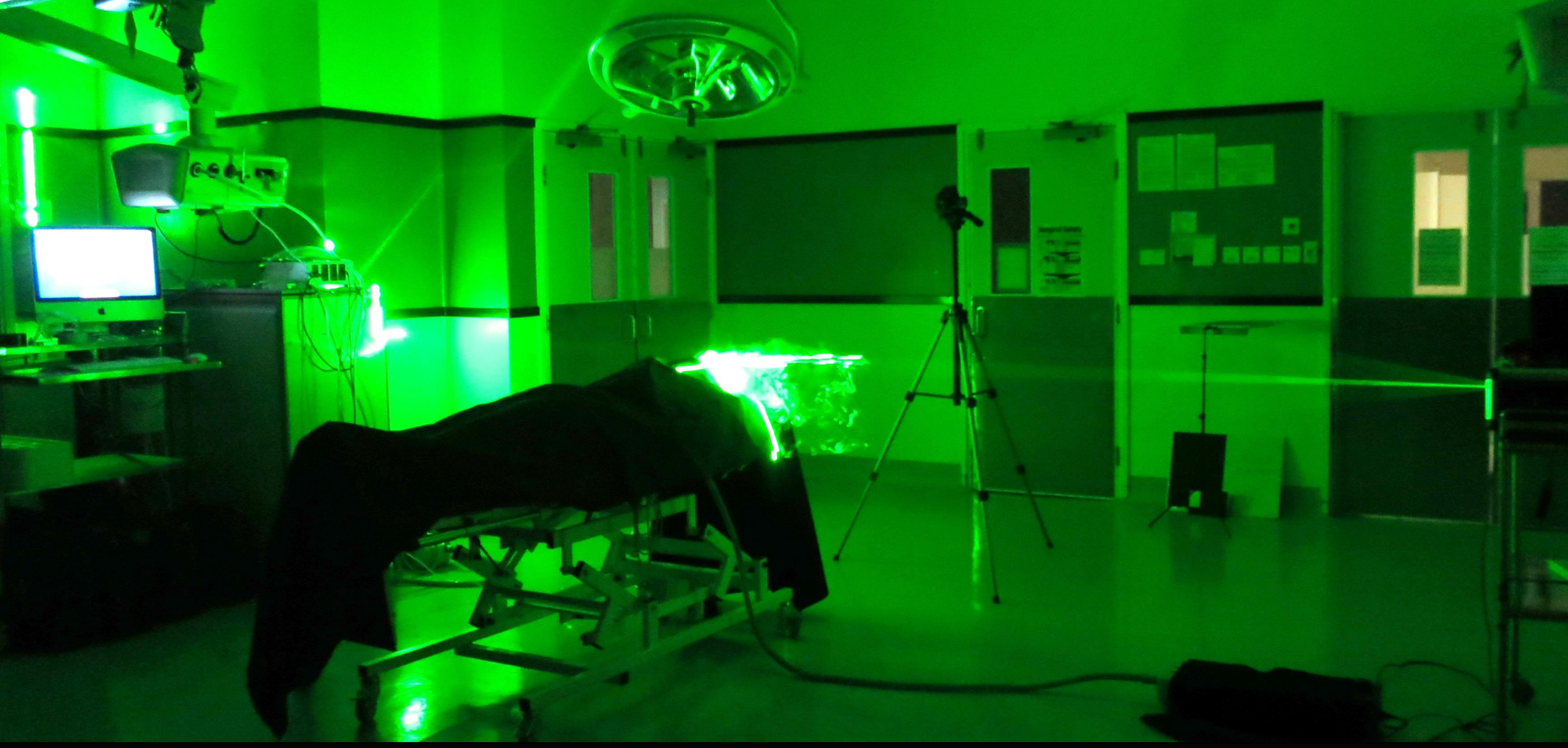


Experimental study on specialized ventilation system of airborne infection isolation room

Dr. Benny Chow

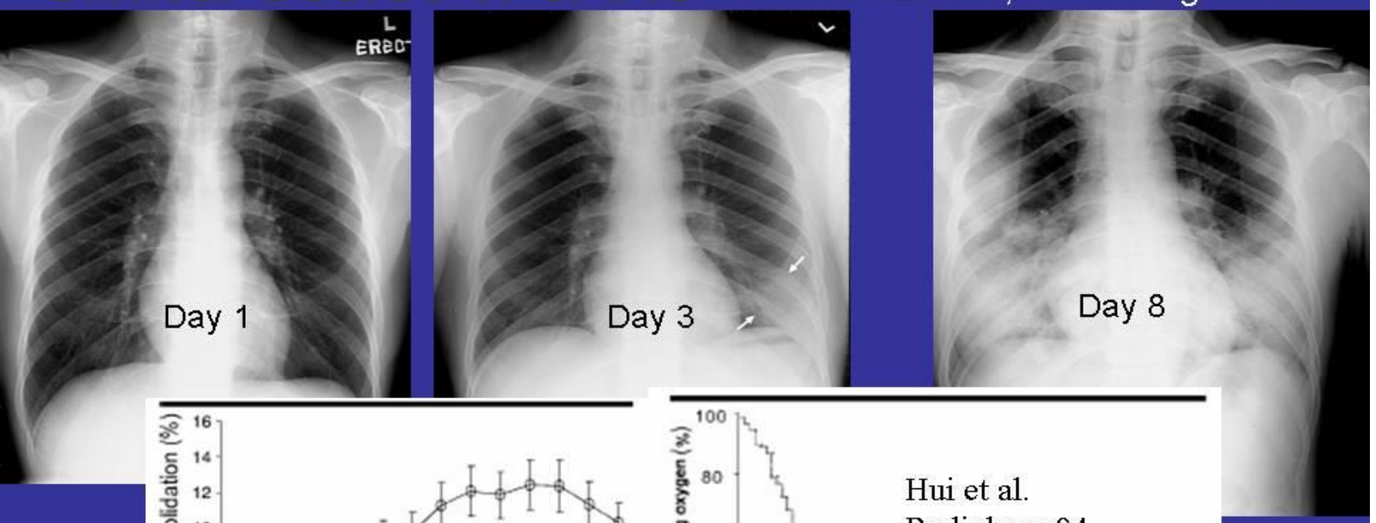
Director of Sustainability, Aedas Ltd
Co-Chairman, Sustainability Committee, ASHRAE HKC
Adjunct Assistant Professor, Faculty of Medicine, CUHK

ASHRAE Hong Kong Chapter

Photo taken with HPS at SARS Ward in 2003
Courtesy: Dr. Benny Chow

Clinical Course of SARS

Lee et al. NEJM 03; Hui & Sung Chest 03



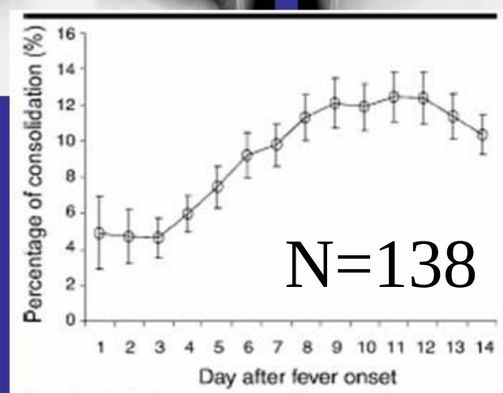


Figure 1. Graph shows progression of lung consolidation over time. Mean percentages of consolidation are plotted against corresponding days after fever onset. Clinically determined and radiographically depicted disease progression generally occurred at the beginning of the 2nd week after fever onset. The first pulse of methylprednisolone was administered a median of 8 days after fever onset.

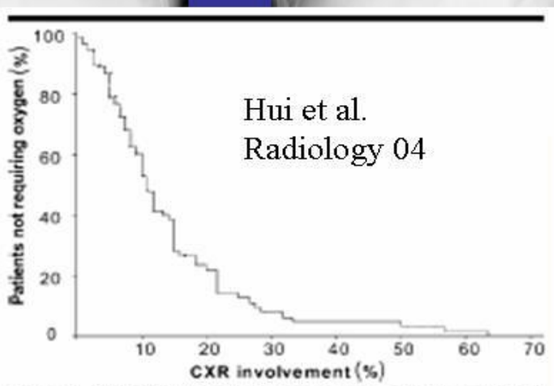
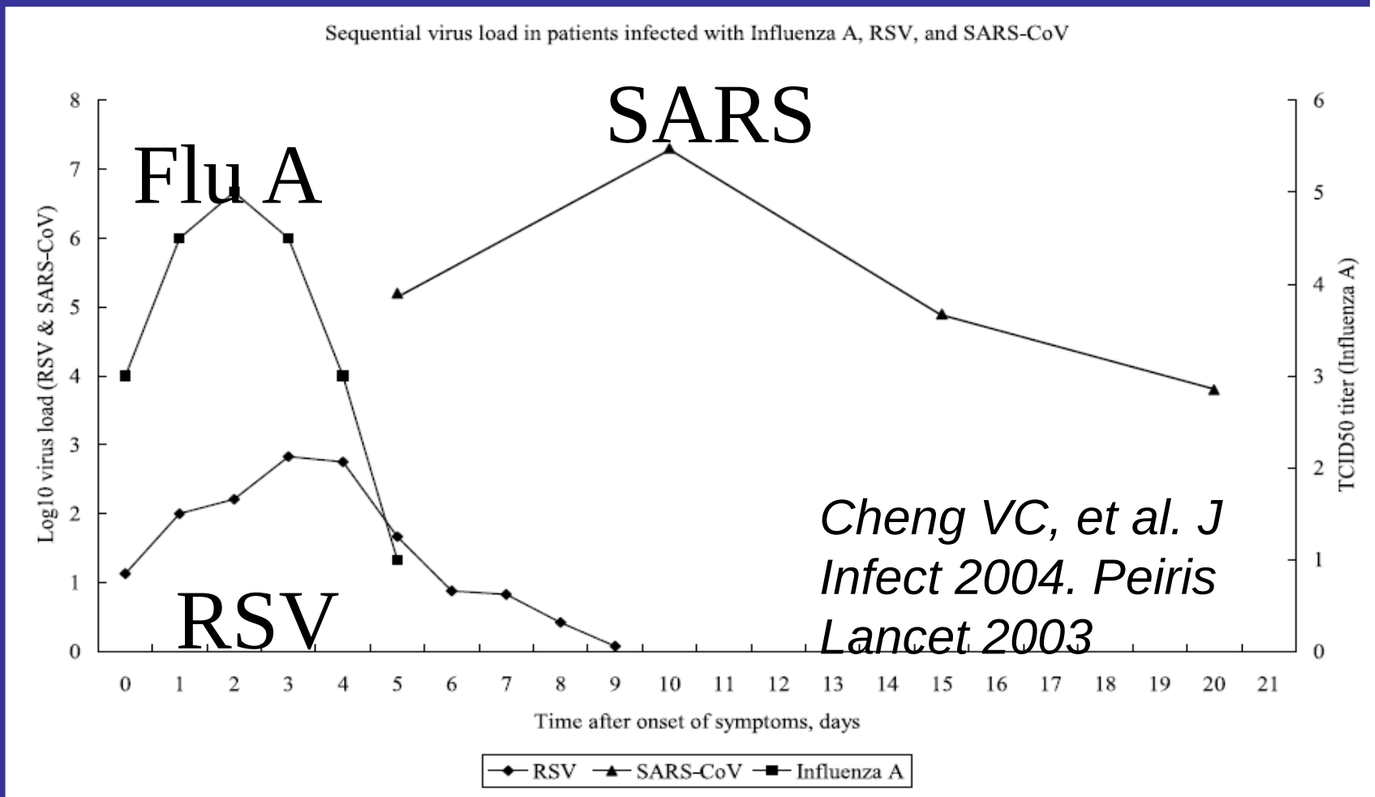
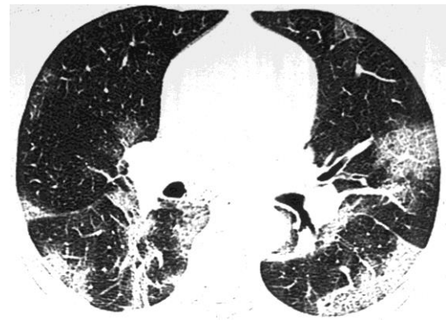


Figure 4. Kaplan-Meier curve shows percentages of patients who did not require supplementary oxygen versus percentages of consolidation. The morbidity associated with SARS is reflected by the curve data, which show that even when there was only 10% lung involvement, 50% of patients in the cohort required supplemental oxygen. *CXR* = chest radiograph.



Among 8,096 cases of SARS globally, 1,706(~21%) were HCWs. SARS patients ill & yet highly infectious esp in 2nd week of illness.



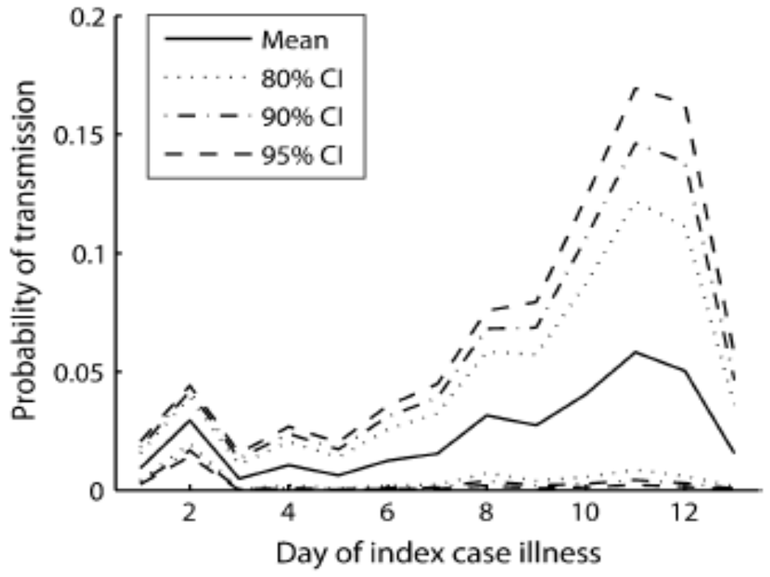


FIGURE 1. Probability of transmission of severe acute respiratory syndrome (SARS) according to day of index case illness during the 2003 SARS epidemic in Hong Kong, China. The solid line represents the estimated mean transmission probability, while the dotted, dash-dotted, and dashed lines represent the 80%, 90%, and 95% credible intervals (CIs), respectively.

NPPV – Independent Risk Factor for Nosocomial Outbreak

Why Did Outbreaks of Severe Acute Respiratory Syndrome Occur in Some Hospital Wards but Not in Others?

Ignatius T. Yu,[1,2] Zhan Hong Xie,[4] Kelvin K. Tsoi,[1] Yuk Lan Chiu,[1] Siu Wai Lok,[1] Xiao Ping Tang,[5] David S. Hui,[3] Nelson Lee,[3] Yi Min Li,[4] Zhi Tong Huang,[6] Tao Liu,[7] Tze Wai Wong,[2] Nan Shan Zhong,[4] and Joseph J. Sung[1,3]

[1]Centre for Emerging Infectious Diseases and Departments of [2]Community and Family Medicine and [3]Medicine and Therapeutics, The Chinese University of Hong Kong, Hong Kong, and [4]Guangzhou Institute of Respiratory Diseases, Guangzhou Medical College, [5]Guangzhou No. 8 People's Hospital, [6]Second Affiliated Hospital, Zhongshan University, and [7]Guangdong Provincial Hospital of Traditional Chinese Medicine, Guangzhou, China

Background. Most documented "superspreading events" of severe acute respiratory syndrome (SARS) occurred in hospitals, but the underlying causes remain unclear. We systematically analyzed the risk factors for nosocomial outbreaks of SARS among hospital wards in Guangzhou and Hong Kong, China.

Methods. A case-control study was conducted. Case wards were hospital wards in which superspreading events of SARS occurred, and control wards were wards in which patients with SARS were admitted, but no subsequent nosocomial outbreaks occurred. Information on environmental and administrative factors was obtained through visits to the wards and interviews with ward managers or nursing officers. Relevant information about host factors was abstracted from the medical records. Logistic regression analyses were used to identify the major risk factors for superspreading events.

Results. Eighty-six wards in 21 hospitals in Guangzhou and 38 wards in 5 hospitals in Hong Kong were included in the study. Six risk factors were significant in the final multiple-logistic regression model: minimum distance between beds of ≤1 m (odds ratio [OR], 6.94; 95% confidence interval [CI], 1.68–28.75), availability of washing or changing facilities for staff (OR, 0.12; 95% CI, 0.02–0.97), whether resuscitation was ever performed in the ward (OR, 3.81; 95% CI, 1.04–13.87), whether staff members worked while experiencing symptoms (OR, 10.55; 95% CI, 2.28–48.87), whether any host patients (index patient or the first patient with SARS admitted to a ward) required oxygen therapy (OR, 4.30; 95% CI, 1.00–18.43), and whether any host patients required bi-level positive airway pressure ventilation (OR, 11.82; 95% CI, 1.97–70.80).

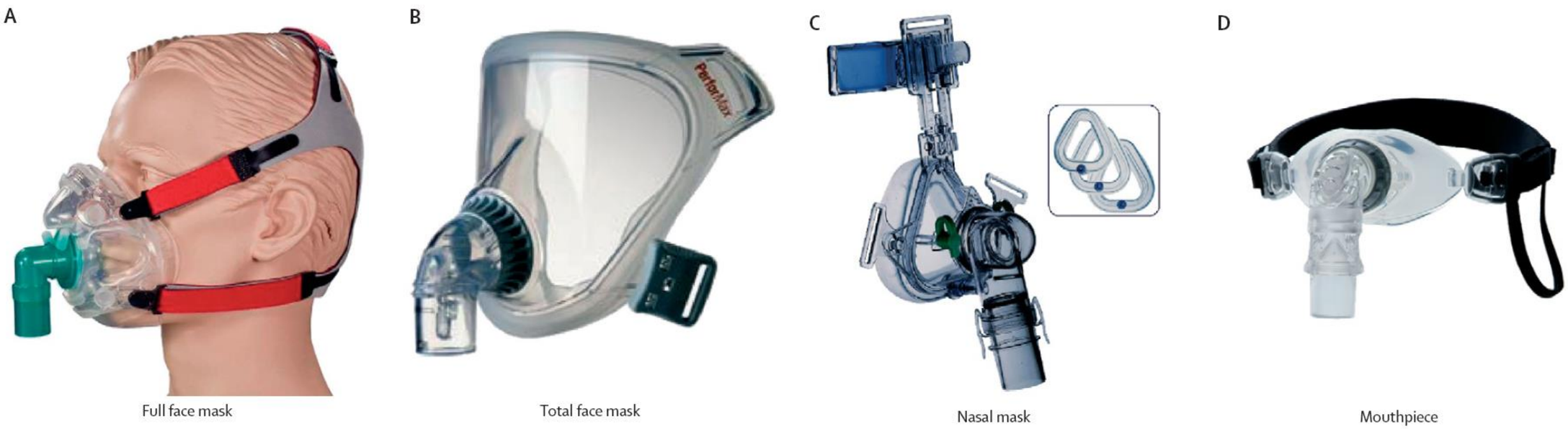
Conclusions. Our results revealed that factors that were associated with the ward environment and administration were important in nosocomial outbreaks of SARS. The lessons learned from this study remain very important and highly relevant to the daily operation of hospital wards if we are to prevent nosocomial outbreaks of other respiratory infections in the future.

Yu, Ignatius T. Xie, Zhan Hong; Tsoi, Kelvin K. et al. (2007). "Why Did Outbreaks of Severe Acute Respiratory Syndrome Occur in Some Hospital Wards but Not in Others?", Clinical Infectious Diseases. 44 (8), pp. 1017-1025.

NPPV – Independent Risk Factor for Nosocomial Outbreak

Type of factor, factor	Guangzhou OR (95% CI)	Guangzhou *P*	Hong Kong OR (95% CI)	Hong Kong *P*	Overall OR (95% CI)	Overall *P*
Environmental or administrative factors						
Minimum distance between beds of ⩽1 m	**11.77 (1.54–90.13)**	.02	10.28 (0.58–182.10)	.11	**6.94 (1.68–28.75)**	.008
Washing or changing facilities for staff	…	>.15	…	>.15	0.12 (0.02–0.97)	.05
Never used exhaust fan	4.16 (0.98–17.72)	.05	…	>.15	…	>.15
Performance of resuscitation	…	>.15	…	>.15	**3.81 (1.04–13.87)**	.04
Staff working while experiencing symptoms	**11.18 (1.99–62.81)**	.006	**19.27 (1.12–332.48)**	.04	**10.55 (2.28–48.87)**	.003
Host factors						
Requiring oxygen therapy	**10.14 (1.70–60.37)**	.01	…	>.15	**4.30 (1.00–18.43)**	.05
Use of BIPAP ventilation	6.67 (0.90–49.23)	.06	…	>.15	**11.82 (1.97–70.80)**	.007
Systemic symptoms	12.71 (0.70–232.03)	.09	…	>.15	…	>.15

Figure: The summary of the major risk factors associated with the nosocomial outbreak in medical ward environments (Yu 2007).



Source: Yu, Ignatius T. Xie, Zhan Hong; Tsoi, Kelvin K. et al. (2007). “Why Did Outbreaks of Severe Acute Respiratory Syndrome Occur in Some Hospital Wards but Not in Others?”, Clinical Infectious Diseases. 44 (8), pp. 1017-1025.

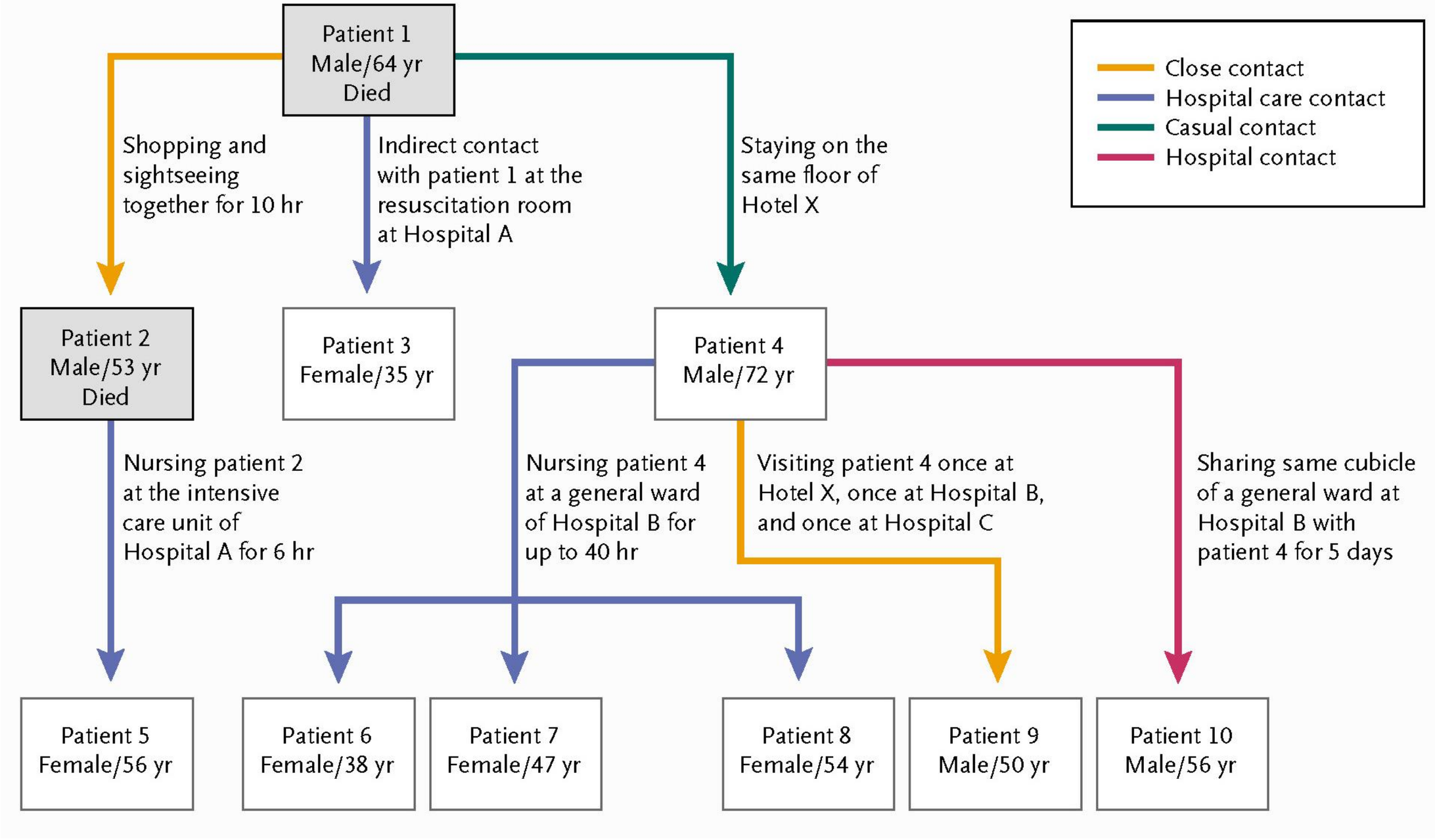
Nosocomial Infection (hospital-acquired)

"Even with the current stringent design and practice guidelines, nosocomial (hospital-acquired) infection of healthcare workers (HCWs) and inpatients continues to occur. What might be the limitations in current isolation ward designs?"

Source: https://medstudentinmoz.wordpress.com/page/2/

Dr. Benny CHOW
(ASHRAE-HKC/Med.CUHK)

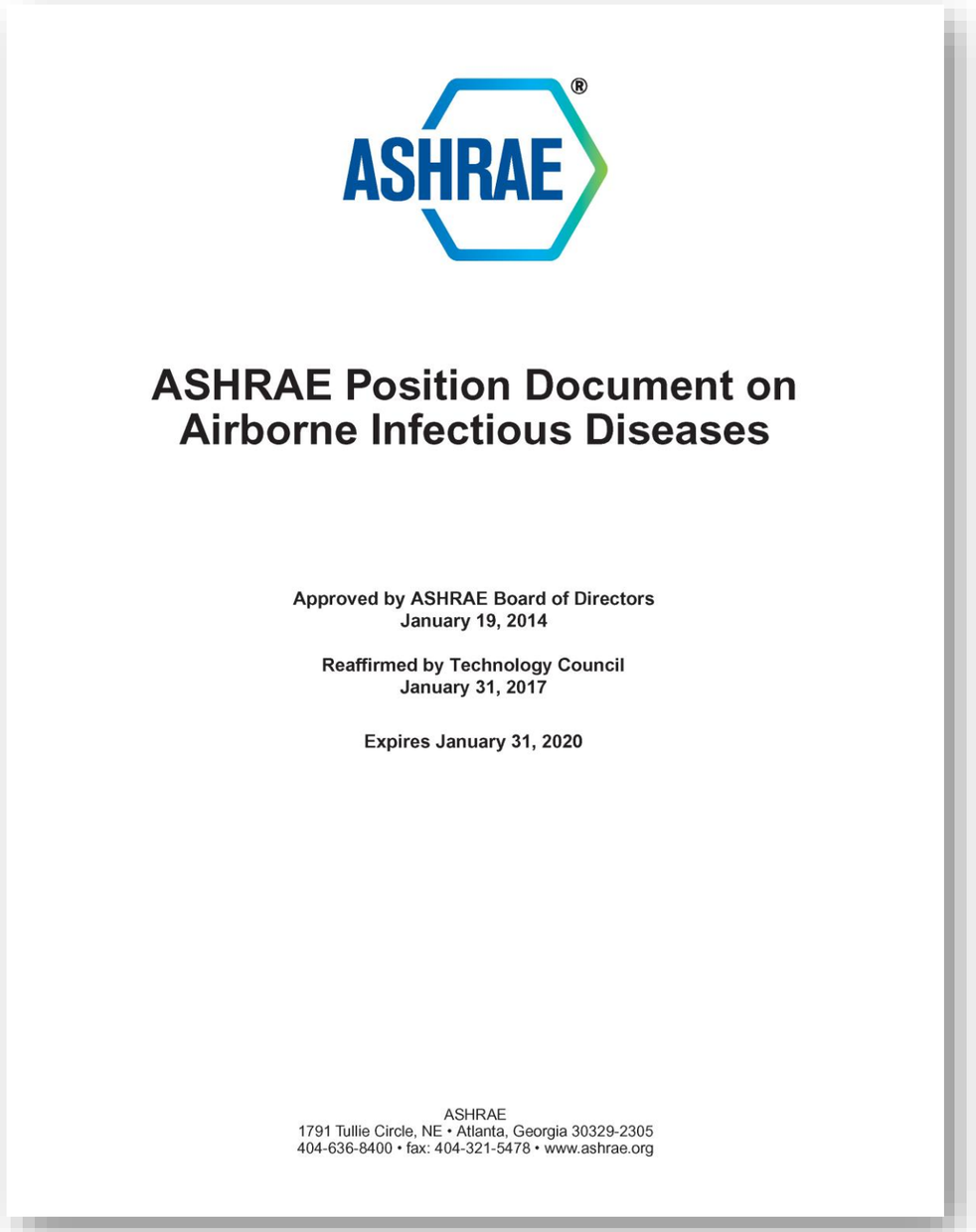
Nosocomial Infection (hospital-acquired)



Source: Tsang, K.W. et al. "A Cluster of Cases of Severe Acute Respiratory Syndrome in Hong Kong." New England Journal of Medicine 348, no. 20 (May 15, 2003): 1977–85.

