APPLICATION BRIEF

Mobile COVID-19 Sample Collection Booth

In today's highly contagious environment, it is important to reduce the spread of the COVID-19 virus. One way to reduce the spread of infection at the community level is through early detection [1], which requires that large numbers of people be tested in a short time. Presently, testing is limited to people who are showing symptoms of COVID-19. To test more widely, hospitals need to build facilities for mass testing. Traditional laboratory-based sample collection methods [2,3] are not suitable for testing large numbers of people during the community transmission phase. A separate sample collection method needs to be implemented for the general public following BSL-2 standards [2].

This document proposes the design of a mobile COVID-19 sample collection booth that can be assembled quickly and moved easily to facilitate sample collection from urban and remote areas. The safety of the sample collection staff and persons visiting the booth to be tested has utmost priority according to BSL-2 standards [2]. South Korea has already adopted such a testing booth [4], and they found it to be effective in flattening out the curve [5].

Products Used:

Ansys Fluent

Design Concept

The main objective of the COVID-19 sample collection booth is to avoid direct contact between the sample collecting staff and the person providing the sample. Further, the next person visiting the booth should not become infected by the nasal or oral plumes of the previous person. The overall sample collection time — including changing plastic gloves and disinfecting the booth — should not be more than five to seven minutes per person, so that a large number of samples can be collected in a day. The booths are built on the negative pressure room (NPR) concept, which involves maintaining a negative pressure in the room so that air inside the room does not leak out through the gaps. Air from inside the booth is discharged outside in a controlled manner after filtering.

Figure 1. COVID-19 sample collection booth used in South Korea [4]

Figure 1 shows the mobile COVID-19 sample collection booth used in South Korea [4]. The booth consists of a negative pressure cabin for the person giving the sample and works on the principle of a biosafe, isolation glove box design. The sample is collected in the following manner:

1. Sample collecting staff stays outside of the cabin wearing PPE kit.
2. Person enters the disinfected cabin, removes mask and talks by speaker phone with the sample collecting staff to provide the required information.
3. Sample collecting staff collects the swab sample using glove-box-style hand gloves fitted to the cabin.
4. Person leaves the cabin after putting the mask back on.
5. A staff member of the sample collection team changes the plastic gloves, disinfects the room and puts the sample in a box.
6. The cabin is then ready for the next person.

Proposed Design

In the proposed design, negative pressure is maintained in the booth to prevent leakage of any contaminants outside. Smoke detection can be done at the key openings to ensure that air is moving inwards. Ventilated air is discharged outside the room and filtered through a portable HEPA filtration unit to discard cleaned exhaust to the outside environment. The air flow rate is set to around 24 air changes per hour so that it takes approximately 2.5 minutes to ventilate most of the room air. The air flow rate can be controlled using a flow control valve before the HEPA filter/blower unit. The medical staff interacts with the patient through an isolation glove box to avoid physical contact or direct air contact. This flow ventilation system is designed and validated with computational fluid dynamics (CFD) modeling using Ansys Fluent simulation software [6]. The flow rate is selected so that the expelled gases from the patient's breathing, coughing or sneezing are directly ventilated outward without much circulation in the room.

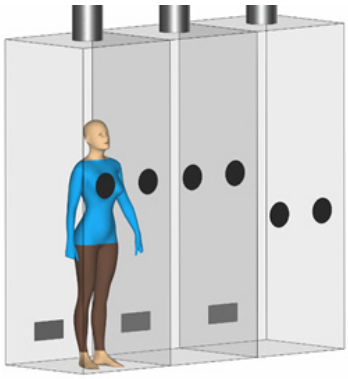


Figure 2. Proposed design of COVID-19 sample collection booth

Figure 2 shows the proposed design. It consists of multiple sample collection cabins with dimensions of 2.5 ft. x 2.5 ft. x 7 ft., each with a door. A square 45-degree downward louver is fitted 6 in. above the ground on the door of the cabin. A circular exhaust duct is fitted in the center at the top of the cabin. The transparent wall of the cabin has two circular holes for glove-box-style hand gloves. The exhaust duct is connected to an exhaust system consisting of a HEPA filter and exhaust blower. The sizes of the inlet vent and circular exhaust are selected such that the flow area at the inlet and exhaust are similar. Table 1 shows the overall dimensions and operating parameters for the cabin.

