EXPRESSION OF INTEREST

GROUP 9

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1.0 APPLICATION AREA RATIONALE

The proposed implementation of this project addresses the transmission of airborne diseases within restaurants, specifically small, local restaurants like those found in neighbourhoods such as Kitsilano or South Granville. Within these establishments, social interaction over the table creates a potential hotspot for the build-up of aerosols, creating an opportunity for solutions. For example, the CDC considers restaurants among the highest risk environments for community Covid-19 (CDC, 2020). In a US study, adults with Covid-19 were approximately twice as likely to report dining at a restaurant less than 14 days before becoming ill (Fisher, 2020).

We aim to reduce transmission across restaurant tables by defining non-medical mask usage as the benchmark for improving risk. Not only would this project serve to increase the safety of restaurant patrons and the Vancouver community, but there are also several additional benefits to reducing transmission.

In our sample of 73 people surveyed, 64.4% said that their dining out habits were negatively affected by the prevalence of covid. Additionally, 76.6% of people said they were more likely to support restaurants that specifically prioritised Covid safety. Therefore, we firmly believe that this project will increase the income of these small businesses. Sample survey results are shown in Figure 1.

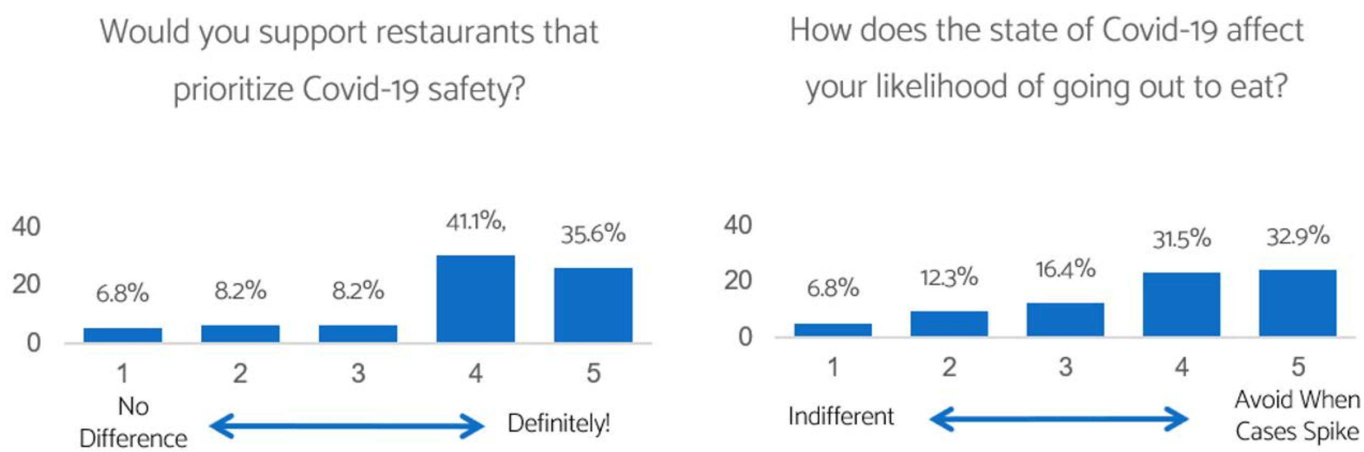

Figure 1 *Stakeholder Consultation, Support for Further COVID-19 Safety Measures in Restaurants.*

2.0 APPLICATION ANALYSIS

A standard 'protection' method employed in restaurants is the placement of plexiglass barriers between tables. However, several studies (Bagherirad et al., 2014),(Gilkeson et al., 2013) indicated that physical barriers lead to the build-up of highly concentrated infection aerosols and may increase the risk of airborne disease transmission.

Additionally, the BC CDC requires that guests use masks when not eating to reduce transmission. The issue with this approach is that people spend most of their time eating and drinking at the restaurant; expecting people to raise and lower their masks continuously is impractical. There is much room for improvement in protection methods.

One considerable challenge with implementing this project would be compatibility with the site and patrons. For example, if the design is incompatible with the space or interior design, it could drive customers away or make patrons uncomfortable. Similarly, if the design is too intrusive or intense, patrons may be reluctant to cooperate with the system.

The most significant barriers to consider in the design are cost, power, and infrastructure limitations. Many restaurants have faced financial struggles due to the pandemic, and as a result, they would be unable to afford expensive and complex solutions.

3.0 PILOT SITE CHARACTERISTICS

The pilot site for this project would be Mazahr Lebanese Kitchen, located in South Granville. They are a small restaurant, matching the size and characteristics of our models. These characteristics are listed below and depicted in Figure 2.