Dr. Benny CHOW
(ASHRAE-HKC/Med.CUHK)

Nosocomial Infection (hospital-acquired)



ASHRAE Position Document on Airborne Infectious Diseases

Approved by ASHRAE Board of Directors
January 19, 2014

Reaffirmed by Technology Council
January 31, 2017

Expires January 31, 2020

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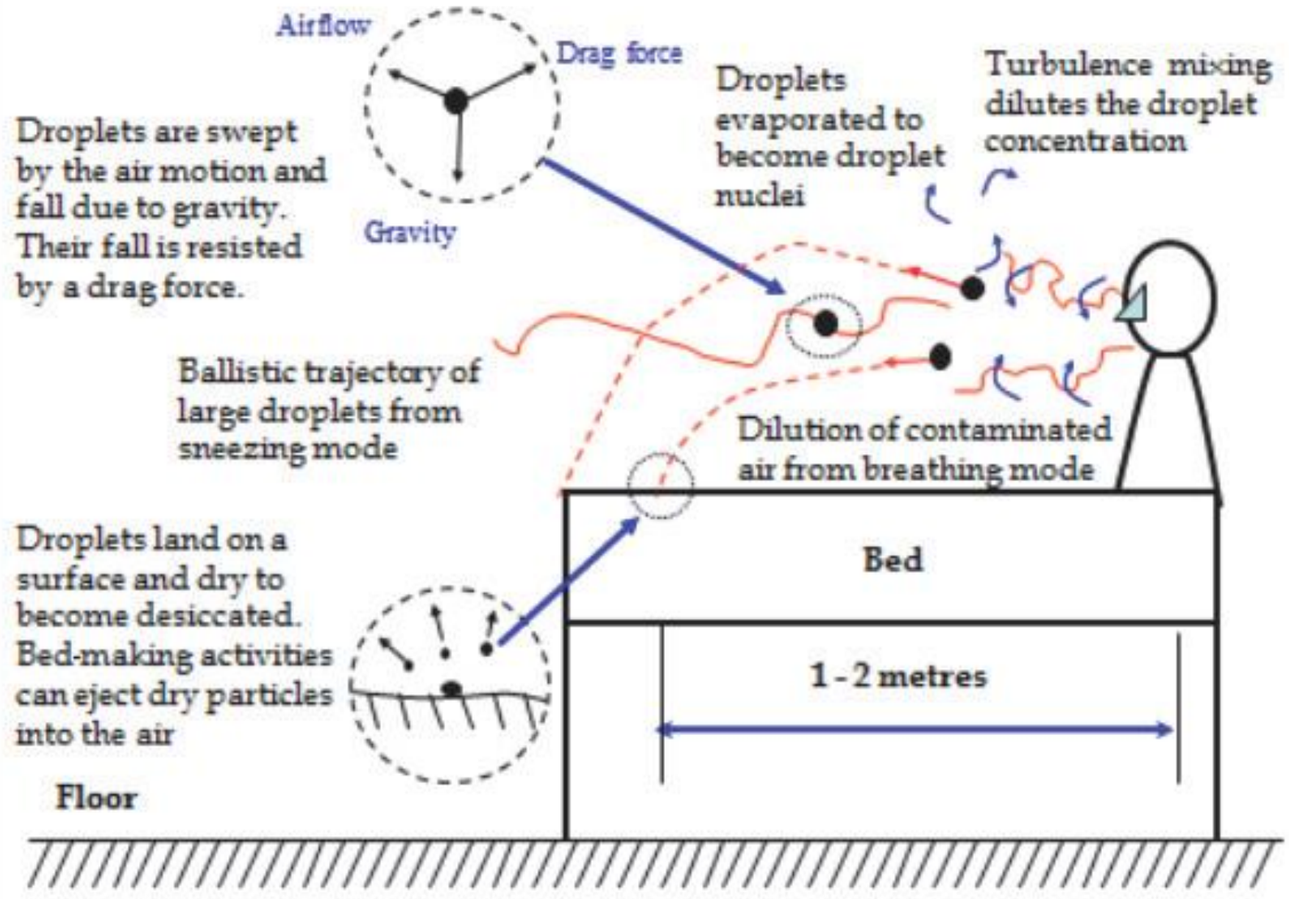

Source: ASHRAE Position Document on Airborne Infectious Diseases (2017)

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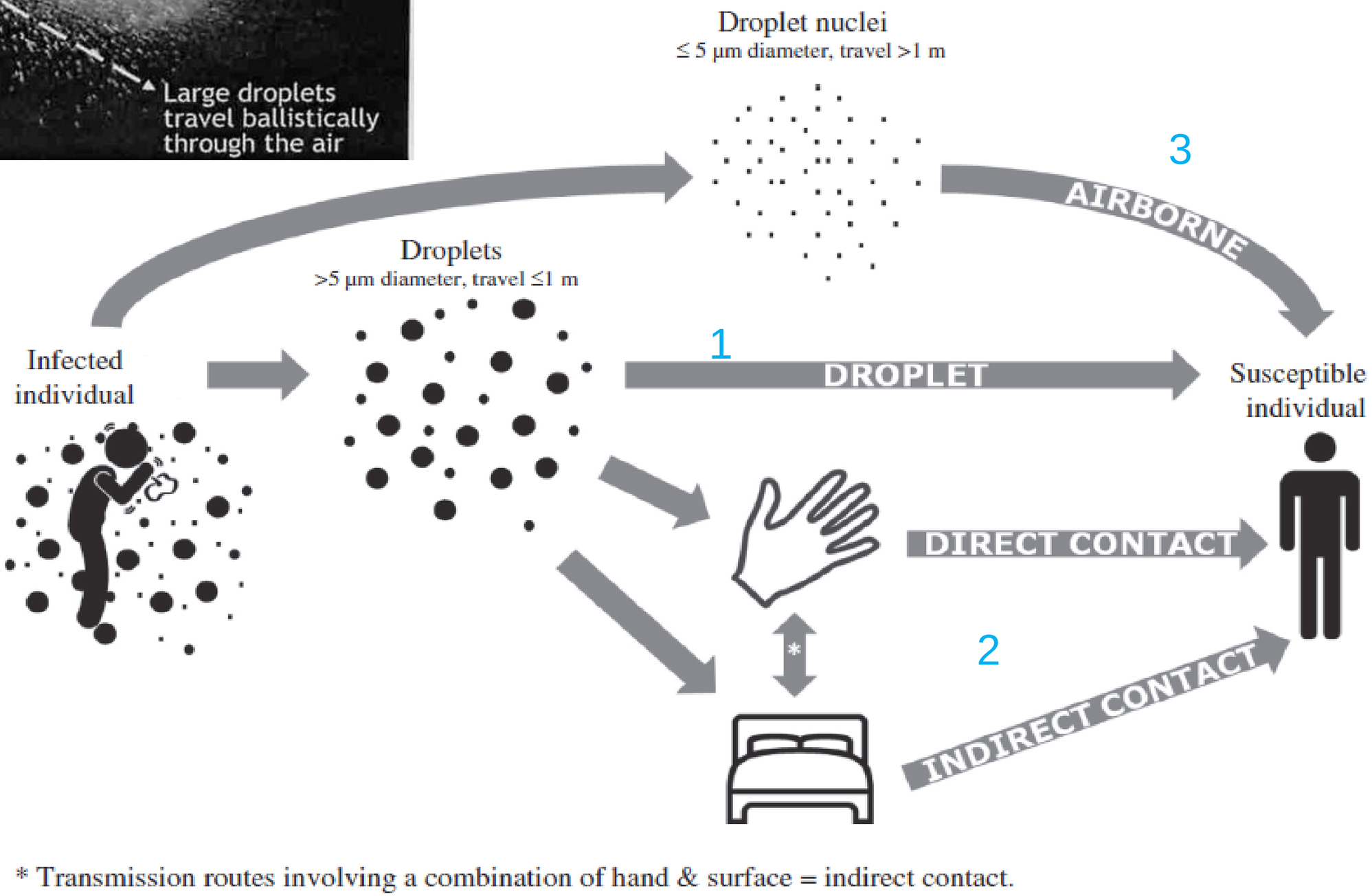
Otter JA, et al. J Hosp Infect 2015



* Transmission routes involving a combination of hand & surface = indirect contact.

Figure 1. Transmission routes: droplet, airborne, direct contact, and indirect contact. (Indirect contact: routes involving a combination of hand and surface.) Definitions of 'droplet' and 'droplet nuclei' are from Atkinson *et al.*[5]

Exhaled Air and Aerosolized Droplet Dispersion During Application of a Jet Nebulizer*

(CHEST 2009; 135:648–654)

David S. Hui, MD, FCCP; Benny K. Chow, MPh; Leo C. Y. Chu, MBChB; Susanna S. Ng, MBChB; Stephen D. Hall, PhD; Tony Gin, MD; and Matthew T. V. Chan, MD

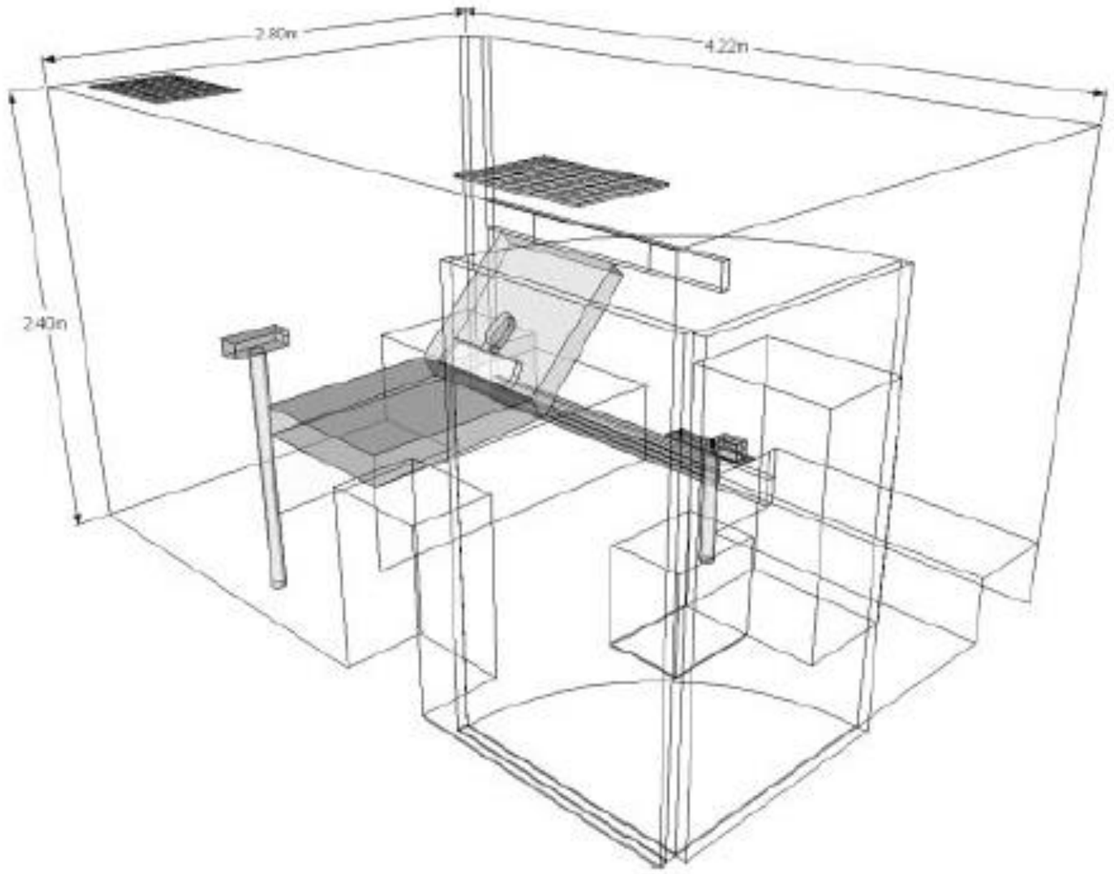


FIGURE 1. The room dimension and equipment layout inside the negative pressure isolation room. The room measured 4.22 m (depth) by 2.80 m (width) by 2.4 m (height). The camera and laser device were positioned along the sagittal plane and the coronal plane of the head of patient, respectively. Two fresh air diffusers as air inlet were mounted on the ceiling. The negative pressure of the isolation room was provided by the air exhausts positioned at the bottom of the bed.

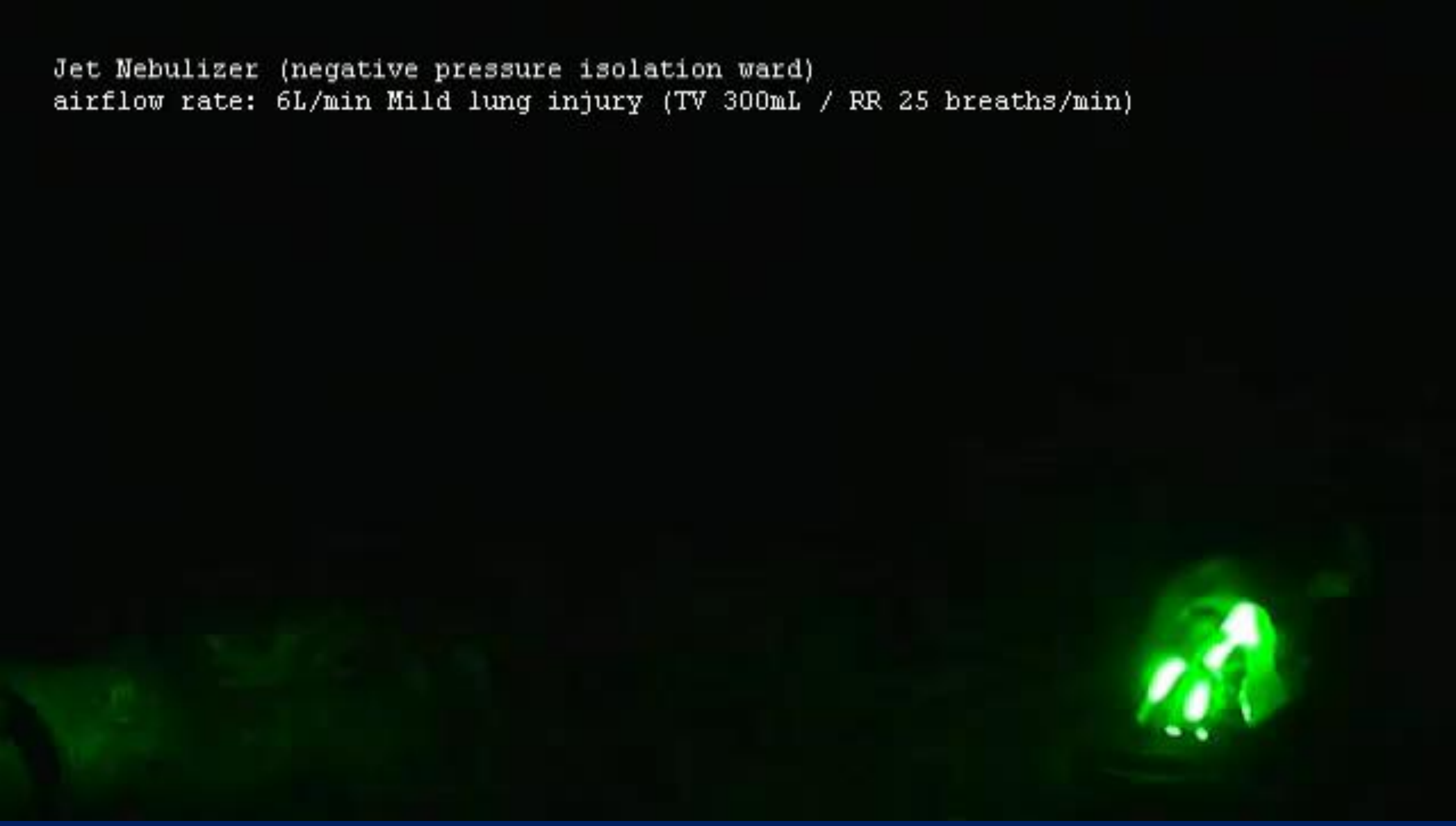
Table 1—*Three Different Lung Settings of HPS Applied in this Study

Settings	Normal Lung Condition	Mild Lung Injury	Severe Lung Injury
Oxygen consumption, mL/min	200	300	500
Lung compliance, mL/cm H_2O	70	35	10
Respiratory rate, breaths/min†	12	25	40
Tidal volume, mL†	700	300	150

*From Kuhlen et al[16] and Light.[17]

†Respiratory rate and tidal volume were adjusted by the HPS program to achieve primarily the target oxygen consumption and lung compliance.

Jet Nebulizer (negative pressure isolation ward)
airflow rate: 6L/min Mild lung injury (TV 300mL / RR 25 breaths/min)



Jet nebulizer (negative pressure isolation ward)

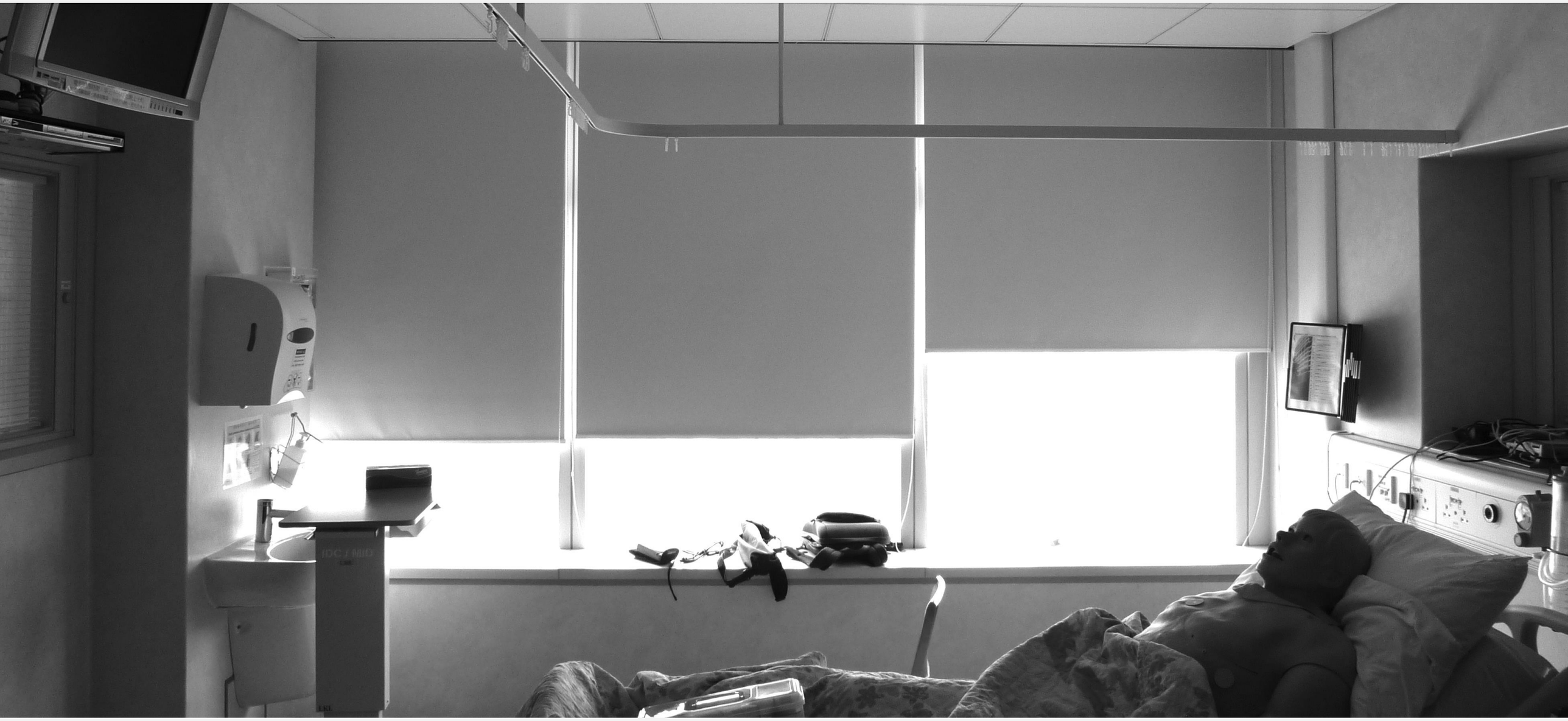
(*Hui DS, Chow Benny, et al. Chest 2009;135:648-54***)**

Main Topics for Today

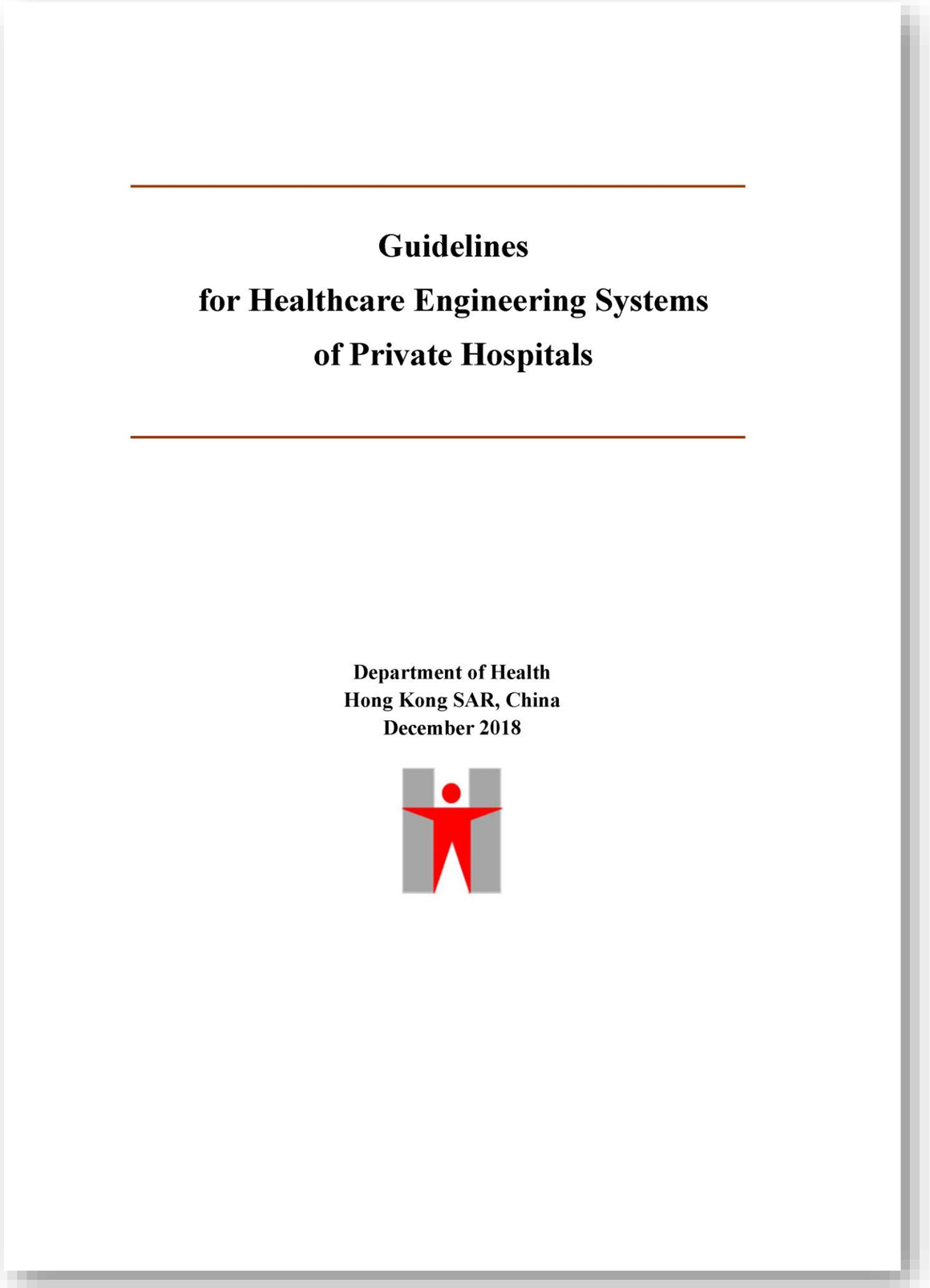
1. Verify the **ventilation performance** based on the detailed indoor airflow environment of existing isolation wards for both renovation and new construction hospitals;
2. Examine the **distinctive patient exhaled airflow patterns**, from different oxygen delivery interventions for patient with different lung breathing conditions and oxygen flow rate settings, as modeled by a human patient simulator (HPS);
3. Investigate the dynamic airflow interaction between **patient exhaled air plumes** as induced by common clinical oxygen administration and the indoor airflow environment of an AII room.

Dr. Benny CHOW
(ASHRAE-HKC/Med.CUHK)

ISOLATION WARD DESIGN



Ventilation Design for Health Care Facilities

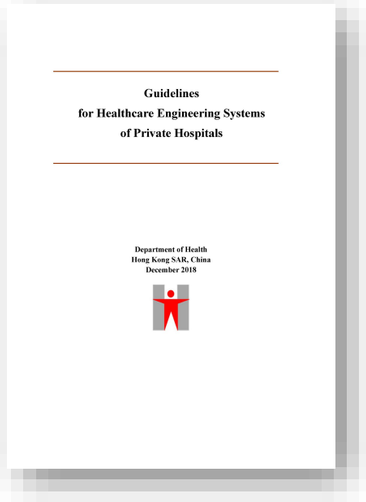

Guidelines
for Healthcare Engineering Systems
of Private Hospitals

Department of Health
Hong Kong SAR, China
December 2018

Guidelines for Healthcare Engineering Systems of Private Hospitals

Department of Health Hong Kong SAR, China December 2018

Ventilation Design for Health Care Facilities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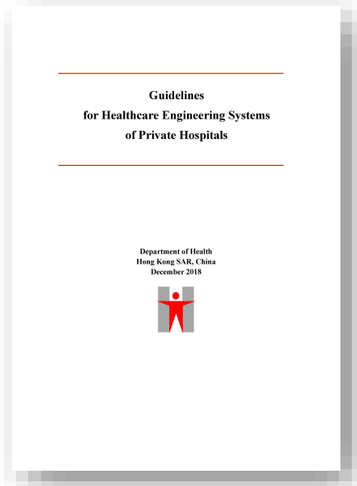
Guidelines for Healthcare Engineering Systems of Private Hospitals (2018) Department of Health Hong Kong SAR, China December 2018

Ventilation Design for Health Care Facilities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December 2018

2.2 Design and Installation

2.2.1 The design and installation of the specialised ventilation systems are of internationally acceptable healthcare standards such as ANSI/ASHRAE/ASHE Standard 170 – "Ventilation of Health Care Facilities" of the US, or Health Technical Memorandum (HTM) 03-01 – "Specialised ventilation for healthcare premises" of the UK, or equivalent.

2.2.2 In specialised ventilation areas, including but not limited to airborne infection isolation (AII) rooms, protective environment (PE) rooms, operating theatres/rooms and aseptic preparation clean rooms, the ventilation systems provide appropriate pressure relationship, air change rate, filtration efficiency, temperature and relative humidity, and air movement generally from clean to less clean areas. (Detailed guidelines on the specialised ventilation requirements are provided in Annex 2A.)

2.2.3 Where gaseous anaesthetic agents are used, appropriate gas administration devices and exhaust systems are in place, and relevant requirements on occupational safety are observed.

