Workshop on infection control aspects in hospital reconstruction, Hospital Authority/ Infection Control Branch, Centre for Health Protection, 14-16 Jan 2014

Design of ventilation system and risk of infection

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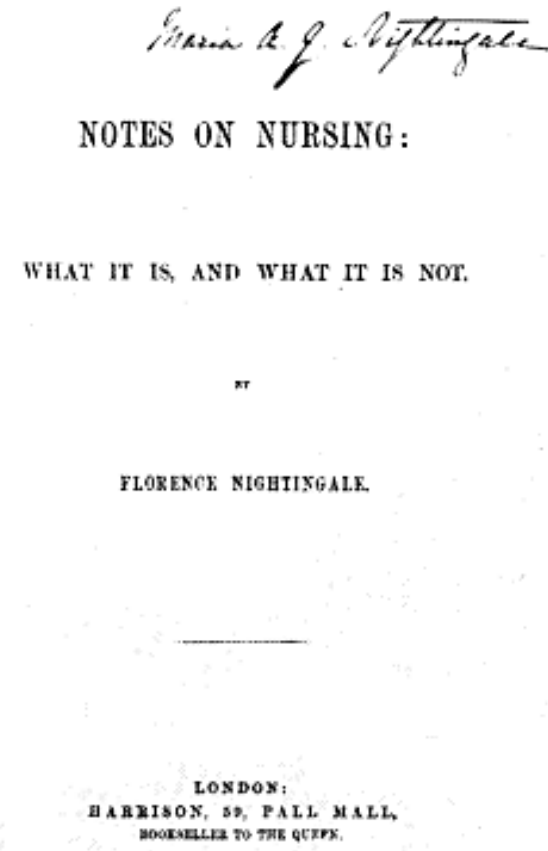
A note from the 19th century

"The **very first** canon of nursing, the **first and the last** thing upon which a nurse's attention must be fixed, the first essential to the patient, without which all the rest you can do for him is as nothing, with which I had almost said you may leave all the rest alone, is this:

TO KEEP THE AIR HE BREATHES AS PURE AS THE EXTERNAL AIR, WITHOUT CHILLING HIM."

Florence Nightingale (1820-1910), Notes on Nursing - What It Is and What It Is Not, 1860.



Florence Nightingale

NOTES ON NURSING:

WHAT IT IS, AND WHAT IT IS NOT.

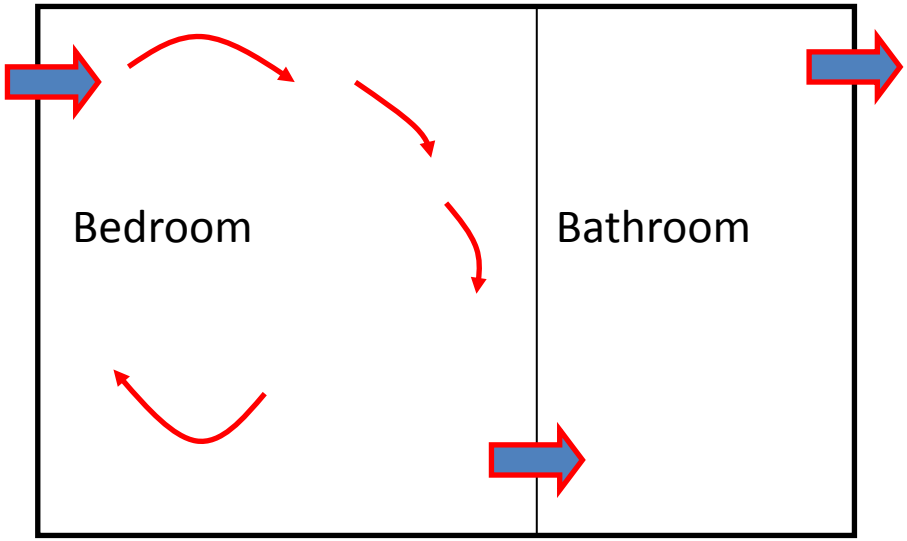
BY

FLORENCE NIGHTINGALE.

LONDON:
HARRISON, 59, PALL MALL,
BOOKSELLER TO THE QUEEN.

Ventilation refers to supply of outdoor or "properly filtered" air in a building and distribute within it.

- Ventilation (outdoor) flow rates
- Airflow direction
- Air distribution



Three elements of ventilation

Element	Description	Requirements/ Guideline	Design or Operation	Buildings
Primary	**External air flow rate**	Minimum ACH Minimum L/s	Fan, duct, openings or streets	**ASHRAE 62** **CDC** **WHO** **Isolation rooms: 6-12 ACH**
Secondary	**Overall flow direction between zones**	Flow clean to “dirty” spaces	Pressure control through airflow imbalance Prevailing winds	**Positive/ negative 2.5-15 Pa** **Isolation/ smoke control**
Tertiary	**Air distribution within a space**	Ventilation effectiveness, no short-circuiting	Use of CFD Smoke visualization	**Ventilation strategies**

Ventilation needs in hospitals

- Differs from conventional buildings in terms of ventilation needs

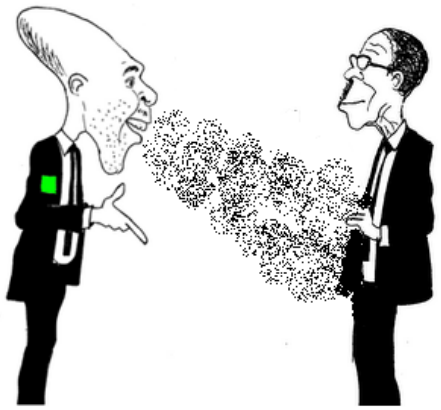
- Exhaled droplet nuclei of an infected patient need to be removed in general wards, waiting areas and isolation rooms.
- Harmful micro-organisms and infectious aerosols may exist in relatively high concentration.
- Ventilation requirements in some can be much higher than non-hospital environments.

