Victorian Health Building Authority

VICTORIA State Government

Aerosol hot spot study within healthcare environments

Health Technical Advice HTA-2021-001

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1 Preface

This Health Technical Advice has been provided in the context of recent developments in the COVID-19 pandemic in Victoria which include increased health service worker transmissions and the need to reduce the risk of transmission of COVID-19 in healthcare settings.

Recent data and early studies[1] demonstrate increased risk and a steady rise in the number of healthcare workers contracting COVID-19. The data highlights the importance of effective infection prevention and control strategies in health facilities to reduce the risk of transmission of COVID-19.

Statement regarding aerosol transmission of COVID-19

The potential for aerosol transmission of COVID-19 has been a matter of much discussion worldwide. Different jurisdictions, national bodies and countries have various interpretations of the potential risk, and the science is still emerging. The Healthcare Worker Infection Taskforce discussed this issue in October 2020, acknowledging that regular reviews of the scientific evidence were ongoing through groups such as the Infection Control Expert Group (ICEG). The Australian Commission on Safety and Quality in Health Care is also currently working to revise the National Safety and Quality Health Service Preventing and Controlling Healthcare-Associated Infection Standard.

It was agreed to make a statement on the mode of transmission which acknowledged the potential for aerosol transmission.

Mode of transmission statement

"Evidence to date suggests that, similar to other respiratory viruses, SARS-CoV-2 (the virus that causes COVID-19) is mainly transmitted by respiratory droplets which are spread from an infected person to others, during talking, shouting, singing, coughing or sneezing. These droplets can also land on objects or surfaces so the virus is transmitted through contact with a contaminated surface or object. Experts agree there is a gradient from large droplets to aerosols, however, those who have been in close or direct contact with a COVID-19 case are at highest risk.

SARS-CoV-2 can be transmitted via aerosols in specific circumstances. The extent of transmission via aerosols is still being researched, but is well recognised during aerosol generating procedures in a health care setting, and probably important in the context of other behaviours, such as singing or shouting. This risk may be higher in certain conditions such as poorly ventilated crowded indoor environments.

Given the potential for aerosol spread, a precautionary approach has been taken toward controlling this risk in Victoria. This includes the requirement of particulate filter respirators (for example, P2, N95 respirators) in all care interactions for patients with COVID.

The most effective individual measures to prevent the spread of SARS-CoV-2 are good hand and respiratory hygiene, physical distancing, staying home and getting tested if you are unwell, and wearing a mask. Together, these measures minimise the risk of transmission of SARS-CoV-2."

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[1] Nguyen, L.H., Drew, D., Graham, M. et al, 2020, 'Risk of COVID-19 among front-line health-care workers and the general community: a prospective cohort study', *The Lancet Public Health,* vol.5, issue 9, E475-E483 <https://www.thelancet.com/journals/lanpub/article/PIIS2468-2667(20)30164-X/fulltext>

1.1 Aerosol hot spot analysis study

The aerosol hot spot analysis study was commissioned to simulate aerosol behavior on a cough from a patient in four standard hospital rooms types and to track particles as they distributed throughout the room and the HVAC airstreams, until they impact and stick to a surface.

Details of the simulated cough particle distribution and insertion characteristics can be found in Appendix 2 and within references.

The distribution used is based on Zayas et al. Other research L. Morawska and Han ZY et al give varying droplet sizes and quantities, but all are within the range that creates an aerosol and simulation work in parallel with this report based on their distribution profiles yield similar results in terms of aerosol distribution pattens.

The study did not model or draw conclusions on how COVID-19 is transmitted, whether COVID-19 infections are acquired through airborne transmission or the infectiousness of aerosol particles.

The purpose of this Health Technical Advice (HTA) is to provide guidance to infection prevention specialist and hospital engineers on coagulation spots, represented in a heat map and actions that could be taken to reduce the risk of contact transmission in health care settings.

This HTA is not to take the place of any health agency specific infectious diseases or pandemic mode plans or any facility specific emergency response plans associated with acute infectious disease outbreak. Instead this HTA provides additional guidance to assist in identifying high risk areas to support infection control practices that can be adopted to ensure clinical spaces reduce the risk of transmission.

1.2 Who should read this?

Health service leaders, infection control specialists, engineering and infrastructure staff, healthcare workers and health service employees in contact with patients or working in the patient space.

2 The issue

Aerosols are unique, they are suspended particles on which gravity has little effect due their size, they mostly behave as the air they are mixed with. This is until the airflow turns sharply near a surface, at which point the momentum of the particles can cause them to collide with the surface and come to rest. Most worldwide studies have assumed that aerosols only behave as a gas and ignore the fact that they will come to rest on a surface.

The aerosol hot spot analysis study selected four room types from the *Australasian Health Facility Guidelines*, identified airflow patterns, and then predicted likely infection hot spots on surfaces, and equipment in the room type. The modelling accurately simulates the aerosol behaviour, and then tracks the particles (which can be in their millions in a single cough) as they are carried in the HVAC airstreams, until they impact and stick to a surface. This is then represented in a heat map identifying the areas (hot spots) of greatest concentration, and therefore potential indirect infection.

2.1 Computational fluid dynamics

Computational fluid dynamics (CFD) analysis is a technique by which real fluid flow is approximated using computer calculations. This is done by creating a three dimensional mesh of the region under analysis (for example, in this analysis the air in a room, known as the domain) and then solving a number of equations that link each mesh ‘cell’ to its neighbouring ones. For most simulations this will involve many millions of equations and it is only with more modern and powerful processors that the use of CFD has been possible.

Importantly with the software used in the study, it is possible to create a two-phase fluid (water droplet nuclei suspended in air). The droplet nuclei and air have very different physical properties that must be allowed for, and their respective interactions must also be correctly captured as an aerosol (i.e. ‘fully coupled’ interactions).

The advantages of CFD are:

- detailed and accurate results – nearly every piece of information can be individually tracked
- non-intrusive analysis of areas that may be hazardous or in use
- relatively less resource intensive than traditional methods such as smoke or spray testing.

Some of the limitations include:

- limited by inputs – the more accurate inputs or boundary conditions that are given the better the final outputs
- the mesh and analysis are only an approximation of real fluid flow, where flows are extremely turbulent or chaotic (such as in a combustion engine) a very fine mesh and analysis may be necessary, however this can be computationally expensive.

2.2 Study limitations and disclaimer

The CFD analysis is predictive in nature and will not necessarily match the pattern in all real-world applications, nor is it specific to any unique characteristics of the COVID virus. The results are indicative and based on modelling only and no on-site testing has been done to verify the modelled results. The number of variables that can constantly be observed in healthcare applications will change the outcome of all modelled scenarios. However, the modelling will enable health services to draw conclusions from the analysis patterns observed and extrapolate them across other scenarios.

Once inside a controlled zone the ventilation system has limited influence over how aerosol suspended particles are distributed. This is because most healthcare HVAC ventilation systems, other than spaces like operating theatres or isolation rooms, are designed to mix the air in the space to provide uniform environmental conditions.

Importantly, the locations of all diffusers and grilles were selected for good design conditions, however in actual installation these can often be placed very differently. Air patterns throughout installed rooms may therefore vary greatly.

This study did not model COVID-19 particles, nor does it assume COVID-19 transmission rates and or risks. This is an ongoing area of research by specialist teams and the World Health Organisation (WHO) suggests more studies are urgently needed to investigate instances and significance of modes of transmission of COVID-19. WHO, together with the scientific community, has been actively discussing and evaluating whether SARS-CoV-2 may also spread through aerosols in the absence of aerosol generating procedures, particularly in indoor settings with poor ventilation.

This study simulated aerosols generated from a single cough and identified the settling points of these aerosols within four typical healthcare settings to assist with infection prevention and control strategies.

2.3 Real world study

The study is a theoretical study using Computational Fluid Dynamic modelling; however, the findings closely align with real life investigation work carried out by Santarpia et al ‘Aerosol and surface contamination of SARS-CoV2 observed in quarantine and isolation care’.

It is understood additional ‘real world studies’ are being carried out by both locally and internationally to better understand impacts of aerosol distribution through the healthcare setting. These studies are pending and it is proposed that the findings be assessed against this CFD study, and inform future updates of this HTA.

3 Analysis

Computational fluid dynamic analysis on four different *Australasian Health Facility Guidelines* room types has been conducted to determine where aerosols from a patient coughing will likely deposit.

Typical layouts for rooms, mechanical systems and cough insertion have been determined and input, however many variations to these factors can occur in real facilities (see **Appendix 2**). It is nevertheless possible to draw conclusions from the patterns observed in analysis and extrapolate them across other scenarios and facilities.

The following areas have been considered as part of the study. These spaces were chosen as these would most likely be areas where infected patients would be treated. The functional room layouts have been derived using the standard Australasian Health Facility Guidelines 3D (Revit) models <www.ausHFG.com>

Area	Room (AusHFG reference)
Negative isolation room	1BR-IS-N1
ICU bay	1BR-1C
Standard 4-bed ward room	4BR-ST
Standard 1-bed ward room	1 BR-ST-A1

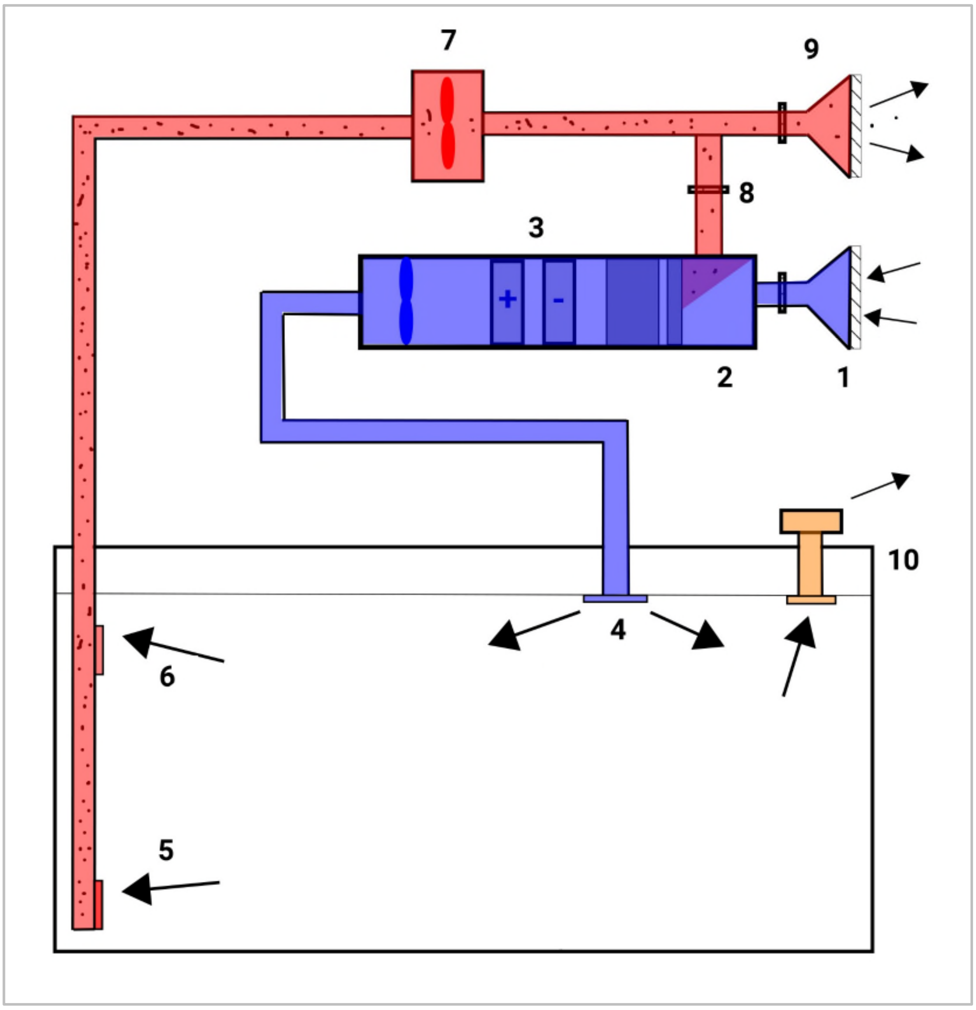
3.1 Drawings

The following drawings have been provided to visually aid with interpretations and analysis provided here. Refer **Appendix 4** for all drawings.

Drawing No.	Room (AusHFG reference)	Model
[01]	1BR-IS-N1	Swirl diffuser
[02]	1BR-IS-N1	4-way diffuser
[03]	1BR-IC	Swirl diffuser
[04]	1BR-IC	4-way diffuser
[05]	1BR-IC	Swirl diffuser – intubated patient
[06]	4BR-ST	Swirl diffuser – corridor return
[07]	4BR-ST	Swirl diffuser – balanced system
[08]	4BR-ST	4-way diffuser – balanced system
[09]	1 BR-ST-A1	Swirl diffuser
[10]	1 BR-ST-A1	4-way diffuser

3.2 Mechanical HVAC system

Figure 1: Main components of a mechanical HVAC system



1. Outside air intake – outside air is drawn into the air handling unit via outdoor louvres
2. Mixing box – outside air is mixed with return air within the mixing box
3. Air handling unit (filtration and treatment of air)
4. Supply air diffuser – supply air delivered to the room
5. Low level extract/return grille – room air extracted or exhausted
6. High level extract/return grille – room air extracted or exhausted
7. Extract/return air fan
8. Return air back to mixing box
9. Extract air discharge – extract air is discharged to outdoors
10. Exhaust air system inclusive of exhaust grille and discharge to atmosphere.

4 Key findings

Key findings of the CFD modelling study can be broken into two main phases:

Phase 1 – Hot spot deposits

- stages of aerosol pattern development
- coagulation of particles
- development of ‘hot spot’ drawings indicating the locations where aerosols are likely to coagulate.

Phase 2 – Airflow movements and patterns

- air movement patterns and controlled zones
- impact of supply air diffuser selection and location.

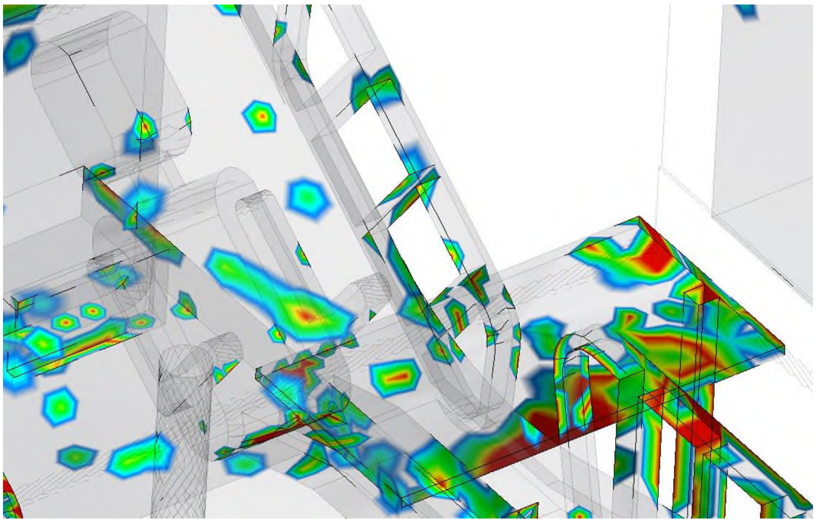
4.1 Three stage systems

In studying aerosol pattern development, it can be seen that particles generally deposit around rooms in three stages.

4.1.1 Stage 1: 0-30 secs

Coughed aerosols initially group up within a small cluster. In the first 30 seconds there is the potential while they are grouped for a large percentage of particles to deposit in a single area, often close to the patient. This is seen in Figure 2 below, where the patient table directly in front of the occupant is seen to be covered in deposits. These early deposits are not influenced by the full room air pattern, but instead by local airflows and obstructions.

Figure 2: Aerosol collected on the patient table



4.1.2 Stage 2: 30-240 secs

In stage 2, the aerosols are now dispersed around the room evenly enough for the HVAC dynamics to have a greater influence. It is during this period that the majority of aerosols are deposited, particularly in areas where airflow sharply changes.

Figure 3: Aerosol distribution at 60 secs

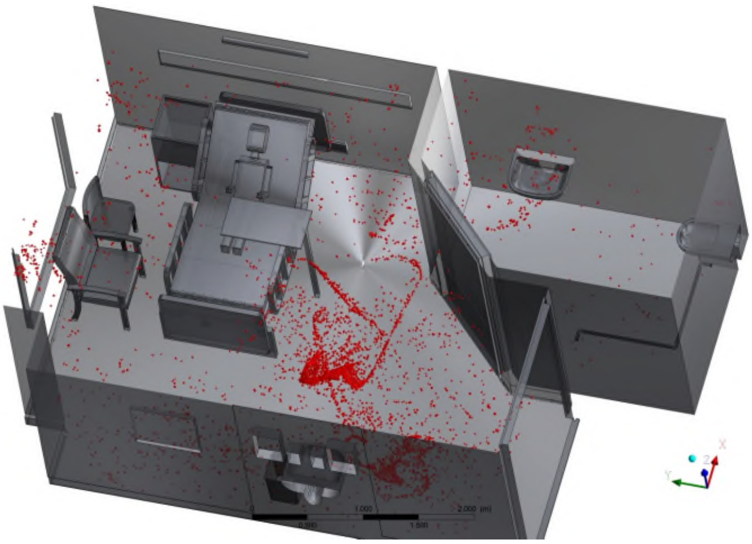
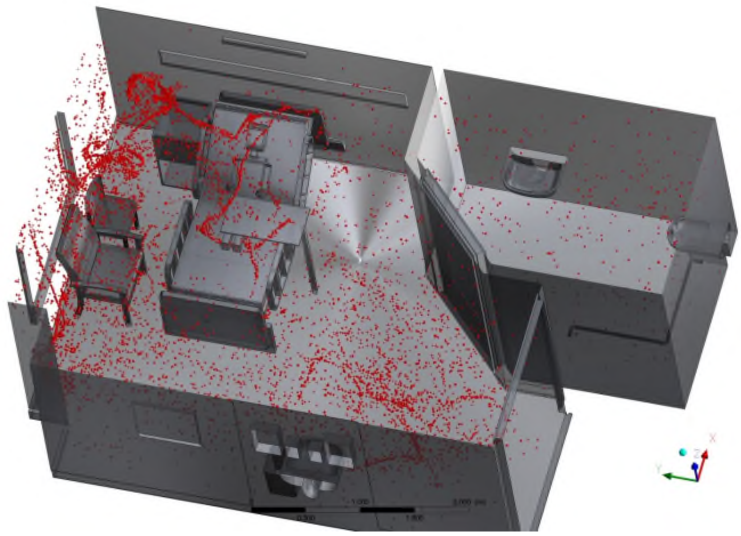


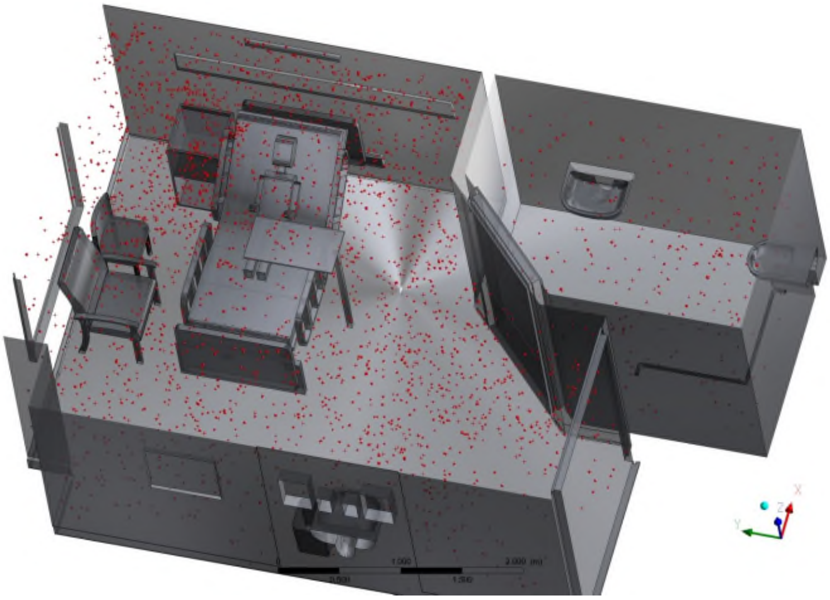
Figure 4: Aerosol distribution at 120 secs



4.1.3 Stage 3: 240 secs+

At around 240 seconds most of the particles have either deposited within the room or been removed by the HVAC system. At this point the remaining aerosols are evenly distributed throughout the room volume. The removal of aerosol is now largely dependent on air changes per hour (refer to **Appendix 3**).