2.2.4 Outdoor air intakes for air handling units are situated away from vehicle staging areas, exterior designated smoking area, cooling towers and all exhaust and vent discharges.

2.2.5 The discharges from general extract systems are placed at a suitable location to minimise the recirculation of discharged air back into the building. In addition, the discharges from AII rooms and local exhaust ventilation systems are preferably vertical and at sufficient height above roof level. (Detailed guidelines on the exhaust discharge requirements are provided in Annex 2B.)

1. **Airborne Infection Isolation (AII) Rooms (Isolation Ward),**
2. **Protective Environment (PE) Rooms,**
3. **Operating Theatres (OT)**

Guidelines for Healthcare Engineering Systems of Private Hospitals (2018) Department of Health Hong Kong SAR, China December 2018

Ventilation Design for Health Care Facilities

Annex 2A

Specialised Ventilation Requirements

1. Specialised ventilation areas are ventilated according to the following requirements :

	Function of Space	Pressure Relationship to Adjacent Areas	Min. Outdoor ACH	Min. Total ACH	All Room Air Exhausted Directly to Outdoors	Air Recirculated by Means of Room Units[1]	Design Relative Humidity %	Deign Temp. ^{0}C	Min. Filter Efficiency
1	Operating theatre / room (OT/OR)	Positive	4	20	NR	No	20-60	20-24	MERV-14
2	Airborne Infection Isolation (AII) room	Negative	2	12	Yes	No	Max 60	21-24	MERV-14
3	Protective Environment (PE) room	Positive	2	12	NR	No	Max 60	21-24	HEPA

Note:

NR – no requirement

[1] Recirculating devices with high-efficiency particulate air (HEPA) filters may be used in existing facilities to achieve the required room ACH, provided the specified minimum outdoor ACH is supplied.

Guidelines for Healthcare Engineering Systems of Private Hospitals (2018) Department of Health Hong Kong SAR, China December 2018

Ventilation Design for Health Care Facilities

2. Airborne Infection Isolation (AII) rooms

2.1 AII rooms are sealed to provide a minimum differential pressure of -2.5 Pa across the envelope.

2.2 AII rooms have a permanently installed device and / or mechanism to constantly monitor the differential air pressure between the room and the corridor. A local visual means is provided to indicate whenever negative differential pressure is not maintained.

2.3 Exhaust air grilles in the patient room are located directly above the patient bed, on the ceiling or on the wall near the head of the bed.

Airborne Infection Isolation
Negative Pressure -2.5Pa
Differential Air Pressure Monitor
Exhaust air grilles location

3. Protective Environment (PE) rooms

3.1 PE rooms are sealed to provide a minimum differential pressure of +2.5 Pa across the envelope.

3.2 PE rooms have a permanently installed device and / or mechanism to constantly monitor the differential air pressure between the room and the corridor. A local visual means is provided to indicate whenever positive differential pressure is not maintained.

3.3 Supply air diffusers are located above the patient bed and return/exhaust grilles are located near the patient room door.

Protective Environment
Positive Pressure +2.5Pa
Differential Air Pressure Monitor
Supply Air Diffusers Location

4. Operating theatres/rooms (OTs/ORs)

4.1 OTs/ORs are maintained at a positive pressure with respect to all adjoining spaces at all times.

4.2 A pressure differential is maintained at a valve of at least +2.5 Pa.

4.3 Each room has individual temperature control.

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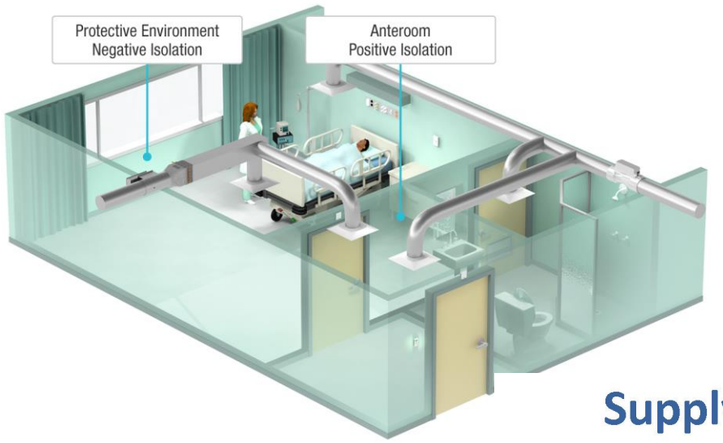
Ventilation Design for Health Care Facilities



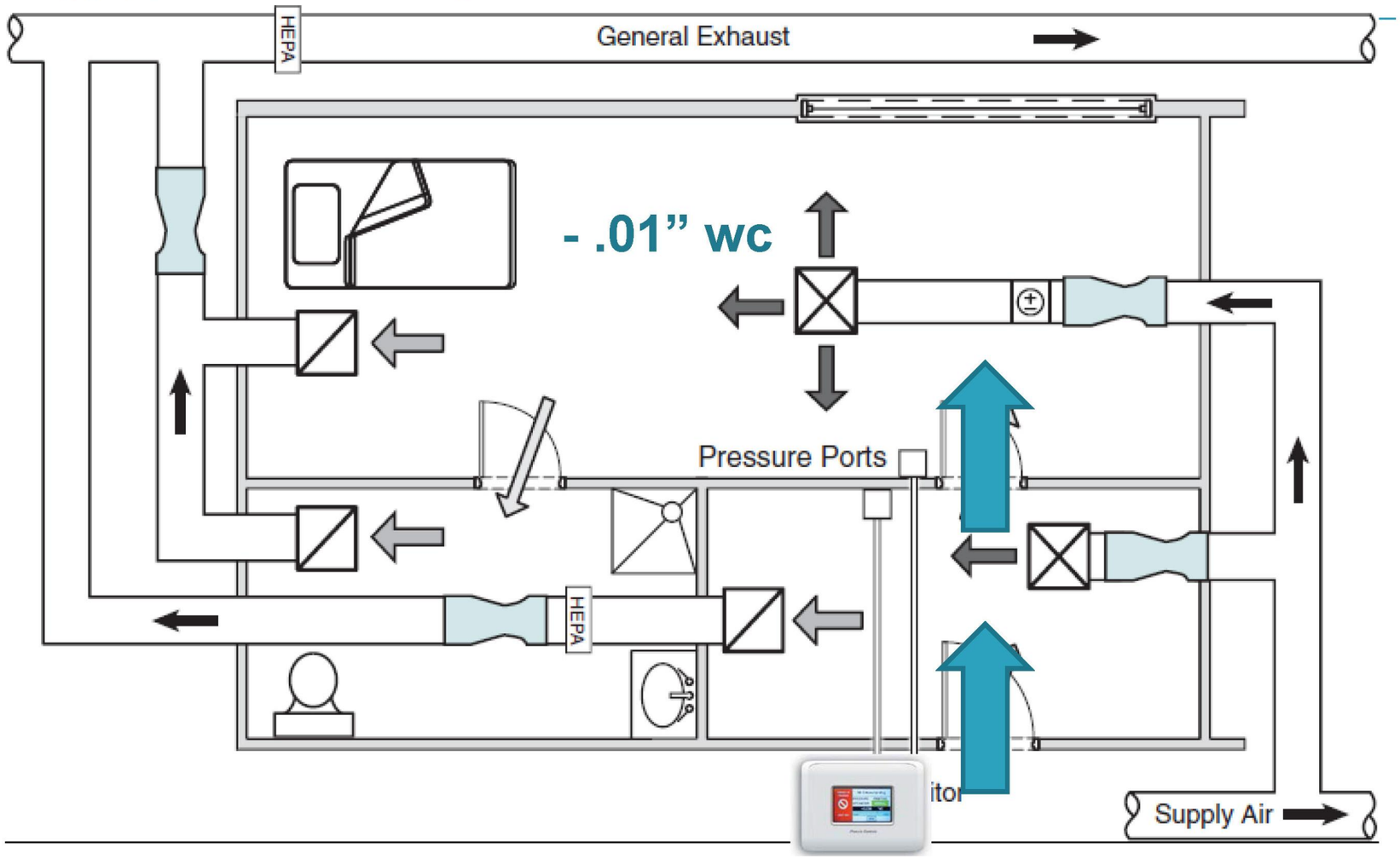
Airborne Infection Isolation

Negative Pressure -2.5Pa

Differential Air Pressure Monitor

Exhaust air grilles location

Supply / Exhaust Tracking Pairs



Source: ASHRAE Madison Chapter (Don MacDonald, Phoenix Controls)

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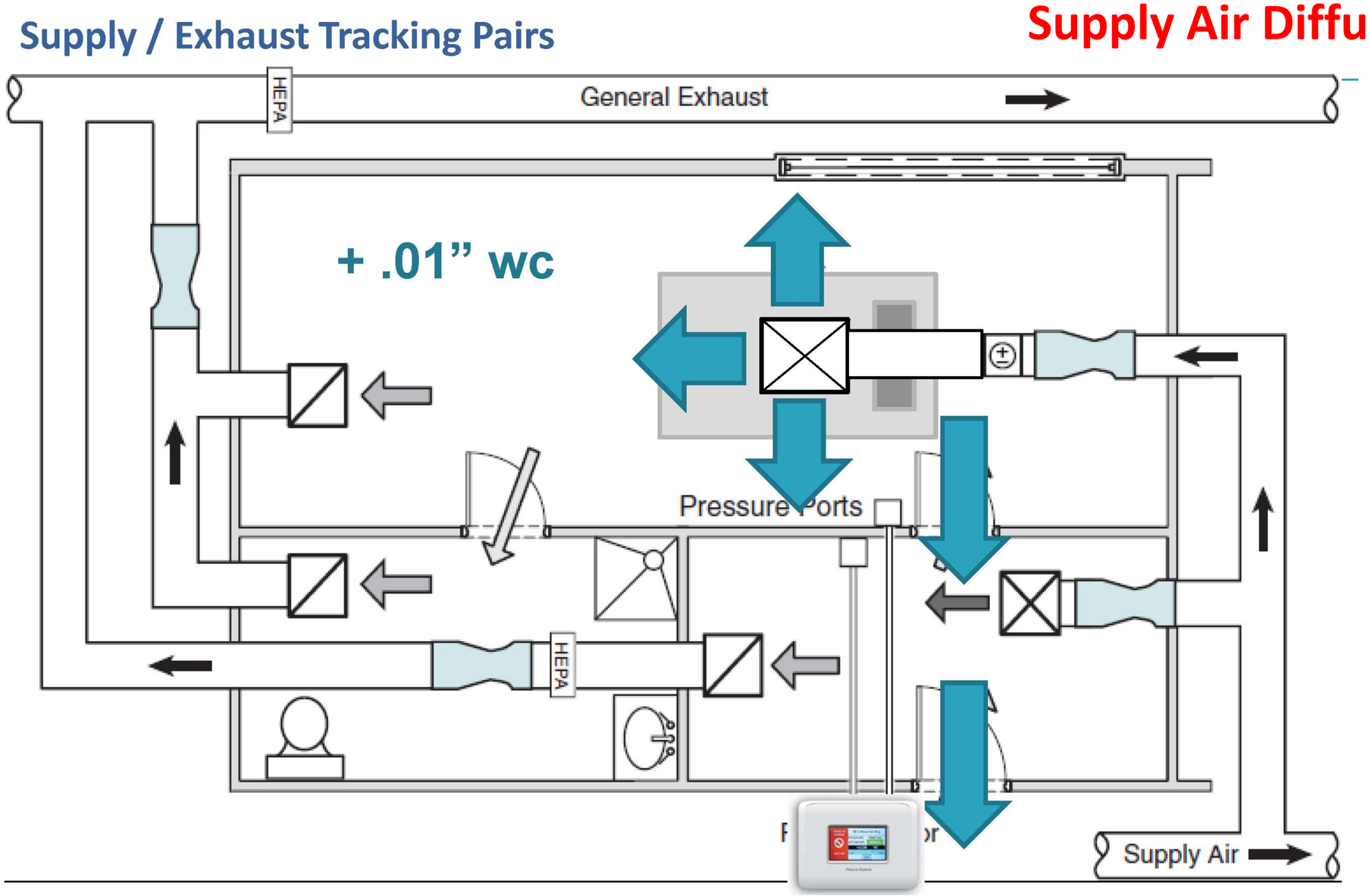
Ventilation Design for Health Care Facilities

Protective Environment

Positive Pressure +2.5Pa

Differential Air Pressure Monitor

Supply Air Diffusers Location



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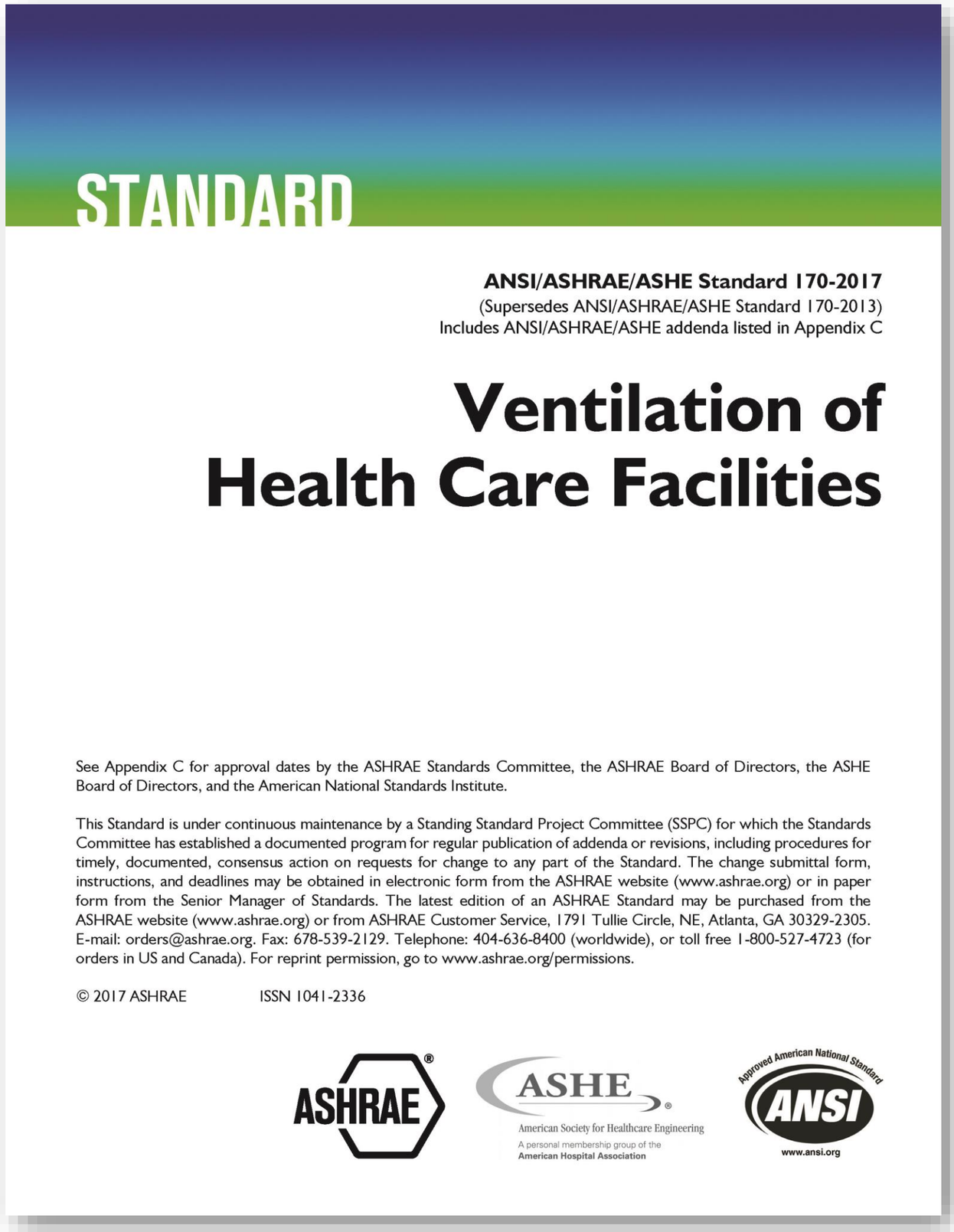
STANDARD

ANSI/ASHRAE/ASHE Standard 170-2017
(Supersedes ANSI/ASHRAE/ASHE Standard 170-2013)
Includes ANSI/ASHRAE/ASHE addenda listed in Appendix C

Ventilation of Health Care Facilities

See Appendix C for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, the ASHE Board of Directors, and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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American Society for Healthcare Engineering
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ASHRAE Standard 170-2017

(Supersedes ASHRAE Standard 170-2013) Includes ANSI/ASHRAE/ASHE addenda listed in Appendix C

Dr. Benny CHOW
(ASHRAE-HKC/Med.CUHK)

Ventilation Design for Health Care Facilities

CONTENTS

ANSI/ASHRAE/ASHE Standard 170-2017
Ventilation of Health Care Facilities

SECTION

Approved addenda website at www.as

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Table 7.1 Design Parameters—Hospital Spaces

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
SURGERY AND CRITICAL CARE							
Critical and intensive care	NR	2	6	NR	No	30–60	70–75/21–24
Delivery room (Caesarean) (m), (o)	Positive	4	20	NR	No	20–60	68–75/20–24
Emergency department decontamination	Negative	2	12	Yes	No	NR	NR
Emergency department exam/treatment room (p)	NR	2	6	NR	NR	Max 60	70–75/21–24
Emergency department public waiting area	Negative	2	12	Yes (q)	NR	Max 65	70–75/21–24
Intermediate care (s)	NR	2	6	NR	NR	Max 60	70–75/21–24
							70–75/21–24
							NR
							72–78/22–26
							68–75/20–24
							68–75/20–24
							70–75/21–24
							70–75/21–24
							70–75/21–24
							NR
							70–75/21–24
							70–75/21–24

Normative Notes for Table 7.1:

a. Except where indicated by a "No" in this colur HVAC units (with heating or cooling coils) are ing that portion of the minimum total air chang mitted by Section 7.1 (subparagraph [a][5]). B difficulty and potential for buildup of contar room units shall not be used in areas marke devices with high-efficiency particulate air (H permitted in existing facilities as interim, supple controls to meet requirements for the control agents. The design of either portable or fixed s stagnation and short circuiting of airflow. The shall also allow for easy access for schedulec nance and cleaning.

b. Pharmacy compounding areas may have additi ential pressure, and filtering requirements be this table, depending on the type of pharmacy, ments (which may include adoption of USP level of risk of the work, and the equipment use *mative Note:* See USP (2017a) in Appendix B.

c. The term *trauma room* as used herein is a first- gency department room used for general initial victims. The OR within the trauma center tha emergency surgery is considered to be an OR

d. Pressure relationships need not be maintain unoccupied.

e. See Section 7.2 and its subsections for pressur ments.

f. Higher ventilation rates above the total ach list dictated by the laboratory program requirement of the potential contaminants in each laboratory ach ventilation rates shall be permitted when a H formed as part of an effective Laboratory Ve Plan per ANSI/AIHA/ASSE Z9.5, *American Laboratory Ventilation*[13] determines that eithe sure concentrations in the laboratory work area lower minimum total ach ventilation rate than i (b) a demand control approach with active sens appropriate surrogates is used as described in *HVAC Applications*, Chapter 16, "Laboratorie See ASHRAE [2015] in Informative Appendix

g. All air need not be exhausted if darkroom equ ing exhaust duct attached and meets ventilatic NIOSH [5], OSHA, and local employee exposure

h. A nonrefrigerated body-holding room is appli that do not perform autopsies on-site and use th ods while waiting for the body to be transferre

i. Minimum total air changes per hour (ach) sh provide proper makeup air to kitchen exhaust s ANSI/ASHRAE Standard 154 [6]. In some cases infiltration to or from exit corridors compron restrictions of NFPA 90A [7], the pressure requir or the maximum defined in the table. During op the number of air changes to any extent require be permitted when the space is not in use.

j. In some areas with potential contamination a exhaust air shall be discharged directly to the culated to other areas. Individual circumstanc consideration for air exhausted to the outdoors. To satisfy exhaust needs, constant replacement air from the outdoors is necessary when the system is in operation.

k. The RH ranges listed are the minimum and/or maximum allowable at any point within the design temperature range required for that space.

l. Systems shall be capable of maintaining the rooms within the range during normal operation. Lower or higher temperature shall be permitted when patients' comfort and/or medical conditions require those conditions.

m. National Institute for Occupational Safety and Health (NIOSH) criteria documents [9] regarding occupational exposure to waste anesthetic gases and vapors and control of occupational exposure to nitrous oxide indicate a need for both local exhaust (scavenging) systems and

x. If the planned space is designated in the organization's ope plan to be used for both bronchoscopy and gastrointestinal copy, the design parameters for "bronchoscopy, sputum col and pentamidine administration" shall be used.

y. For single-bed patient rooms using Group D diffusers, a mini six total ach shall be provided and calculated based on the from finished floor to 6 ft (1.83 m) above the floor.

z. See AAMI Standard ST79 [11] for additional information fo spaces.

aa. Examination rooms programmed for use by patients with nosed gastrointestinal symptoms, undiagnosed respiratory toms, or undiagnosed skin symptoms.

the individual space requirements as defined by this standard.

ii. System minimum outdoor air quantity shall be calculated by the Ventilation Rate Procedure (multiple zone formula) of ASHRAE Standard 62.1 [1]. The minimum outdoor air change rate listed in this standard shall be interpreted as the V_{oz} (zone outdoor airflow) for purposes of this calculation.

b. Air filtration for spaces shall comply with Table 6.4.

c. Supply air outlets for spaces shall comply with Table 6.7.2.

d. In All rooms, protective environment rooms, wound intensive care units (burn units), and operating and procedure rooms, heating with supply air or radiant panels that meet the requirements of Section 6.5.3 shall be provided.

7.2 Additional Room-Specific Requirements

7.2.1 Airborne Infection Isolation (AII) Rooms. Ventila tion for AII rooms shall meet the following requirements whenever an infectious patient occupies the room:

a. Each AII room shall comply with requirements of Table 6.4, 6.7.2, and 7.1. AII rooms shall have a permanently installed device and/or mechanism to constantly monito the differential air pressure between the room (when occu pied by patients with a suspected airborne infectious dis ease) and the corridor, whether or not there is an anteroom A local visual means shall be provided to indicate when ever negative differential pressure is not maintained.

b. All air from the AII room shall be exhausted directly t the outdoors.

Exception to 7.2.1(b): AII rooms that are retrofitted fron standard patient rooms from which it is impractical t exhaust directly outdoors may be provided with recircu lated air from the room's exhaust on the condition tha the air first passes through a HEPA filter.

c. All exhaust air from the AII rooms, associated anterooms and associated toilet rooms shall be discharged directly t the outdoors without mixing with exhaust air from any other non-AII room or exhaust system.

d. Exhaust air grilles or registers in the patient room shall b located directly above the patient bed, on the ceiling or o the wall near the head of the bed, unless it can be demon strated that such a location is not practical.

e. The room envelope shall be sealed to provide a minimun differential pressure of 0.01 in. of water (2.5 Pa) acros the envelope.

f. Differential pressure between AII rooms and adjacen spaces that are not AII rooms shall be a minimum of –0.0 in. of water (–2.5 Pa). Spaces such as the toilet room an the anteroom (if present) that are directly associated wit the AII room and open directly into the AII room are no required to be designed with a minimum pressure differ ence from the AII room but are still required to maintai the pressure relationships to adjacent areas specified i Table 7.1.

g. When an anteroom is provided, the pressure relationship shall be as follows: (1) the AII room shall be at a negativ pressure with respect to the anteroom, and (2) the ante room shall be at a negative pressure with respect to the corridor.

7.2.2 Protective Environment (PE) Rooms. Ventilation for PE rooms shall meet the following requirements:

a. The room envelope shall be sealed to provide a minimum differential pressure of 0.01 in. of water (2.5 Pa) across the envelope.

b. Each PE room shall comply with the requirements of Tables 6.4, 6.7.2, and 7.1. When occupied by patients requiring a protective environment, PE rooms shall have a permanently installed device and/or mechanism to constantly monitor the differential air pressure between the room and the corridor, regardless of whether there is an anteroom. A local visual means shall be provided to indicate whenever positive differential pressure is not main-

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX A OPERATIONS AND MAINTENANCE (O&M) PROCEDURES

A1. O&M IN HEALTH CARE FACILITIES

The following operations and maintenance (O&M) procedures are recommended for health care facilities.

A1.1 Operating Rooms (ORs)

a. Each OR should be tested for positive pressure semi-annually or on an effective preventative maintenance schedule.

b. When HEPA filters are present within the diffuser of ORs, the filter should be replaced based on pressure drop.

c. Operating and Caesarean delivery room ventilation systems shall operate at all times, except during maintenance and during conditions requiring shutdown by the building's fire alarm system.

A1.2 Protective Environment (PE) Rooms. PE rooms should remain under positive pressure, with respect to all adjoining rooms, whenever an immunocompromised patient is present. PE rooms should be tested for positive pressure daily when an immunocompromised patient is present. When HEPA filters are present within the diffuser of PE rooms, the filter should be replaced based on pressure drop.

A1.3 Airborne Infection Isolation (AII) Rooms. AII rooms should remain under negative pressure, relative to all adjoining rooms, whenever an infectious patient is present. They should be tested for negative pressure daily whenever an infectious patient is present.

A1.4 Filters. Final filters and filter frames should be visually inspected for pressure drop and for bypass monthly. Filters should be replaced, based on pressure drop, with filters that provide the efficiencies specified in Table 6.4.

A2. SPECIAL MAINTENANCE FOR HVAC UNITS

The following special maintenance procedures are recommended for health care facilities.

A2.1 Fan-Coil Unit and Heat Pumps. The fan-coil unit and heat-pump filters serving patient rooms should be inspected for pressure drop monthly, or on an effective preventative maintenance cycle, and should be replaced when that pressure drop causes a reduction in airflow. Fan-coil unit and heat-pump drain pans under cooling coils should be cleaned monthly or on an effective preventative maintenance cycle.

A2.2 Fin-Tube Radiation Units, Induction Units, and Convection Units. Fin-tube radiation units, induction units, and convection units serving patient rooms should be cleaned quarterly or on an effective preventative maintenance cycle.

A2.3 Fan-Powered Terminal Units. Fan-powered terminal-unit filters serving patient rooms should be inspected for pressure drop monthly, or on an effective preventative maintenance cycle, and should be replaced when the pressure drop causes a reduction in airflow.

A3. AIR INTAKE OPENING FOR AREAWAY

Figure A3 illustrates the provisions of Section 6.3.1.4 for air intake openings for areaways.

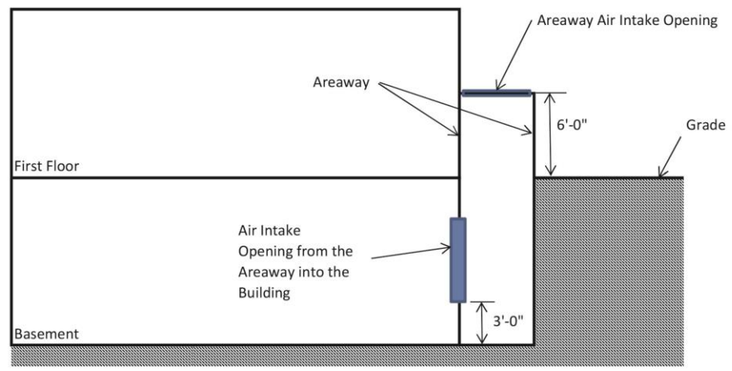

Figure A3 Provisions for areaways.

Isolation System in a Hospital

Level 1 - Administrative Control

Such as proper triage of patients, detecting infections early and, separating infectious patients from others (WHO 2007; CDC 2007); Adequate staff training and patients education; Effective communication with all relevant departments.

Level 2 - Environmental and Engineering Controls

Include cleaning of the environment, spatial separation, ventilation of spaces

Level 3 - Personal Protection

Have personal protective equipment (PPE), including, masks, respirators, gowns, gloves, eye protection, etc.

Figure: Three levels of isolation precautions controls as stipulated at WHO.