- Most hospitals operate 24/7/365. The energy consumption can be much higher than in a non-hospital environment.
- Patients in hospitals can be more sensitive to thermal discomfort, such as draft.

Infected Susceptible

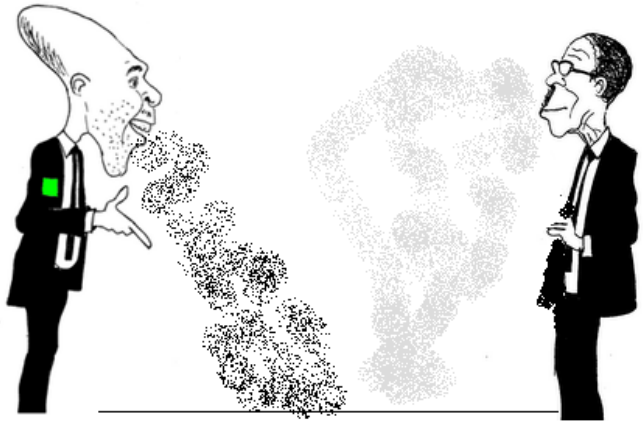
Direct (spray) droplet

Infected Susceptible



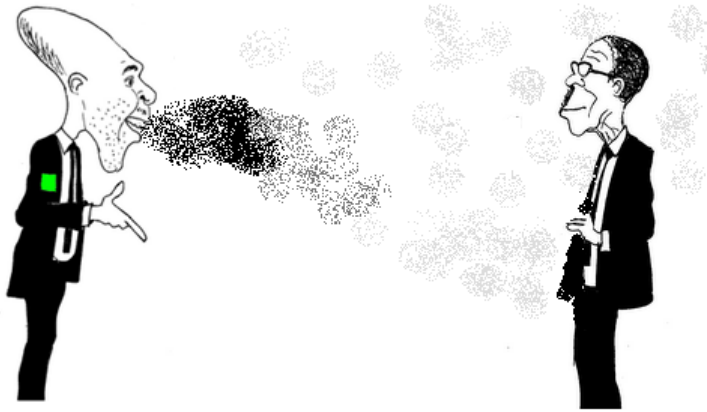
Indirect contact

Infected Susceptible

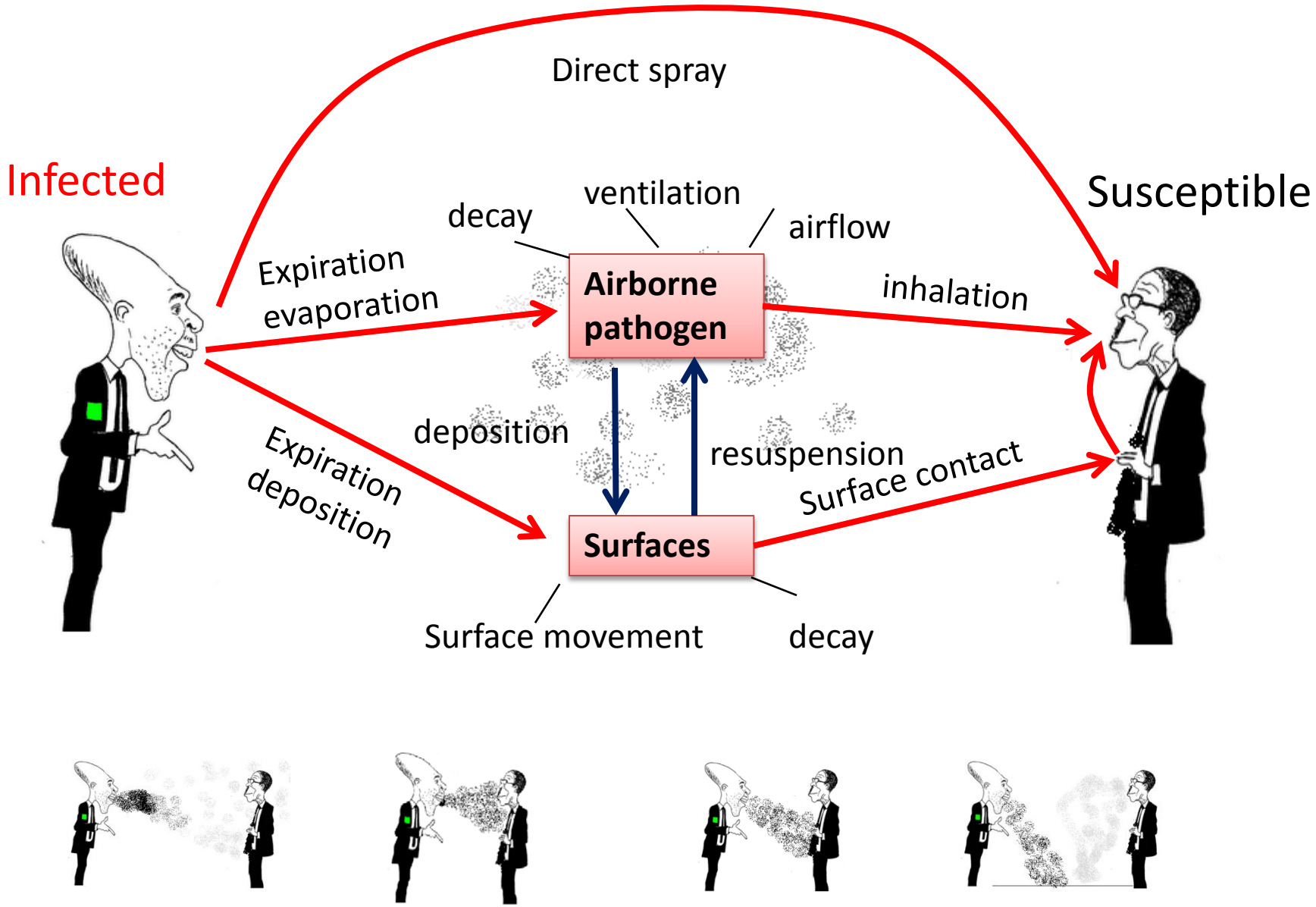


Dust-borne

Infected Susceptible



Airborne



Modified from Atkinson and Wein, Bulletin of Mathematical Biology, 2008, 70:820-867

"Right" ventilation costs!

- Assume 10 litre/second per person。
- Assume outdoor air 37°C DB, 25°C WB, indoor air 23°C DB, RH50%. This makes 400 W per person.
- The population is 1.3 billion in China. This makes 500 million kW. 365 days per year, 24 hours a day, this makes 4,380 billion kWh。
