manufacturer*	*Price per unit*	*Quantity*	*Total price*
Glass with Low-E Coating	*Low-E Coating, Tempered, Glass Pane*	*Link*	*Fab Glass and Mirror*	*$82 (24x16 1' ¼" thickness)* *$110 (80x30 1' ¼" thickness)*	*24* *8*	*$2,848*
Fluorescent Paneling	*Duralens*	*Link*	*Emco Industrial Plastics, Inc.*	*$13.48 (47.75x23.75 0.063" thickness)*	*20*	*$269.8*
Piping	*Galvanized Steel Coating*	*Link*	*Spiral Manufacturing*	*$99.33 (10' diameter)*	*8*	*$794.64*
Cellulose	*Insulation*	*Link*	*Green fiber*	*$2.52 per sf*	*2000 sf*	*$5,040*
Thermal Acoustic Panels	*Theater Room Material*	*Roof* *Wall* *Floor*	*Eterno Ivica SRL* *Eterno Ivica SRL* *Celenit*	*$25.94 48" x YD*	*280 sf*	*$7,263*
MVHR	*Mechanical Ventilation and Heat Recovery with Geothermal Heat pump*	*Link*	*VentacitySystems*	*$3,459*	*1*	*$3,459*
Grand Total:	**$19,676.44**					


MVHR
17.6%
Glass with Low-E...
14.5%
Fluorescent Pane...
1.4%
Piping
4.0%
Cellulose
25.6%
Thermal Acoustic...
36.9%

Proposed Theater Bill of Material

Sub-Committees	Price
Snackbot	$ 700.92
Covid-Web	$2,133.03
The Biomimetic Cinema	$19,676.44
MatControl	$1,948.75
Total Cost of Theater	$24,373.14



Conclusion

As stated previously, the COVID-19 pandemic has had a large impact on American industries, causing nation-wide shutdowns, resulting in heavy losses in revenue and jobs. Pandemic Cinemas worked together to determine an engineering solution for movie theaters to stay open during the pandemic.

The Snac-Man design meets the requirements specified by our team. Sectioned compartments will allow the device to carry up to a maximum of eight orders and allow for a fast turnaround time at the concession stands in the event of a large influx of food orders. A total height of 31 inches will allow our device to stay within the height constraint and not disturb people while they are watching the movie. The use of differential steering for our device, allows for precise maneuvering within the theater room. A circular design will help our device to navigate through obstacles that may exist in its path. The system that drives Snac-Man is a simple, yet effective design. The application (a theater) is a static environment wherein the shortest path can be easily determined and encoded into the robot to cover all scenarios. Similar applications include but are not limited to office environments, classrooms, or warehouses.

With the introduction of multiple filters and an incline fan, this will reduce the travel of COVID-19 molecules and ultimately create a safe environment for people attending the movie theater. Our goal is to simulate an outdoor environment while being in an enclosed space. Following the requirements, every product used is in par with the objectives that have been set such as having a MERV rating of 14 or higher, an ashrae rating of 95%, low-cost, and fans that will allow the audience to watch the movie comfortably. The overall design of the cinema will include ramps used inside of the cinema will make the theater both wheelchair accessible and allow the Snac-Man to travel between the rows easily. The dimensions of the cinema will be 30,000 cubic feet, which is to allow the geothermal heat pump to properly regulate the temperature of the theater without consuming an unnecessary amount of energy.

The combination of our major design principles provides customization and adaptability for the issue of energy-efficient cooling systems. Given that airflow will always be a concern in any environment, our design helps narrow down the focus to simple fluid mechanics of wind in the main structure area. On top of that, heat exchange is still guaranteed even with low-velocity winds as the air inside the theaters is cycled out and temperatures closely maintained by geothermal cooling. In addition, the radiative cooling system will always work because it depends only on the sun and atmosphere, which can be accounted for in any environment. Also, the window panes are movable, the radiative cooling panels are customizable, the theater size is customizable, and the ground floor lobby of the glass tower could be customized for use as a concession or ticket area. The only issue is cost, but this could be remedied, accounted for, or optimized according to the needs of the particular environment. Considering the overall customizability of the theaters themselves in this design, the SNACKBOT, and COVID Web designs are poised to further increase the efficiency of this design and thereby increase moviegoer satisfaction while maintaining safety and health. All of this is done without the use of air conditioning or excessive power demands in line with a modern eco-friendly approach and an aesthetically pleasing structural design so that customers can return once more to their beloved pastime of movie watching.

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