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Negative Pressure Isolation Ward

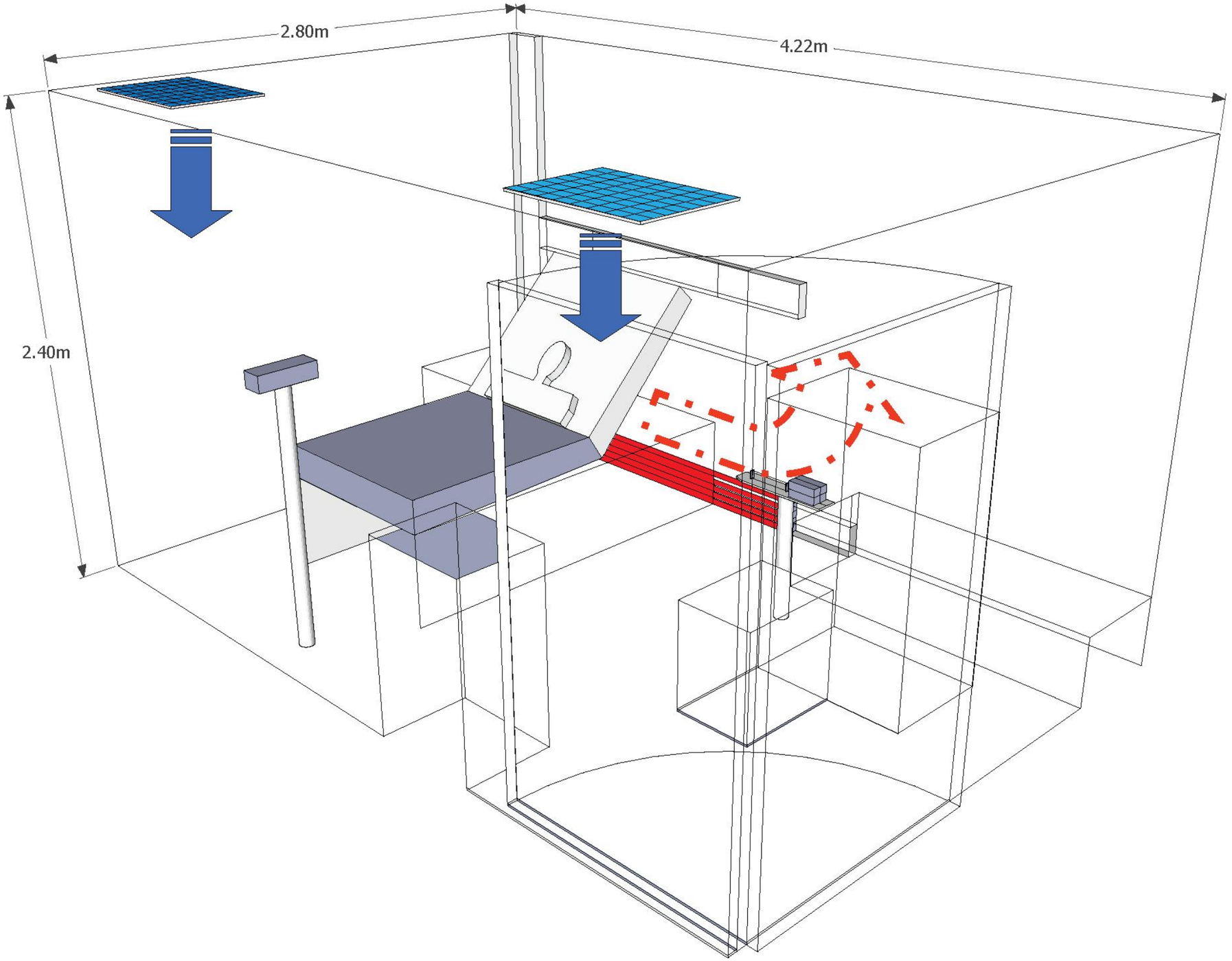

Figure: Downward ventilation system provides negative pressure to isolation room B of PWH. (Source : Benny Chow)

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Negative Pressure Isolation Ward

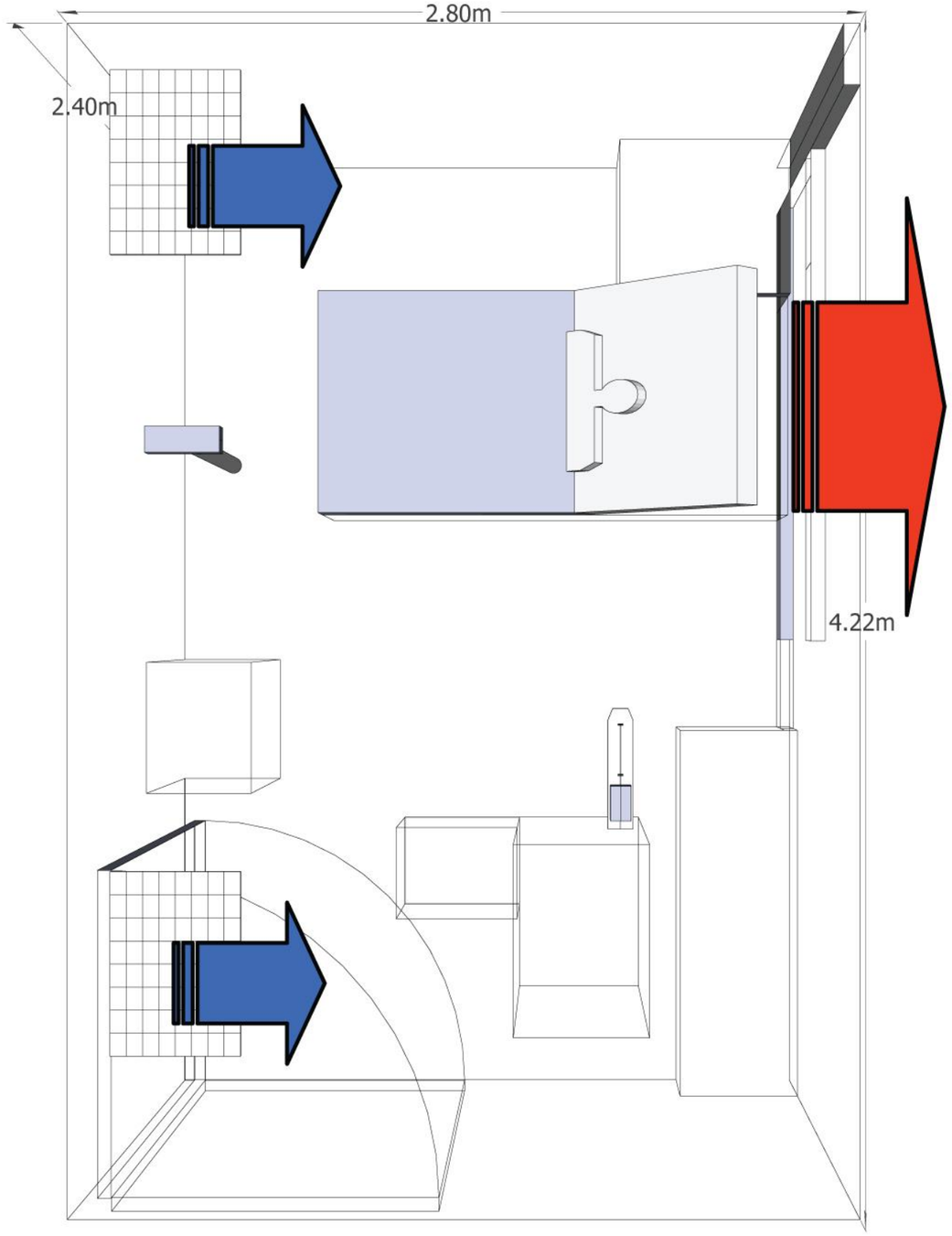

Figure: Downward ventilation system provides negative pressure to isolation room B of PWH.

Source: Benny Chow

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Main Design Principles for an Isolation Room

1. The AII room should be at least **2.5 Pa** (0.01-inch water gauge) **Negative Pressure** with respect to adjacent spaces, between patient rooms and the double door anteroom to prevent air leaking outward;

2. The **Dilution Ventilation Rate** should be at least 6 ACH for existing facilities and **12 ACH** for new facilities;

3. The AII room can be constructed with or without an anteroom. An **anteroom** can act as an airlock space and is recommended to store personal protective equipment (PPE);

4. **Outdoor fresh air intakes** shall be located at not less than 7.6 m horizontally from **all exhaust outlets**. The exhaust shall be discharged above roof level. Avoid direct exhaust towards operable windows, walkways, public areas, and parking areas;

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Main Design Principles for an Isolation Room

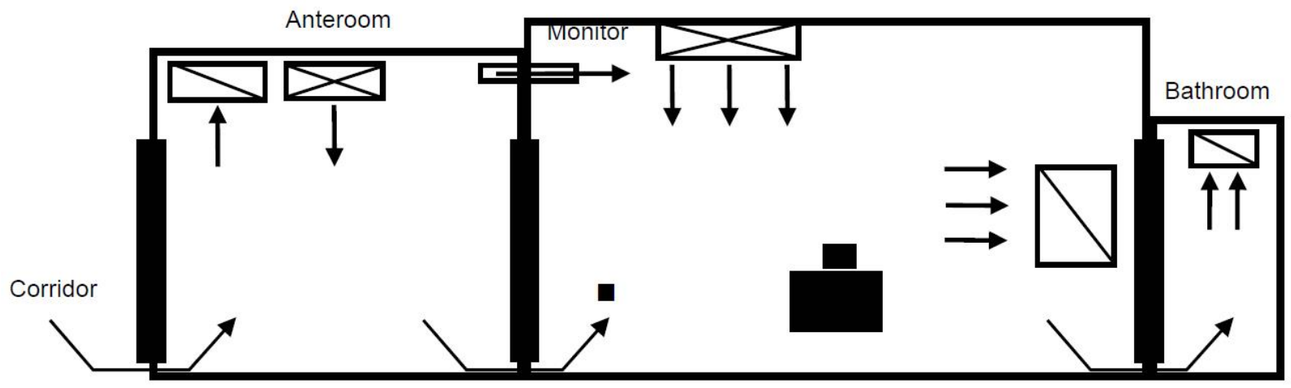

Figure: Sectional view of the conceptual of airflow diagram of AII room with anteroom (CDC 2003)

[engineering features]	**Airborne Infection Isolation room (AII)**	**Operating Theatres (OT)**	**Protective Environment (PE)**
Air pressure	Negative	Positive	Positive
Pressure differentials in relation to the adjacent areas	> -2.5 Pascal (i.e. 0.01 inch water gauge)	Positive	> +2.5 to +8 Pascal
Room air changes per hour (ACH)	Minimum 6 ACH (for existing facilities); > 12 ACH (for renovation or new construction)	> 15 ACH	> 12 ACH
Sealed	Yes	Yes	Yes
Filtration efficiency of supply air	As per local hospital policy	> 90%	HEPA filter at 99.97% at 0.3µm
Filtration efficiency of exhaust air	Not required if direct exhaust air to the outside; or HEPA filter at 99.97% at 0.3 µm for re-circulated air	Not required if exhaust air to outside; or HEPA filters should be installed for re-circulated air	Not required
Recirculation	No, unless HEPA filters are installed	Yes	Yes
Clean to dirty airflow	All towards patient and exhausted	For supply across patient and exhausted	From supply across patient and exhausted

Figure: The summary of the engineering control specification for AII room, operating theatres and protective environment issued by the Center for Health Protection (CDC 2003; WHO 2009; CHP 2007)

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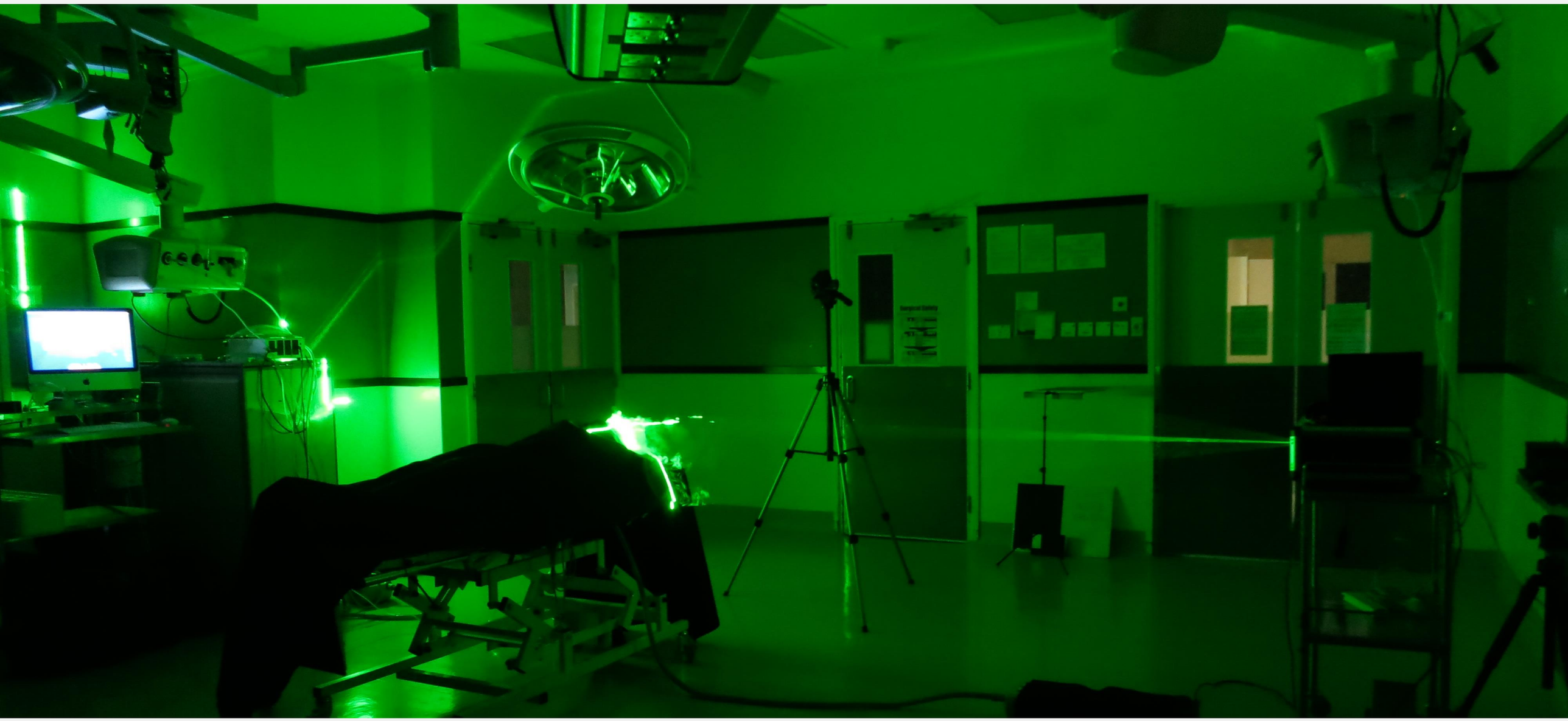
ON-SITE MEASUREMENT



Isolation Room A at PMH

Figure: Isolation Room A at PMH showing a spacious single bed patient room with an anteroom as airlock between corridor and patient room.

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Clinical Settings & Human-centred Design

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Isolation Room A at PMH

Figure: Fully glazed air-tight, auto-swing door (left) and the ultraviolet germicidal irradiation (UVGI) lamp mounted on the top of patient bed (right) for isolation room A at PMH.

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Isolation Room A at PMH

Figure: Spacious single bed patient room of isolation room A at PMH, with air supply diffusers mounted on the ceiling at the end of the patient bed and floor level exhaust underneath the head of the patient bed.

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Isolation Room B at PMH

Figure: The more congested isolation room B at PWH, with air supply diffusers mounted on the ceiling at the foot of the patient bed and floor level exhausts underneath the head of the patient bed.

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Common Oxygen Therapies

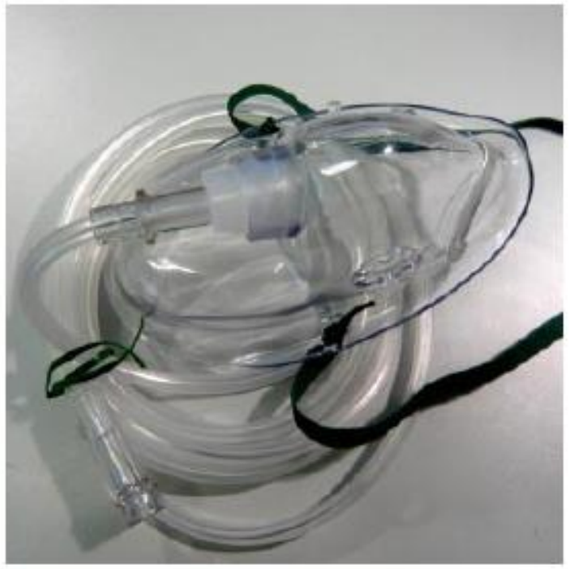
Mask Types	Technical Comments	Visual Appearance of Masks
Simple (Hudson) Mask Brand: Well Lead Model: Oxygen mask, Adult elongated [www.welllead.com.cn]	1. Most commonly used oxygen mask; 2. Cannot control O_2%; it depends on O_2flow rate, mask fit and patient IPAP; 3. Performance: 4L/min, oxygen is around 35%; up to 14L/min, oxygen is around 65%.	
Venturi Mask Brand: Salter Labs Model: Accu-Flow Venturi System (Adult) [www.salterlabs.com]	1. Design to deliver accurate O_2 concentration (24%, 28%, 31%, 35%, 40%) with five individual diluter jets; 2. Operate with Venturi principle; 3. Combination of oxygen flow rate and the diluter jets determine the O2 concentration.	

Figure: The illustrations of the common oxygen masks and its laser flow visualization in a negative pressure isolation room.

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Common Oxygen Therapies

Mask Types	Technical Comments	Visual Appearance of Masks
Nasal Cannula Mask Brand: Airlife Model: Nasal Oxygen Cannula Cat. 001325 [www.cardinal.com]	1. Deliver supplementary oxygen directly to patient via nostrils directly; 2. The oxygen flow rate ranges from 1 to 6 L/min; can deliver 28% to 44% oxygen; 3. Allow patient to receive high volume of oxygen therapy accurately.	
Jet Nebulizer Brand: (Salter Labs Model: Nebulizer adult, REF 8924 [www.salterlabs.com]	1. Nebulizes 3cc in less than 10 minutes; Shortened treatment times; 2. Nebulizes in horizontal or vertical position; Allow patient to be in a comfortable position for treatment; 3. Larger surface area provided by unique convex cone design.	

Figure: The illustrations of the common oxygen masks and its laser flow visualization in a negative pressure isolation room.

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Common Oxygen Therapies

Mask Types	Technical Comments	Visual Appearance of Masks
NPPV Mask Brand: Respironic Model: Image 3 full face mask, Lot. 040219/ 1004884 [www.respironics.com]	1. Exhalation device NOT INCLUDED; 2. "Whisper Swivel" exhalation port was attached, which caused a large scale diffused contamination around the patient head; 3. Entrainment valve included.	
NPPV Mask Brand: Respironic Model: Comfort Full 2 full face mask, Lot. 070105/1004873 [www.respironics.com]	1. Exhalation device - "Quiet Diffuser" - Three rows of tiny ports creating a strong directional air jet projected towards the end of patient bed; 2. Entrainment valve type - provides quick access to room air if pressure is less than 3cm H_2O.	

Figure: The illustrations of the common oxygen masks and its laser flow visualization in a negative pressure isolation room.

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INSTRUMENTS

Airflow Visualization – Laser Imaging System

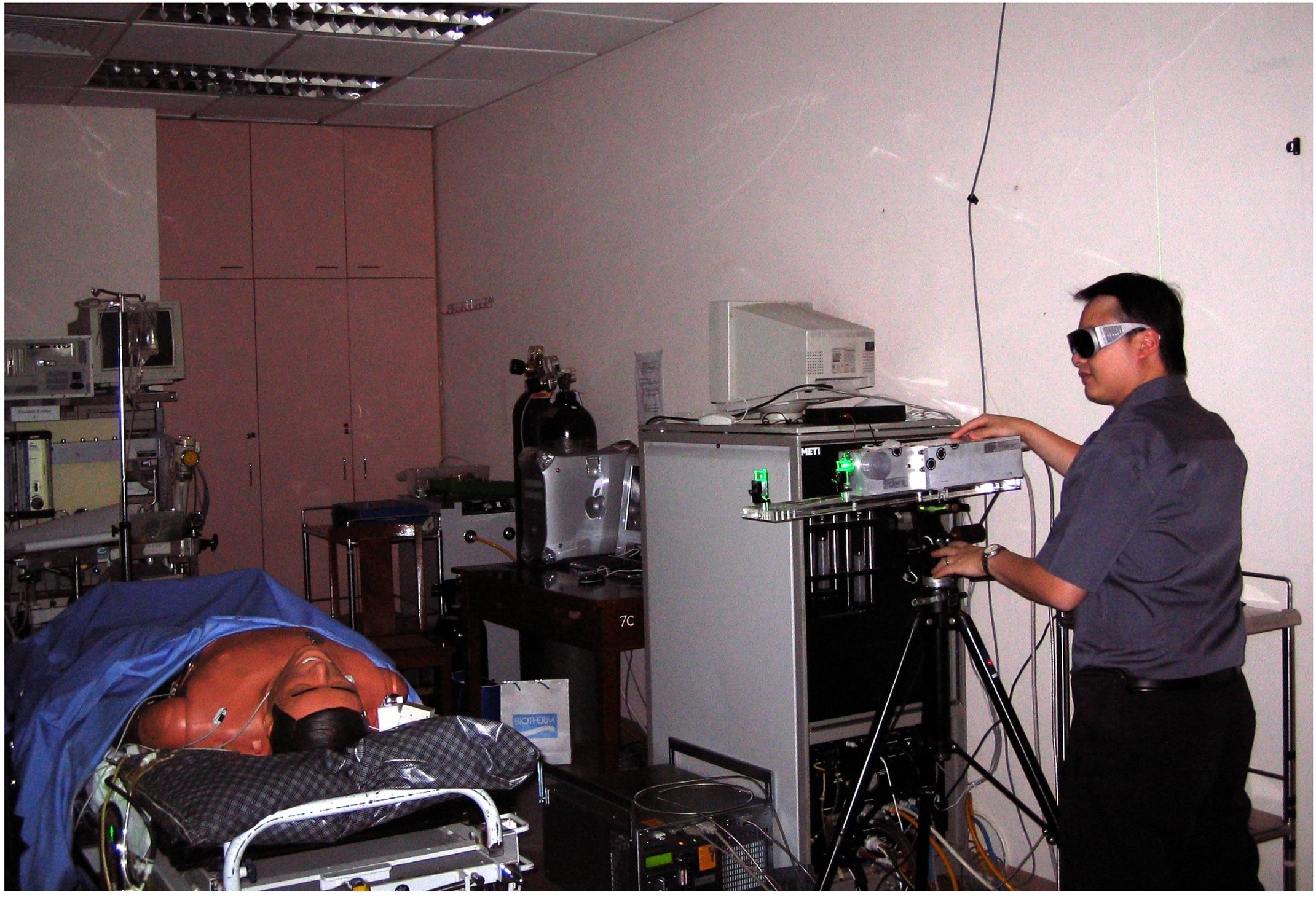

Figure: Set-up of Spectra Physic OEM 532nm DPSS of the Laser Imaging System (LIS).

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Airflow Visualization – Laser Imaging System

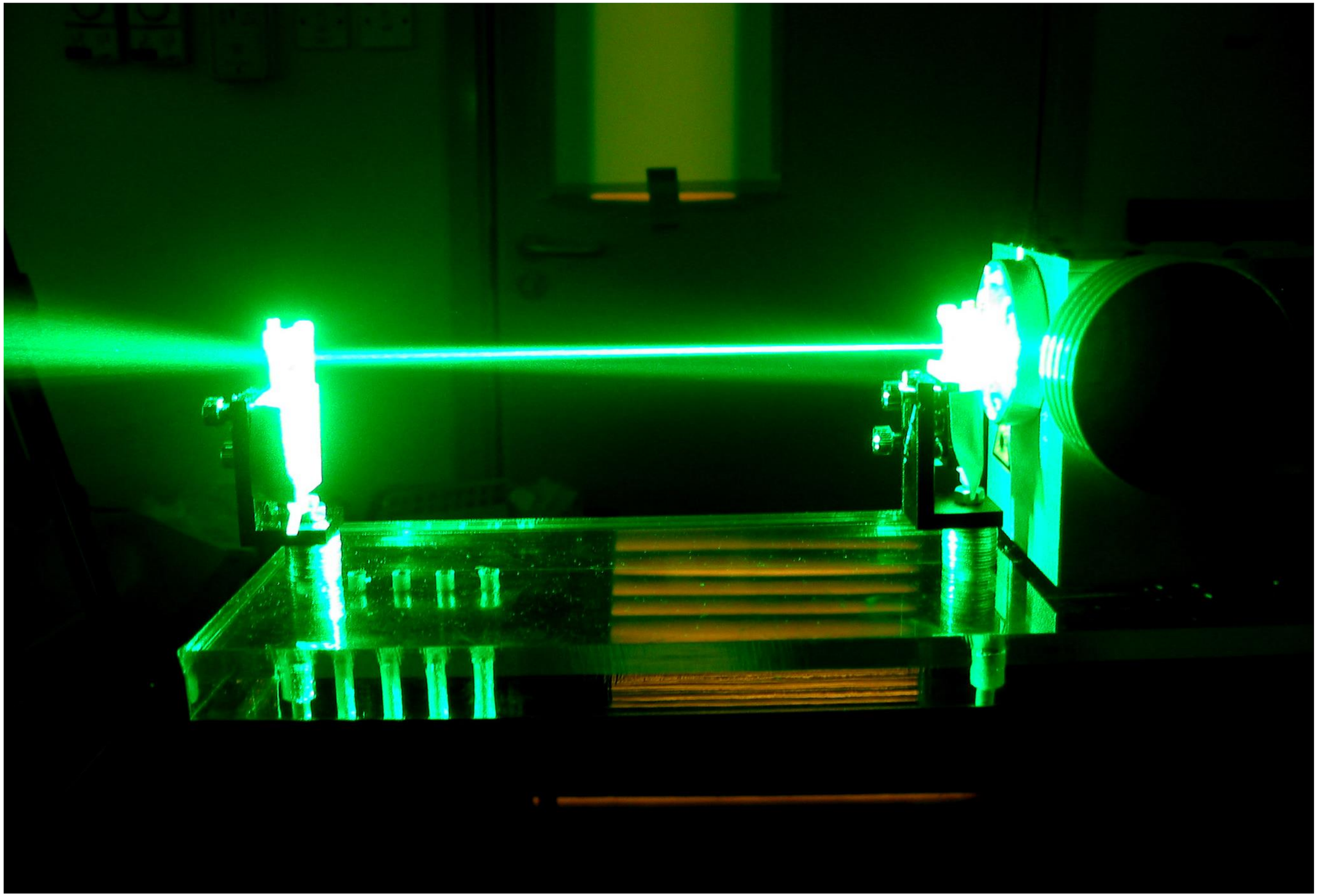

Figure: Powerful laser beam and light sheet was generated from Nd:YAG DPSS laser system passing through an optical system developed for this study.