Figure 5 : Aerosol distribution at 240 secs



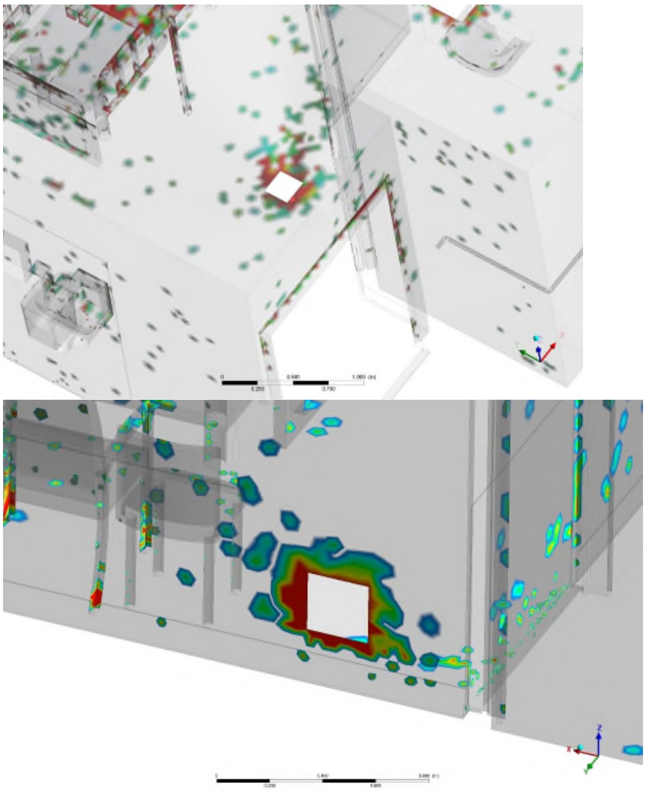
4.2 Locations where aerosols are likely to coagulate

Throughout all models, the following locations are repeatedly found to have more particles deposited than others and infection and hygiene practices should be reviewed to ensure these areas are not contributing to the spread of infections in healthcare settings. A full set of hot spot drawings can be found at **Appendix 4.**

4.2.1 Around return/exhaust grilles

As air throughout the room is drawn towards the return/exhaust grille, it draws the particles with it. The sharp direction change of airflow around the grille causes aerosols to deposit across the adjacent surfaces. While these surfaces are usually on ceilings and occupants generally will not come into contact with them, low level grilles (including those on doors and undercuts) pose a larger risk.

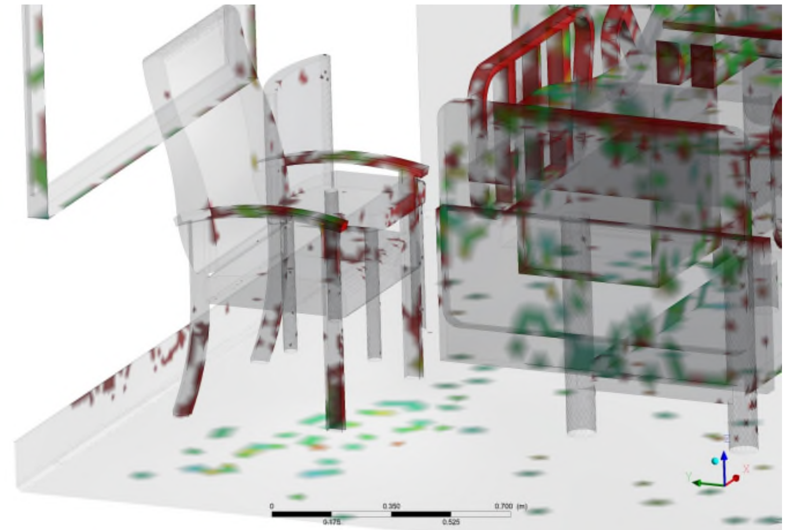
Figure 6: Aerosol collecting on surfaces near to extract grilles



4.2.2 Sharp obstructions jutting out from flat surfaces

Airflow along flat surfaces such as walls, ceiling and floor is generally parallel and carries particles well. Where a sharp perpendicular object comes out and breaks up this flow, particles are often left. Examples of such surfaces include chair legs, phones on walls and push bars on doors. Often the thinner these objects the more likely they are to collect particles.

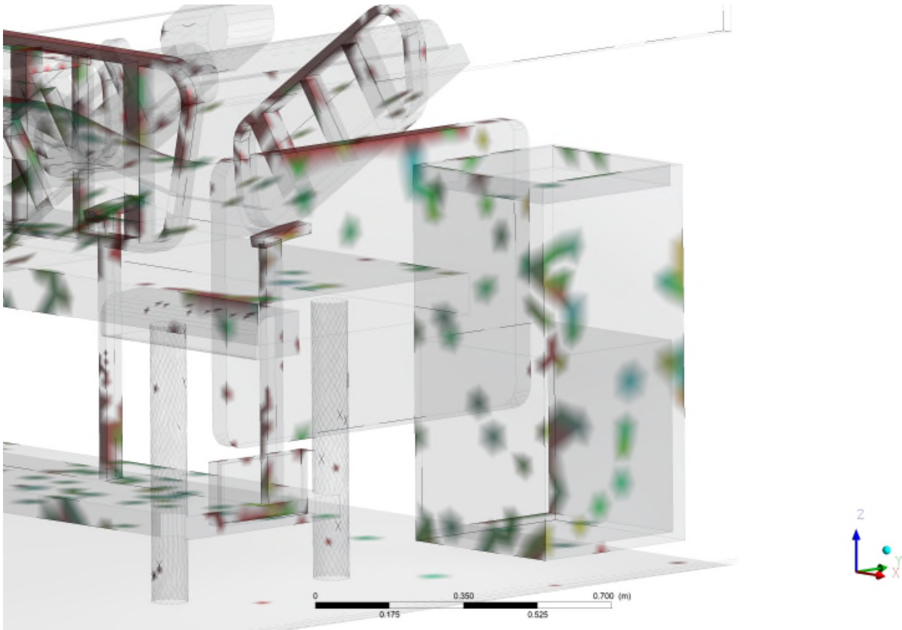
Figure 7: Aerosol collection on chair legs



4.2.3 Around and in small gaps

While a general location, particles often gathered at the entry to and within areas where air flows between two parallel planes. Examples of this include between nearby bins and behind the patient draw unit.

Figure 8: Aerosol collection behind patient draw unit



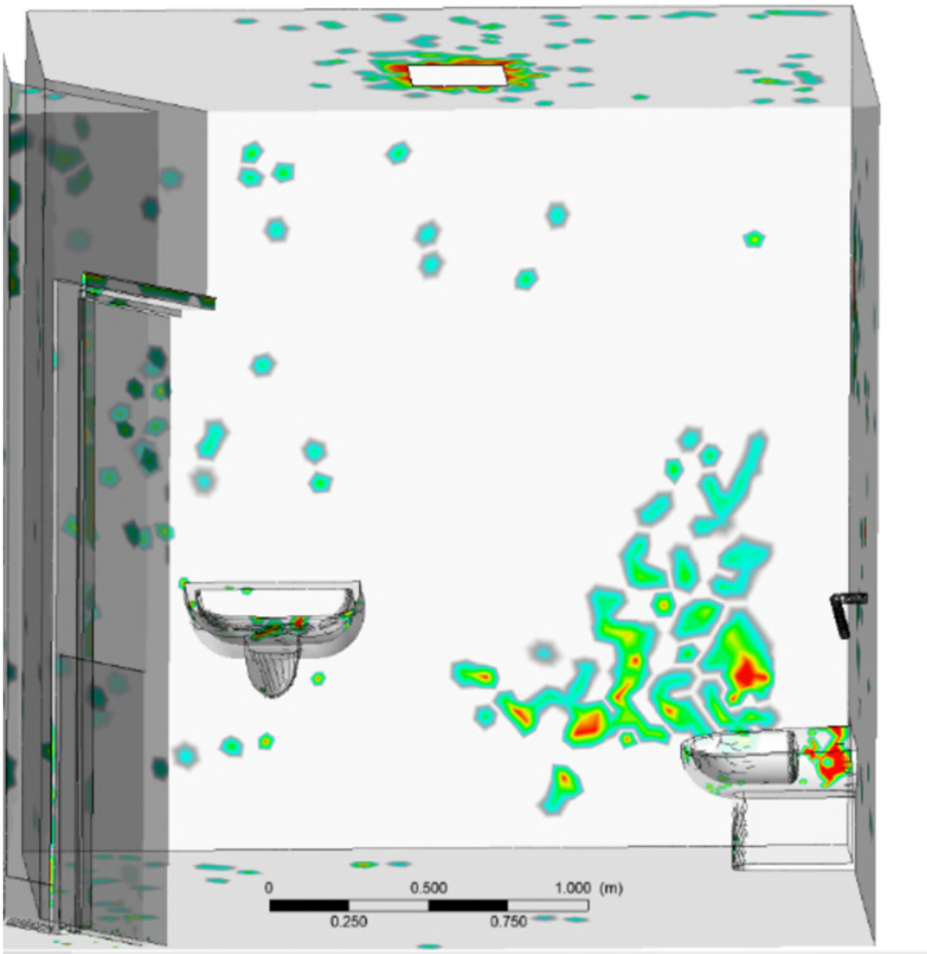
4.2.4 Window and door frames

Deposits can be seen around door and window frames. Deposits also appear on the top surfaces and underside of tables and bed rails. Refer Figure 7 and 8 above.

4.2.5 Ensuite walls and side of the toilet pan.

Deposits in these areas is a result of air movement patterns created by the transfer of air through the undercut of the ensuite door. Refer Figure 9 below.

Figure 9: Deposits on ensuite walls and side of the toilet pan



4.3 Phase 2 - Air movement and patterns

The CFD modelling provided insight to air movement patterns. It identified the importance of barrier air flow for segregation areas (controlled zones) and reinforces advice that controlled volumetric air movement should be configured to encourage a net air movement into the controlled zone.

This configuration can be achieved by adjusting the balance of supply air to extract air by adjusting the fan speed via the VSD (variable speed drive) or adjusting the volume control damper positions. Alternatively increasing the supply air into the adjacent zone will force air towards the controlled zone. The aim is to achieve a net air movement into the controlled zone.

Typically, the differential pressures between the controlled zone and the adjacent space will be low (in the order of -2pa to -5pa). The re-balance should target 150 to 200 litres per second of differential between supply and exhaust per double door into the zone.

The study found that open patient rooms have a greater risk for particle migration to other areas within the ward, when compared with isolated enclosed patient rooms. Open entryways provide an easy pathway for particles to leave the rooms, which can occur even when the amount of supply air and extract air are the same in the room (balanced air flow).

The modelling found that the diffuser selection contributed to a difference in the initial distribution of aerosols in the room with more aerosols remaining suspended when swirl diffusers where simulated in the initial 300 sec after a cough. Once the aerosol is diffuse in the room there is little difference in the two supply air diffusers. This should be a consideration when selecting supply air diffusers to dedicated infectious diseases wards and or dedicated pandemic treatment spaces.

4.4 Summary of findings

Room type	Diffuser type	Isothermal or thermo-dynamic	Return air system	Collected on surfaces	Particles still suspended	Exhausted through room exhaust / return system	Exhausted through amenities exhaust	Particles through entryway	Ref
Isolation	Swirl	Isothermal	Room exhaust system	65%	2%	32%	1%	N/A	Fig 10
Isolation	4-way	Isothermal	Room exhaust system	49%	4%	41%	6%	N/A	Fig 11
ICU	Swirl	Isothermal	Room return system	50%	37%	13%	N/A	N/A	Fig 12
ICU	4-way	Isothermal	Room return system	24%	11%	65%	N/A	N/A	Fig 13
ICU with intubated patient modelled	Swirl	Isothermal	Room return system	24%	75%	1%	N/A	N/A	Fig 14
4 bedroom	Swirl	Isothermal	Corridor return system	18%	2%	N/A	1%	79%	Fig 15
4 bedroom door open	4 way	Isothermal	Room return system	35%	1%	N/A	Trace amount	64%	Fig 16
4 bedroom door closed	Swirl	Isothermal	Room return system	59%	29%	11%	1%	N/A	Fig 17
Single bedroom	4 way	Isothermal	Corridor return system	44%	2%	4%	1%	49%	Fig 18
Single bedroom	Swirl	Thermo-dynamic	Corridor return system	58%	20%	4%	2%	16%	Fig 19

Notes:

1. Isolation rooms have dedicated exhaust systems to atmosphere
2. ICU patient areas will have return/recirculating air system
3. Four bedroom and single bedroom areas will have return/recirculating air system.

4.5 Isolation room

AusHFG reference: 1 BR-IS-N1

Drawings: 01 & 02

The isolation room model includes an anteroom, main isolation room and amenities. Correctly in simulation no particles transferred from the main isolation room back to the anteroom, although note that in real use there is the potential for particles to do so as doors are opened and turbulence created.

4.5.1 Observations

- The higher air change rate of the isolation room means the amount of particles suspended in the room at five minutes was generally lower than all other models (where particles did not flow out through an opening into an adjacent area).
- In a properly designed isolation room the main room exhaust accounts for far more particle removal than the amenities exhaust. This is due to two factors; the far higher flow rate through these grilles and the proximity to the patient source. Note that when the patient enters the amenities area and coughs, more particles will be collected by the exhaust there.
- While the model simulated a cough in the main room with correct airflow balances, during actual usage with anteroom doors opening there is the potential for particles to become trapped on surfaces. This simulation does not alleviate the requirement for anteroom surfaces to also be treated.

4.6 Intensive care unit

AusHFG reference: 1 BR-IC

Drawings: 03, 04 & 05

The intensive care room is unique in the amount of obstructions that are within the room from extra equipment. This includes any items next to the bed and arms from the pendant above.

4.6.1 Observations

- The four-way diffuser from particle locations at 300 seconds was able to remove more aerosol than the swirl diffuser. Care should be taken in applying these findings, as a driving factor is the effectiveness of each diffuser in mixing air. The four-way diffuser directs flow along the ceiling (via coanda effect) drawing particles towards the return grille, while the swirl diffuser more evenly mixed air. In an actual HVAC application, this is likely to mean greater discomfort for occupants in rooms with four-way diffusers, which in turn may lead to ramping up of HVAC systems to achieve the same internal conditions. Ramping up systems will lead to less energy efficiency and greater mixing, achieving a similar dispersal result.
- The intubated model proved to be very effective at distributing large amounts of particles quickly. As the flow was continuous, minor fluctuations in air were able to spread aerosols well. While it is known that intubation can be a hazardous process for staff, this model emphasises how quickly particles can accumulate given a continuous insertion rate.

4.7 Standard four bedroom

With the four bed and single person bedroom findings it is first important to gain an understanding of the types of HVAC system configurations that may be encounter within these general ward spaces given they are not designed to treat infectious patients. Whilst supply air and exhaust air locations and approaches may be consistent across multiple ward areas, the return air path options back to the air handling unit may vary significantly. These include the following (summary of return air path) options:

- return air from bedroom area (balanced system)
- corridor return system – with return air grilles placed with the communal (corridor) zones of the ward (air-handling) system.

Two of these options were modelled as part of this CFD analysis with the four bedroom and single bedrooms spaces. These included the ducted corridor return system and the ducted return from bedroom area (balanced) system.

4.7.1 Corridor return system

AusHFG reference: 4 BR-ST

Hot Spot Drawings: 06

4.7.1.2 Observations

See 4.8.1 below.

4.7.2 Standard 4 bed – Return air within room (balanced)

AusHFG reference: 4 BR-ST

Drawings: 07 & 08

4.7.1.2 Observations

- With its large area, the entryway provided an easy pathway for particles to leave the model, even with a balanced system. These models therefore illustrated how effectively aerosol from one room can flow out to communal spaces if there is no barrier.
- When a room is designed exactly symmetrically, including with airflow patterns, it is reasonable that aerosols will generally deposit on the side they initiated at. This can be observed with the particle streamlines shown in drawings in plain view. In a simulated environment this will be far more pronounced than reality, where further factors such as occupants moving will mix air. Regardless, more attention should be paid to areas when cleaning on the side of the room with a sick occupant.
- It is generally considered good HVAC design to place diffusers closer to the perimeter of a building where loads will be higher, with return air taken from internal spaces. These models suggest that more careful consideration of airflow direction in hospitals may be necessary, especially where rooms will have open doorways.
- There is significant aerosol movement from the 4 bedroom into the corridor. With multiple rooms in a ward, this will lead to significant volumes of aerosol circulating and settling in the corridors seemingly remote from the sources.