- Assume only 10% of time for heating or cooling considering winter, summer and intermediate seasons. This make 438 billion kWh。
- The Three-Gorges Dam power station was 64 billion kWh (2005 figure).
- **The energy needed for cooling and heating the minimum ventilation required by 1.3 billion people in China needs 6 three-gorge stations!**

How much ventilation is needed?

Measurement of amount of supplied ventilation air

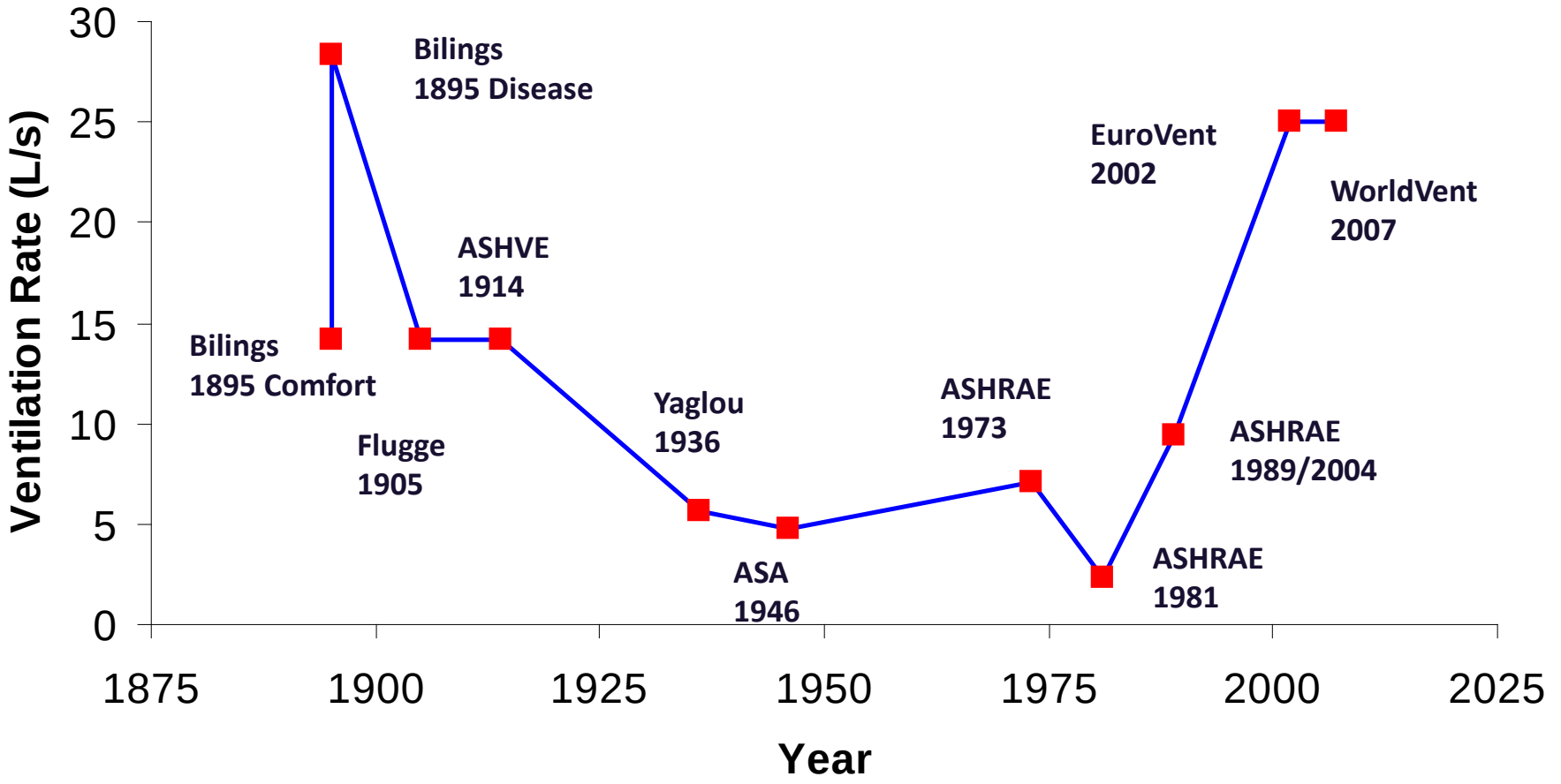
- The absolute amount of inflow air per unit time (litre per second or l/s, cubic meter per hour, or m^3/hr) – refers to as ventilation rate
  - In an office, 10 l/s per person
- The relative amount of inflow air per unit time (air change per hour or ACH) – refers to air change rate
  - In an isolation room, we need 12 ACH
- We prefer the use of the former.