Layout

- 5X six-person tables
- 70" x 40" tables
- Square footage: ~1000sqft
- Restaurant height: 10ft

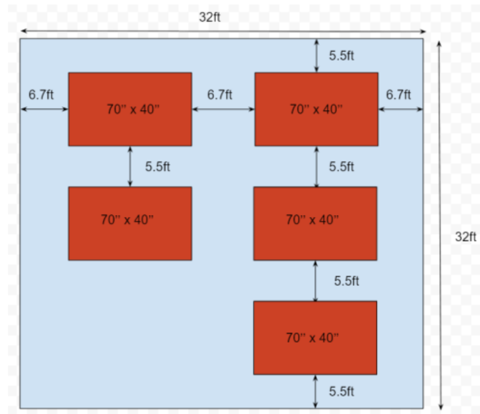

Figure 2 *Layout of Pilot Site Considered for Analysis.*

This pilot site will be impactful because Mazahr has particularly struggled financially through the pandemic, resorting to reduced operating hours to remain open. Additionally, the restaurant owners have a rapport with one of our team members, opening critical lines of communication with stakeholders.

4.0 STAKEHOLDER ASSESSMENT

We have identified four primary categories of stakeholders: the client, local governments and regulatory bodies, site operators, and site users. In Figure 3 below, key stakeholders within each group are identified and arranged in a Venn diagram that indicates whether stakeholders possess **power**, **legitimacy**, and **urgency**.

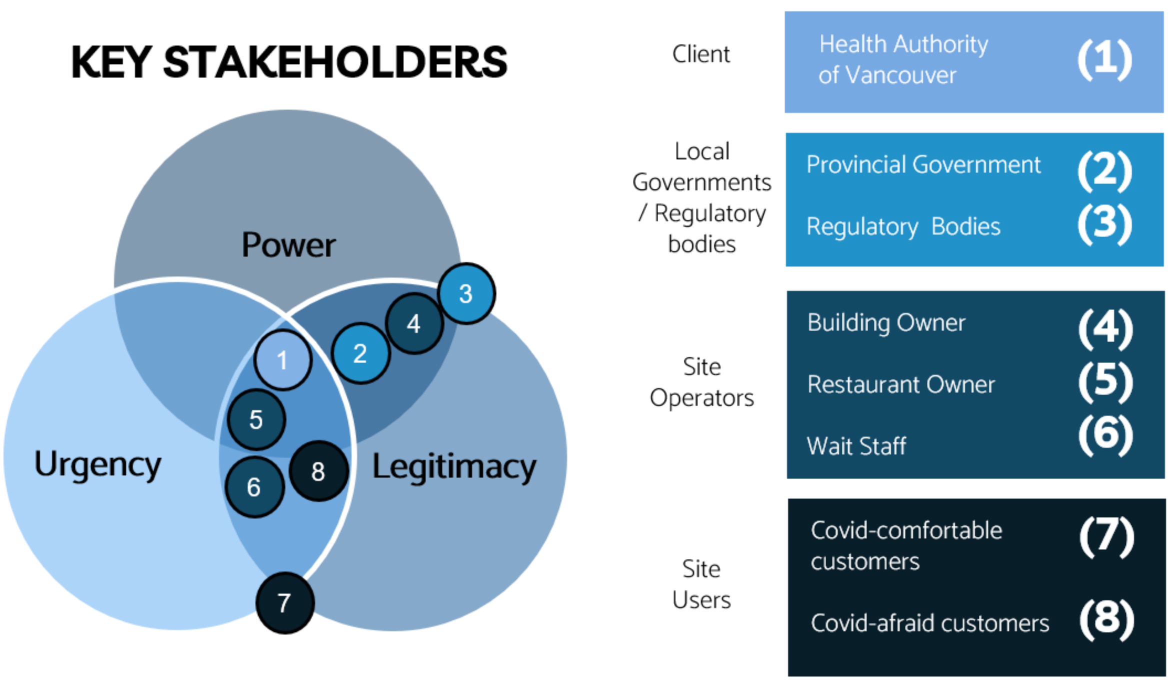

Figure 3 *Identified Stakeholders Categorised and Prioritised.*

The diagram also indicates the importance of each stakeholder, with the most influential stakeholders closer to the centre of the chart. Our three most important stakeholders are the HAV, Restaurant Owners, and Covid-Afraid Customers.