4.8 Standard single bedroom findings

AusHFG reference: 1 BR-ST-A1

Drawings: 09 & 10

Similarly, to the standard four bed room this room was initially modelled with an open door. With a swirl diffuser, this scenario also caused most particles to leave the model. When four way diffuser was instead simulated, it pushed the cough early in the simulation away from the door allowing for better dispersal.

To further investigate this scenario, a thermodynamic model (introduction of external heat load) was then run with the swirl diffuser again. A heat load was applied to the window and external walls and supply air was given a temperature to balance this load at 24°C. No other changes were made. This model illustrated a similar pattern to other scenarios with regard to deposit patterns, but also showed small amounts of particles collecting on nearly all surfaces in the space.

4.8.1 Observations

- Key observations within the single bedroom aligned with the findings of the four bedroom simulations. This is reflected in aerosol deposit locations and air pattern movement through the doorway.
- A thermodynamic model, (added external heat load) generates a more complex air system. However, modelling has showed that similar hot spot patterns were generated, validating the use of isothermal spaces (no external heat loads added) in the earlier modelling. The modelling shows that the dominant air movement patterns are created by the supply diffusers.
- A key point is that this report identifies areas where particles are more likely to gather, it does not however identify spots where they will not. There is a possibility that any surface in a contaminated room will have some amount of aerosol deposit on it.

5 Approaches for healthcare facilities

5.1 Infection prevention and control strategies

There are a range of infection prevention and control strategies to minimise the risk of transmission in the built environment. Resources, information and guides for the care of patients and at-risk groups during a pandemic can be found at <https://www.dhhs.vic.gov.au/infection-prevention-control-resources-covid-19

5.1.1 Environmental controls - cleaning and disinfection

Room contamination from this study has shown there is deposition of infectious drops in various surfaces in patient/resident/client shared rooms. In addition to cleaning frequently touched surfaces, the following items should also be included in terminal clean and considered in daily cleaning routine or before handling. Commonly contaminated surfaces found in this study include heavy and dense contamination on frequently touched and other room surfaces:

- patient zone
- chair legs
- bedside table
- phones on walls
- push bars on doors
- bed rails
- intravenous stands
- nearby bins
- under flatbed trolleys
- sides of bed
- bed table
- bedside cupboard
- exhaust vents
- equipment (deposition of infectious drops)
- vertical and horizontal surfaces in rooms

Minimal contamination:

- walls
- windows
- floor and outside the corridor in the proximity to the room with door open

Sparse contamination:

- ceiling

Cleaning strategy:

- cleaning must focus on room surfaces both vertical and horizontal, with a focus on frequently touched surfaces, and including exhaust vents, and other minimally touched surfaces (such as dispensers attached to walls) which are usually less frequently cleaned
- options to use peroxide decontamination systems should be considered
- use TGA approved cleaning and disinfectant chemical/wipes to clean surfaces with bactericidal and virucidal claim
- consider the use of longer gloves for cleaning staff to ensure full coverage of gown sleeves
- use appropriate PPE when performing cleaning tasks
- establish a cleaning schedule as evidence of cleaning
- monthly auditing system to ensure cleaning standards are monitored and corrective action is taken

5.1.2 Equipment management

- Declutter shared rooms and leave essential equipment
  - Remove excess furniture in isolation rooms as they may be potentially contaminated by dense deposition of infectious deposits.
  - Only essential equipment should be inside the room and post discharge, the items should be discarded if they cannot be safely cleaned (e.g. trolleys, consumables etc.)
- Provide dedicated equipment if practical, otherwise clean shared equipment between use. Consider use of disposable equipment if practical.
  - All shared equipment must be decontaminated between patients/residents/clients using approved TGA listed cleaning and disinfected products.

5.1.3 Air handling implementation strategies

The *HVAC system strategies to airborne infectious outbreaks* provides ventilation and air cleaning strategies to reduce risk to respiratory infections such as COVID-19 and supports this HTA. <https://www.vhba.vic.gov.au/health-technical-advice-HVAC-system-strategies-airborne-infectious-outbreaks>

Room space air replacement (ventilation rate) ensures air in confined spaces is replaced every hour to ensure adequate ventilation.

The effect of evaporation, light, humidity and temperature on the concentration and infectivity (capacity to infect and reproduce) of the pathogen needs to be further researched to make conclusions on the threat level of the airborne route.

Recirculation of air within zones with confirmed infected cases or zones with suspected infected cases, into other areas such as non-affected patients/residents/clients' rooms and food preparation areas should be avoided.

Where health facilities have been zoned to accommodate dedicated confirmed or suspected cases, recirculation ventilation systems or mixing indoor air and outdoor may cause turbulence of air flow with air being recirculated back into other rooms which should be avoided. Dedicated exhaust vents and separate air handling units should be installed and maintained as per manufacturer's instructions.

Recirculated air saves electricity usage however may lead to delivery of insufficient fresh air and consequent rapid dilution of infective particles.

Where practical, ventilation systems supplying clean outside fresh air should be operated continuously with the maximum supply airflow rate to prevent potential exposure to room occupants.

Isolation rooms should have doors closed at all times to prevent aerosols from migrating into the corridor space and adjacent rooms.

Shared quad or double rooms should have barrier curtains drawn between bed spaces to reduce projectile movement of aerosols generated by coughing/sneezing patients/resident/clients.

Implement regular scheduled service maintenance of air dampers and regular cleaning schedules

Where shared rooms rely on natural ventilation and not a building HVAC system:

- increase ventilation with outside air by opening windows, screened doors and by pulling curtains back (drawing curtains)
- avoid use of portable fans
- install HVAC units with outside air intake units located outside the shared rooms
- ensure filter change and preventive maintenance of installed HVAC is in place.

5.1.4 Patient/resident/clients room placement strategy

Safer Care Victoria (SCV) has developed recommendations about healthcare worker infections based on lessons learnt in the second wave. Further details can be found on the Clinical guidance and resources - coronavirus (COVID-19) page of the former Department of Health and Human Services website <https://www.dhhs.vic.gov.au/clinical-guidance-and-resources-covid-19>.

The following outlines the proposed standards for:

- the number of patients in COVID-19 wards (based on bed capacity and the type of patient)
- cleaning procedures for COVID wards
- rostering of staff working in COVID wards including their deployment to other facilities/wards.
- best practice approaches to the use of PPE.

6 Conclusion

Most healthcare ventilation systems are designed to mix the air in the space to provide uniform environmental conditions. Aerosols are carried by the ventilation system until they collide with a surface, at which point they stick. This is a highly effective distribution mechanism for aerosols.

Rooms or spaces with a net negative airflow will act as collection points for aerosols (i.e. ensuite bathrooms).

Significant aerosol deposits can be found in non-obvious locations such as around extract and transfer grilles in walls and ceilings, chair legs, around waste bins, curtain rails and the patient television screen. Unexpected surfaces can also include the underside edge of tables, patient drawer units and wash hand basins.

The selection and placement of diffusers can have significant impact on the aerosol distribution anywhere within the controlled zones. Once inside a controlled zone the air patterns created by the ventilation system has a significant influence over how aerosols are distributed.

7 Acknowledgements

The simulations have been carried out using Ansys CFX 2020 R2.

The Victorian Health Building Authority wishes to acknowledge the contribution made by:

- LCI Consultants
- Infection Prevention and Control Advice Cell, Department of Health
- Safer Care Victoria
- Health care specialists at Barwon Health and Western Health
- Department staff who have contributed to the production of this Health Technical Advice.

8 References and bibliography

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Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care

Santarpia JL, Rivera DN, Herrera VL, Morwitzer MJ, Creager HM, Santarpia GW, Crown KK, Brett-Major DM, Schnaubelt ER, Broadhurst MJ, Lawler JV, Reid SP, Lowe JJ. (29 July 2020) 'Aerosol and surface contaminiation of SARS-CoV-2 observed in quarantine and isolation care', Scientific Reports 10, 12732 <https://doi.org/10.1038/s41598-020-69286-3>

Droplet fate in indoor environments, or can we prevent the spread of infection?

Morawska, L. (9 June 2006) 'Droplet fate in indoor environments, or can we prevent the spread of infection?', *Indoor Air Vol 16, Issue 5, pp. 335-347* <https://doi.org/10.1111/j.1600-0668.2006.00432.x>

Appendix 1: Key findings

Isolation room findings

AusHFG reference: 1 BR-IS-N1

Drawings: 01 & 02

The isolation room model includes an anteroom, main isolation room and amenities. Correctly in simulation no particles transferred from the main isolation room back to the anteroom, although note that in real use there is the potential for particles to do so as doors are opened and turbulence created.

Figure 10: Single isolation room – Swirl diffuser particle locations at 300 seconds

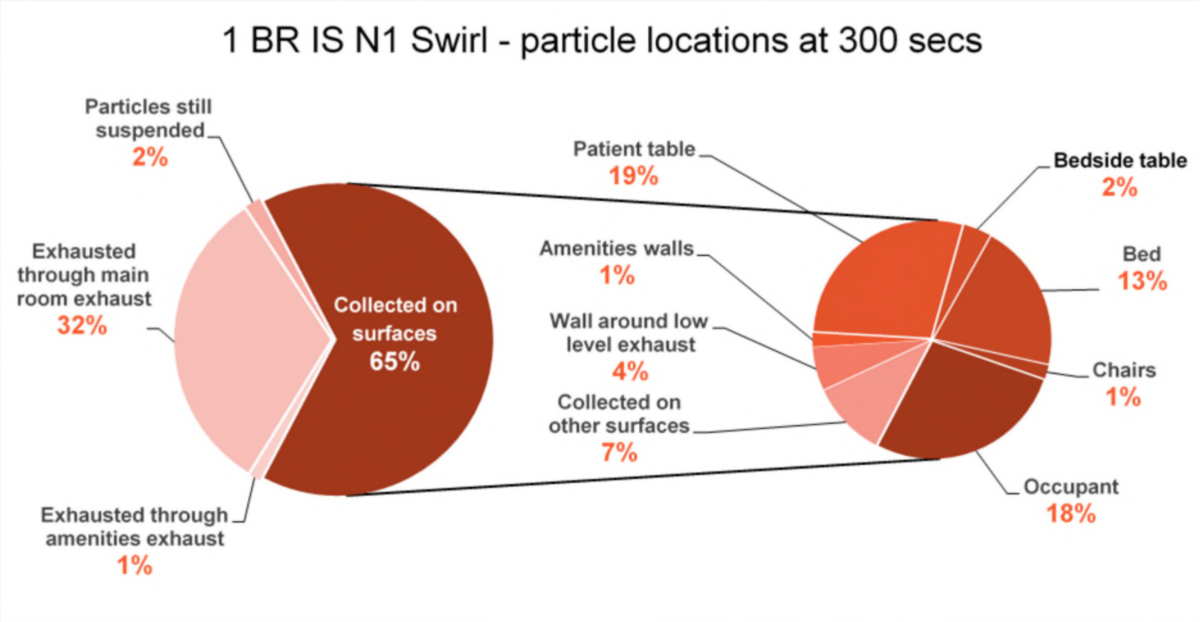
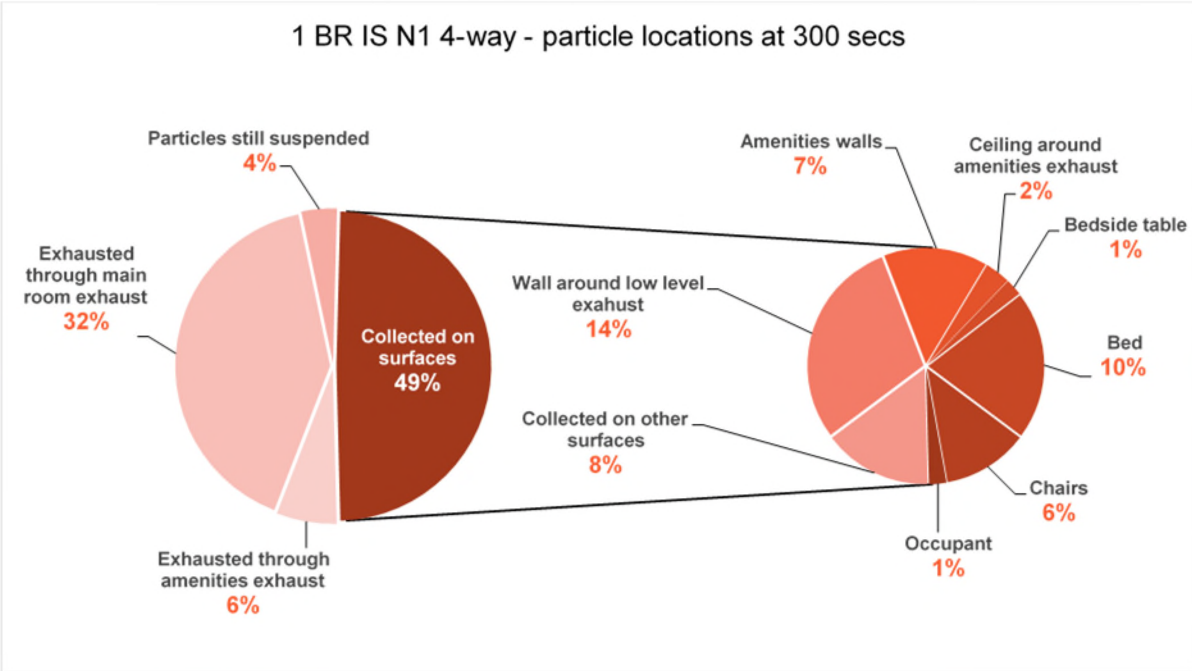


Figure 10 above shows that at 300 seconds with a swirl diffuser 32 per cent of particles are exhausted through the main room exhaust, with 65 per cent remaining within the room collected on surfaces.

In comparison, a four-way diffusers exhausts nine per cent more particles from the room than a swirl diffuser at 300 seconds (four-way diffuser: 41 per cent). There is only 49 per cent of particles collected on surfaces at 300 seconds with a four-way diffuser, this is a reduction of 17 per cent comparted to a swirl diffuser.

Figure 11 below shows the findings for a four-way diffuser. It's noted that more particles are suspended in the air (increase of two per cent) and exhausted through amenities exhaust (increase of five per cent) in four-way diffusers than swirl diffusers in a single isolation room.

Figure 11: Single isolation room – 4-way diffuser particle locations at 300 seconds



Intensive care bed findings

AusHFG reference: 1 BR-IC

Drawings: 03, 04 & 05

The intensive care room is unique in the amount of obstructions that are within the room from extra equipment. This includes any items next to the bed and arms from the pendant above.

Figure 12 shows that at 300 seconds with a swirl diffuser, 37 per cent of particles are still suspended in the room, with 50 per cent remaining within the room collected on surfaces.

In comparison, a four-way diffusers exhausts 65 per cent of particles through the exhaust grille leaving only 11 per cent of particles suspended at 300 seconds. This is a reduction of 26 per cent of particles suspended in the air with a four-way diffuser.

The four-way diffuser collected only 24 per cent of particles on surfaces at 300 seconds compared to 50 per cent of particles collected on surfaces with a swirl diffuser. This is reduction of 26 per cent. Figure 13 below shows the findings for a four-way diffuser.

Figure 12: Single intensive care room – Swirl diffuser particle locations at 300 seconds

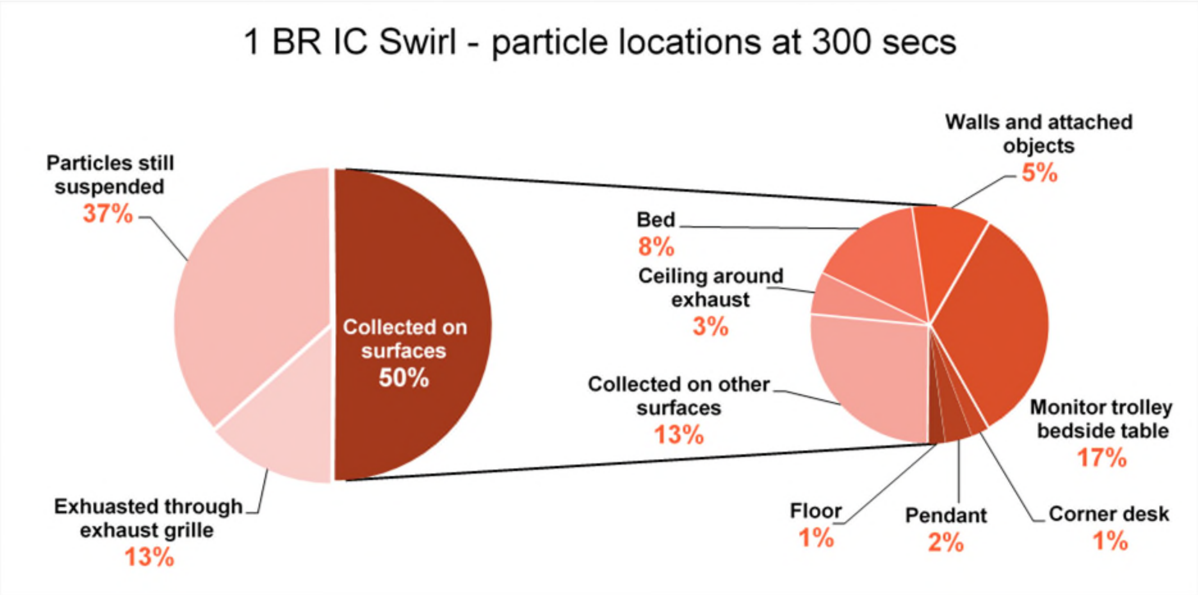
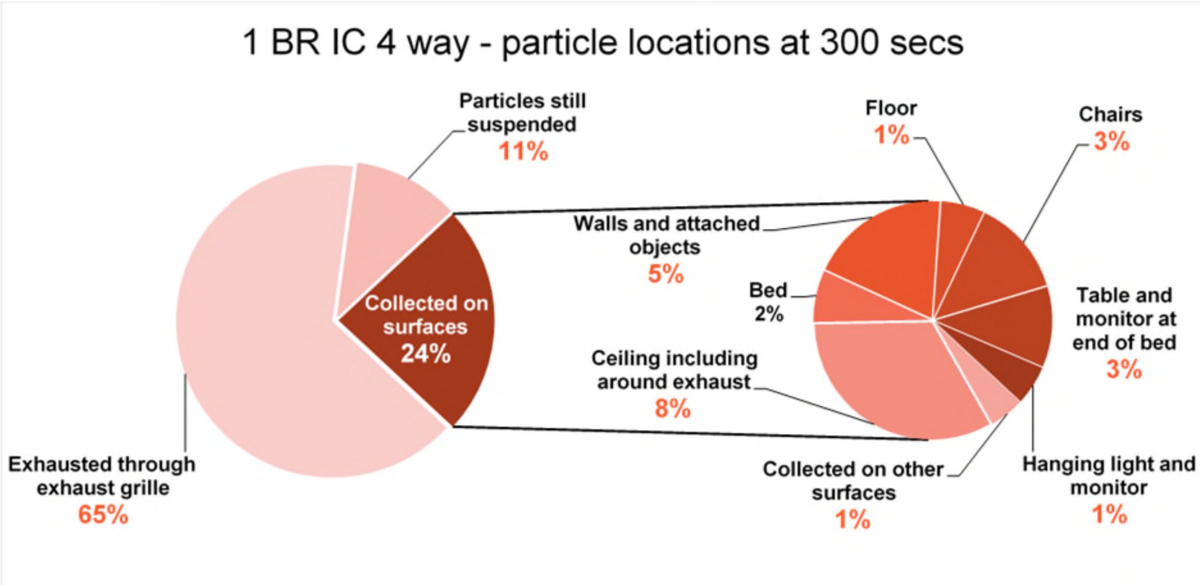