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Image Capture and Frame Extraction

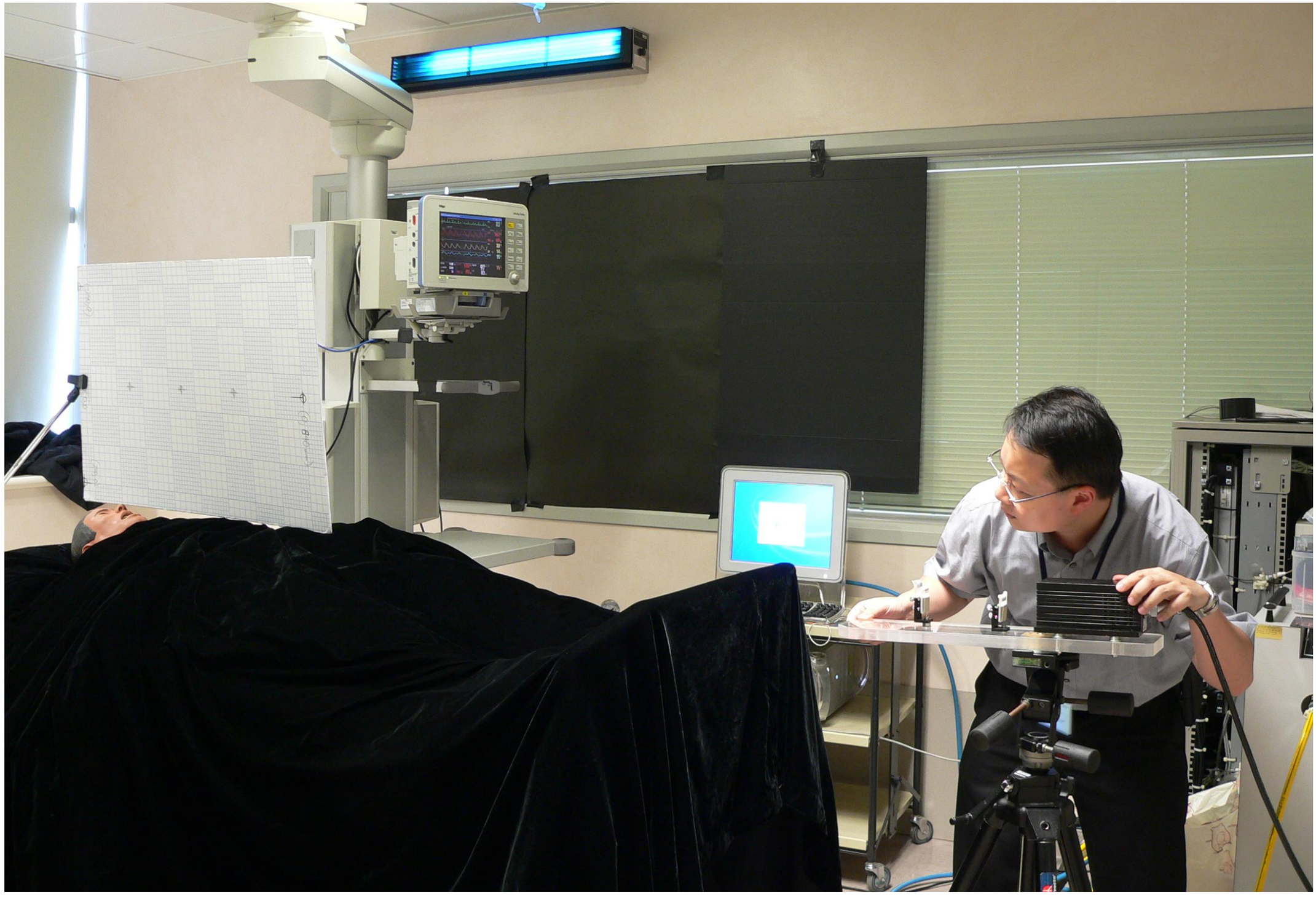

Figure: Calibrating the low-powered LIS with the dimension grid mounted on the median sagittal plane of the mannequin.

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Experiments on Jet Nebulizer

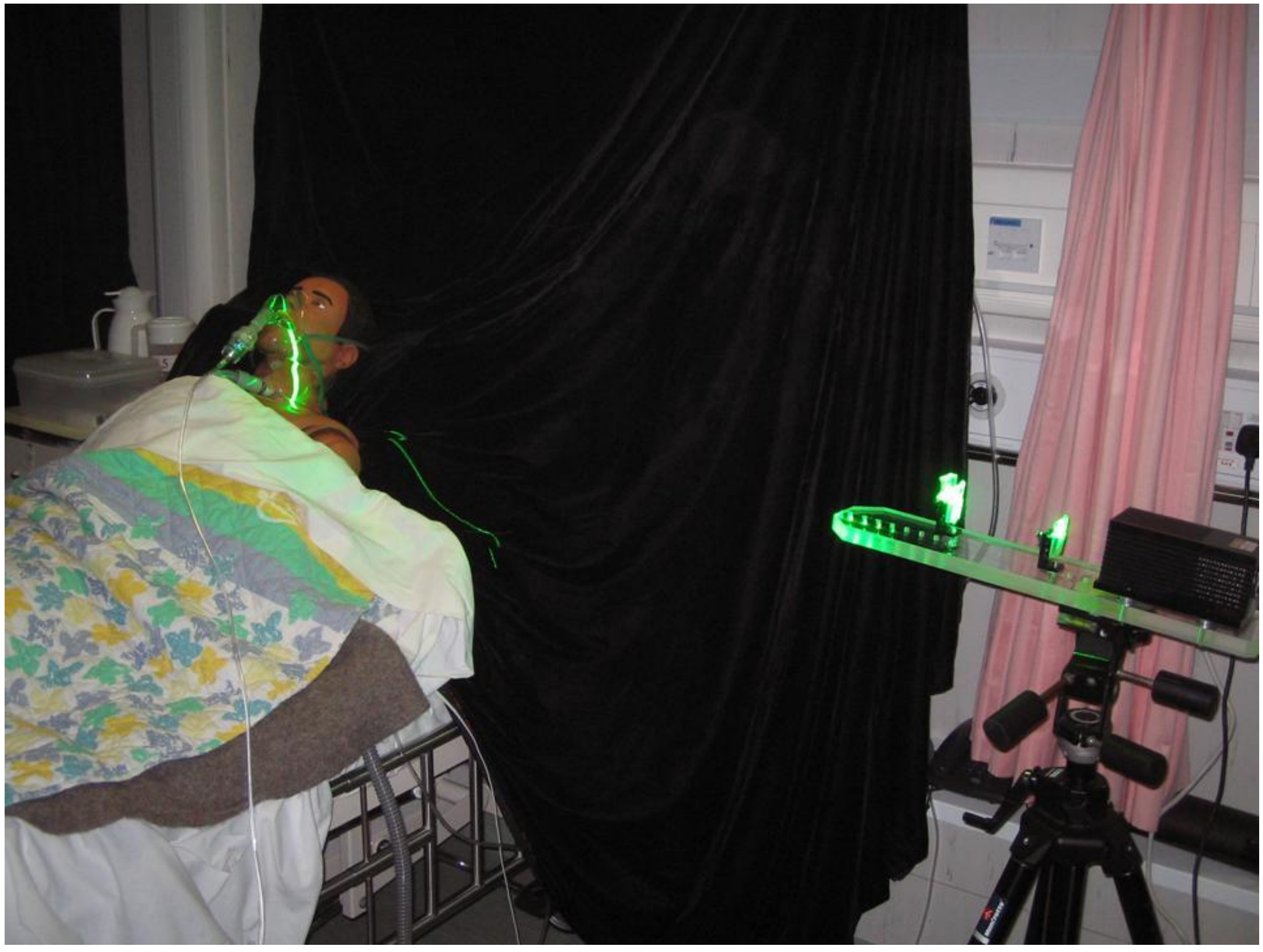

Figure: A jet nebulizer was attached to a HPS with a LST laser light sheet in the transverse plane.

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Experiments on Jet Nebulizer

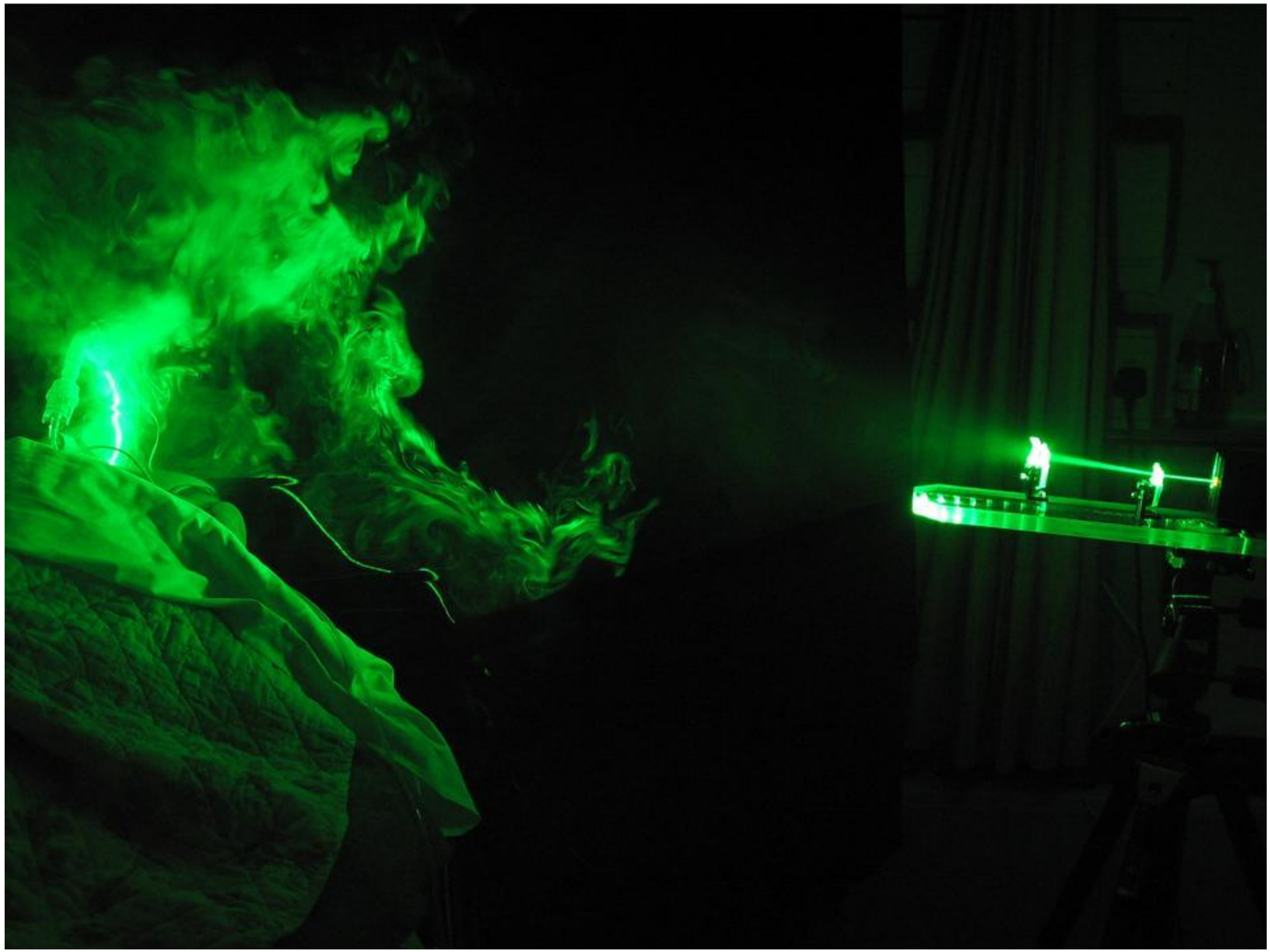

Figure: Photograph showing aerosol dispersion and patient exhaled air plume of jet nebulizer.

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Image Capture and Frame Extraction

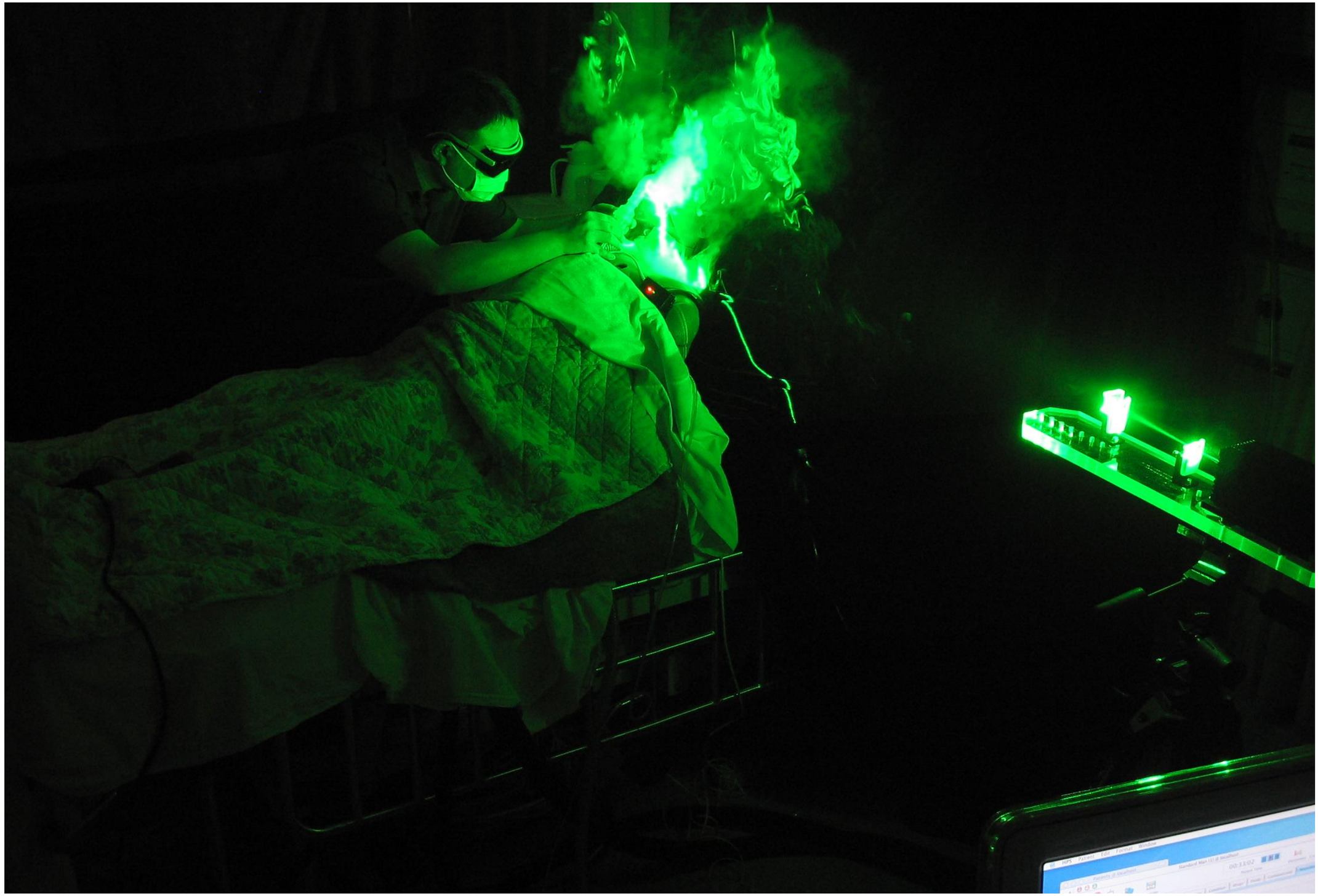

Figure: Mask fitting to seal the air leakage and aliging the laser light sheet to the centerline of the mask side vents.

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Deliberated Air Leakage of ResMed Ultra Mirage Full Face Mask

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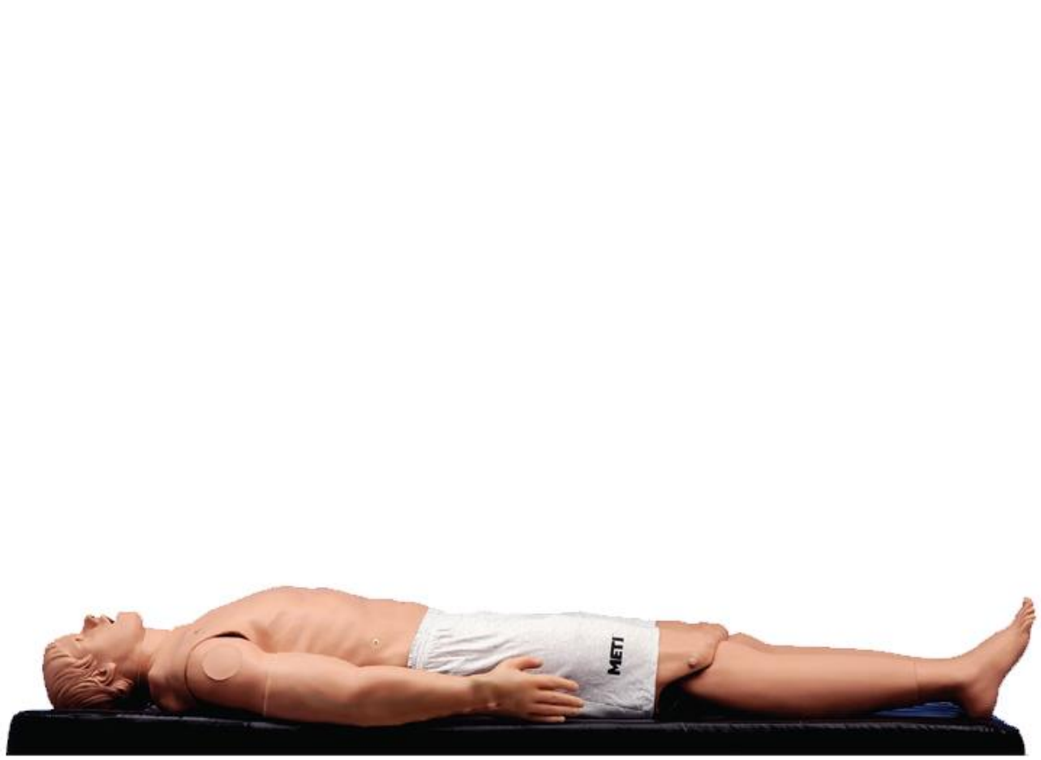
Human Patient Simulator – Support Physiological Functions



HPS Mannequin

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HPS Console

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HPS Lab Rack

Figure: HPS system includes a mannequin, a control console and a lab rack (METI 2009).

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Human Patient Simulator – Support Physiological Functions

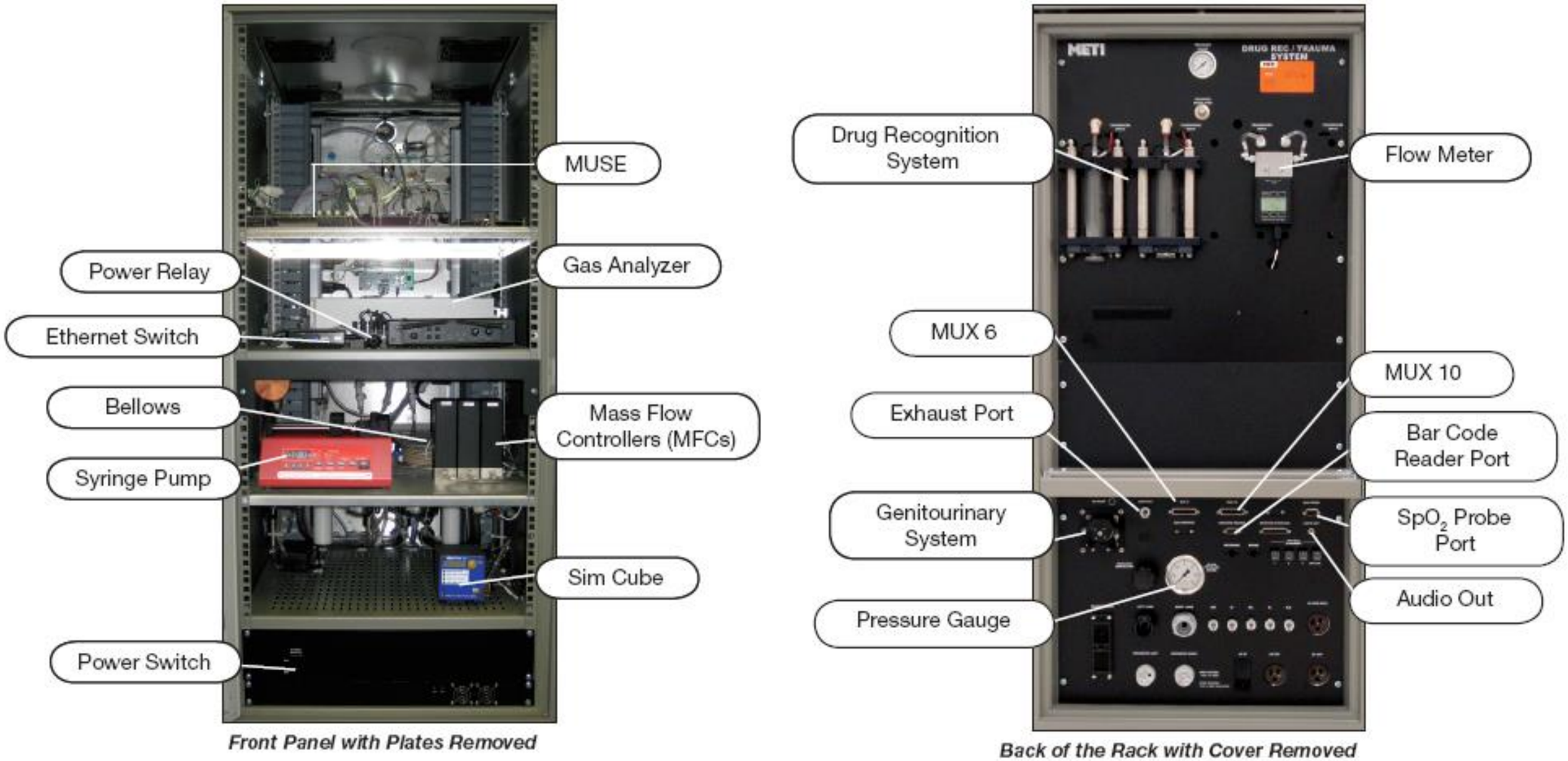

Figure: The HPS lab rack is equipped with sophisticated mechanical lung bellows and precise mass flow controllers to simulate the human airway and oxygen compliance physiology (METI 2009).

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Human Patient Simulator – Support Physiological Functions

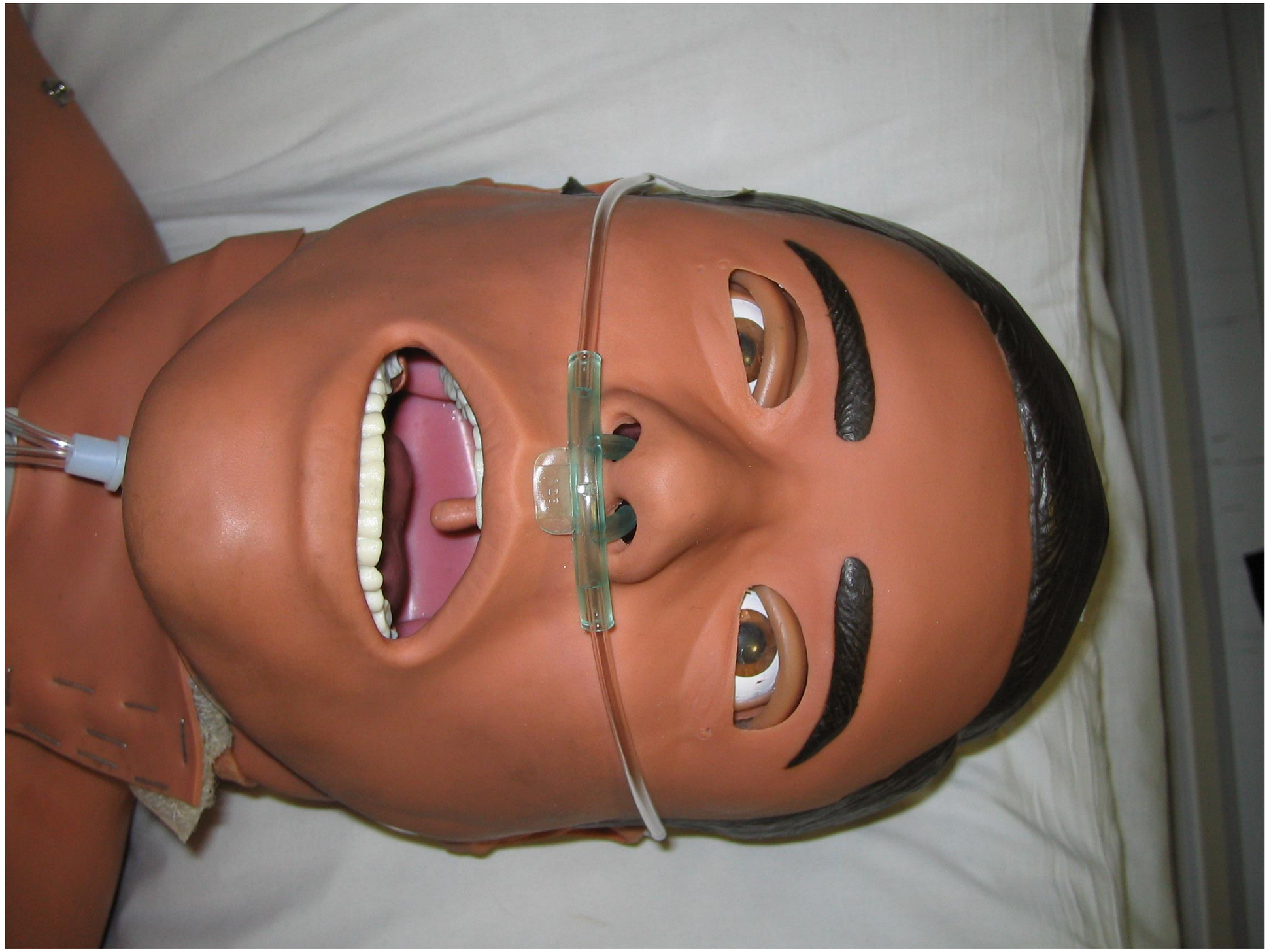

Figure: HPS mannequin with realistic airway including oropharynx, nasopharynx and larynx for simulating human respiratory physiology.

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Human Patient Simulator – Support Physiological Functions

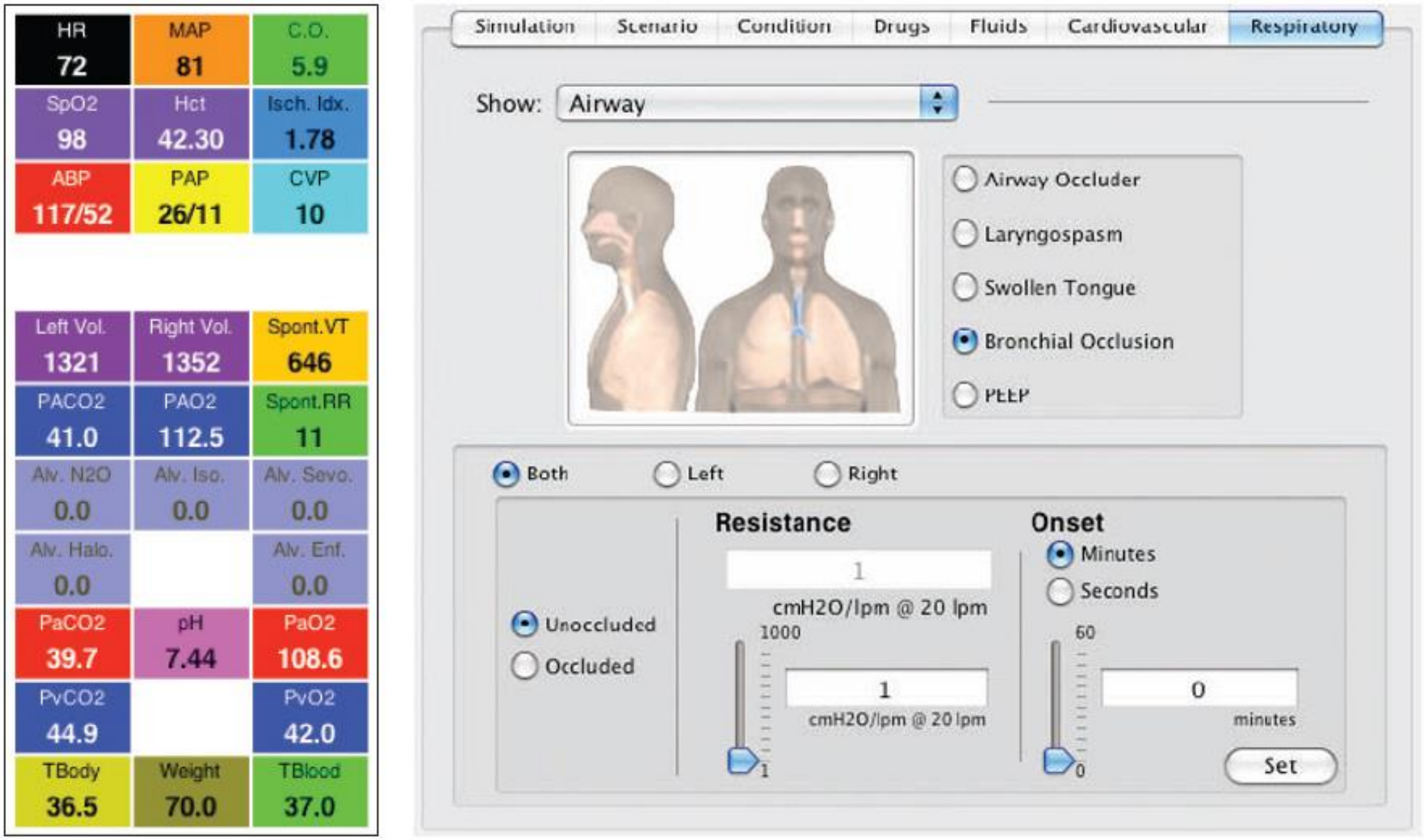

Figure: HPS system console can dynamically control the airway parameters, including variation of tidal volume, respiratory rate and oxygen consumption (METI 2009).