We engaged Site Users by surveying 73 different people to determine how Covid-19 has impacted their dining habits. We found that due to the pandemic, instances of dining outside the home have decreased by approximately 30% in September 2021 compared to 2019 levels. Additionally, 54.8% of participants felt that there should be more safety measures in place, and 74.0% were comfortable with the level of obtrusiveness of existing solutions.

Furthermore, our team interviewed Site Operators to validate our design requirements and gain insight into any needs that we may have overlooked. For example, a waitress we interviewed suggested that we would need to design features that prevent guests from tampering with the device. The owner of Mazahr agreed with all our requirements and provided a maximum budget for the project.

We performed extensive research to engage provincial government and regulatory bodies. We gathered a list of applicable regulations and codes that impact the design detailed in section 6.0.

5.0 PROPOSED SOLUTION

The proposed solution is a 'Bulk-Flow Blower' system with integrated filtration installed above each table, consisting of a fan, HEPA filter, and diffuser. The solution works by providing a low-velocity stream of clean air directly to guests seated at the table. Contaminated air exhaled by guests is drawn upwards to the blower, filtered and recirculated.

The blower is designed to be mounted to the ceiling directly above tables with custom brackets that are determined by existing structures. The design is compatible with a 120V outlet so that it can be directly plugged in with an extension cord or wired directly into a junction box. A diagram representing the proposed system is shown in Figure 4.

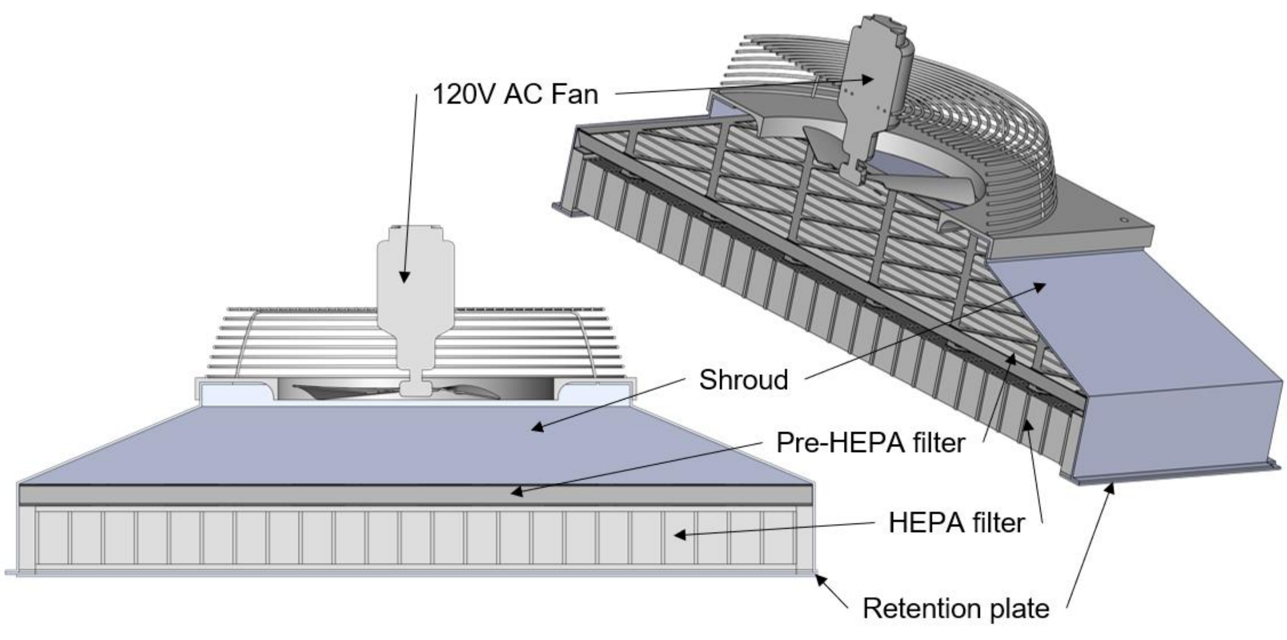

Figure 4 *Proposed System CAD Model.*

Figure 5 shows the theoretical pathways of clean air (blue lines) and contaminated air (red lines).