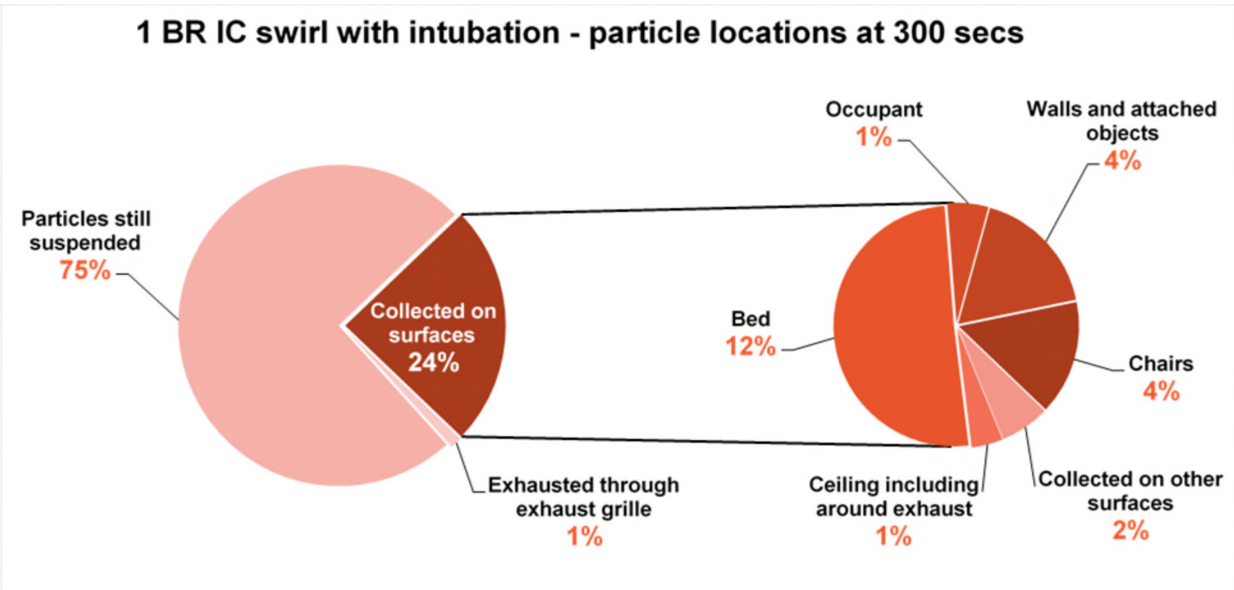
Figure 13: Single intensive care room – 4-way diffuser particle locations at 300 seconds



The model with an intubated patient is an estimate on the number of particles only for comparative purposes. For this simulation, a continuous stream of particles at five per cent the flowrate of a cough was inserted into the model. While this may seem like far less aerosol, with a cough only running for 0.25 sec the same mass is inserted into the intubation model in only five secs.

From research, the same observation is not made with general talking or breathing, as particle sizes created from these are larger and readily fall out of air streams.

Figure 14: Single intensive care room – 4-way diffuser particle locations at 300 seconds with intubation



Standard four bedroom findings

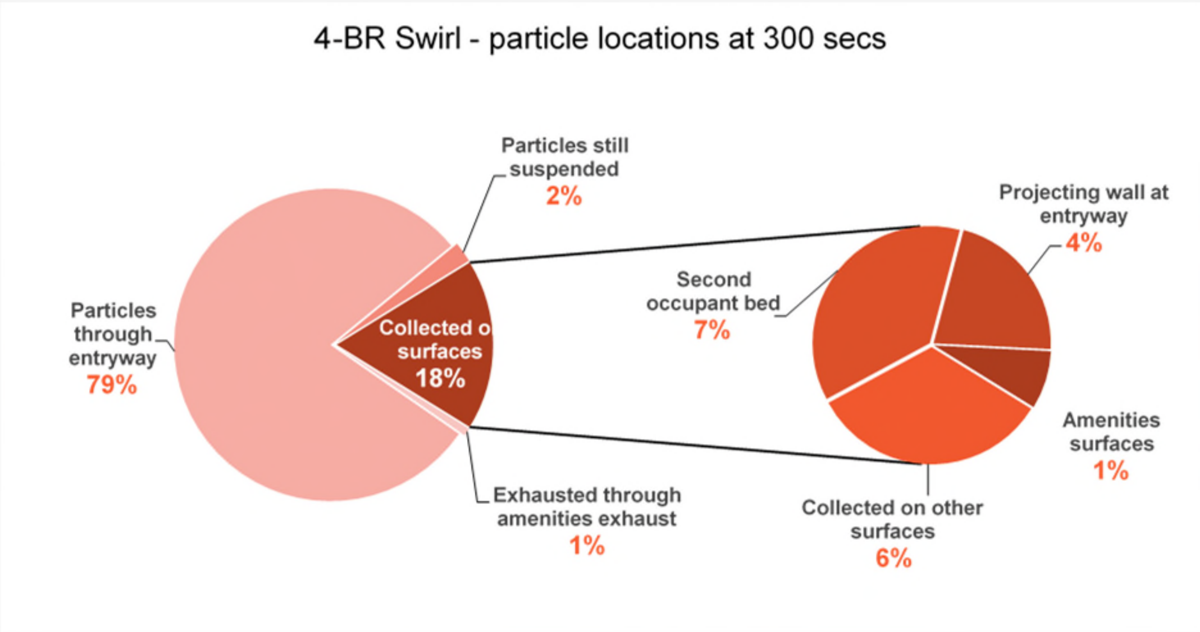
Corridor return system

AusHFG reference: 4 BR-ST

Drawings: 06

The four bed single person bedroom was initially designed to include a common return air duct from an adjacent corridor. This was included with a large open boundary at the entryway into the room. This design is not uncommon in general ward areas where patients are assumed to be non-infectious and it simplifies ductwork runs. This design is seen to be effective at allowing aerosol to pass from the room straight into the adjacent space as shown on Figure 15 below.

Figure 15: Four person room corridor return – swirl diffuser particle locations at 300 seconds



Standard 4 bed – Return air within room (balanced)

AusHFG reference: 4 BR-ST

Drawings: 07 & 08

The next two simulations were implemented with balanced local systems (so that supply air = return air + amenities exhaust). Even with a balanced system, particles still flowed out to the corridor, with local inflows and outflows at the entryway developing. This emphasises the importance of creating physical barriers between areas in wards, especially where aerosol spread diseases may be present.

A final simulation was run where the door was made a closed boundary, with particles only circulated through the room. In this model similar deposit patterns to other simulations were observed, with areas such as beds and curtain rails collecting large amounts. The following two figures summarise the main differences between door open and door closed conditions for with the four bedroom assessments.

Figure 16: Four person room balanced airflow with door open – 4-way diffuser particle locations at 300 seconds

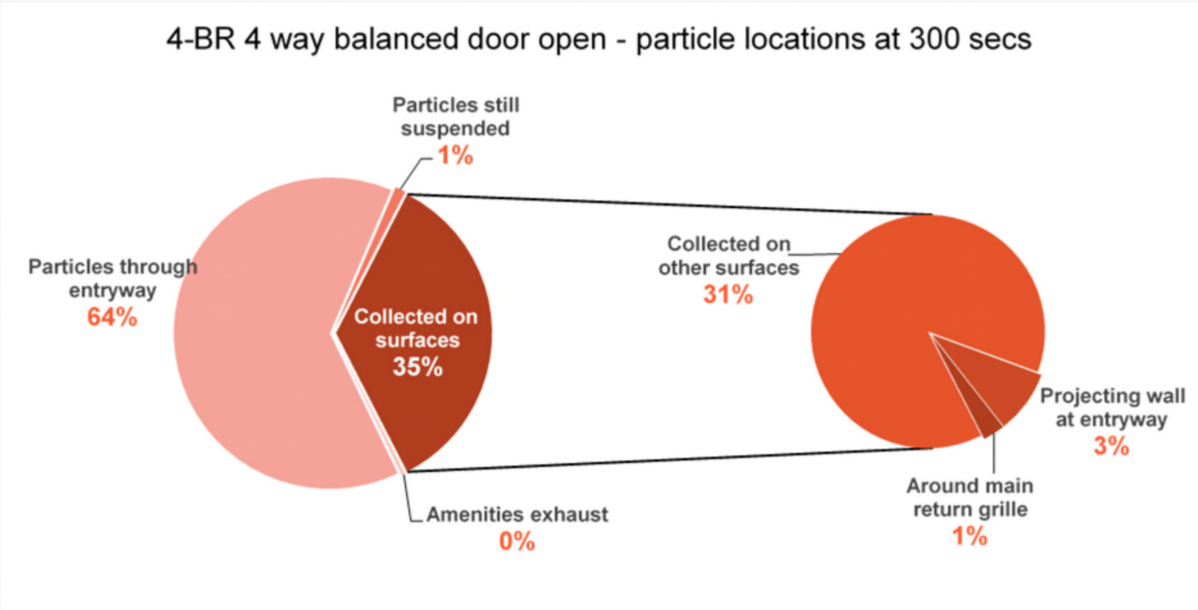
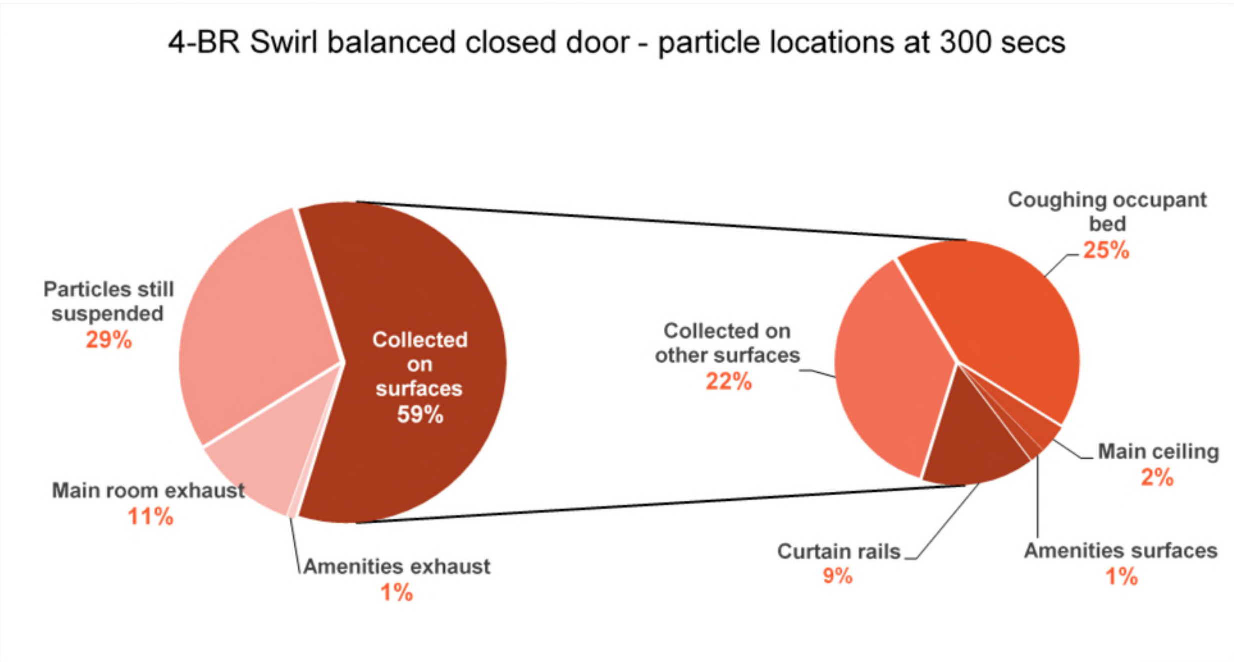


Figure 17: Four person room balanced airflow and closed door – swirl diffuser particle locations at 300 seconds



Standard single bedroom findings

AusHFG reference: 1 BR-ST-A1

Drawings: 09 & 10

Similarly, to the standard four bed room this room was initially modelled with an open door. With a swirl diffuser, this scenario also caused most particles to leave the model. When four way diffuser was instead simulated, it pushed the cough early in the simulation away from the door allowing for better dispersal. (see Figure 18).

To further investigate this scenario, a thermodynamic model (introduction of external heat load) was then run with the swirl diffuser again (see Figure 19). A heat load was applied to the window and external walls and supply air was given a temperature to balance this load at 24°C. No other changes were made. This model illustrated a similar pattern to other scenarios with regard to deposit patterns, but also showed small amounts of particles collecting on nearly all surfaces in the space.

Figure 18: Single room airflow – 4-Way diffuser particle locations at 300 seconds

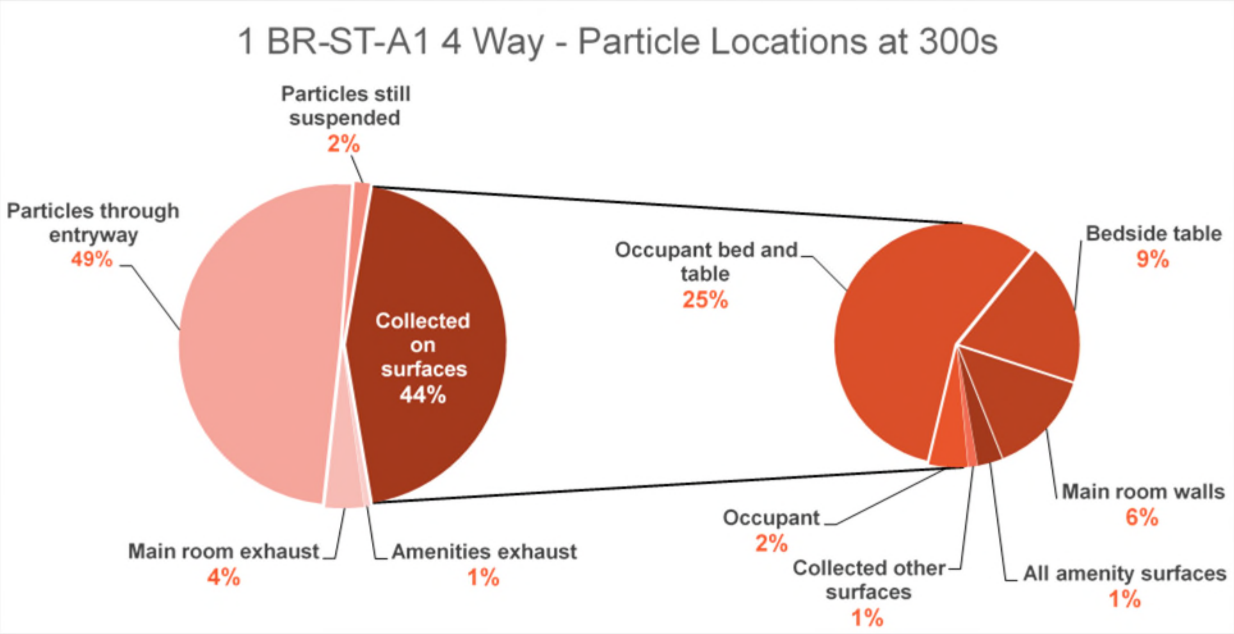
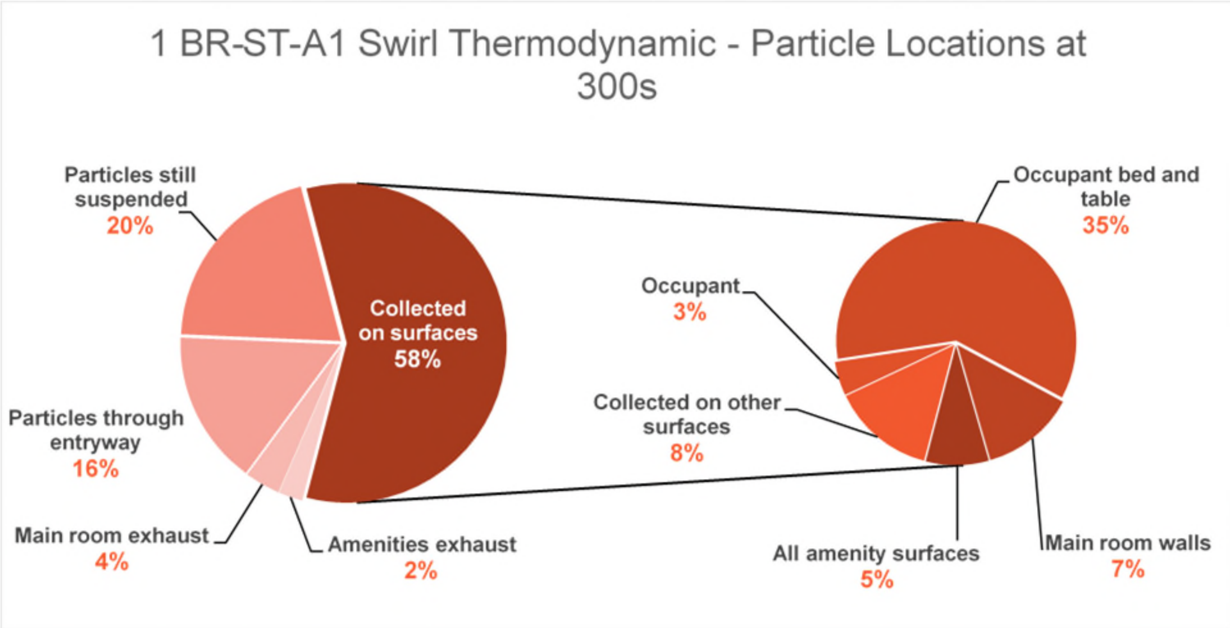