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Human Patient Simulator – Support Physiological Functions

Control Parameters	Normal Lung Condition	Mild Lung Injury	Severe Lung Injury
Oxygen consumption (ml/min)	200	300	500
Lung compliance (ml/cmH_2O)	70	35	10
Respiratory rate (breaths/min)*	12	25	40
Tidal volume (ml)*	700	300	150

* The respiratory rate and tidal volume were adjusted by the HPS program to achieve the target oxygen consumption and lung compliance.

Figure: Three different lung settings of the HPS applied in this study.

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Human Patient Simulator – Support Physiological Functions

Figure: On-site equipment setup of the HPS, including HPS lab rack and HPS control console with supporting accessories.

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Human Patient Simulator – Support Physiological Functions

Figure: A mini device developed for the study to synchronize the mechanical movement of the HPS bellows with the laser imaging system (LIS).

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Quantitative Flow Visualization Analysis

Figure: Background intensity image with ambient lighting switched off for stray background light subtraction.

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Quantitative Flow Visualization Analysis

Figure: Grey scale camera frames captured for light intensity analysis routine to generate normalized particle concentration contours.

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Quantitative Flow Visualization Analysis

Mean of intensity $c := 1.3$ background reducer $\min(AG) = 7$ $\max(AG) = 255$

$$AM_{i,j} := \frac{A_{i,j}}{N} - \frac{AG_{i,j}}{c}$$

subtract background later

$\min(AM) = -56.185$ $\max(AM) = 205.058$

Checkmean concentration contours

$P := 2$ squarepixel summing region $rows(AM) = 720$ $cols(AM) = 1280$

Counters

$Imax := rows(AM)$

$Jmax := cols(AM)$

$\frac{Imax}{P} = 360$ $floor\left(\frac{Imax}{P}\right) = 360$ $rows(AM) - floor\left(\frac{Imax}{P}\right) \cdot P = 0$ pixelsat bottom edge ignored

$\frac{Jmax}{P} = 640$ $floor\left(\frac{Jmax}{P}\right) = 640$ $cols(AM) - floor\left(\frac{Jmax}{P}\right) \cdot P = 0$ pixelsat right edge ignored

$i := 1 .. floor\left(\frac{Imax}{P}\right)$ $j := 1 .. floor\left(\frac{Jmax}{P}\right)$

Meancalculation

$BX_j := \frac{P}{2} + (j-1) \cdot P + 0.5$ x ypixel values at center of square region

$BY_i := \frac{P}{2} + (i-1) \cdot P + 0.5$

$$IM_{i,j} := \frac{\sum_{b=1}^{P} \sum_{a=1}^{P} AM_{a+(i-1)\cdot P, b+(j-1)\cdot P}}{P \cdot P}$$

$\min(IM) = -19.832$ $\max(IM) = 197.068$

Proportionalise $IMave := 130$

$$IM_{i,j} := \frac{IM_{i,j}}{IMave}$$

x y scaling correction

Centre point in pixels $Cx := 990$ $Cy := 506$

Magnification factor - pixels over 200 mm length on grid

Horizontal $PHleft := 282$ $PHright := 932$

$$MH := \frac{800}{PHright - PHleft}$$ $MH = 1.23076923$

Vertical $PVbott := 465$ $PVtop := 144$

$$MV := \frac{400}{PVbott - PVtop}$$ $MV = 1.24610592$

Magnification Factor

$$MF := \frac{MH + MV}{2}$$ $MF = 1.23843757$

Scaling $\min(BX) = 1.5$ $\max(BX) = 1279.5$ $\min(BY) = 1.5$ $\max(BY) = 719.5$

$rows(BX) = 640$ $cols(BX) = 1$ $rows(BY) = 360$ $cols(BY) = 1$

$BX_j := (BX_j - Cx) \cdot MF$

$BY_i := (BY_i - Cy) \cdot -MF$

$Z := 0$ Z plane

Convert to columns

$DX_{i,j} := BX_j$

$DY_{i,j} := BY_i$

$DZ_{i,j} := Z$

$DM_{i,j} := IM_{i,j}$

Combine mean in matrix C

$D := stack(DX, DY, DZ, DM)$

$WRITEPRN("cmean.prn") := D$ Nolines in C $rows(BY) \cdot rows(BX) = 230400$

VARIABLES= "X""Y""Z""Cmean"
ZONE T="01" I=no.lines F=BLOCK

Figure: MathCAD routines developed for the calculation of ensemble-averaged intensity and normalized particle concentration contours.

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Quantitative Flow Visualization Analysis

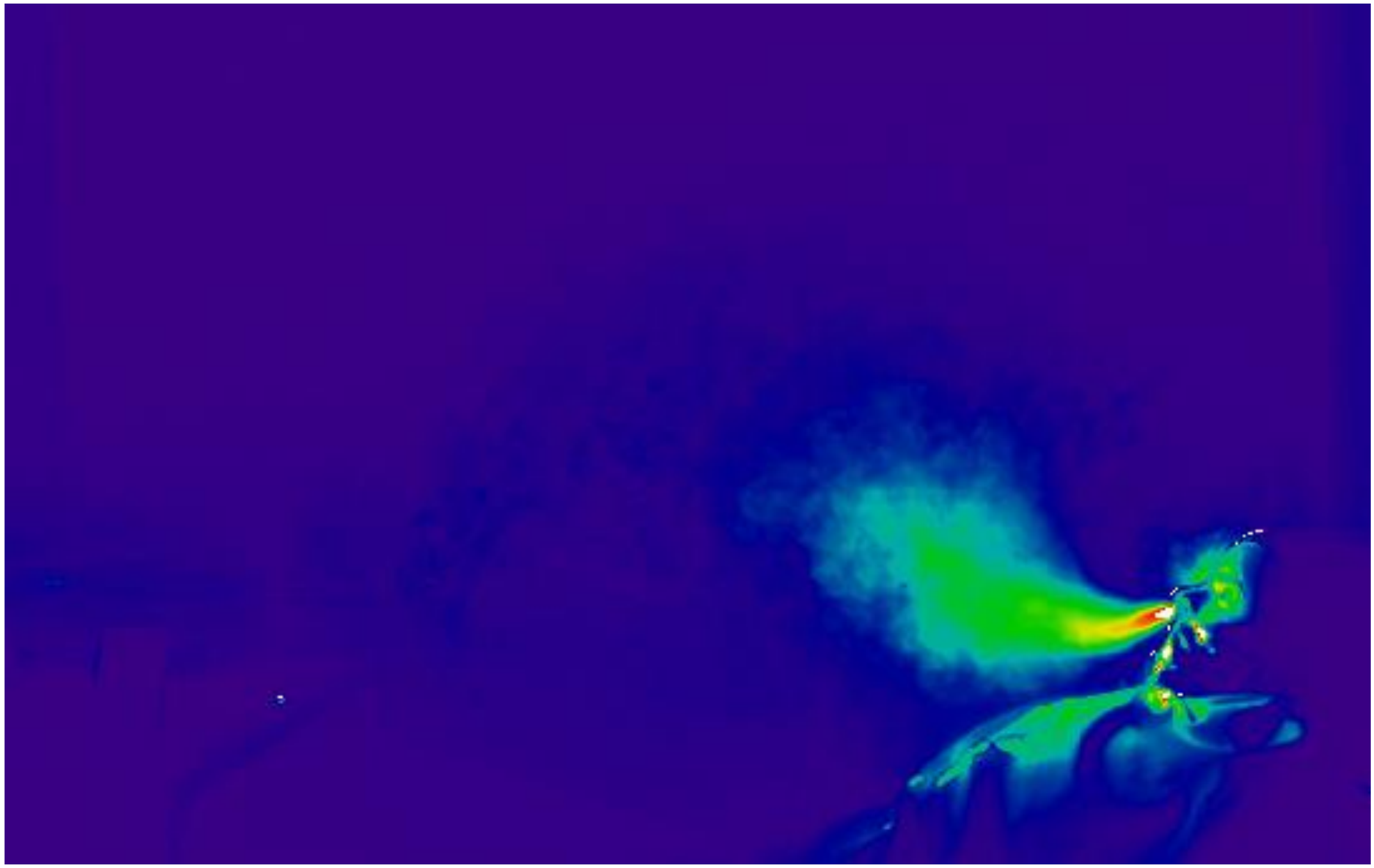

Figure: Normalized concentration contour after the background light subtration and intensity averaging routine.

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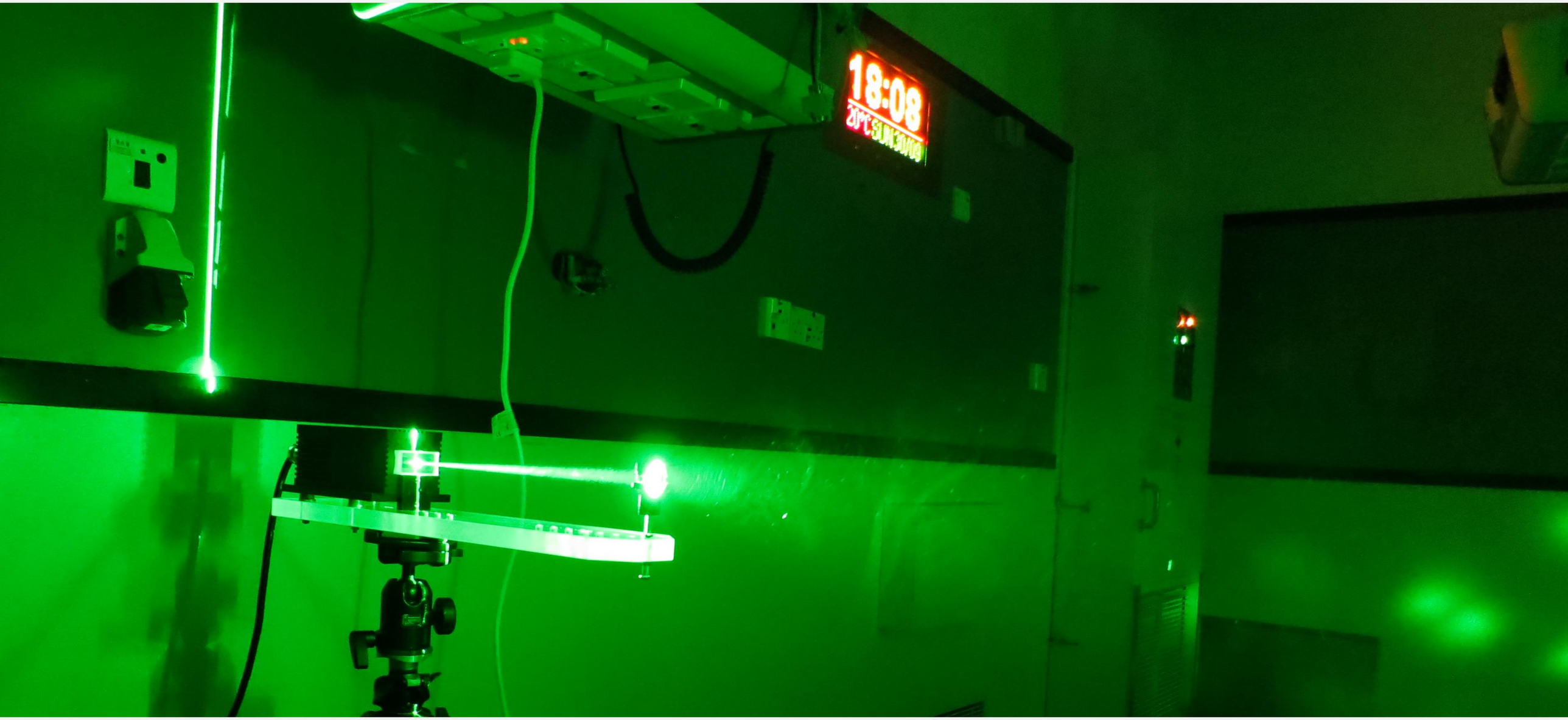
EXPERIMENTS ON DIFFERENT ISOLATION WARD DESIGNS



Negative Pressure Isolation Ward

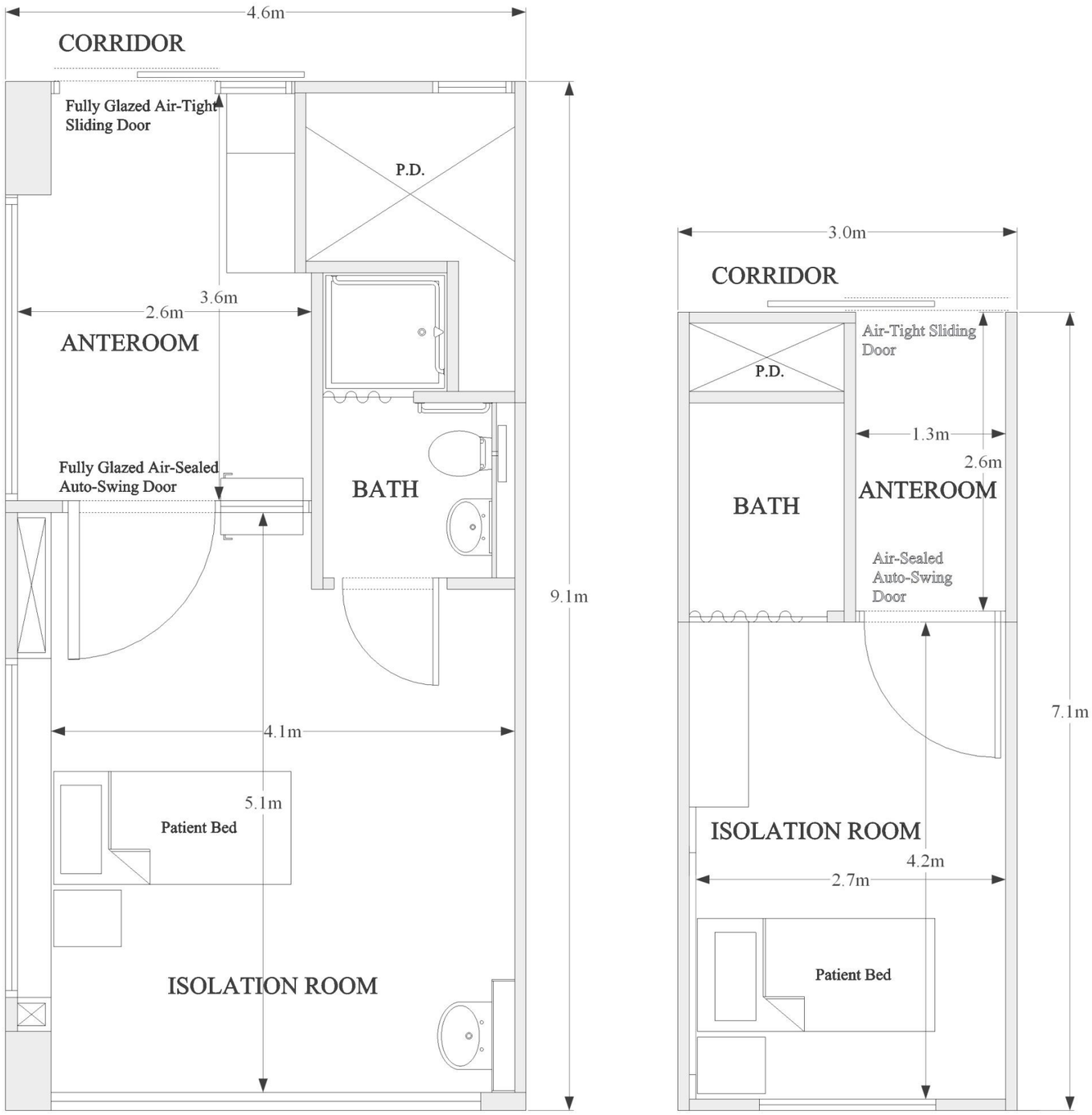


Figure: Isolation room A at PMH (left) and isolation room B of PWH (right) used in experiments.

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Summary of the Configurations of the Isolation Rooms

Settings	Room A	Room B
Dimension (W x L x H)	4.1 x 5.1 x 2.6m	2.7 x 4.2 x 2.4 m
Pressure	-7 Pa	-5 Pa
Air changes per hour	16	12
Number of beds	1	1
Ambient temperature (C)	21.4 degree	23.4 degree
Relative humidity	62%	65%
Double exhaust fans	No	No

Figure: Summary of the patient ward configurations, geometries and physical settings for the experiments.

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Ventilation Performance of Isolation Room A

Figure: Room interior of the single patient bed isolation room for on-site measurement.

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Ventilation Performance of Isolation Room A

Figure: Unoccupied isolation floor at PMH for the smoke particle experiment.

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Ventilation Performance – Air Changes per Hour

Figure: The whole 7th floor of Infectious Disease Center at PMH holds large scale mechanical plants for supporting the air change and negative pressure requirements of All rooms.

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Ventilation Performance – Air Changes per Hour

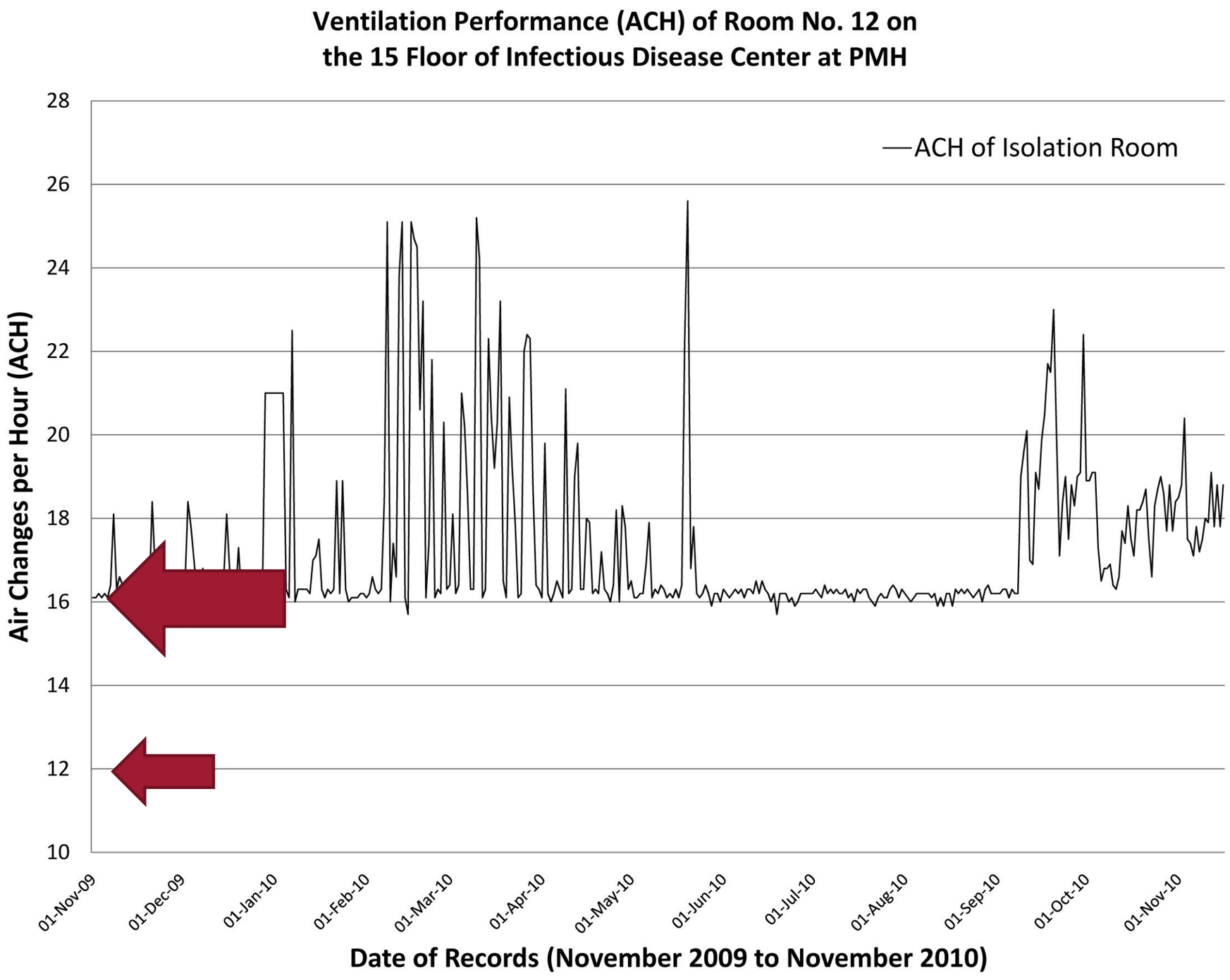

Figure: Ventilation performance of the isolation room A at PMH in daily averaged ACH.

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Ventilation Performance – Negative Pressure Control

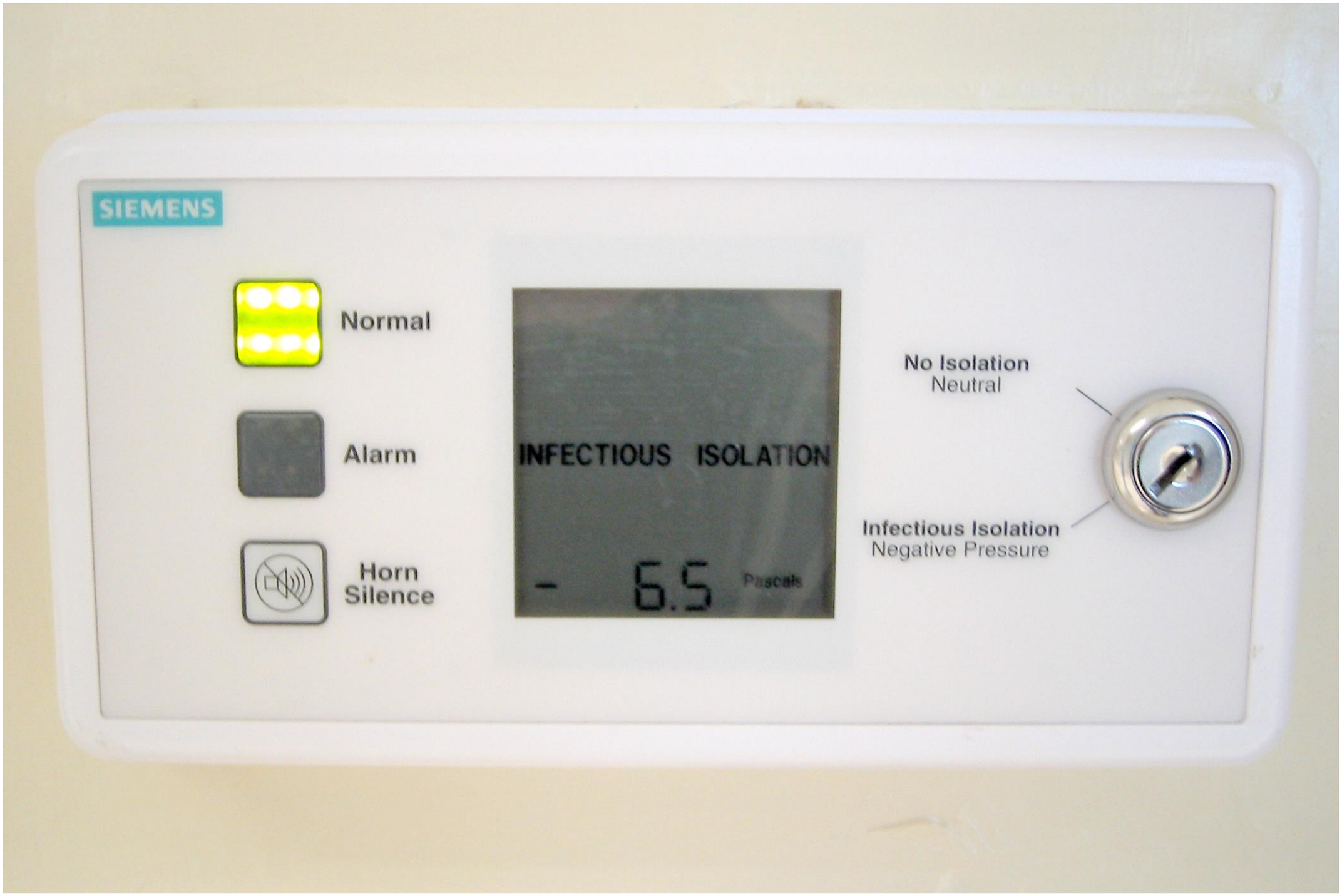

Figure: Front door panel for monitoring the negative pressure in the room.

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Ventilation Performance – Auto-Swing Door Closed

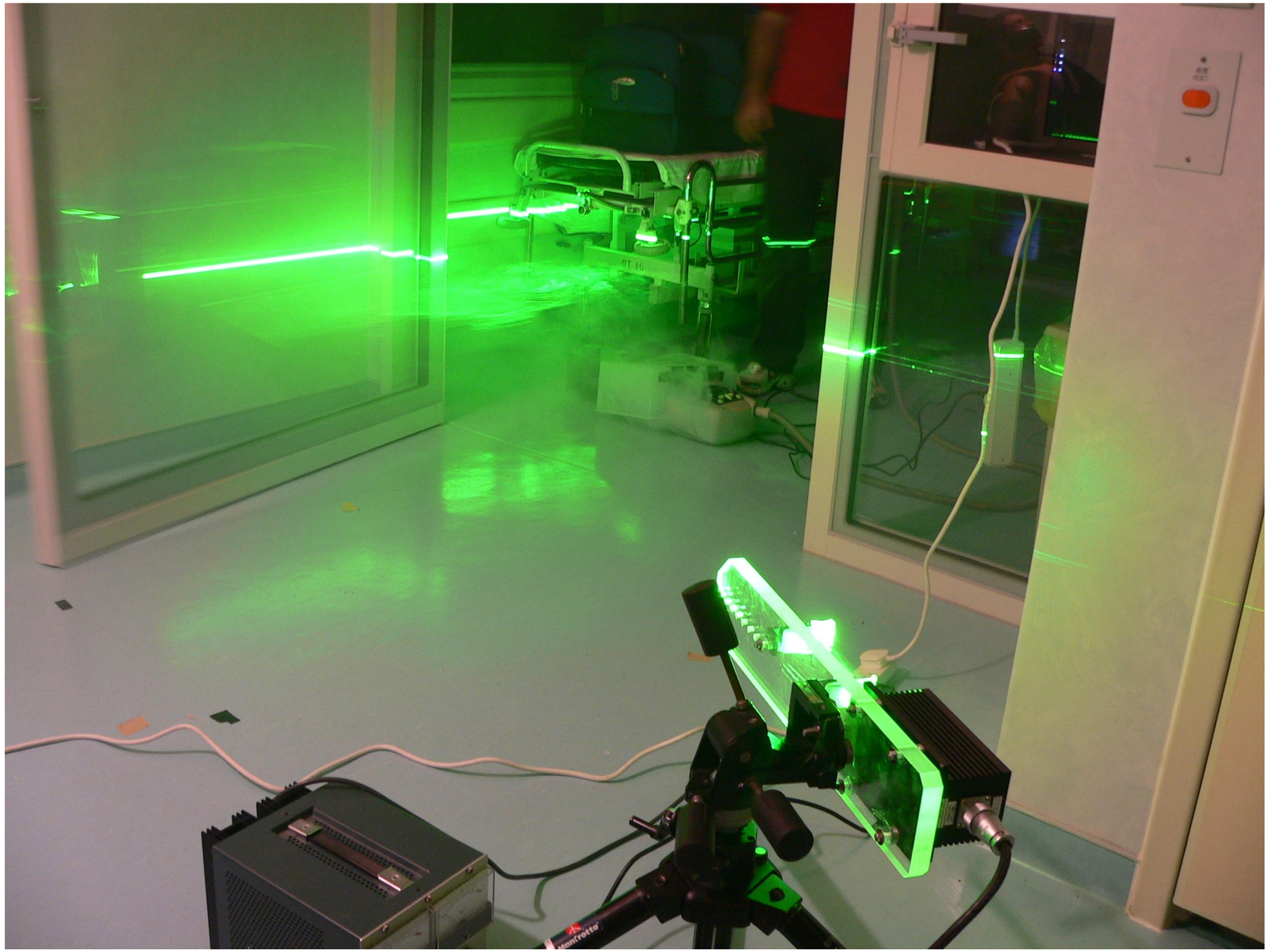

Figure: Laser light sheet parallel to the floor revealed the smoke particle movement between the anteroom and the patient room (viewing from patient room towards anteroom).