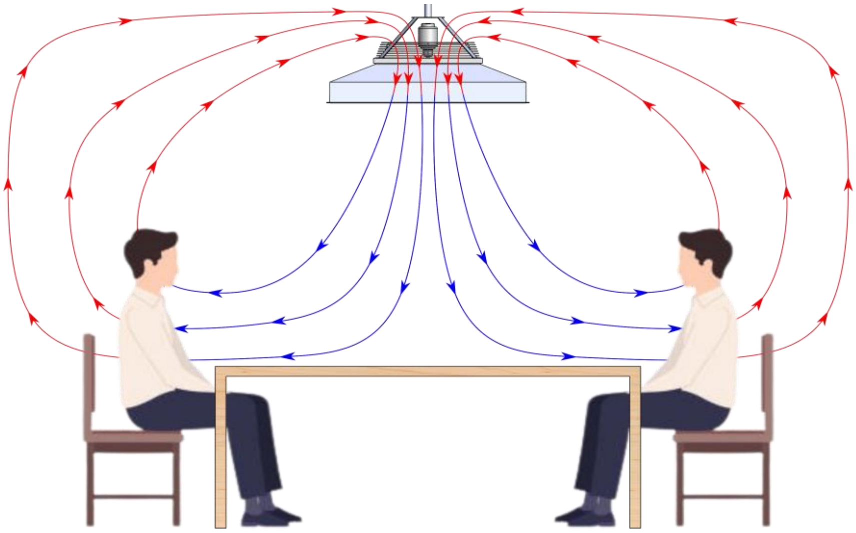

***Figure 5** Theoretical Pathways of Clean and Contaminated Air.*

A summary of system specifications can be found in Table 1 below:

SYSTEM SPECIFICATIONS		
Parameter	**Value**	
	Per-Table	**Total Restaurant**
Flow Rate	0.26 m^3/s	1.31 m^3/s
Downwards Velocity	0.47 m/s	-
Fan Noise @ 1 m	50 dB	-
Filter Size	36 in x 24 in x 1 in	-
Filtration Rating	HEPA	-
Pressure Drop	250 Pa	-
Power Consumption	2.2 kWh / day	11kWh / day

***Table 1** Final System Specifications.*

Preliminary analysis suggests that this solution provides equivalent-to-mask protection across the entire restaurant and potentially better-than-mask protection for guests seated at the tables. Recommendations for further analysis steps to confirm this with greater confidence are listed at the end of this section.

One must consider two regimes of Covid-19 transmission to design this system:

- **Direct transmission:** Transmission between guests at the same table when one guest is within an exhaled plume containing infectious droplets.
- **Indirect transmission:** Transmission between any guests in the restaurant from breathing in the background concentration of infectious aerosols in the well-mixed air.

A minimum downdraft flow rate can be calculated for both regimes by requiring protection that is equivalent to or better than a mask, and the larger of the two calculated flow rates becomes the system requirement. This downdraft flow rate is limited by comfort standards outlined in ASHRAE 55.

In Regime 1 of direct transmission, an infected guest (host) and a susceptible guest can be modelled, as shown in Figure 6 below. In this case, we can set the downwards flow rate by requiring that any exhaled virions be redirected down and hit the table before travelling across to the neighbouring guest. We can determine the downwards airflow rate by using known flow rate ranges for exhalation and a momentum balance. Details of this calculation are in Appendix A.