Figure 19: Single room airflow – Swirl thermodynamic particle locations at 300 seconds



Appendix 2: Technical information

CFD information

- Solver: CFX
- Version: Ansys 2020 R2

Particle source

- Cough particle diameter distribution:
  - Normal in diameter by mass
  - Mean: 5e-7 m
  - Minimum: 4e-7 m
  - Maximum: 5.5e-5 m
  - Standard deviation: 1e-7 m
- Cough insertion characteristics:
  - Particle Mass Flow Rate: 7.55e-7 kg/s
  - Velocity: 3.93 m/s
  - Air input: 7.5e-3 kg/s

BR-IS-N1

- Supply air anteroom: 65 L/s
- Supply air main room: 145 L/s
- Exhaust air anteroom: 65 L/s
- Exhaust air main room: 310 L/s
- Exhaust air amenities: 60 L/s
- Reference pressure location: Anteroom transfer grille

1BR-IC

- Supply air: 128 L/s
- Reference pressure location: Transfer grille

4BR-ST

- Supply air: 254 L/s
- Exhaust air: 100 L/s (50 each amenities)
- Main room exhaust: 154 L/s
- Reference pressure location: Corridor

1BRST-A1

- Supply Air: 84 L/s
- Reference pressure location: Transfer grille

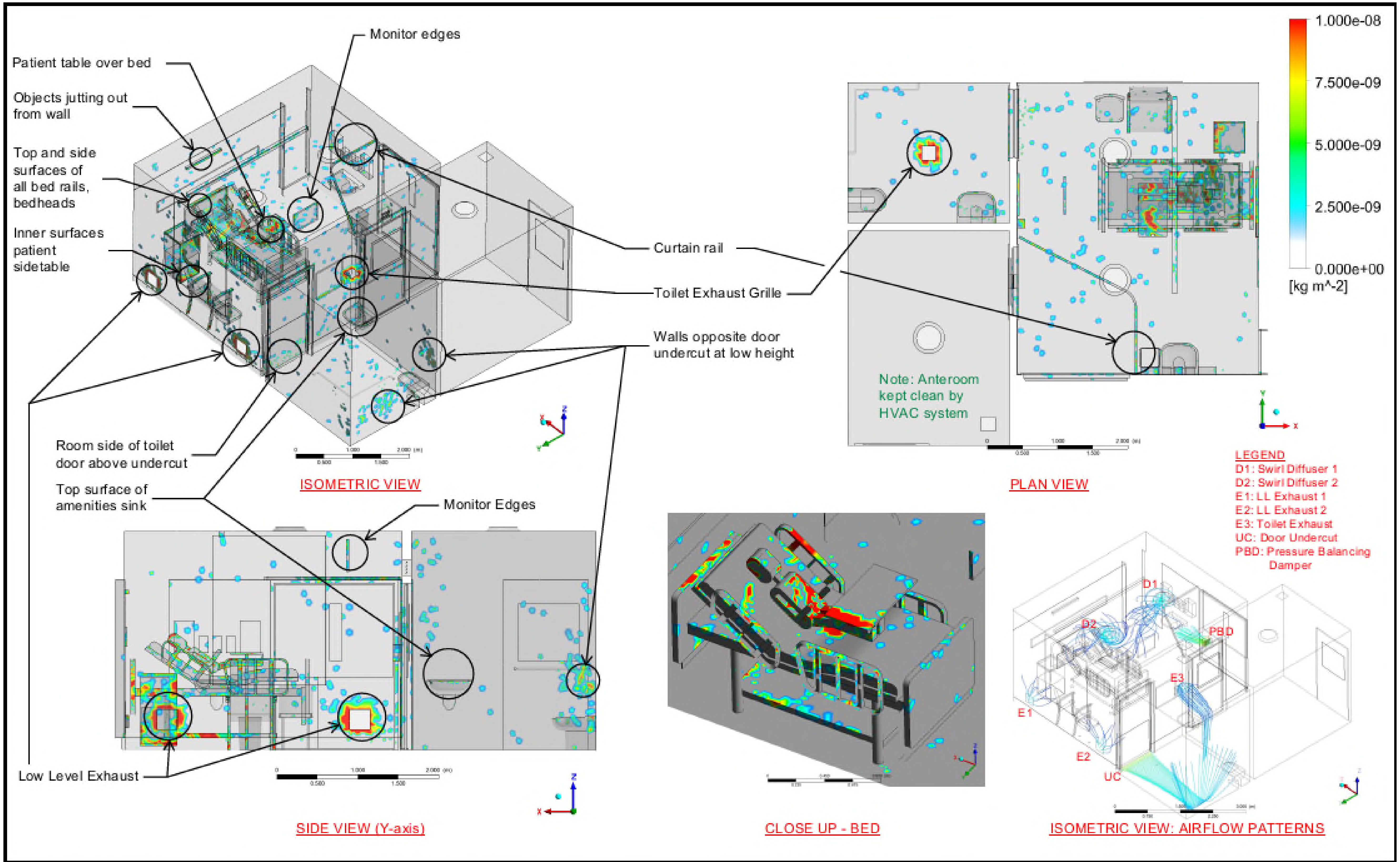
Appendix 3: Air changes/hour contaminant removal rate

Refer to the Centers for Disease Control and Prevention (CDC) *Guidelines for Environmental Infection Control in Health-Care Facilities* (2003) Appendix B. Air <https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html#tableb1>

ACH	Time (mins.) required for removal 99% efficiency	Time (mins.) required for removal 99.9% efficiency
6	46	69
8	35	52
10	28	41
12	23	35

Appendix 4: Drawings

Drawing [01] 1 BR IS N1 Swirl Diffuser [Rev02]



Rev	Date	Amendment Description	By	Chk
01	24.08.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW

Client: Victoria State Government — Health and Human Services

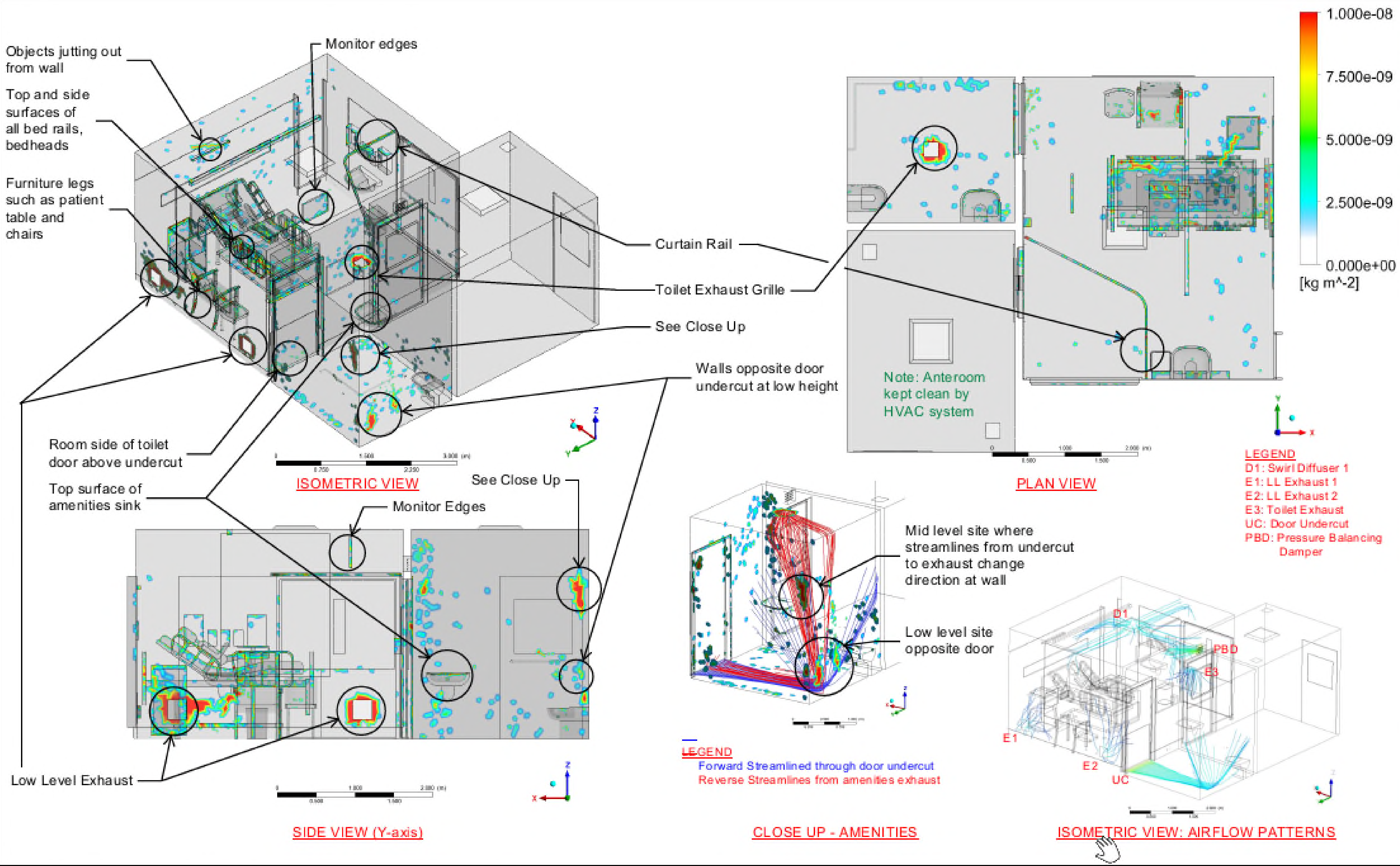
Consulting Engineer: LCI — Lehr Consultants International (Australia) Pty Ltd

Project: COVID AEROSOL STUDY

Drawing Title: 1BR-IS-N1 Swirl Diffuser CFD Results

Drawn: SC/SW
Checked: SW
Approved: -
Date: 11.09.20
Scale: AS SHOWN
Sheet No.: 1
Job No.: 200647
Drawing No.: 01
Revision: 02

Drawing [02] 1 BR IS N1 4 Way Diffuser [Rev02]



Rev	Date	Amendment Description	By	Chk
01	24.08.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW

Client: VICTORIA State Government — Health and Human Services

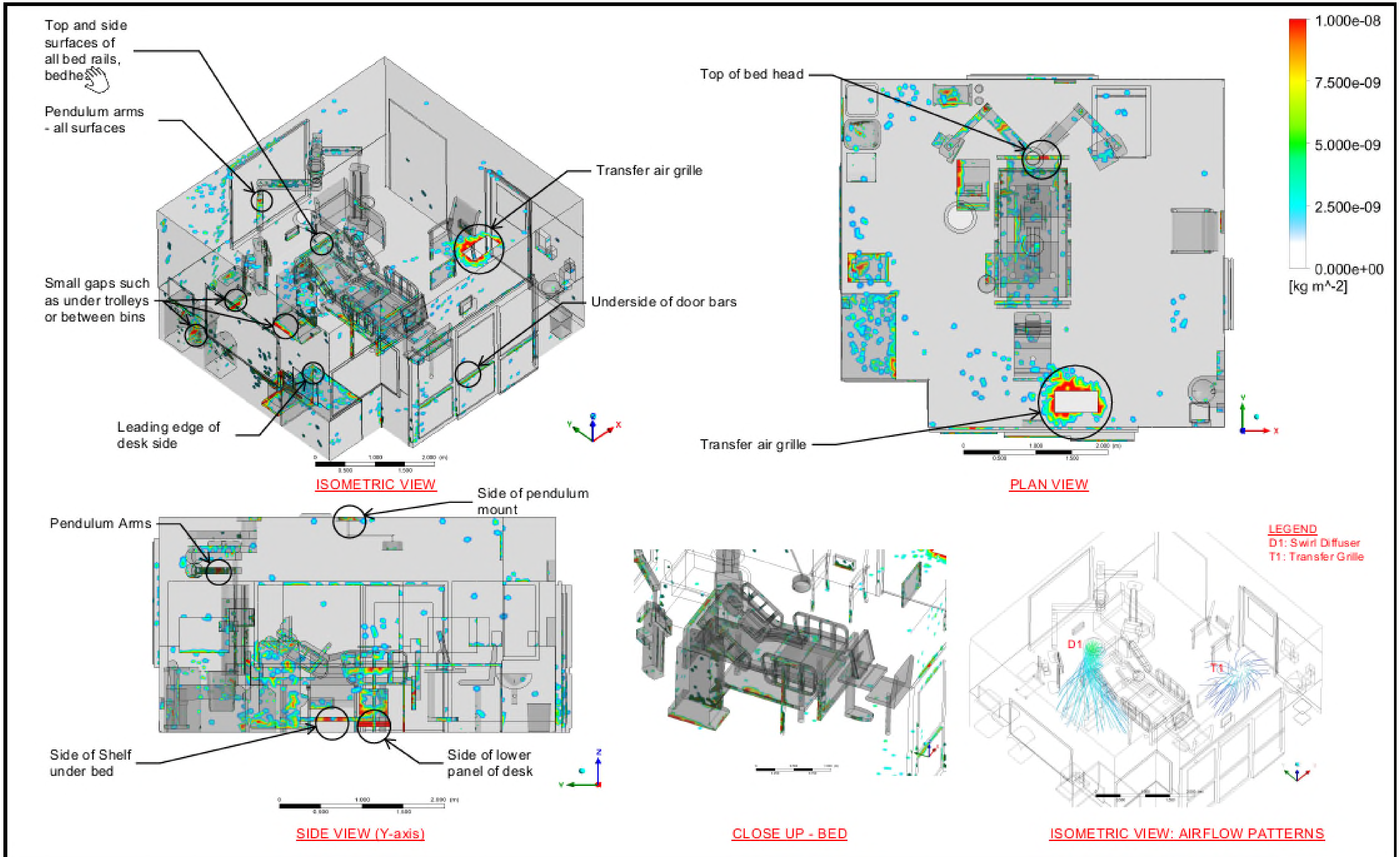
Consulting Engineer: LCI — LEHR CONSULTANTS INTERNATIONAL (AUSTRALIA) PTY LTD

Project: COVID AEROSOL STUDY

Drawing Title: 1BR-IS-N1 4 Way Diffuser CFD Results

Drawn: SC/SW
Checked: SW
Approved: -
Date: 11.09.20 | Scale: AS SHOWN | Sheet No.: 1
Job No.: 200647 | Drawing No.: 02 | Revision: 02

Drawing [03] 1 BR IC Swirl Diffuser [Rev02]



Rev	Date	Amendment Description	By	Chk
01	24.08.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW

Client: VICTORIA State Government — Health and Human Services

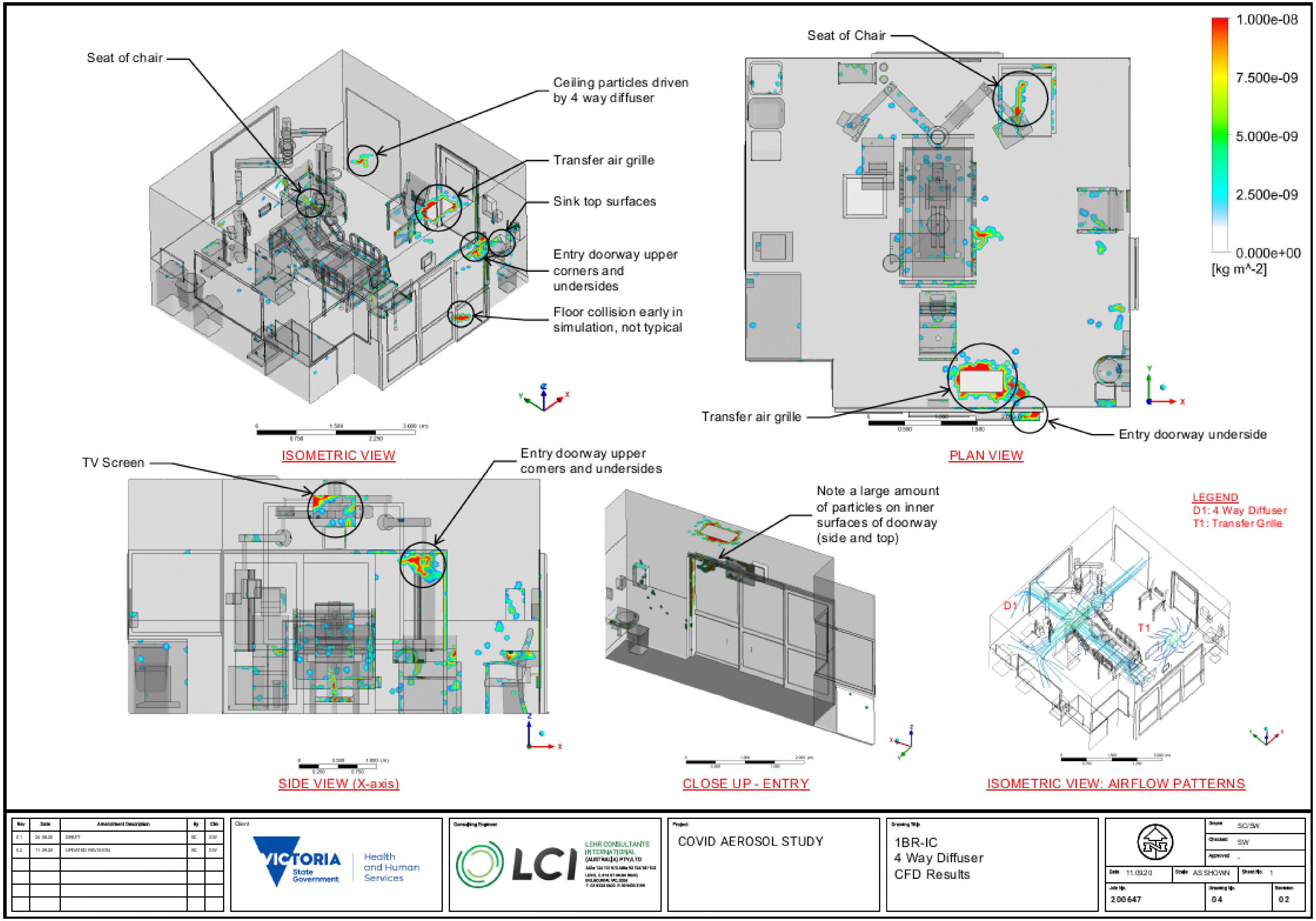
Consulting Engineer: LCI — LEHR CONSULTANTS INTERNATIONAL (AUSTRALIA) PTY LTD