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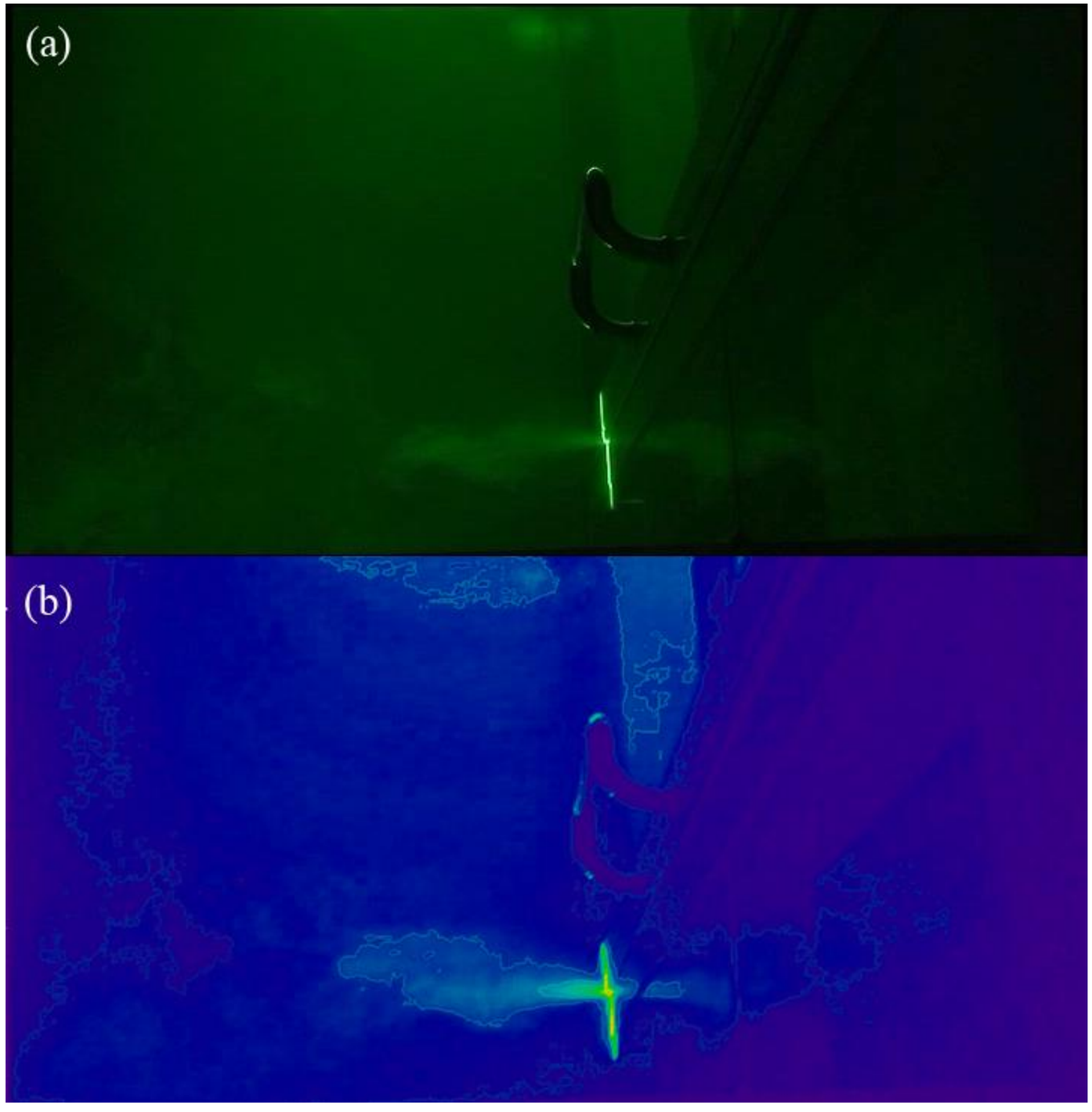
Ventilation Performance – Auto-Swing Door Closed



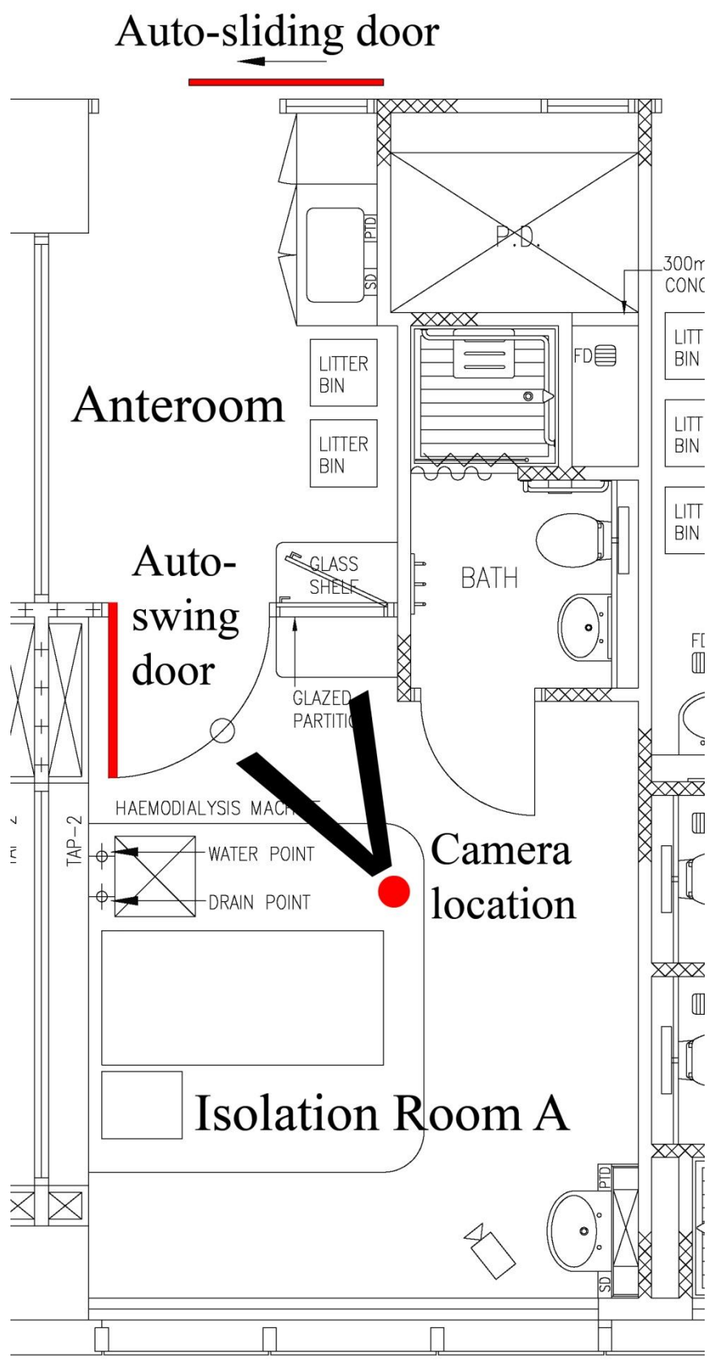


Figure: Laser flow visualization showing air enters in from the anteroom (right) to the patient room (left) from the door gap at the auto-swing door, (above) visual image (below) false color map of normalized smoke particle concentration.

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Airflow Direction Control (view from patient ward to anteroom)

(Isolation Ward)

(-ve Pressure)

(Anteroom)

(designated airflow direction)

Dr. Benny CHOW
(ASHRAE-HKC/Med.CUHK)

Ventilation Performance – Auto-Swing Door is being Opened

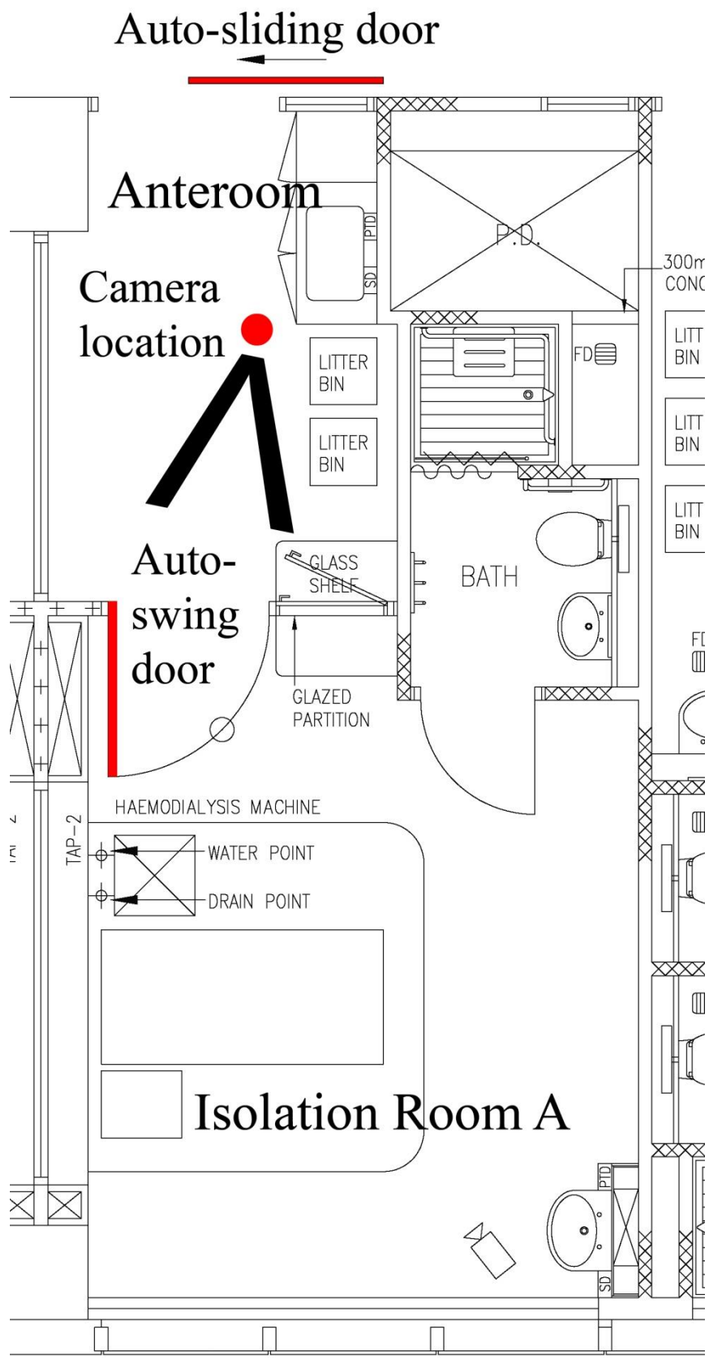

Figure: Laser flow visualization showing air enters in from the anteroom (right) to the patient room (left) from the door gap at the auto-swing door, (above) visual image (below) false color map of normalized smoke particle concentration.

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Airflow Direction Control (view from anteroom to patient ward)

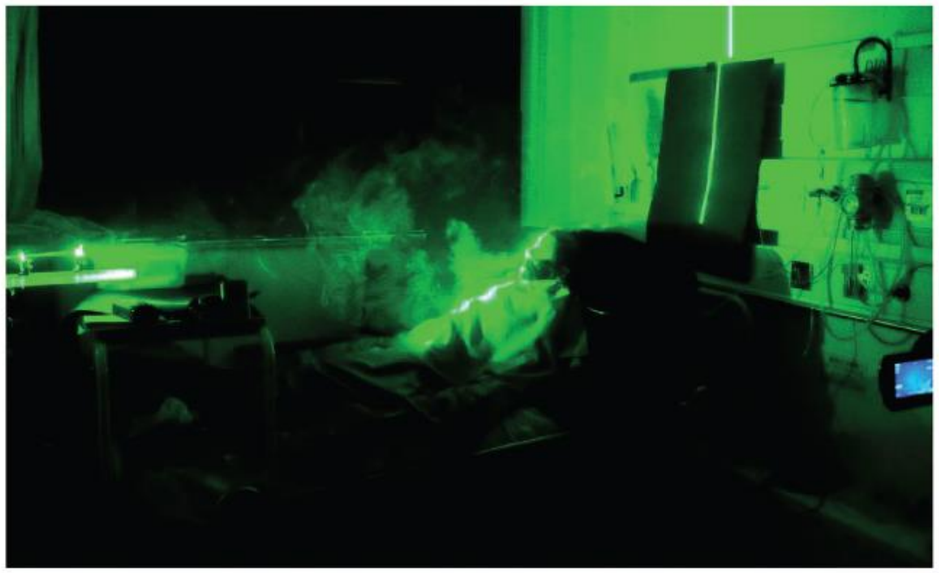


Figure 2 Room ventilation design and experimental set-up. The room (only room B is shown) is fitted with the downward ventilation systems. The design is to supply conditioned and clean air from the ceiling diffuser to sweep away contaminants, which would then be removed via the outlets at the floor level. Nasal cannulae were fitted to the human-patient simulator. The exhaled air plume was marked with intrapulmonary smoke, and was revealed by the laser light-sheet. The images were captured by a high-definition camera positioned to the left side of the simulator. Smoke concentration in the plume was estimated from the light scattered by smoke particles.

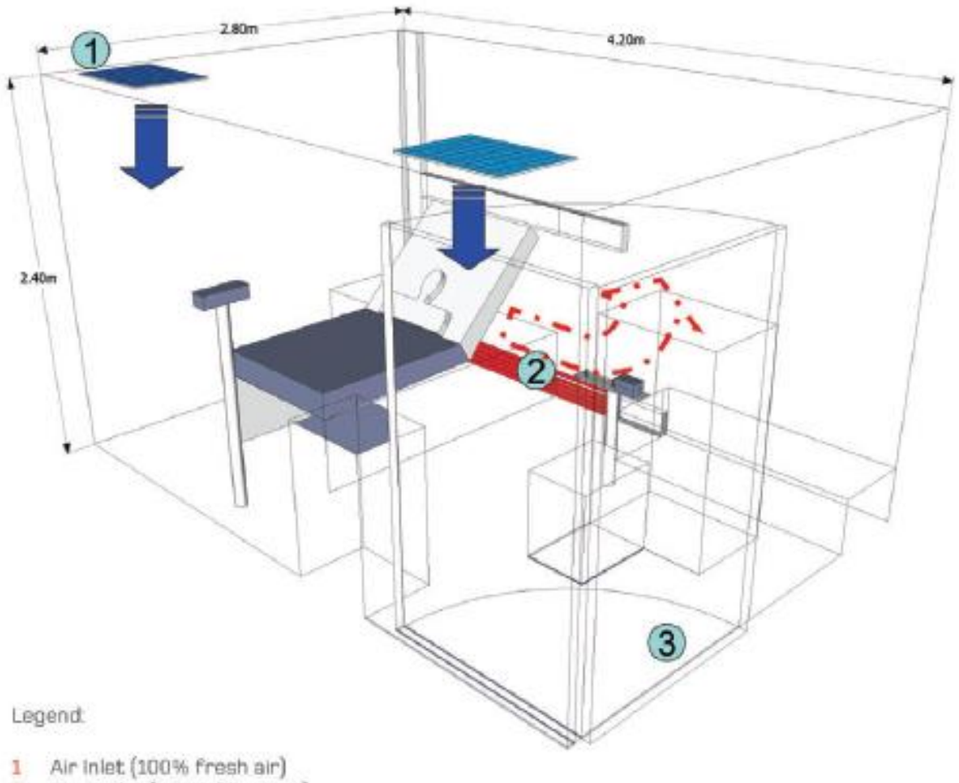
Official Journal of the Asian Pacific Society of Respirology
Respirology

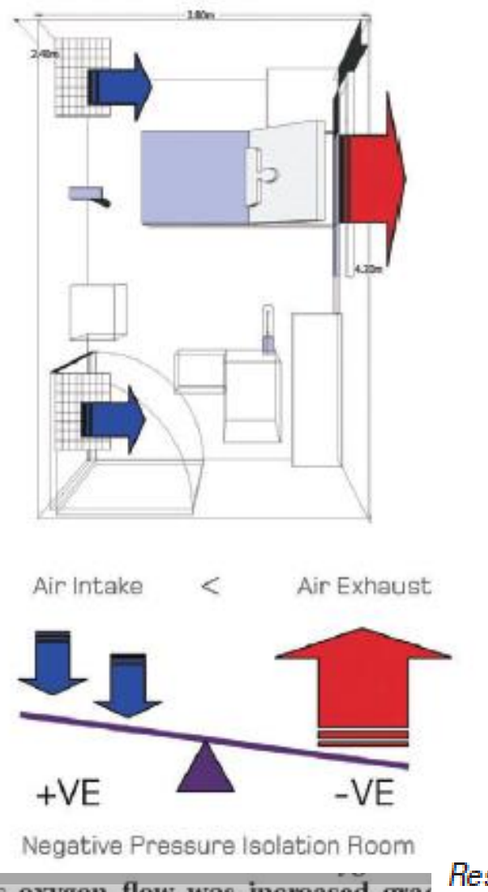
ORIGINAL ARTICLE

Exhaled air dispersion and removal is influenced by isolation room size and ventilation settings during oxygen delivery via nasal cannula

DAVID S. HUI,[1,2] BENNY K. CHOW,[3] LEO CHU,[4] SUSANNA S. NG,[2] SIK-TO LAI,[5] TONY GIN[4] AND MATTHEW T.V. CHAN[4]

[1]Stanley Ho Center for Emerging Infectious Diseases, Departments of [2]Medicine and Therapeutics, [3]Architecture and [4]Anaesthesia and Intensive Care, The Chinese University of Hong Kong, and [5]Department of Medicine and Geriatrics, Princess Margaret Hospital, Hong Kong, China





SUMMARY AT A GLANCE

This study demonstrates that larger isolation rooms with 16 air exchanges/h (ACH) are relatively better than the smaller isolation room with 12 ACH in air mixing and dilution ventilation for removing exhaled air from the patient and preventing room contamination during administration of oxygen therapy.

Key words: exhaled air dispersion, infection control, influenza, nasal cannula, severe acute respiratory syndrome.

INTRODUCTION

Respiratory failure is a major complication of emerging respiratory infections such as severe acute respiratory syndrome (SARS),[1,2] avian influenza H5N1[3] and pandemic influenza (H1N1) 2009 infection.[4] Rapid and effective oxygen delivery is an essential component in the clinical management of critically ill patients with respiratory failure. While mechanical ventilation via non-invasive positive pressure ventila-

Experimental Setup – Effects of Different Room Settings

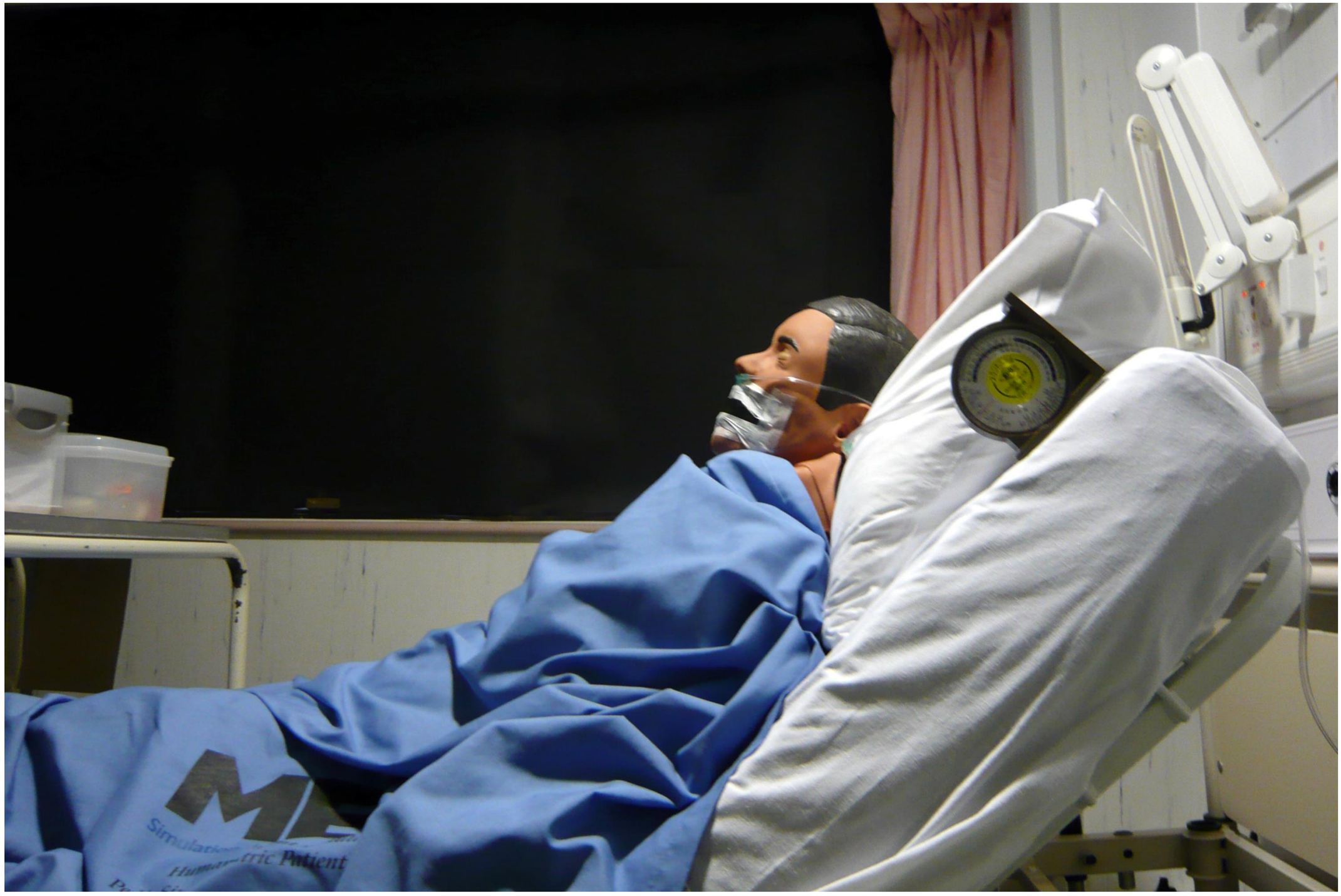


Figure: HPS sitting on a 45 degree inclined hospital bed with nasal cannula.

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(ASHRAE-HKC/Med.CUHK)

Experimental Setup – Effects of Different Room Settings

Figure: Experimental set-up, light sheet in sagittal plane at room B.

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Room A:

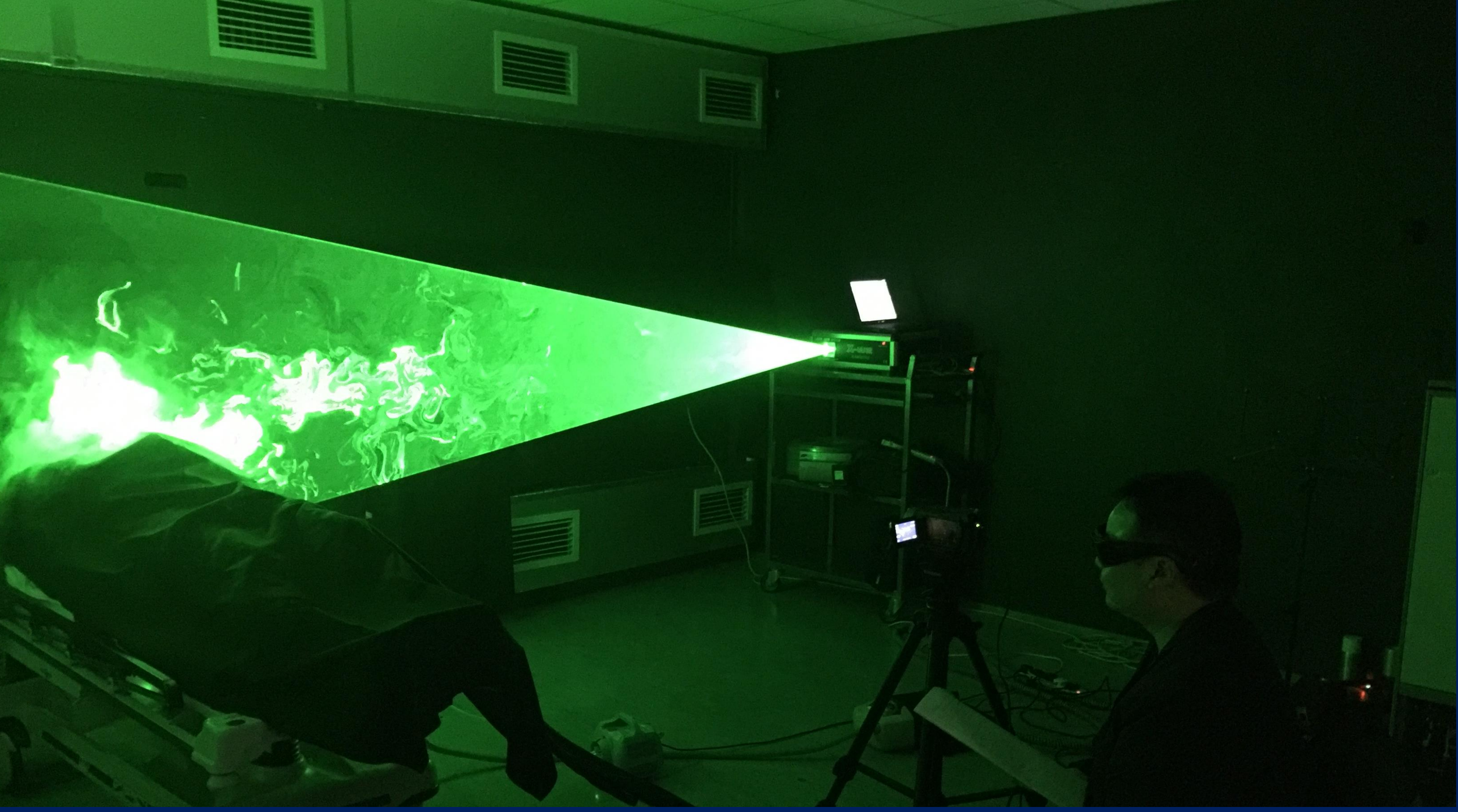
- **Smaller room**
- **12 ACH**
- **Turbulent flow ventilation system**

Room B

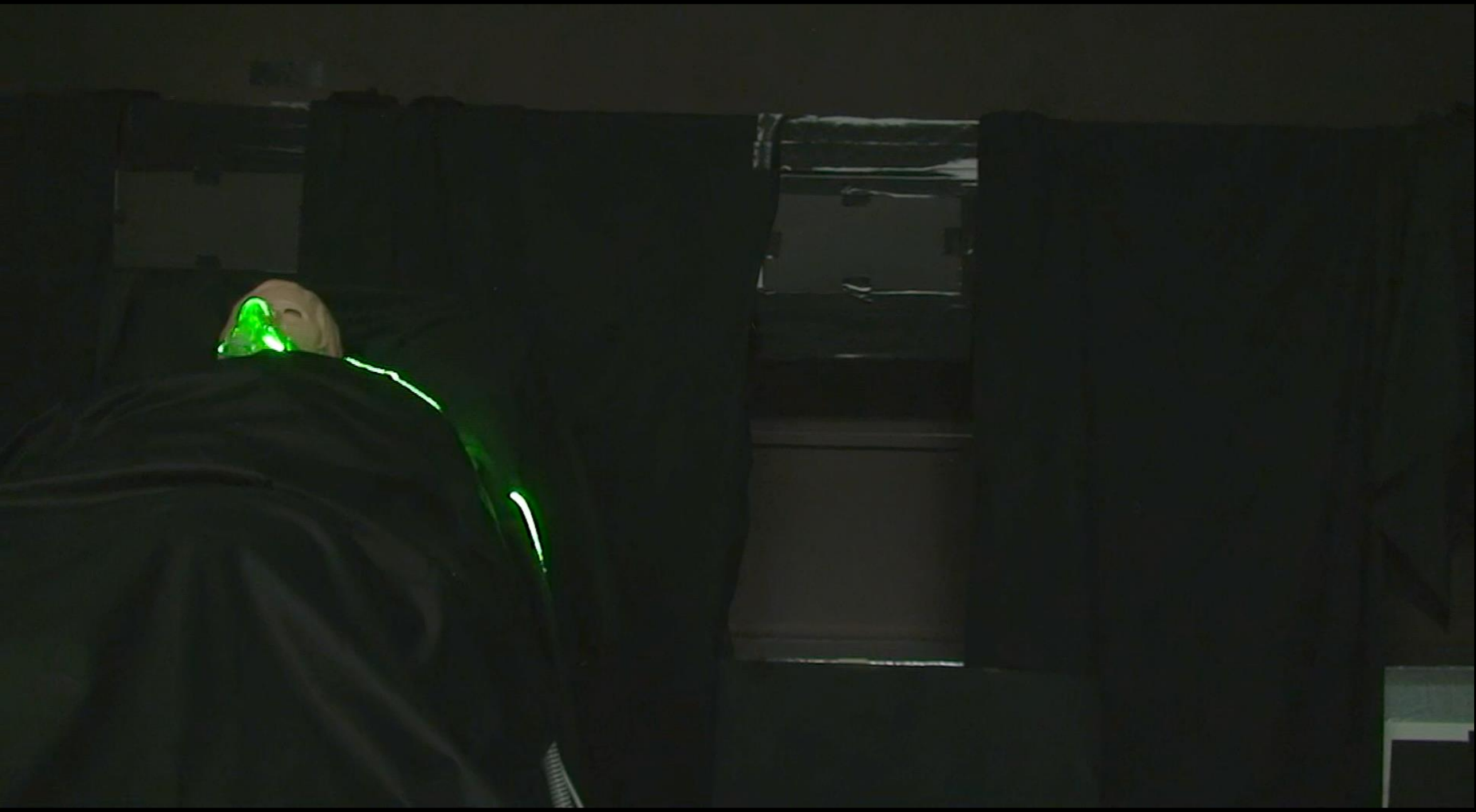
- **Larger room**
- **16 ACH**
- **Downward laminar flow ventilation**

Comparisons of floor vs ceiling vs mixed floor/ceiling level exhaust in a simulated isolation room in removal of exhaled air during aerosol-generating procedures

Rationale: Air exhaust is installed at the floor level in conventional negative pressure isolation rooms on the assumption that this would remove respiratory droplets effectively but the idea has not been proven objectively. We compared the exhaled air dispersion distances and directions during application of a jet nebulizer filled with water and driven by 6L/min of air on a high fidelity human patient simulator (HPS) in a simulated isolation room (6.0 x 6.7 x 2.6m (LWH)) with 12 ACH and the air exhaust located at a) ceiling level, b) floor level and c) both ceiling & floor levels.