Before 1900:
Miasma
Lavoisier 1774 O_2
Lavoisier 1775 CO_2
Polluted cities Paris and London, late 18th and 19th century

After 1900:
Influenza pandemic 1918-1919
Carrier 1919 "manufactured weather"
Fanger thermal comfort
Energy crisis 1973

After 1990:
Sick building syndrome
US Indoor Air Act of 1991
Eurovent 2002
SARS epidemics 2003
WorldVent 2006

Old Health period | **Comfort period** | **New Health period**



Indoor Air 2007; 17: 2–18
www.blackwellpublishing.com/ina

INDOOR AIR
doi:10.1111/j.1600-0668.2006.00445.x

Review Article

Role of ventilation in airborne transmission of infectious agents in the built environment – a multidisciplinary systematic review

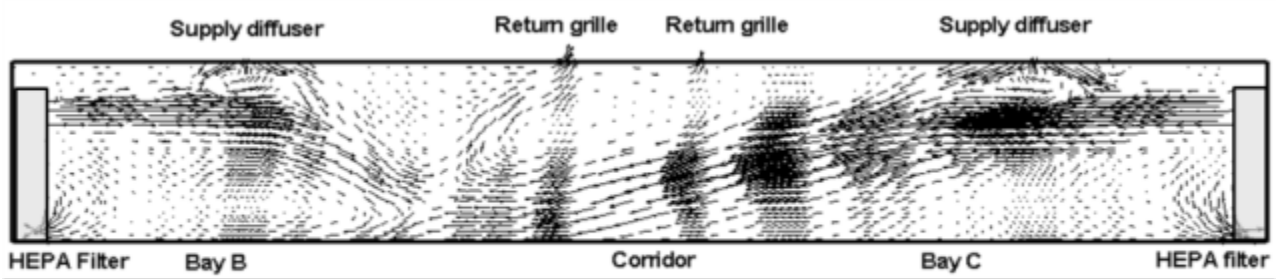
Abstract There have been few recent studies demonstrating a definitive association between the transmission of airborne infections and the ventilation of buildings. The severe acute respiratory syndrome (SARS) epidemic in 2003 and current concerns about the risk of an avian influenza (H5N1) pandemic, have made a review of this area timely. We searched the major literature databases between 1960 and 2005, and then screened titles and abstracts, and finally selected 40 original studies based on a set of criteria. We established a review

Y. Li[1], G. M. Leung[2], J. W. Tang[3], X. Yang[4], C. Y. H. Chao[5], J. Z. Lin[6], J. W. Lu[7], P. V. Nielsen[8], J. Niu[9], H. Qian[1], A. C. Sleigh[10], H.-J. J. Su[11], J. Sundell[12], T. W. Wong[13], P. L. Yuen[14]

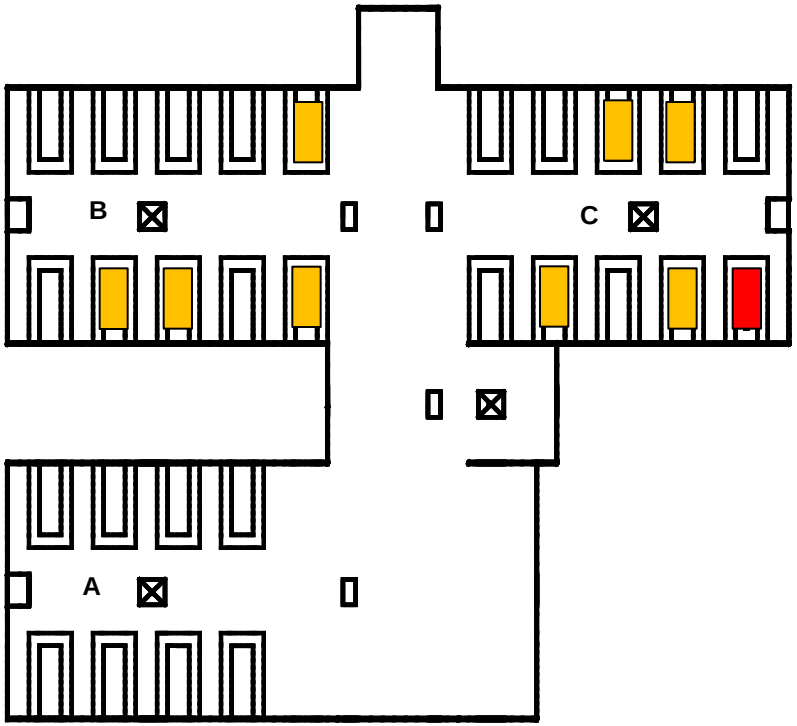
and a 2-day face-to-face consensus meeting. Ten of 40 studies reviewed were considered to be conclusive with regard to the association between building ventilation and the transmission of airborne infection. There is strong and sufficient evidence to demonstrate the association between ventilation, air movements in buildings and the transmission/spread of infectious diseases such as measles, tuberculosis, chickenpox, influenza, smallpox and SARS. There is insufficient data to specify and quantify the minimum ventilation requirements in hospitals, schools, offices, homes and isolation rooms in relation to spread of infectious diseases via the airborne route.