Project: COVID AEROSOL STUDY

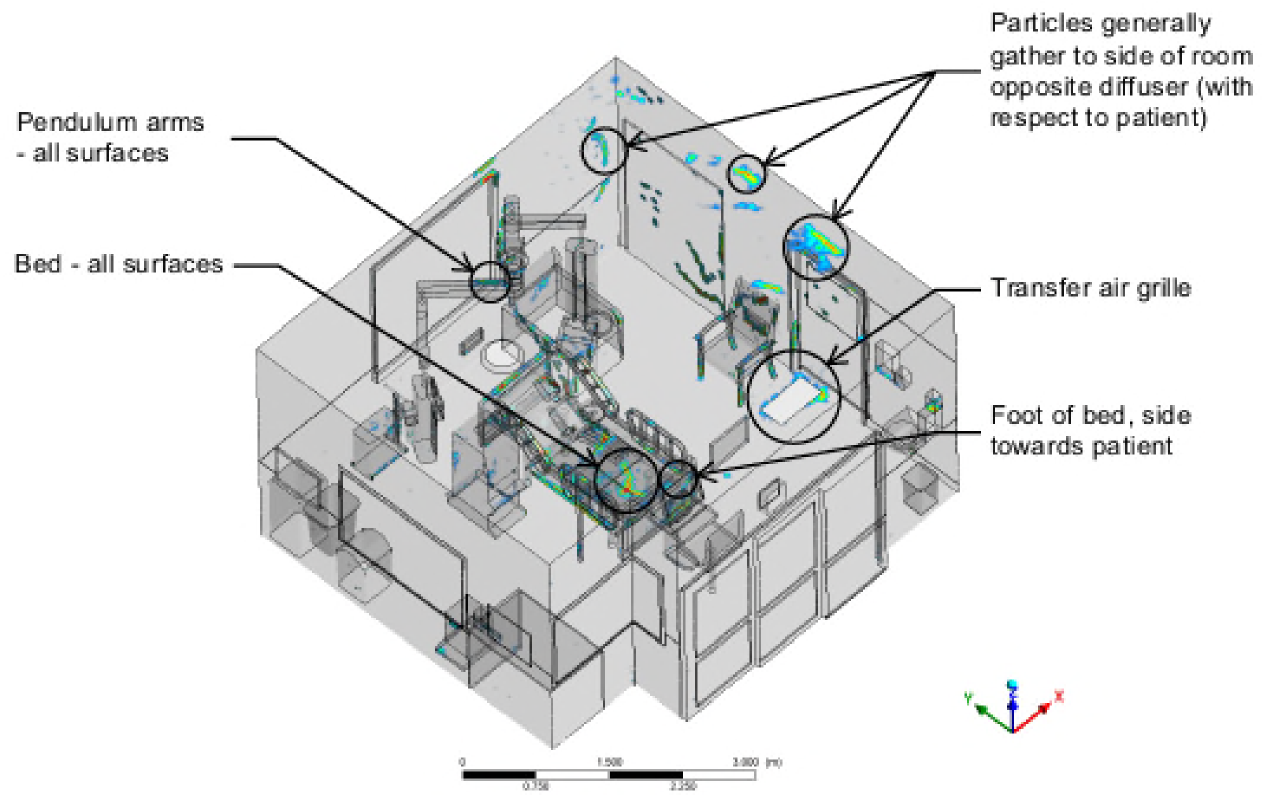
Drawing Title: 1BR-IC Swirl Diffuser CFD Results

Drawn	SC/SW
Checked	SW
Approved	-
Date	11.09.20
Scale	AS SHOWN
Sheet No.	1
Job No.	200647
Drawing No.	03
Revision	02

Drawing [04] 1 BR IC 4 Way Diffuser [Rev02]

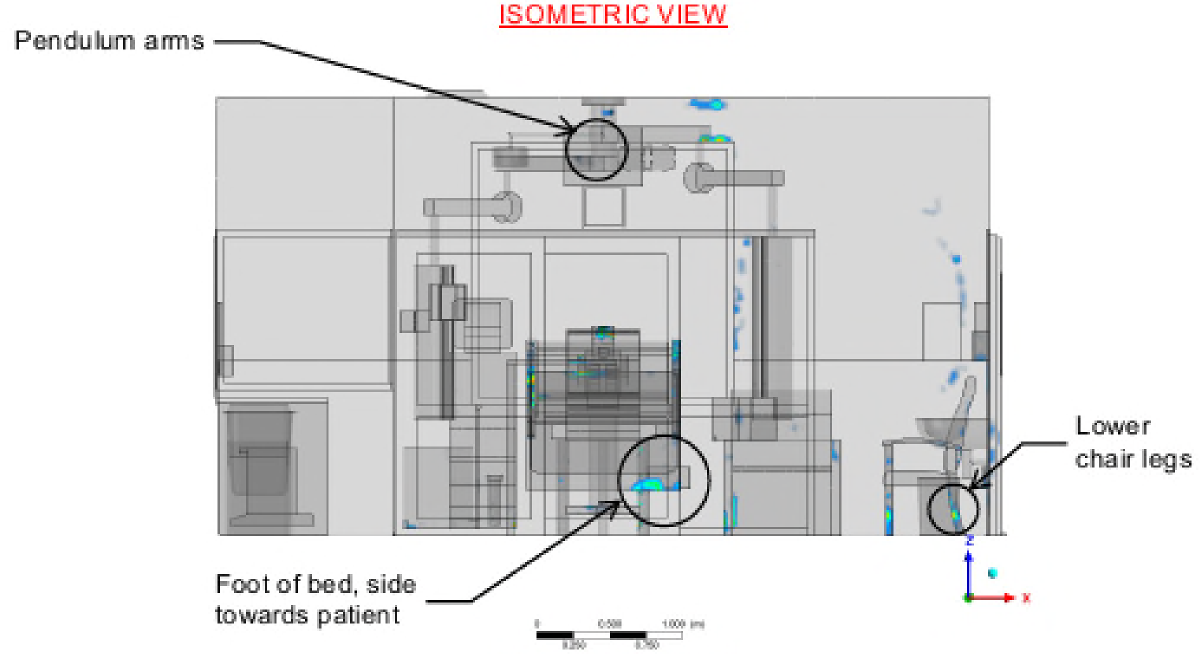


Drawing [05] 1 BR IC Swirl Diffuser with Intubation [Rev02]

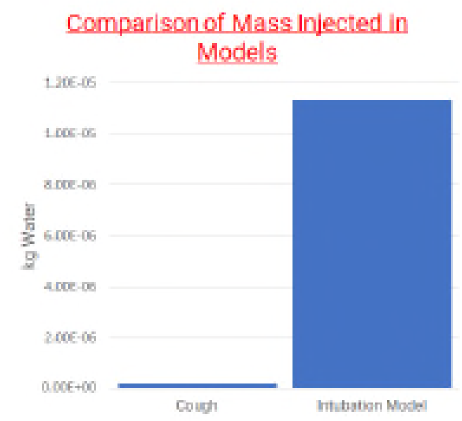


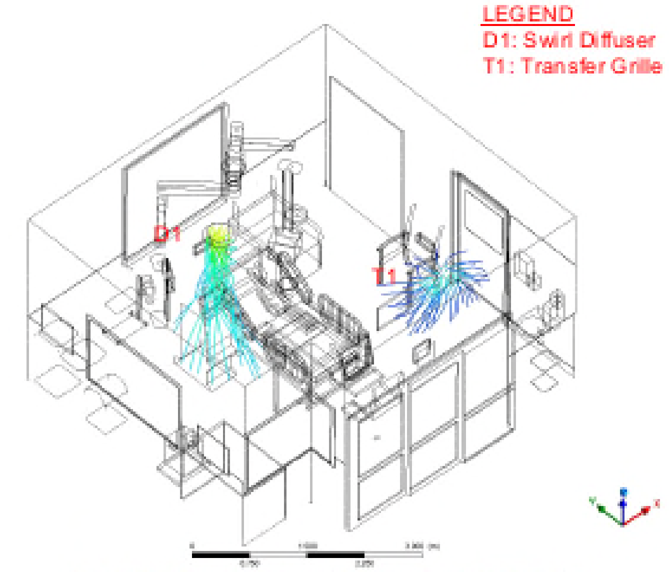
ISOMETRIC VIEW

PLAN VIEW



SIDE VIEW (X-axis)





ISOMETRIC VIEW: AIRFLOW PATTERNS

Rev	Date	Amendment Description	By	Chk
01	24.08.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW

Client: VICTORIA State Government | Health and Human Services

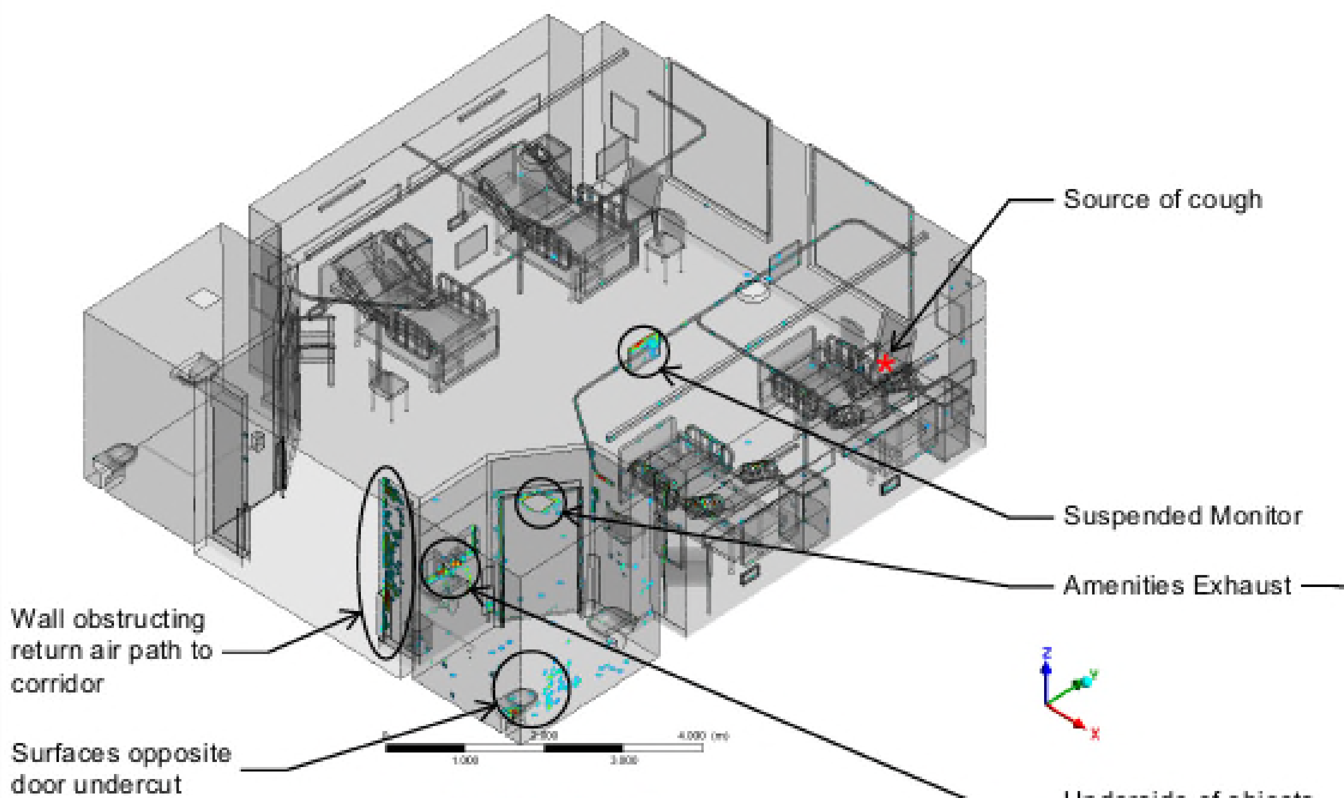
Consulting Engineer: LCI — LEHR CONSULTANTS INTERNATIONAL (AUSTRALIA) PTY LTD

Project: COVID AEROSOL STUDY

Drawing Title: 1BR-IC Swirl Diffuser with Intubated Patient CFD Results

Drawn: SC/SW
Checked: SW
Approved: -
Date: 11.09.20 | Scale: AS SHOWN | Sheet No.: 1
Job No.: 200647 | Drawing No.: 05 | Revision: 02

Drawing [06] 4 BR ST Swirl Diffuser [Rev02]



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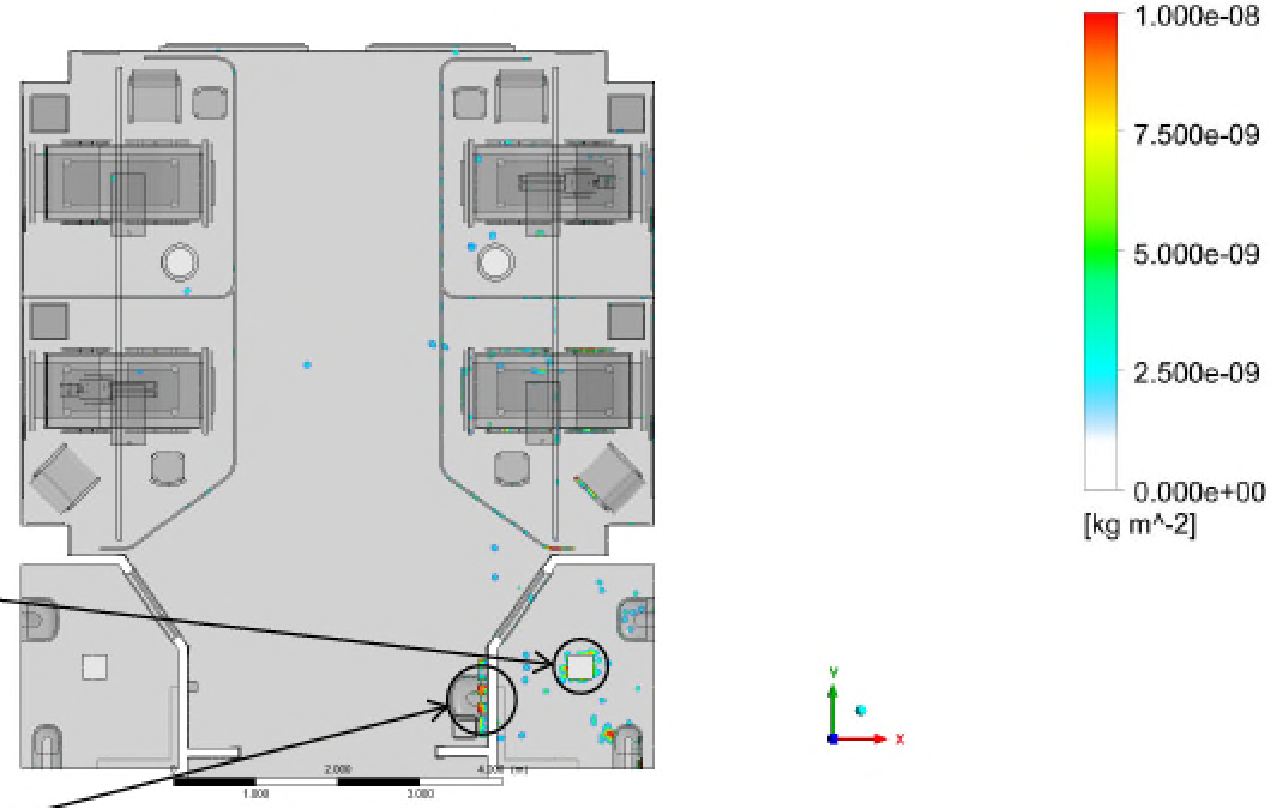
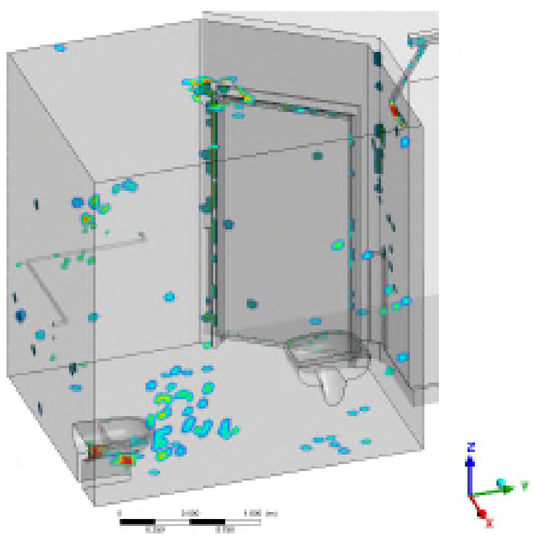
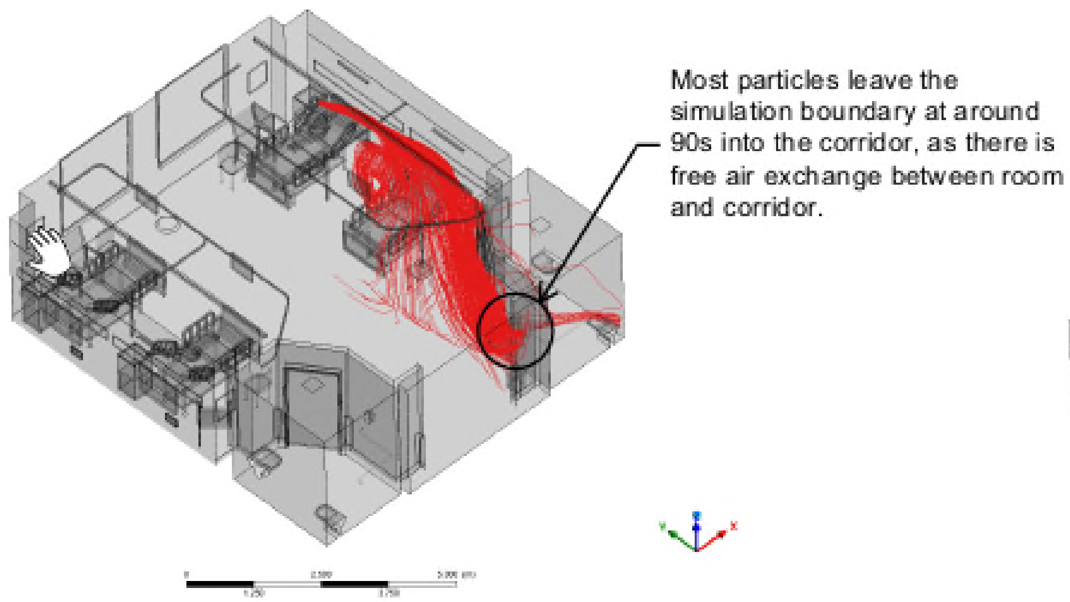