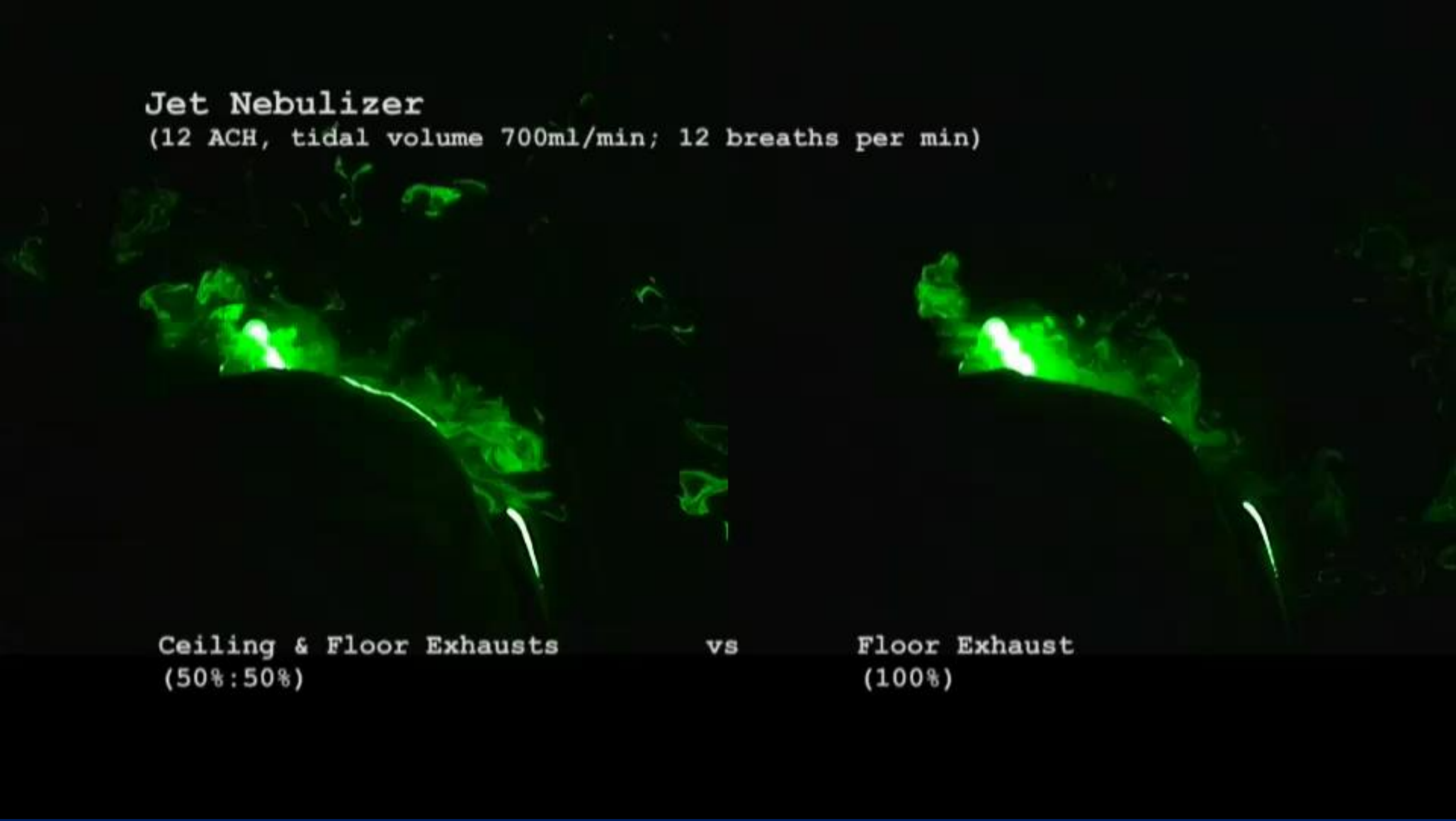


Methods: The HPS was positioned at 45° and programmed to mimic different severity of lung injury. Airflow was marked with intrapulmonary smoke for visualization. A leakage jet plume was revealed by a laser light-sheet and images captured by high definition video.
Normalized exhaled air concentration in the plume was estimated from the light scattered by the smoke particles. Significant exposure was arbitrarily defined as where there was ≥ 20% of normalized smoke concentration.



Application of a jet nebulizer to the HPS - Air exhaust located and operated at floor level led to longer exhaled air distance towards the floor but less spatial contamination at the breathing zone than ceiling level exhaust or a combination of ceiling and floor exhausts. (David Hui et al)

Jet Nebulizer
(12 ACH, tidal volume 700ml/min; 12 breaths per min)



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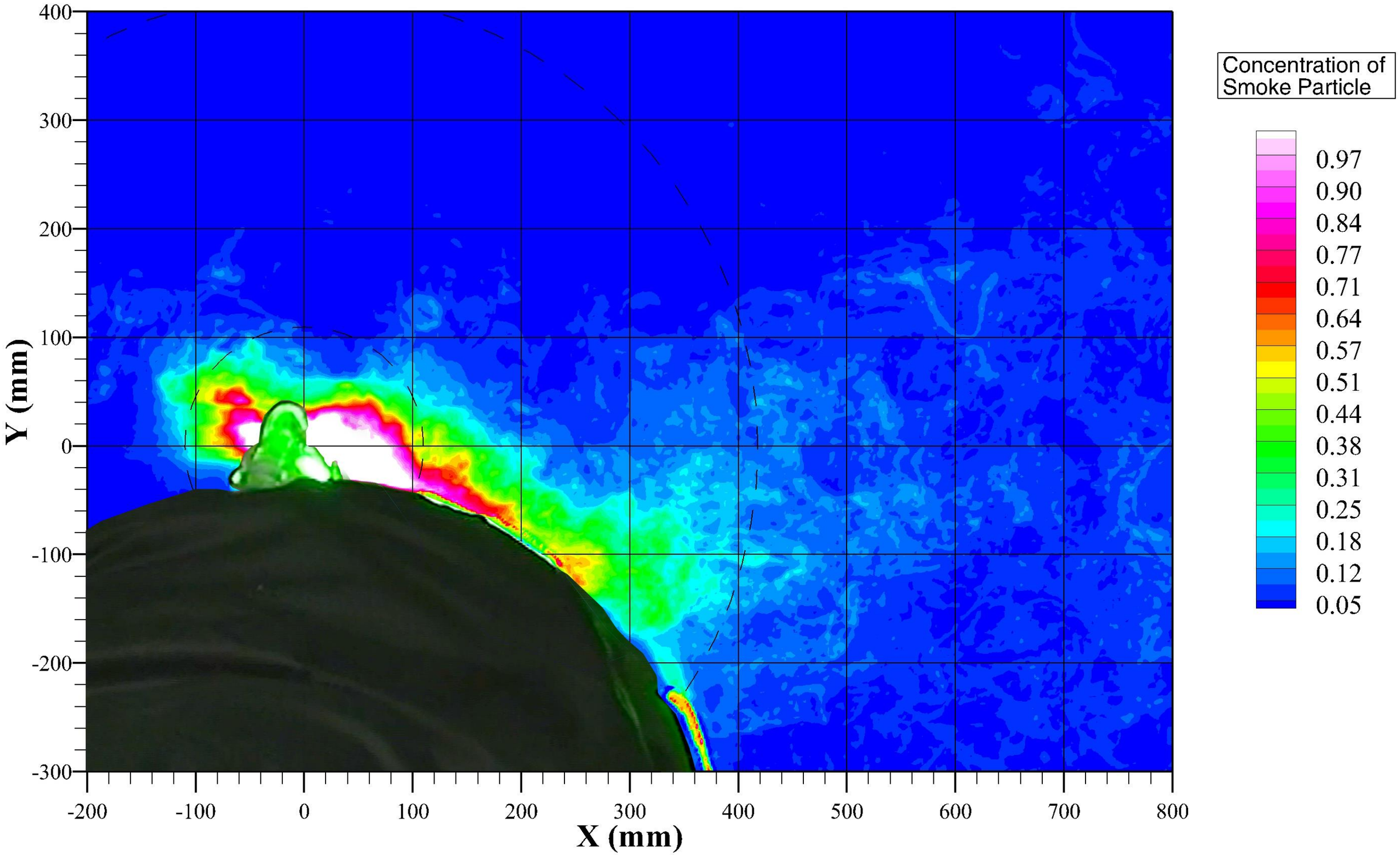

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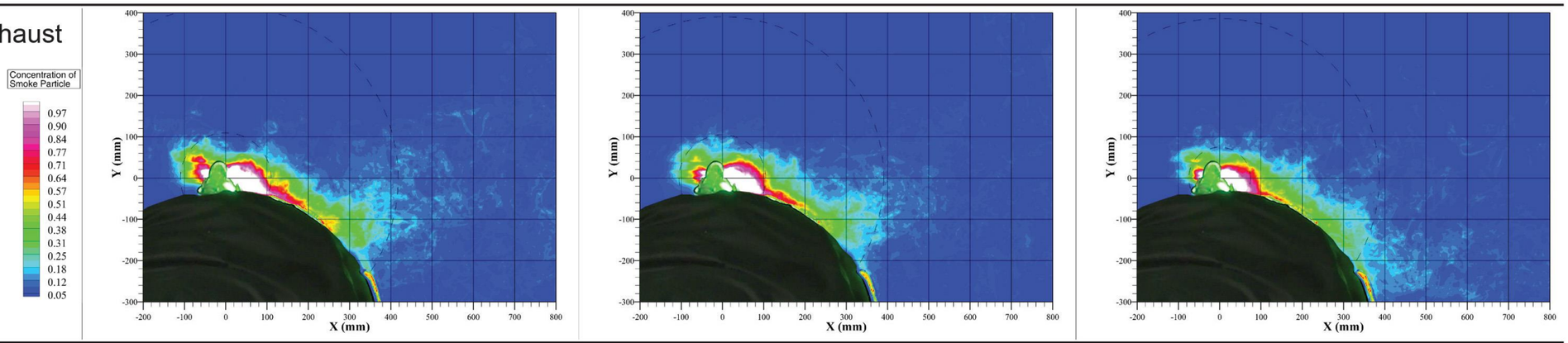
(David Hui et al. Unpublished data)

12 Air Change per Hour

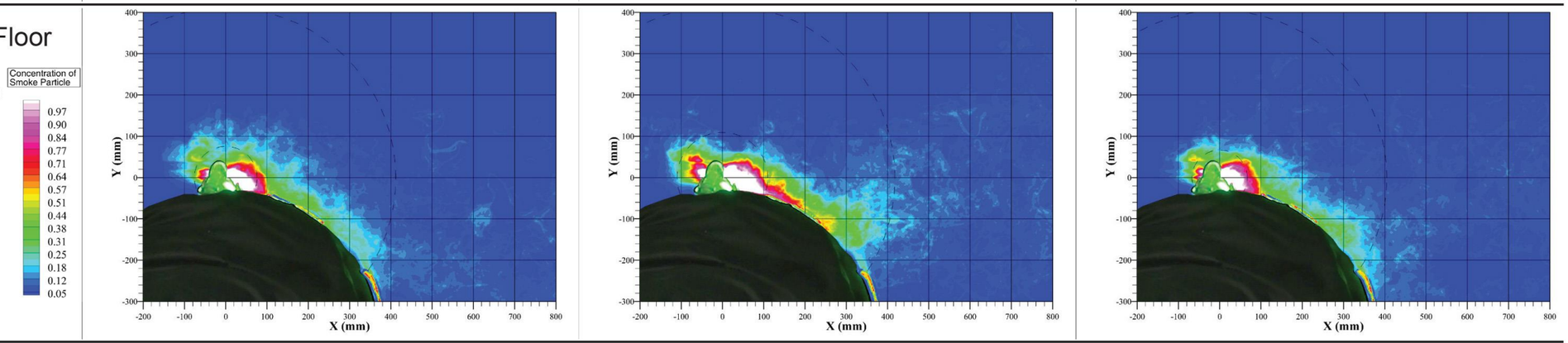
Jet Nebulizer

(Exhaled leakage jet plume with smoke and droplet particles)

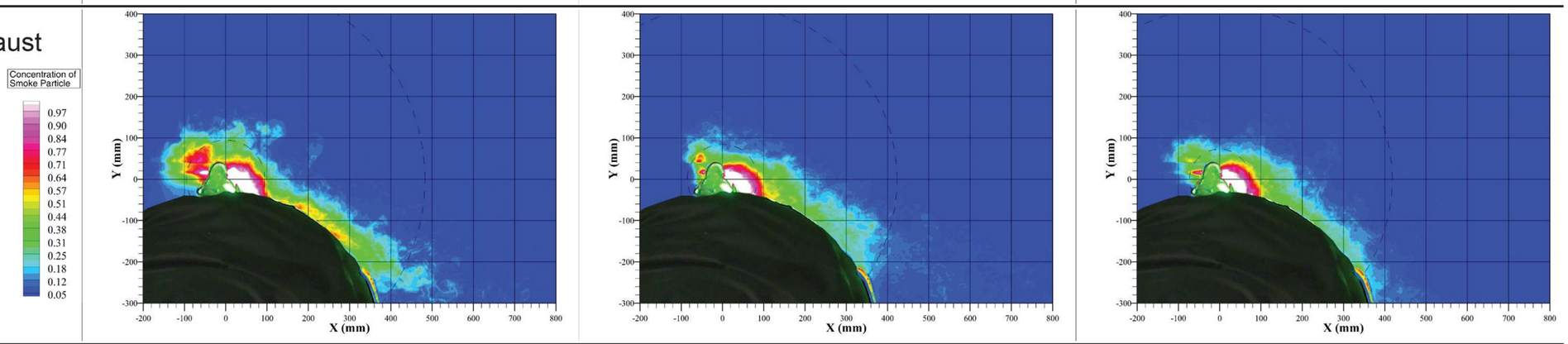
Ceiling Exhaust
(100%)



Ceiling & Floor Exhausts
(50% : 50%)



Floor Exhaust
(100%)



Normal Lung Condition
(700mL / 12 RR)

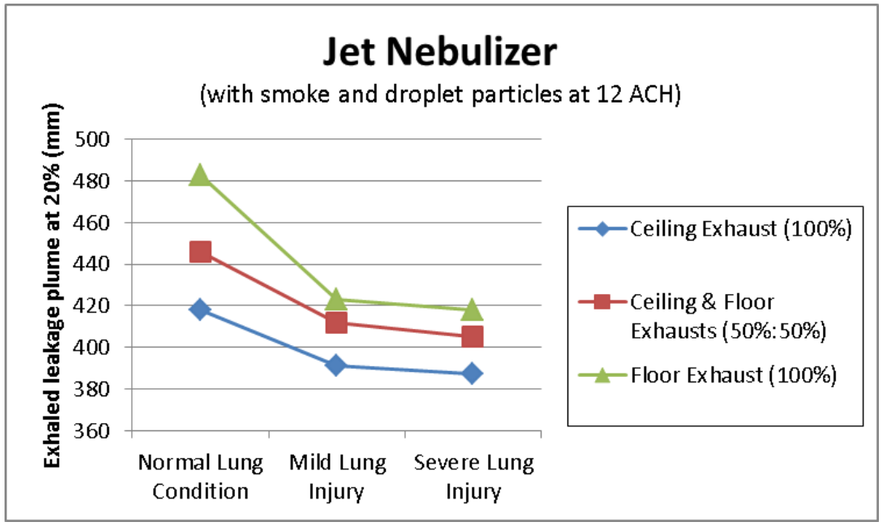
Mild Lung Injury
(300mL / 25 RR)

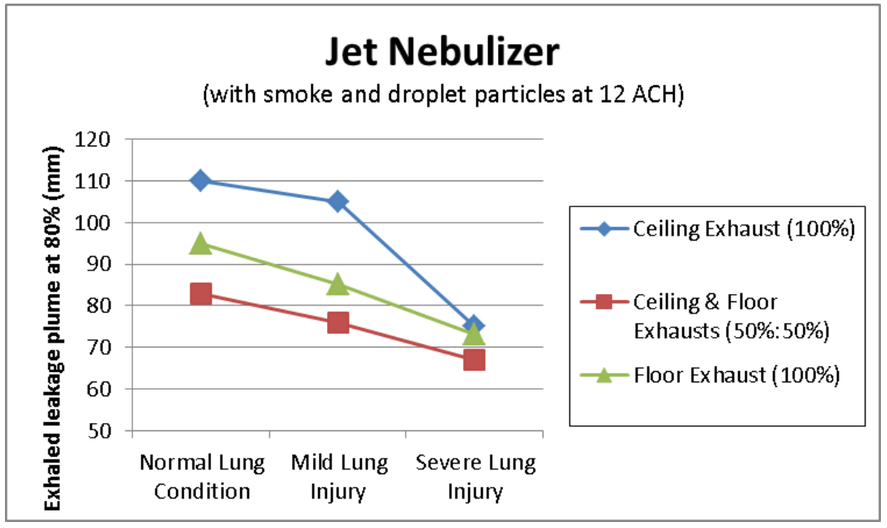
Severe Lung Injury
(150mL / 40 RR)

Application of a jet nebulizer to the HPS - Air exhaust located and operated at floor level led to longer exhaled air distance towards the floor but less spatial contamination at the breathing zone than ceiling level exhaust or a combination of ceiling and floor exhausts.
(David Hui et al. Unpublished data)

Jet Nebulizer (with smoke and droplet particles)

Jet Nebulizer (12 ACH)									
Distance at 20% (mm)	Ceiling Exhaust			A 50/50 Split Between Ceiling and Floor Exhausts			Floor Exhaust		
	S1 Normal	S2 Mild	S3 Severe	S4 Normal	S5 Mild	S6 Severe	S7 Normal	S8 Mild	S9 Severe
Mean Average Distance (mm)	418	391	387	446	412	405	483	423	418
SD	98	85	102	96	81	84	65	60	61





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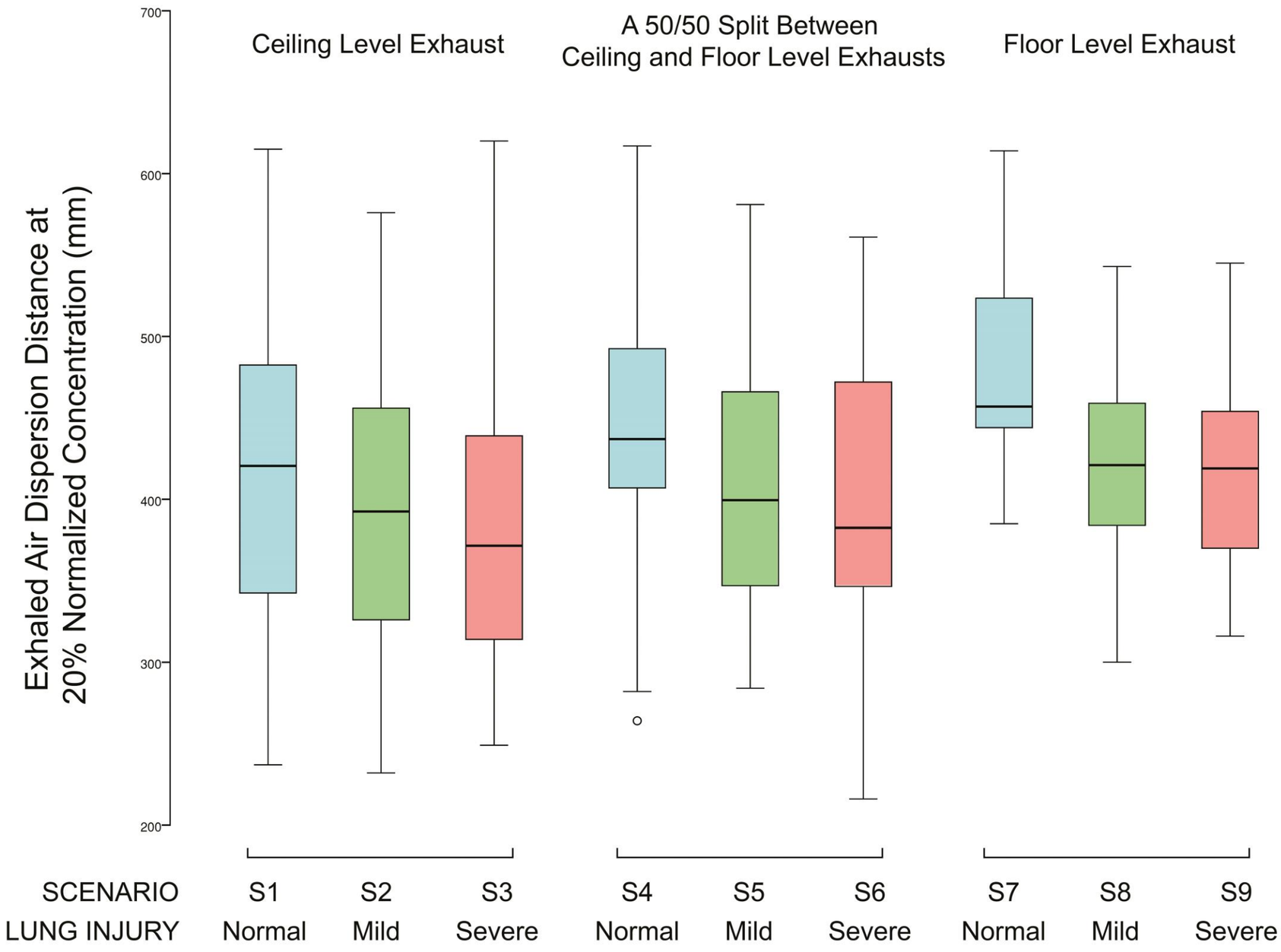
Jet Nebulizer (with smoke and droplet particles)



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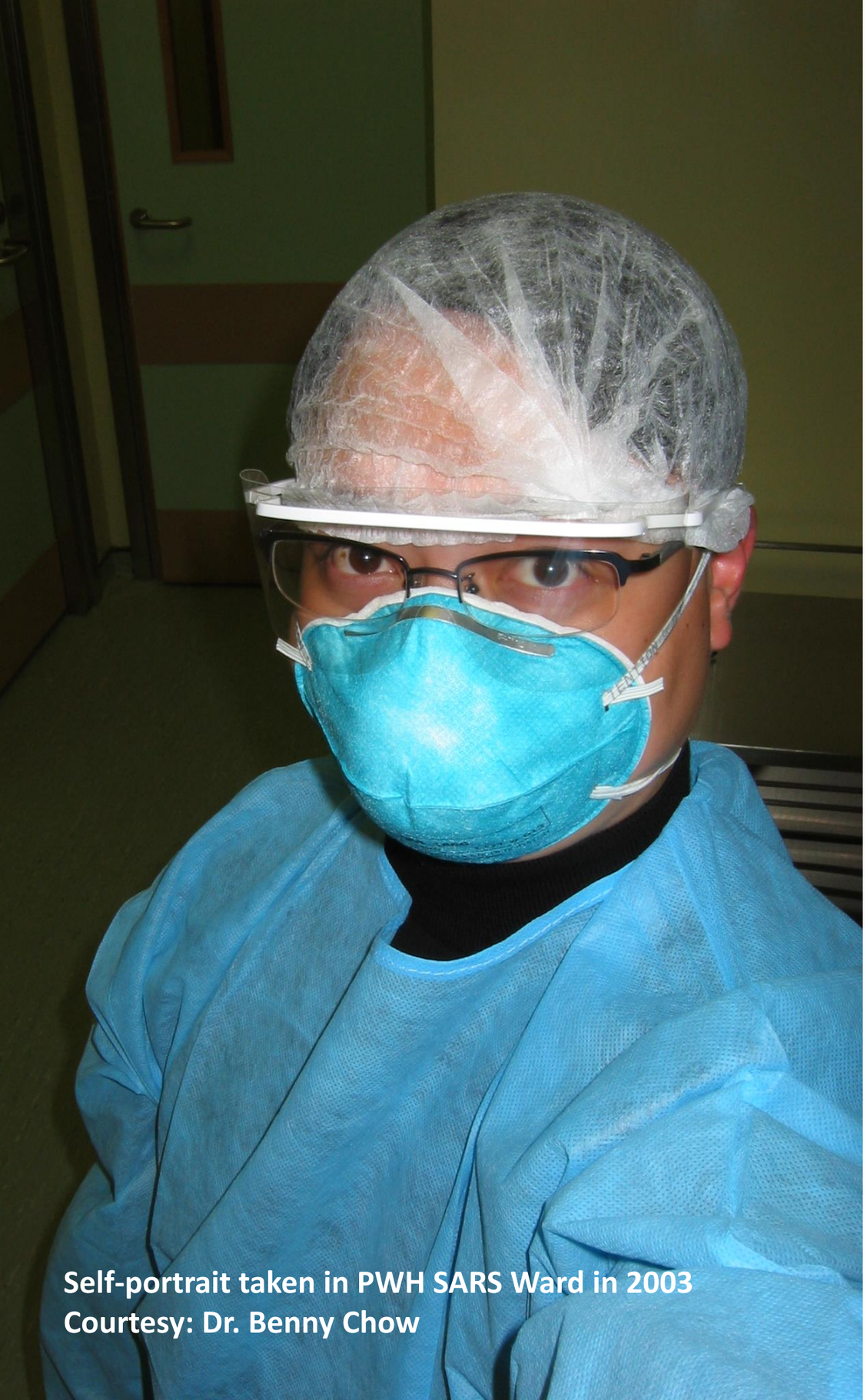

Self-portrait taken in PWH SARS Ward in 2003
Courtesy: Dr. Benny Chow

Wishing YOU Good

Health and Happiness!

Dr. Benny CHOW
(ASHRAE-HKC/Med.CUHK)