A seasonal influenza A outbreak in a PWH ward 2008

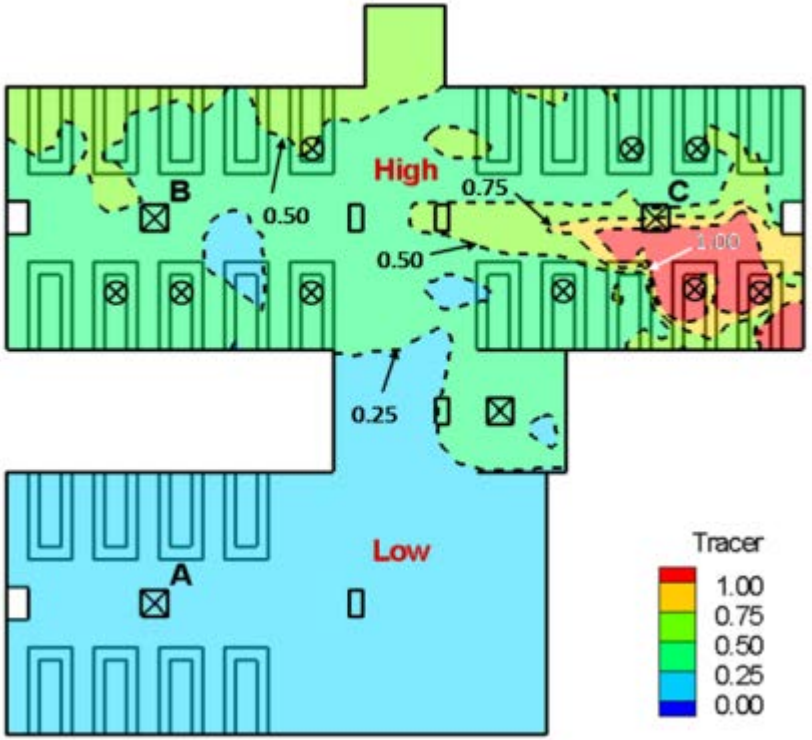
Wong et al, CID, 2010



Velocity distribution at P-P plane



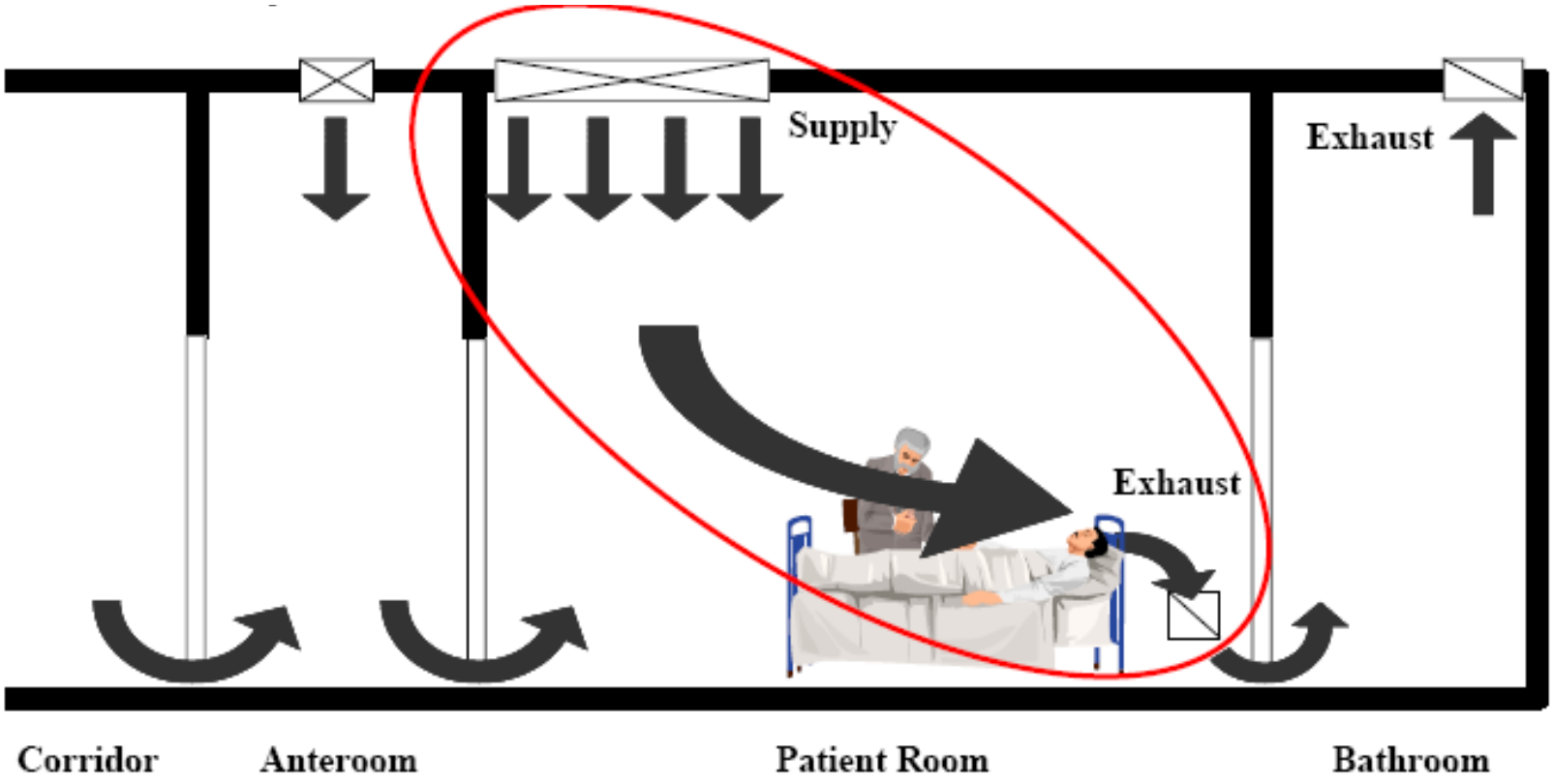
Spatial distribution of infected patients