Table 1. Dimensions of COVID-19 Sample Collection Booth Cabin

Parameter	Value
Cabin dimensions	2.5 ft. x 2.5 ft. x 7 ft.
Inlet vent size	10 in. x 5 in.
Inlet vent location	6 in. above the ground
Exhaust vent diameter	8 in.
Air Flow rate	24 air changes per hour (ACH)
Exhaust velocity	~1fps

The following is a list of materials needed to build a sample collection booth:

1. Acrylic sheets
2. Aluminum frame
3. 45-degree downward louver
4. 125 cubic feet per minute (CFM) HEPA filter/blower unit [7-8]
5. Power backup unit (small generator if needed)
6. 8 in. ID flexible hose
7. Flow control valve (if the HEPA unit does not have provision for flow control)
8. Fumigation system to disinfect the unit
9. PPE kits BSL-2 equipped
10. Rubber gloves

Design Validation Using Computational Fluid Dynamics

The proposed design was validated using Ansys Fluent computational fluid dynamics simulations, as shown in Figure 3. The figure shows the volume rendering of air velocity. The path lines show the paths of the nasal or oral plumes of the person providing the sample. Results show that the nasal and oral plumes are swept out of the cabin easily toward the exhaust without a large recirculation within the cabin. Thus, the design is suitable and ensures minimum contamination of the cabin in case the person providing the sample is COVID-19 positive. Results also highlight the area that needs to be disinfected properly before the next person enters the cabin.

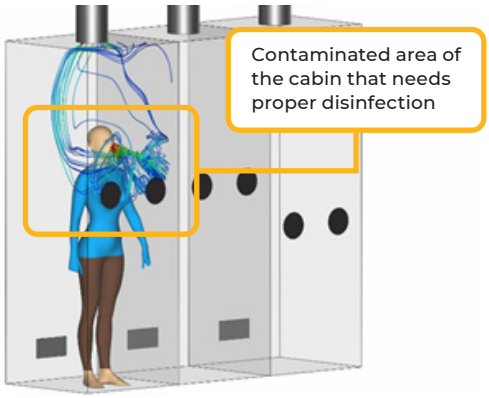


Figure 3. Validation of proposed design for sample collection booth

Summary

This document explains the design of a COVID-19 sample collection booth. The proposed design can be used as a stationary unit or mounted on a small truck as a mobile unit. The booth can be built quickly to test large numbers of patients at a rate of roughly seven minutes per patient. BSL level 2 specifications can be achieved with the correct choice of materials listed in World Health Organization guidelines and as proposed above. To meet BSL 2 specifications, the final exhaust gas discharge region should be located far enough away that it does not come close to the booth or the inlet vents.

References

1. Laboratory Testing Strategy Recommendations for COVID-19, Interim Guidance, March 2020
2. Laboratory Biosafety Manual, Third Edition, 2004
3. WHO interim guidelines for Laboratory for COVID-19, Feb 2020
4. South Korean Hospital's 'Phone Booth' Coronavirus Tests
5. How South Korea Flattened the Curve, The New York Times, March, 2020
6. ANSYS, Inc
7. RPS Ventilation Unit
8. Ventilation Design Guidelines for booth, tents and room