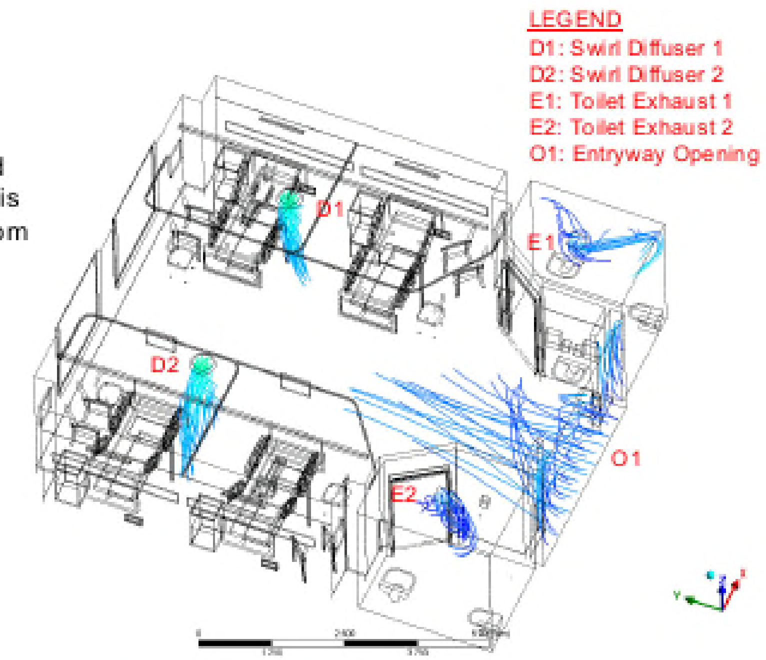
PLAN VIEW



CLOSE UP AMENITIES



ISOMETRIC VIEW - PARTICLE STREAMLINES AT 90s



ISOMETRIC VIEW: AIRFLOW PATTERNS

Rev	Date	Amendment Description	By	Chk
01	01.09.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW

Client: Victoria State Government – Health and Human Services

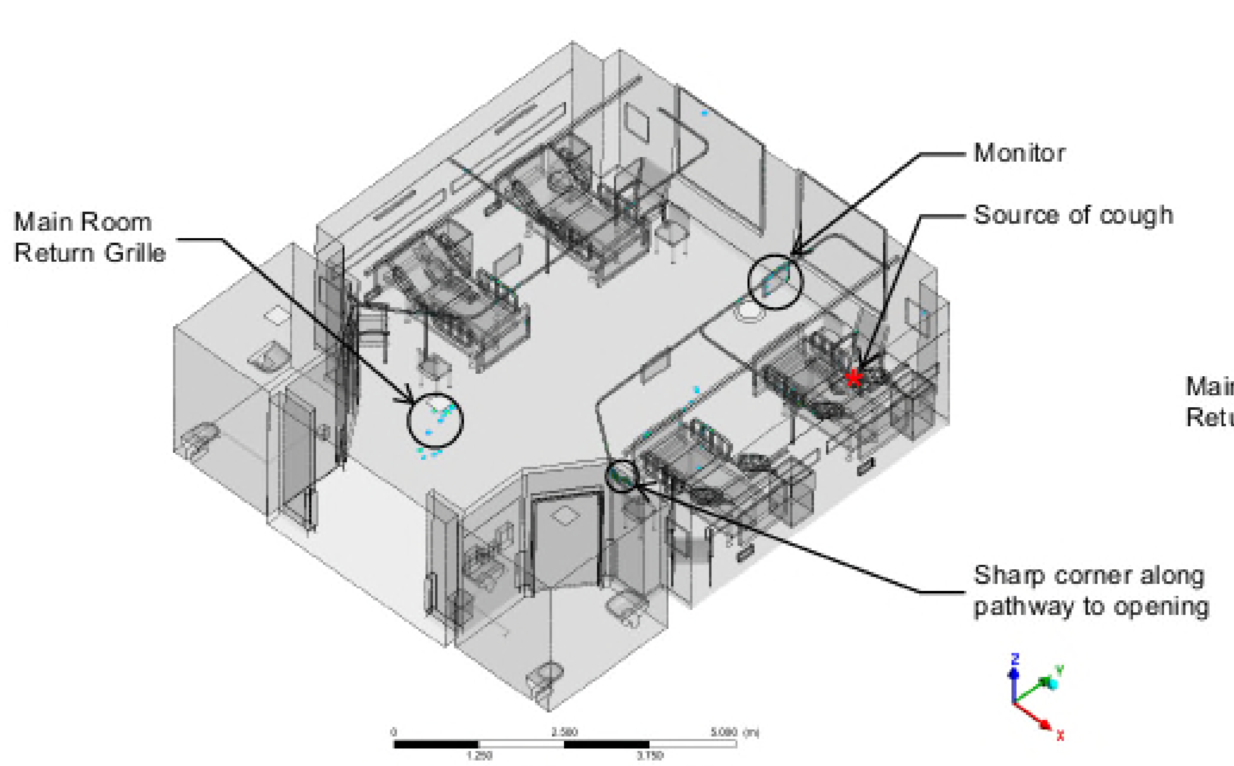
Consulting Engineer: LCI – Lehr Consultants International (Australia) Pty Ltd

Project: COVID AEROSOL STUDY

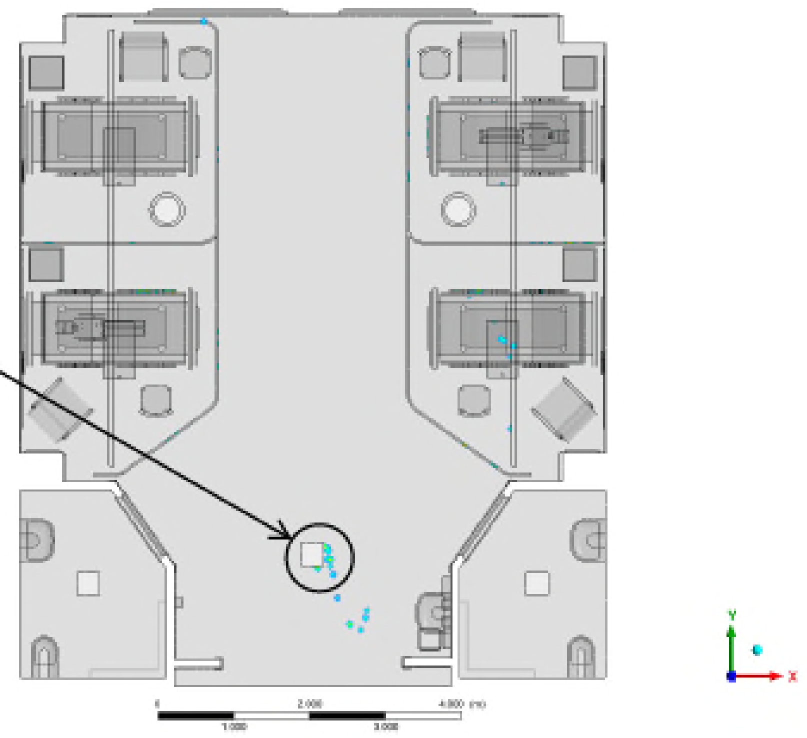
Drawing Title: 4BR-ST Swirl Diffuser CFD Results

Drawn: SC/SW
Checked: SW
Approved: -
Date: 11.09.20 | Scale: AS SHOWN | Sheet No.: 1
Job No.: 200821 | Drawing No.: 06 | Revision: 02

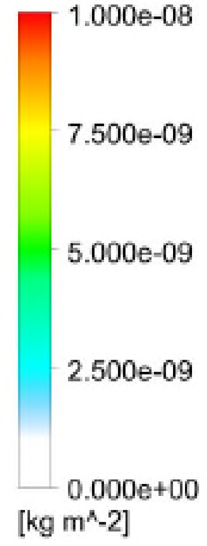
Drawing [07] 4 BR ST Swirl Diffuser Balanced Room [Rev02]

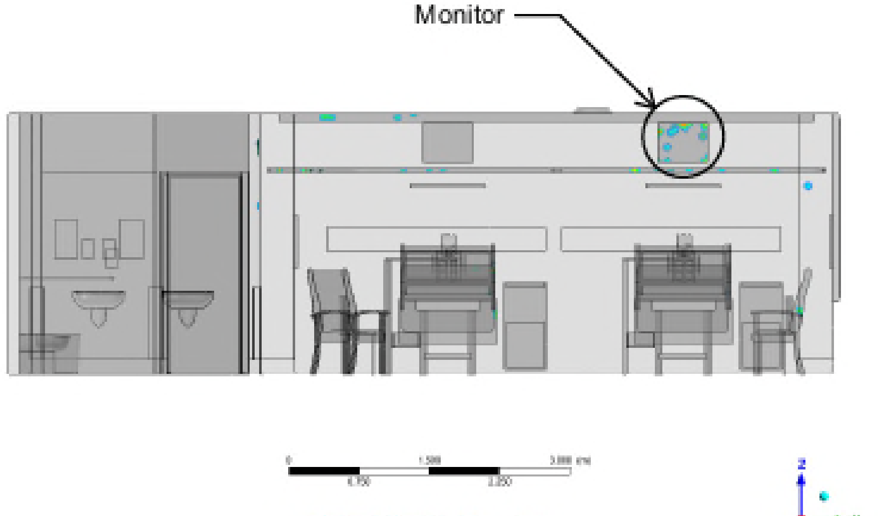


ISOMETRIC VIEW

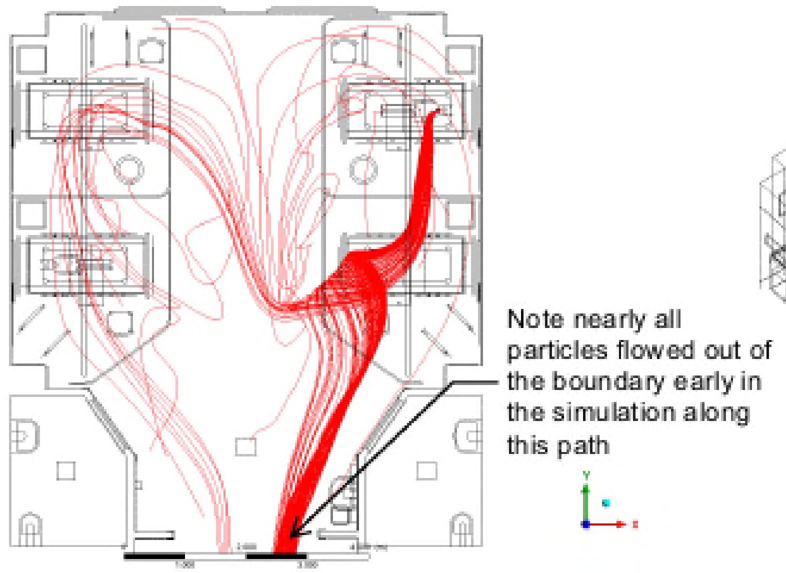


PLAN VIEW

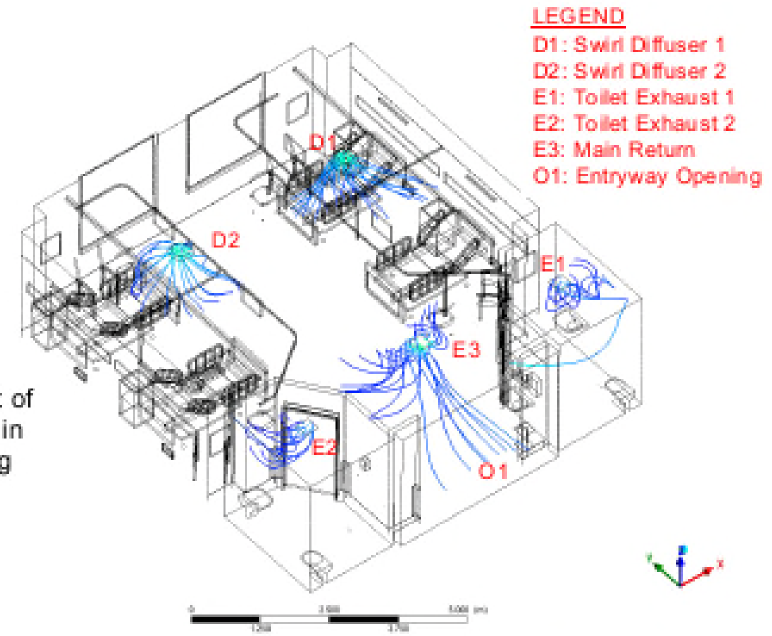




SIDE VIEW (X-axis)



PLAN VIEW - PARTICLE STREAMLINES AT 147s



ISOMETRIC VIEW: AIRFLOW PATTERNS

Rev	Date	Amendment Description	By	Chk
01	01.09.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW

Client: Victoria State Government — Health and Human Services

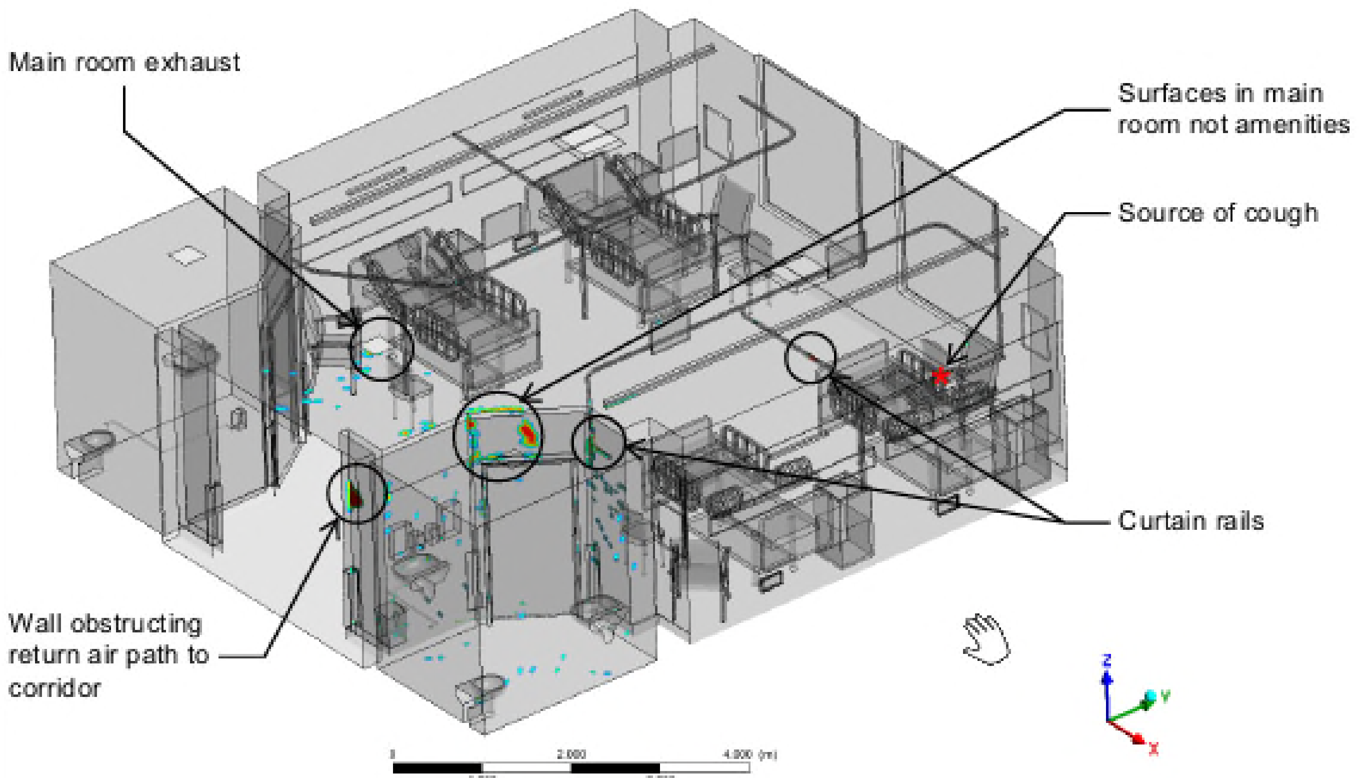
Consulting Engineer: LCI — Lehr Consultants International (Australia) Pty Ltd

Project: COVID AEROSOL STUDY

Drawing Title: 4BR-ST
Swirl Diffuser Balanced Room
CFD Results

Drawn: SC/SW	Checked: SW	Approved: -
Date: 11.09.20	Scale: AS SHOWN	Sheet No.: 1
Job No.: 200821	Drawing No.: 07	Revision: 02

Drawing [08] 4 BR ST 4 Way Diffuser Balanced Room [Rev02]



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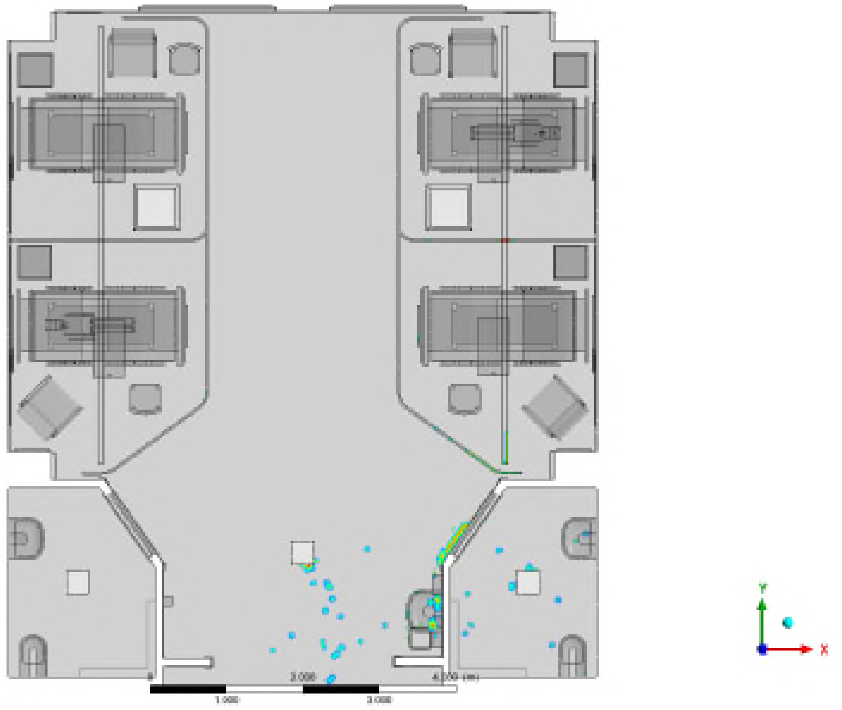
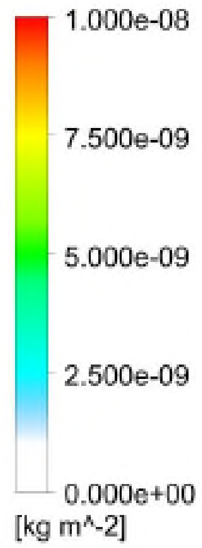
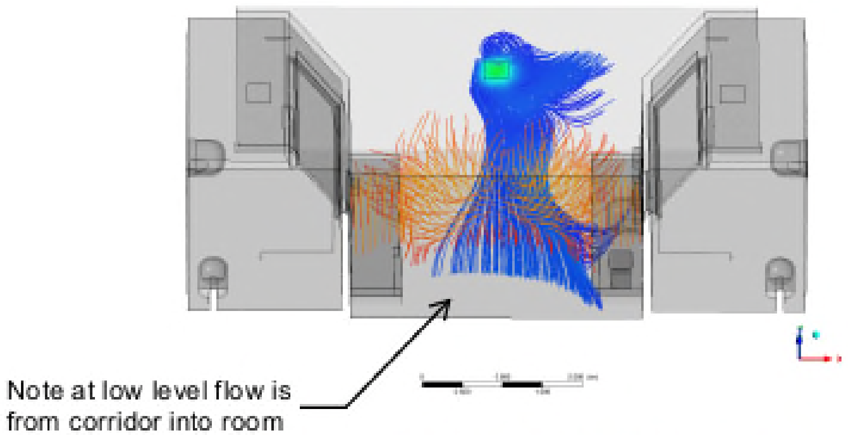