Contour of normalized tracer concentration at z=1.1m

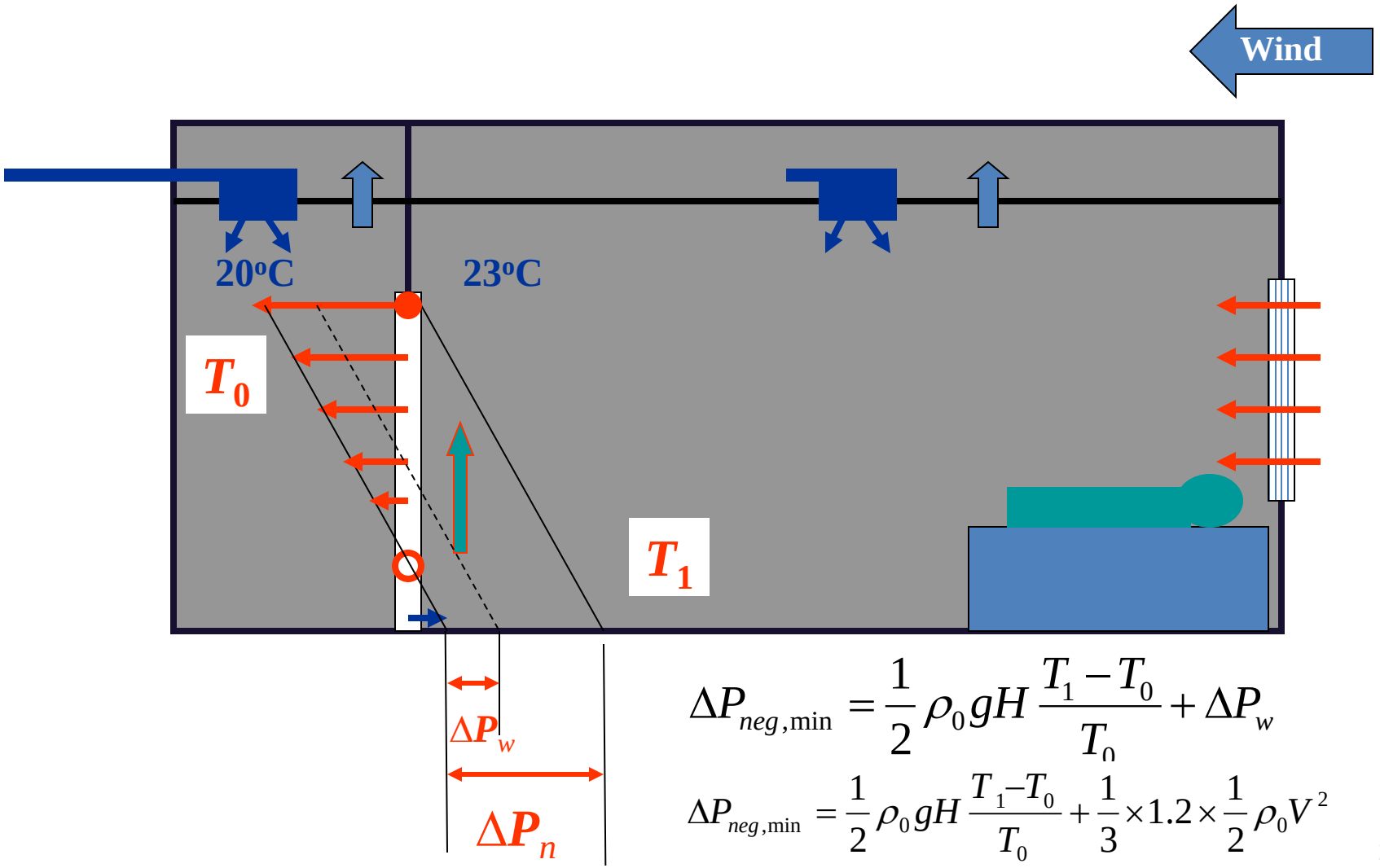
How airflow direction is controlled?

This is how the system is expected to work



(The figure is taken from Internet)

What happens when there is wind pressure?