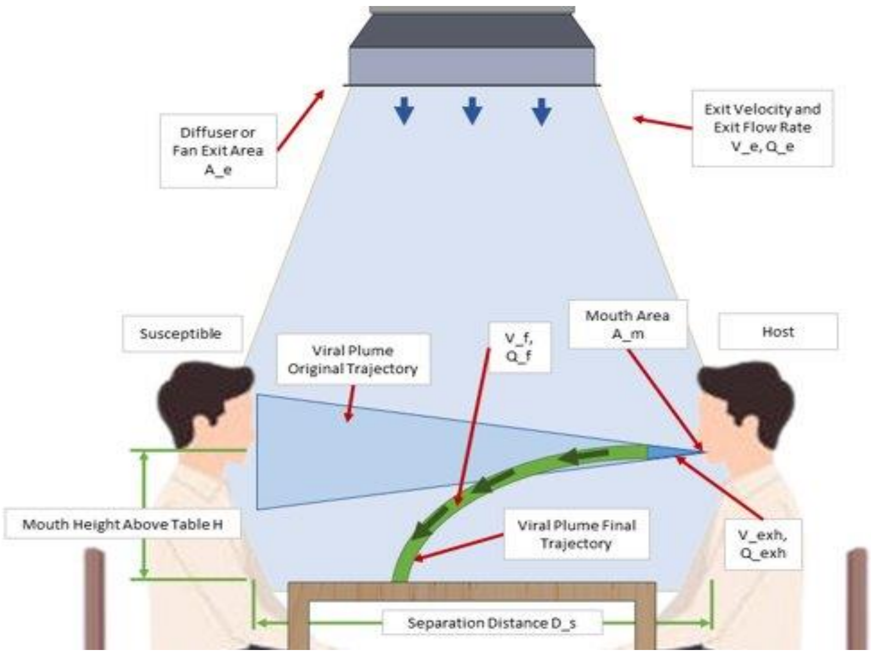

Figure 6 *Required Flow Rates for Different Transmission Regimes.*

In Regime 2 of indirect transmission, an equation modelling the transmission rate in infections per unit time as a function of ventilation rates, respiration rates, and mask and filter efficiency can be applied. The baseline case is when there is no filtration system and guests wear masks. The goal is to calculate the required filtration flow rate that achieves equal transmission risk with a filtration system instead of masks.

By equating the transmission rate with masks and no filtration to the transmission rate without masks but with filtration, it can be shown that the required filtration air change rate is a function of the outdoor air change rate and the filtration efficiencies of masks and the mechanical filter. Details of the derivation can be located in the Appendix:

$$\lambda_f = \lambda_a \frac{1 - p_m^2}{p_f p_m^2}$$

$\boldsymbol{p_m = 1 - Mask\ Efficiency}$, % $\boldsymbol{p_f = Filter\ Efficiency}$, % $\boldsymbol{\lambda_a = Outdoor\ Air\ Change\ Rate, \frac{1}{s}}$ $\boldsymbol{\lambda_f = Air\ Filtration\ Rate, \frac{1}{s}}$

The average efficiency of cloth masks that restaurant patrons are likely to wear is taken to be 60% (Ueki et al., 2020), (Brooks, 2021), and the filtration efficiency is taken to be 99.97% for a High-Efficiency Particulate Air (HEPA) filter, assuming a MERV rating of 17.

The flow rates for both Regime 1 and Regime 2 transmission are calculated and compared in Table 2 below:

Regime 1: Direct Transmission	Regime 2: Indirect Transmission
0.10 m^3/s	0.26 m^3/s

Table 2 *Required Flow Rates for Different Transmission Regimes.*

It can be observed that the required flow rate for Regime 2 is larger than the required flow rate for Regime 1, and so the flow rate of Regime 2 is taken to be the system requirement. Advantages of this system include the following:

- **Modularity:** Easily scaled up to larger establishments or non-restaurant environments, with flexible noise levels and power draw (systems at tables without guests can have fans turned off).

- **Simplicity:** Less than 5 primary system components and all components are standard, easily fabricated or sourced from HVAC suppliers.
- **Effectiveness:** First-order calculations suggest downdraft filtration is as effective as masks for the general room and potentially more effective than masks at the table. See 'Direct Transmission Calculation' in the Appendix for details.

These first-order estimations of filtration system effectiveness indicate that a filtration system with 0.26 m^3/s of filtered air per table of six could feasibly produce the same transmission safety as cloth masks with 60% filtration efficiency worn by all patrons while maintaining a comfortable environment for restaurant guests. However, it is recommended that more complex fluid dynamics phenomena be examined with numerical simulation in the next phase of this project to account for the effects of recirculation at the table and understand the occurrence and infection potential of virions deposited onto food and any unforeseen system behaviours.

6.0 STANDARDS AND CODES

Since the solution relies on blowing air to dilute the concentration of virions in the air surrounding diners, applicable ASHRAE standards should be followed. Particularly ASHRAE standard 55, which delineates standards for thermal comfort within buildings. The Percentage Predicted Dissatisfied (PPD) score can quantify the effects, with the solution having less than a 10% PPD. This considers factors such as the air temperature, speed, relative humidity, and the metabolic rate of patrons to ensure that comfortable climatic conditions are maintained even while the solution is running.

FOODSAFE BC must be followed, and the solution must not endanger diners by violating food safety codes because the solution is in a restaurant and is operating over a table with food on it. The solution will also abide by the BC Electrical Code and BC Fire Code and pose neither an electrical nor fire hazard. An appropriately accredited technician will install the solution to ensure it is properly installed and there are no potential safety hazards.

Finally, the solution aligns with the City of Vancouver's Climate Emergency Action Plan by only using electricity as a power source and not polluting fossil fuels for power.

A list of specific codes applicable to this project is included in Table 3 below.