PLAN VIEW



PLAN VIEW OF STREAMLINES

LEGEND
—Reverse Streamlines flowing into exhaust
—Reverse Streamlines flowing from room to corridor



CLOSE UP OF OPENING TO CORRIDOR

LEGEND
D1: 4 Way Diffuser 1
D2: 4 Way Diffuser 2
E1: Toilet Exhaust 1
E2: Toilet Exhaust 2
E3: Main Return
O1: Entryway Opening

ISOMETRIC VIEW: AIRFLOW PATTERNS

Rev	Date	Amendment Description	By	Chk
01	01.09.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW

Client: Victoria State Government — Health and Human Services

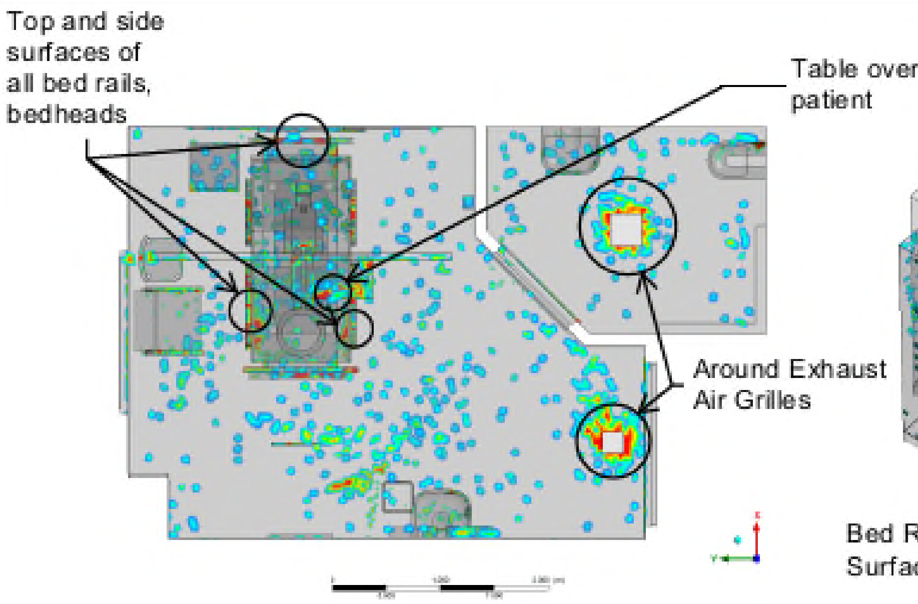
Consulting Engineer: LCI — Lehr Consultants International (Australia) Pty Ltd

Project: COVID AEROSOL STUDY

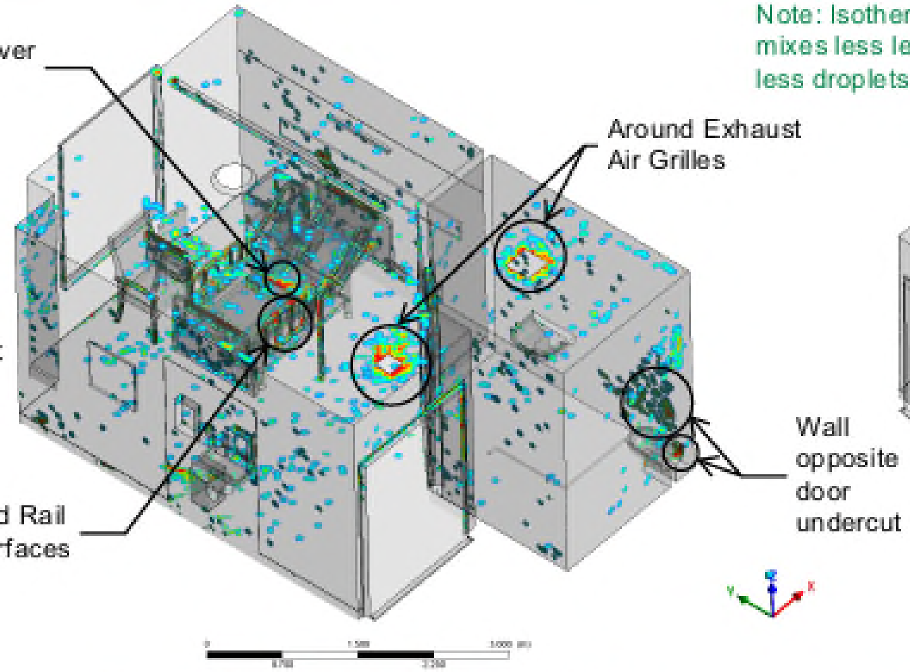
Drawing Title: 4BR-ST
4 Way Diffuser Balanced Room
CFD Results

Drawn	SC/SW		
Checked	SW		
Approved	-		
Date 11.09.20	Scale AS SHOWN	Sheet No. 1	
Job No. 200647	Drawing No. 08	Revision 02	

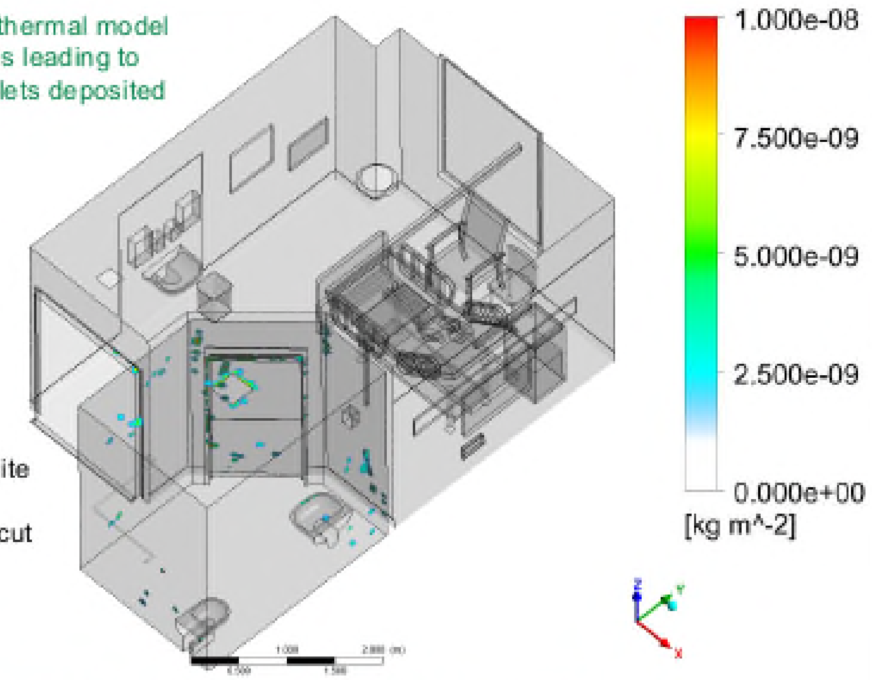
Drawing [09] 1 BR ST A1 Swirl Diffuser [Rev03]



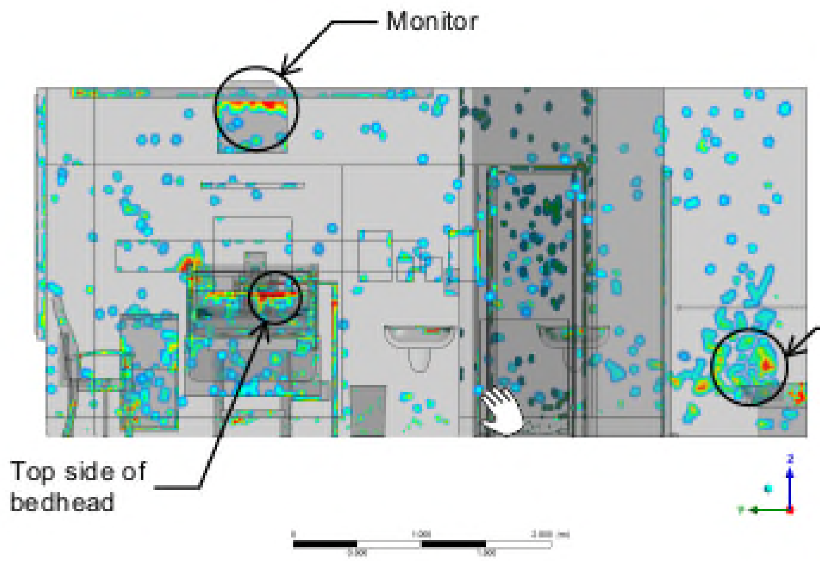
PLAN HEAT MAP: THERMAL MODEL



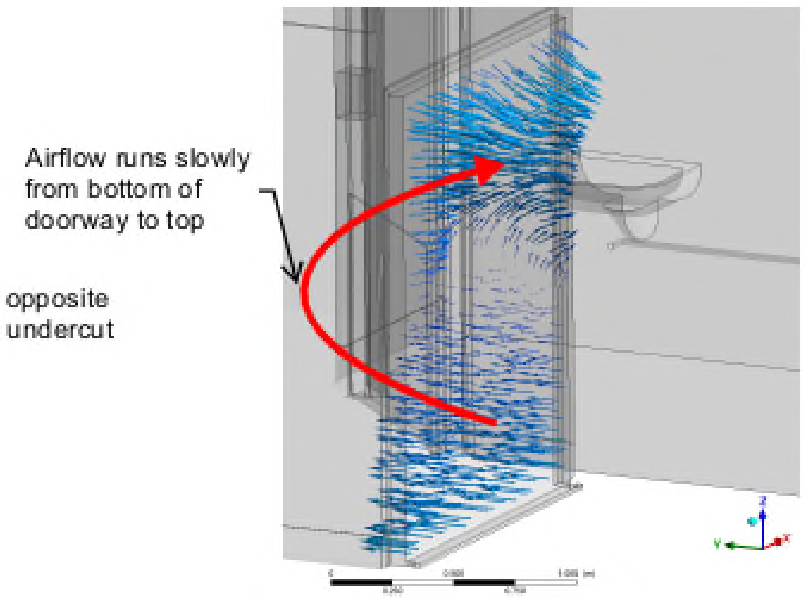
ISOMETRIC HEAT MAP: THERMAL MODEL



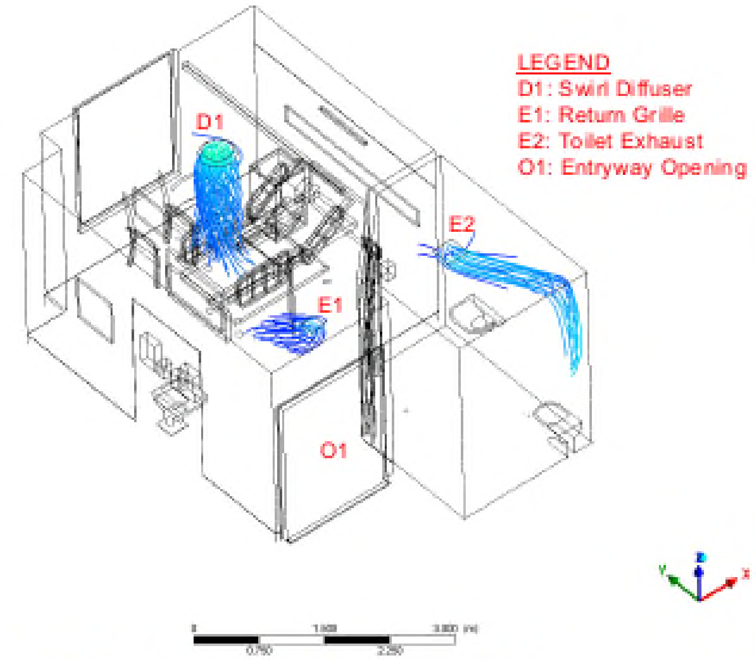
ISOMETRIC HEAT MAP: ISOTHERMAL MODEL



SIDE HEAT MAP: THERMAL MODEL (X-axis)



CLOSE UP - OPEN DOOR LOCAL AIRFLOW



ISOMETRIC VIEW: AIRFLOW PATTERNS

Rev	Date	Amendment Description	By	Chk
01	01.09.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW
03	22.09.20	UPDATED REVISION	SC	SW

Client: Victoria State Government — Health and Human Services

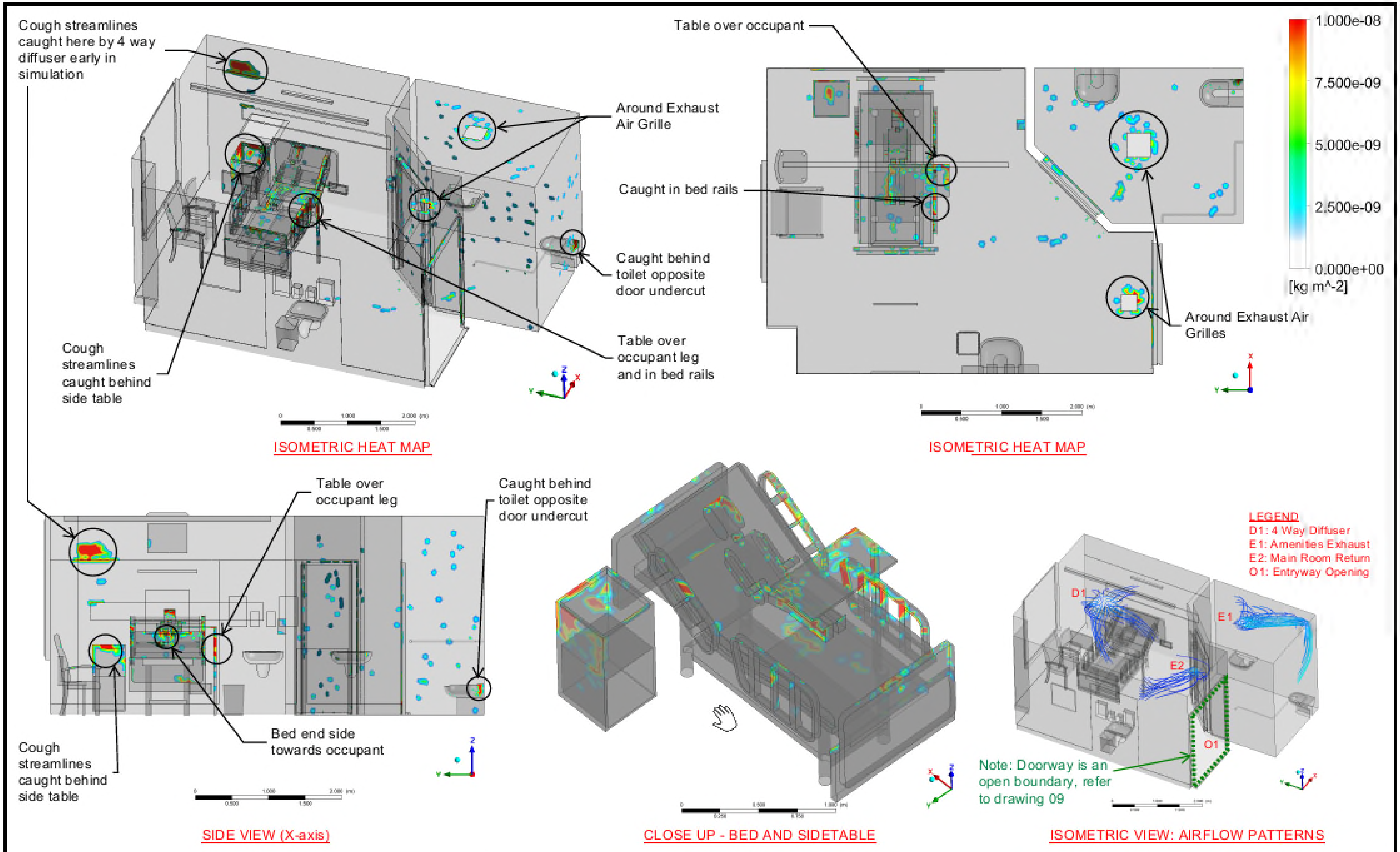
Consulting Engineer: LCI — Lehr Consultants International (Australia) Pty Ltd

Project: COVID AEROSOL STUDY

Drawing Title: 1BR-ST-A1 Swirl Diffuser CFD Results

Drawn	SC/SW
Checked	SW
Approved	-
Date	22.09.20
Scale	AS SHOWN
Sheet No.	1
Job No.	200647
Drawing No.	09
Revision	02

Drawing [10] 1 BR ST A1 4 Way Diffuser [Rev03]



Rev	Date	Amendment Description	By	Chk
01	01.09.20	DRAFT	SC	SW
02	11.09.20	UPDATED REVISION	SC	SW
03	22.09.20	UPDATED REVISION	SC	SW

Client: VICTORIA State Government | Health and Human Services

Consulting Engineer: LCI — LEHR CONSULTANTS INTERNATIONAL (AUSTRALIA) PTY LTD

Project: COVID AEROSOL STUDY

Drawing Title: 1BR-ST-A1 4 Way Diffuser CFD Results

Drawn	SC/SW
Checked	SW
Approved	-
Date	22.09.20
Scale	AS SHOWN
Sheet No.	1
Job No.	200647
Drawing No.	10
Revision	02