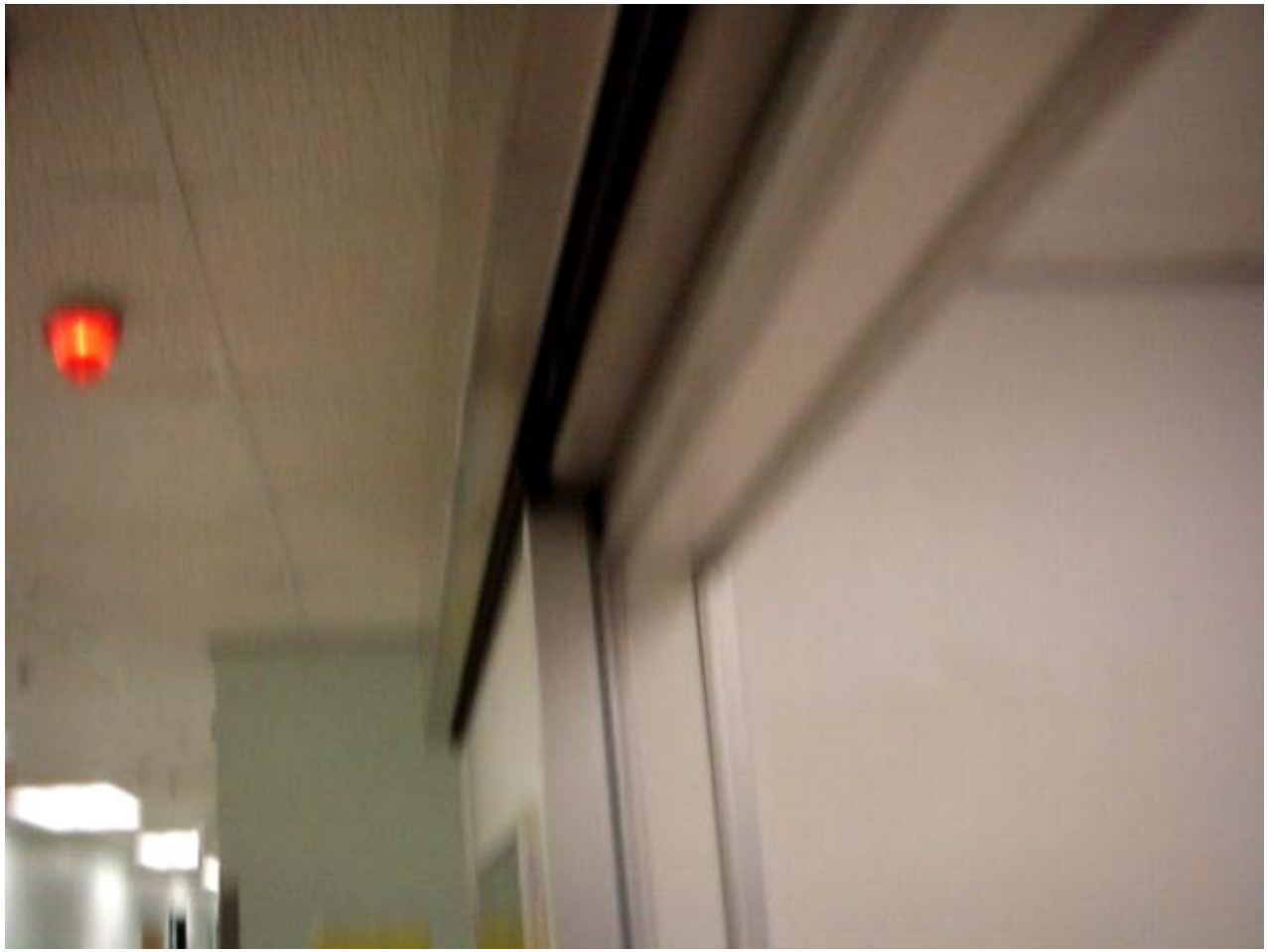


$$\Delta P_{neg,\min} = \frac{1}{2}\rho_0 gH\frac{T_1 - T_0}{T_0} + \Delta P_w$$

$$\Delta P_{neg,\min} = \frac{1}{2}\rho_0 gH\frac{T_1 - T_0}{T_0} + \frac{1}{3}\times 1.2 \times \frac{1}{2}\rho_0 V^2$$

Any air leakage from this SARS ward?

Existence of bi-directional flows – why?