Regulatory Body	Code #	Topic
ASHRAE	52.2-2017	Filter Efficiency Testing
ASHRAE	55-2017	Thermal Comfort
ASHRAE	90.1-2010	Energy Efficiency
ASHRAE	100-2015	Energy Efficiency in Existing Buildings
ASHRAE	129-1997	Air Change Effectiveness
ASHRAE	185.1-2015	UV-C
ASHRAE	33-2013	Contaminant Modeling
BC Building Code	Section 6	Heating, Ventilation, and Air Conditioning
AMCA	201-02 (R2011)	Fan Systems
AMCA	200-95 (R2011)	Air Systems

***Table 3** List of Applicable Codes.*

7.0 IMPACT ASSESSMENT

The most significant benefit of the design is an estimated 56% reduction in Covid transmission while dining compared to the base case of sitting at a table in a group while wearing a mask the whole time. There should also be the incidental health benefit of helping to reduce the transmission of other airborne diseases besides Covid-19.

Restaurants will benefit economically from increased sales as diners feel more comfortable eating out at restaurants. Many potential restaurant diners do not feel safe eating out due to the risk of Covid, so having a system in place to reduce the risk of transmission will likely entice them to eat out again. Increased revenue benefits both the restaurant owners and staff, who are often dependent on tips from patrons. Since the targeted restaurants are small, locally owned businesses, helping them financially will also help preserve the local culture and increase the number of visitors who will spend money at other local establishments. Local community members will also have the opportunity to safely socialise with each other, increasing community cohesion and happiness.

8.0 COST ASSESSMENT

The expected initial cost of the system is $2431, which includes the cost of the fans, shrouds, filters, mounting hardware, and installation costs (See Appendix C for the cost breakdown). Operating costs for one system are $100 per year to power the ¼ hp motors required to run the solution. Estimated maintenance costs are $478 annually to clean the fans and replace worn filters. The total annual operating costs for five systems in a restaurant are $2391, factoring in power and maintenance expenses leading to a total cost of $7253 during the first two years.

Statistics Canada has estimated that the revenue loss in small restaurants due to the pandemic is approximately CAD$600k per year (Government of Canada, 2021). If our solution can bring back even 1.2% of lost revenue, the solution will pay for itself in a year. In the best possible case where 100% of pre-pandemic revenue is restored by this solution, there would be a 164x return on investment.

9.0 CONCLUSION

Implementing the project will reduce the risk of airborne disease transmission within restaurants by 56% compared to wearing a mask. The solution relies upon blowing air onto the table to dilute the concentration of virions surrounding diners, thus reducing transmission risk. This will have the benefit of increasing business at the small, locally-owned restaurants where the solution will be implemented, positively impacting the local community and economy. Relevant standards and codes such as ASHRAE 55, FOODSAFE BC, BC Electrical Code, and BC Fire code are also considered and adhered to. The initial cost, including installation, is $2431, and ongoing costs, such as operating and maintenance costs, are $100 and $2391 per annum.

10.0 APPENDICES

APPENDIX A. Direct Transmission Calculation

To calculate the relative direct transmission risk with a downdraft filtration system vs a mask, consider the simplified diagram given in Figure 5 under section 5.0 'Proposed Solution', where any exhaled virions must be redirected into the table before encountering another guest. In addition, several parameters are assumed, given in Table 4 below:

Parameter	Value	Justification
Guest Separation Distance	0.5 m	Estimation for the enforceable distance between restaurant patrons
Maximum Head Inclination	60 deg	Estimation based on team member comfort inclining heads at several angles
Mouth Height above Table	0.5 m	Estimation based on the height of tables in team member's homes
Respiration Rate	2 L/s	(Mittal et al., 2020)
Mouth Area	25 cm^2	Average of team member mouth measurements
Mask Filtration Rate	60 %	(Ueki et al., 2020), (Brooks, 2021)

***Table 4** Input Values for Direct Transmission Calculations.*

The situation is simplified and modelled as a momentum balance problem as shown below, in which A_m and D_m are the mouth area and diameter in m^2 and m, respectively:

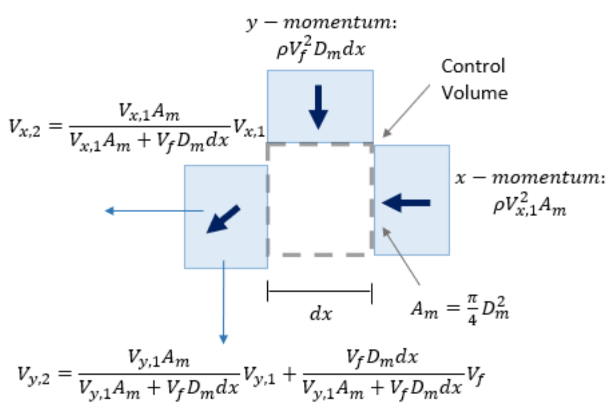

***Figure 7** Momentum Balance Model.*

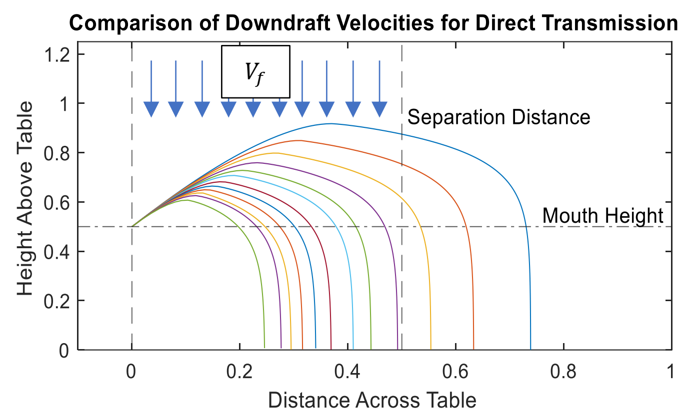

***Figure 8** Plot of Exhaled Plume Paths for several Downdraft Velocities.*

This model is solved numerically by sweeping through a range of downwards velocities V_f, requiring that the total change in y is greater than or equal to the 'Mouth above Table' distance before the total change in x is equal to the 'Separation Distance', and selecting the lowest V_f that meets this requirement. This corresponds to $V_f = 0.18\frac{m}{s}$ and $Q_f = 0.1\frac{m^3}{s}$.

The direct transmission risk can then be calculated using a model from Mittal et al., 2020 as a product of all factors that affect transmission. This model permits the calculation of the relative risk of filtration systems to a masked case by taking the ratio of the 2 factors that change. Note that all calculations have been normalised to the unmasked case.

- **Transport ratio f_t:** Placing masks on both guests adds a factor of $(1 - Mask\ Efficiency)^2 = p_m^2$. For filtration, some recirculation is assumed as a conservative estimate, and transmission risk is calculated for 100% virion blockage, 50% virion blockage, and 0% virion blockage to compare assumption cases.
- **Respiratory droplet number transmission rate $\dot{R}_h$:** This value depends on the concentration virions in exhaled breath, and dilution of this plume via mixing with filtered air reduces this value. The amount of downdraft air that contributes to dilution is Q_f' , the flow rate in the cross-section of the downdraft that the plume interacts with, where $Q_f' = \frac{D_m D_s}{A_{exit}} Q_f$, Q_b is the host respiratory flow rate, and D_s is the separation distance between guests.

$$\textbf{Nominal } \dot{R}_h, \textbf{No Mask} = 1$$

$$\textbf{Masked } \dot{R}_h = 1$$

$$\textbf{Filtration } \dot{R}_h = \frac{Q_b}{Q_b + Q_f'}$$

$$\textbf{Nominal Transport Ratio } f_t, \textbf{No Mask} = 1$$

$$\textbf{Masked Transport Ratio}$$

$$f_t = (1 - Mask\ Effectiveness)^2$$

$$\textbf{Filtration Transport Ratio}$$

$$f_t = 0\%, 50\%, 100\%$$

$$\textbf{Relative Risk} = \dot{R}_h f_t$$

Name	Value	Worst	Best	Units
Mask Effectiveness	60%	50%	70%	%
Host Respiratory Flow Rate	1000	2000	100	mL/s
Filtration Flow Rate	0.1	0.1	0.1	m^3/s
Masked Transport Ratio f_t	16%	25%	9%	%
Assumed Filtration Transport Ratio f_t	50%	100%	0%	%
Nominal Risk (No Mask, Normalized)	100%	100%	100%	
Masked Risk	16%	25%	9%	
Filtration Risk (dilution only)	18.2%	30.8%	2.2%	
Filtration Risk (dilution and transport)	**9.1%**	**30.8%**	**0.0%**	

Table 5 *Input Values for Direct Transmission Calculations*

Considering only the dilution mechanism, the risk of transmission in the average filtration case is within 3% of the risk of transmission with masks. When some amount of decreased transportation (a primary mechanism) is considered, the average value of filtration risk matches the best case for masked risk, and if recirculation is nearly negligible, the downdraft filtration system could bring transmission risk to nearly 0%. Further work to quantify the transport ratio using numerical simulations is recommended for the next stage of this project.