Appendix I

Assembly of the Sample Collection Booth

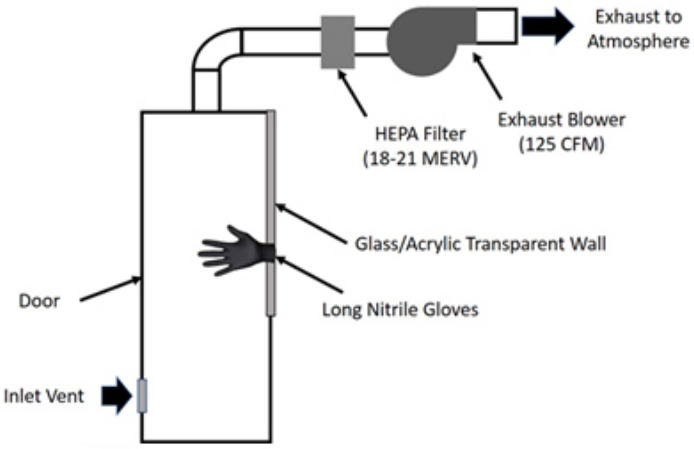
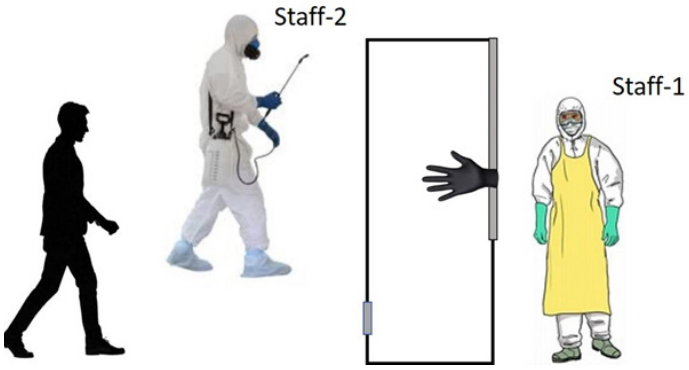


Figure 4. Assembly of sample collection booth

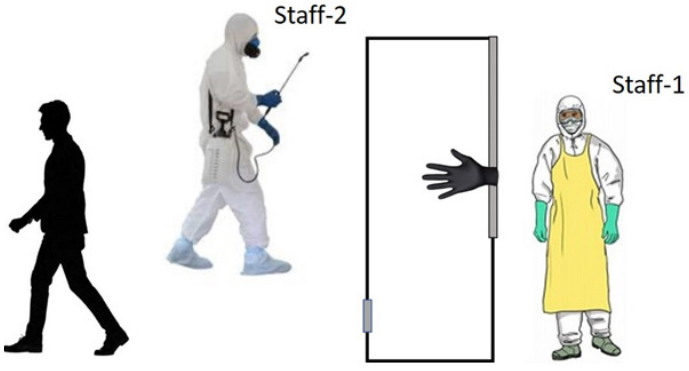
Appendix II

Steps for Operating Sample Collection Booth



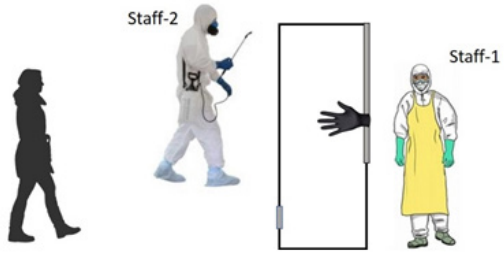
Step 1. Disinfected booth is ready for sample collection

Step 2. Person giving the sample enters the booth, staff-1 collects sample, leaves the virus transport tube on the corner shelf in the booth



Step 3: Person who gave sample leaves the booth

Step4: While the next person in the queue waits outside, staff-2
(i) keeps the viral transport media (VTM) in a leak-proof Zip-Lock pouch and puts it in icebox
(ii) removes the outer plastic gloves from the nitrile gloves
(iii) disinfects the inside of the booth all over
(iv) puts fresh plastic gloves on the nitrile gloves



Step 5: Disinfected booth is ready for next sample collection

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These simulations were designed to replicate physical behaviors under specific circumstances. They should not be considered medical guidance and do not account for environmental variants, such as wind or humidity.