APPENDIX B. Indirect Transmission Calculation

The indirect transmission model uses a modified Wells-Riley model proposed by Professor Martin Z. Bazant in his 'Physics of COVID-19 Transmission' lecture series. This model makes the following assumptions:

1. The air in a given room is well-mixed – the concentration of infectious aerosols is constant at all points in space.
2. The concentration of infectious aerosols can be calculated as a source-sink balance.
3. The concentration of virions in the room being considered is at a steady state.

The base model calculates transmission rate β in units of infections per unit time and is given by Equation 1. A modification to the model accounts for mask filtration, where $p_m = 1 - Mask\ Efficiency$ is given by Equation 2. Finally, an alternate modification to the model accounts for air that is filtered and re-introduced into the room with some filter efficiency p_f and a filtration air change rate λ_f is given by Equation 3. By equating modified models 2 and 3, a filtration air change rate λ_f that provides equal protection to mask-wearing can be calculated as a function of the outdoor air change rate λ_a and mask and filter efficiencies p_m and p_f respectively:

$$\beta = \frac{Q_b^2 C_q p_m^2}{\lambda_a V} \quad (1) \qquad \beta = \frac{Q_b^2 C_q p_m^2}{\lambda_a V} \quad (2) \qquad \beta = \frac{Q_b^2 C_q}{(\lambda_a + p_f \lambda_f) V} \quad (3)$$

$$\frac{Q_b^2 C_q p_m^2}{\lambda_a V} = \frac{Q_b^2 C_q}{(\lambda_a + p_f \lambda_f) V} \quad \rightarrow \quad \frac{p_m^2}{\lambda_a} = \frac{1}{(\lambda_a + p_f \lambda_f)} \quad \rightarrow \quad \lambda_f = \lambda_a \frac{1 - p_m^2}{p_f p_m^2}$$

Outdoor air change rate λ_a is a function of the number of guests N, and ASHRAE recommends 15 CFM of fresh air per room occupant (Bazant et al.). N can be taken to be 35, assuming a total capacity of 30 diners and 5 staff.

Parameter	Value	Justification
Number of Restaurant Occupants	35	6 people x 5 tables, + 5 staff
Fresh Air Flow Rate per Person	15 CFM	(Bazant et al.)
Filter Efficiency	99.97%	HEPA Filtration Efficiency, MERV 17 rating
Mask Efficiency	60 %	(Ueki et al., 2020), (Brooks, 2021)

Table 6 *Input Values for Indirect Transmission Calculations*

$$\lambda_f = \left(15 \frac{CFM}{person}\right)(35\ people) \frac{1 - (0.4)^2}{(0.9997)(0.4)^2} = 1.31 \frac{m^3}{s}\ [FULL\ RESTAURANT] = 0.26 \frac{m^3}{s}\ [PER\ TABLE]$$

APPENDIX C. Cost Breakdown

Component	Cost	Quantity Upfront	Quantity Yearly	Currency	Upfront Cost in CAD	Yearly Cost	Source
Fan	$ 205.00	1	0	USD	$ 254.20	$ -	https://www.homedepot.com/p/Hessaire-3340-CFM-Shutter-Exhaust-Fan-Wall-Mounted-20SFV-H/305621450
Shroud Material	$ 54.00	1	0	USD	$ 66.96	$ -	https://www.mkmetal.net/galvsheet26gax48x120
Manufacturing	$ 65.00	1	0	CAD	$ 65.00	$ -	Based on 2 hours of work and simple tooling, best guess.
Mounting Hardware	$ 40.00	1	0	CAD	$ 40.00	$ -	Based on the best guess of what will be needed, electrical cable, new fuses, screws, mounting boards.
HEPA Filter	$ 260.00	0	1	USD	$ -	$ 322.40	https://www.mcmaster.com/air-filters/trade-size~36-24/
Pre-Filter	$ 15.00	0	3	USD	$ -	$ 55.80	https://www.homedepot.com/p/True-Blue-24-x-36-x-1-Budget-FRP-2-Washable-Filter-HD0124361/202195941
Installation Cost	$ 60.00	1	0	CAD	$ 60.00	$ -	https://ca.indeed.com/career/general-contractor/salaries/Vancouver--BC
Power	$ 100.00	0	1	CAD	$ -	$ 100.00	1/4 hp motor for 1 year according to BC hydro
				Per Table	**$ 486.16**	**$ 478.20**	
				Per Restaurant	**$ 2,430.80**	**$ 2,391.00**	
				Two-year cost	**$ 7,252.60**		

Table 7 *Bill of Materials and Cost Breakdown*

11.0 REFERENCES

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