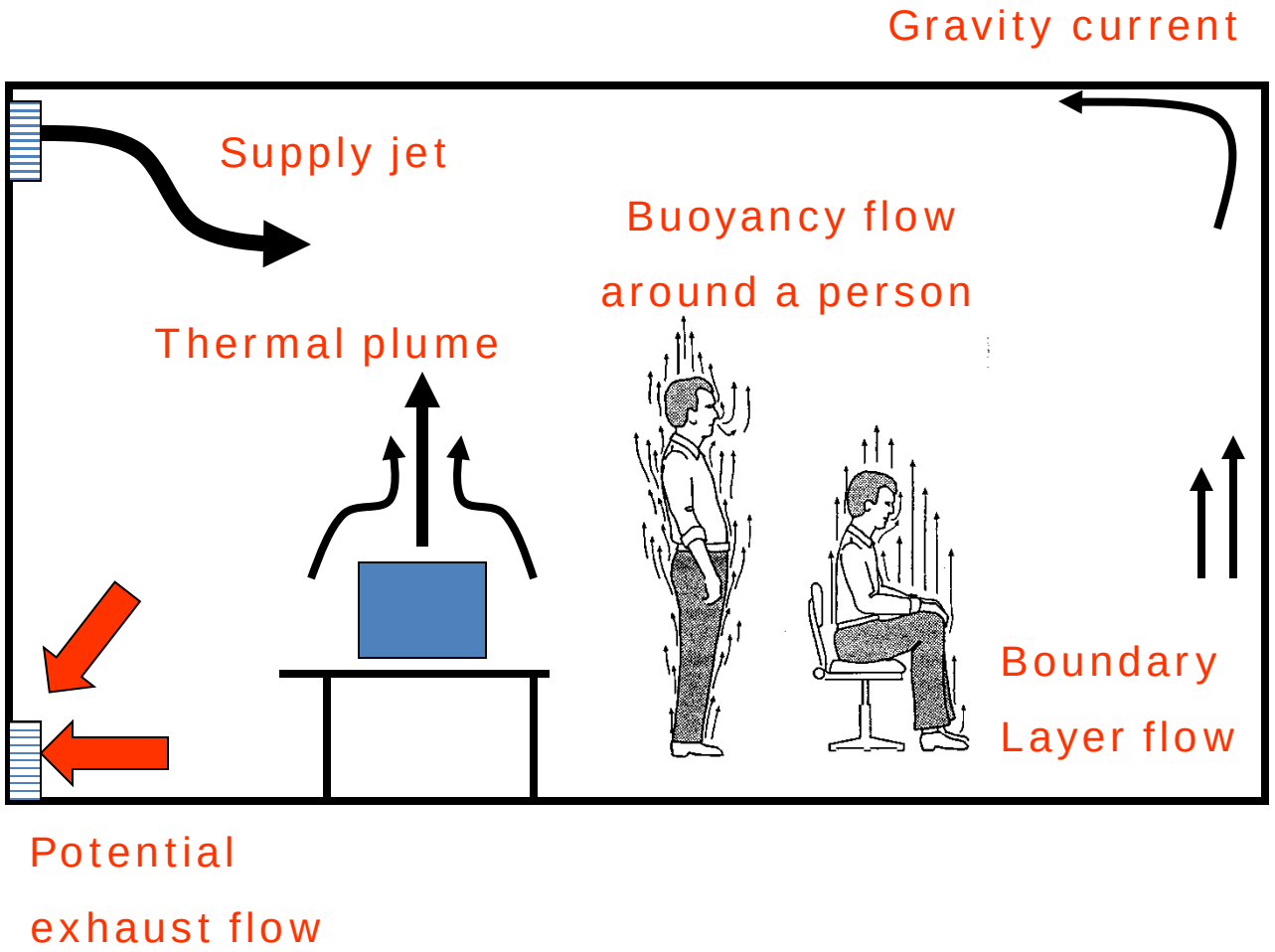


Doorway flow is crucial!

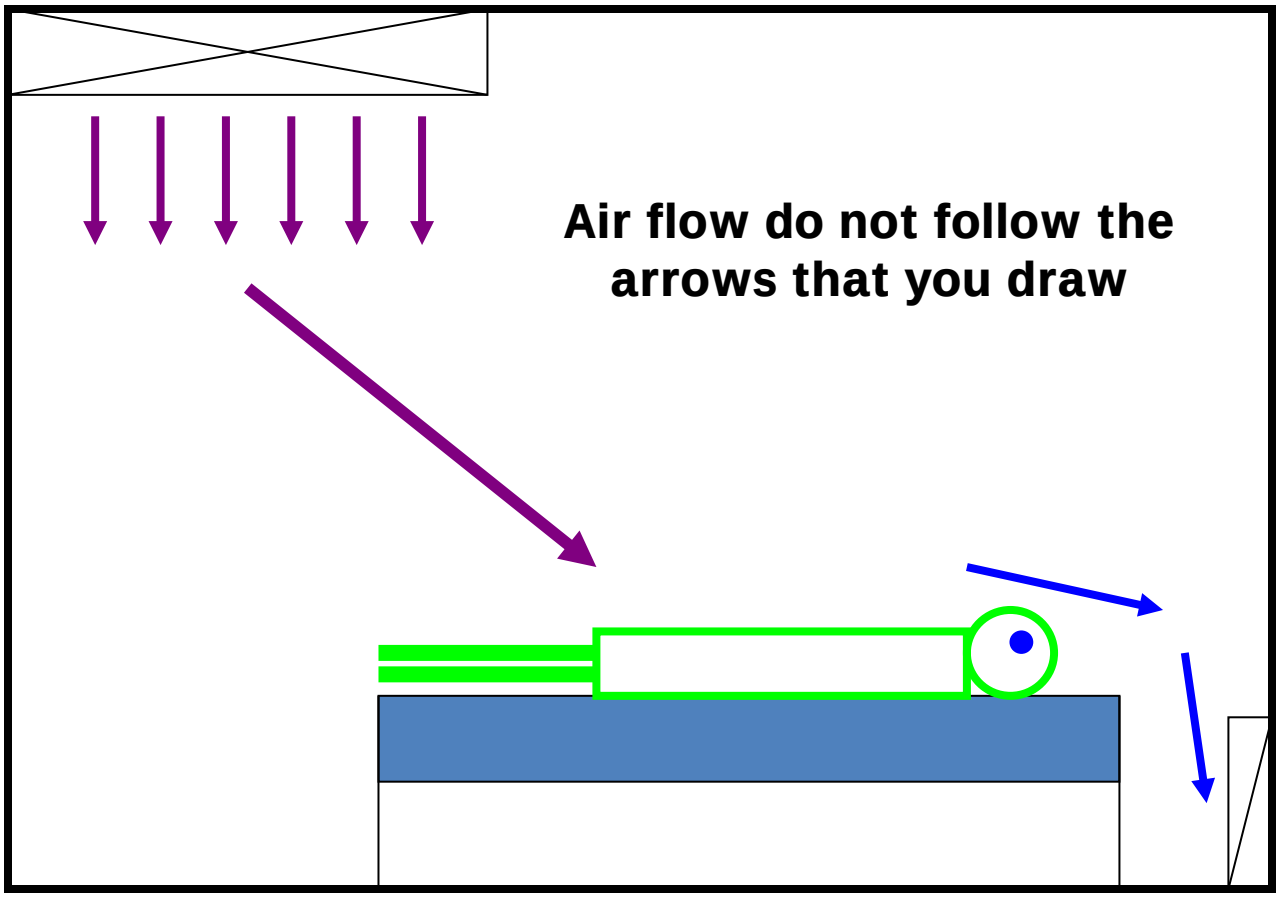
Courtesy of Professor Mats Sandberg

The impact of air distribution?

Flow elements in a ventilated room



Air flow can be visualized and measured, but “cannot be drawn”



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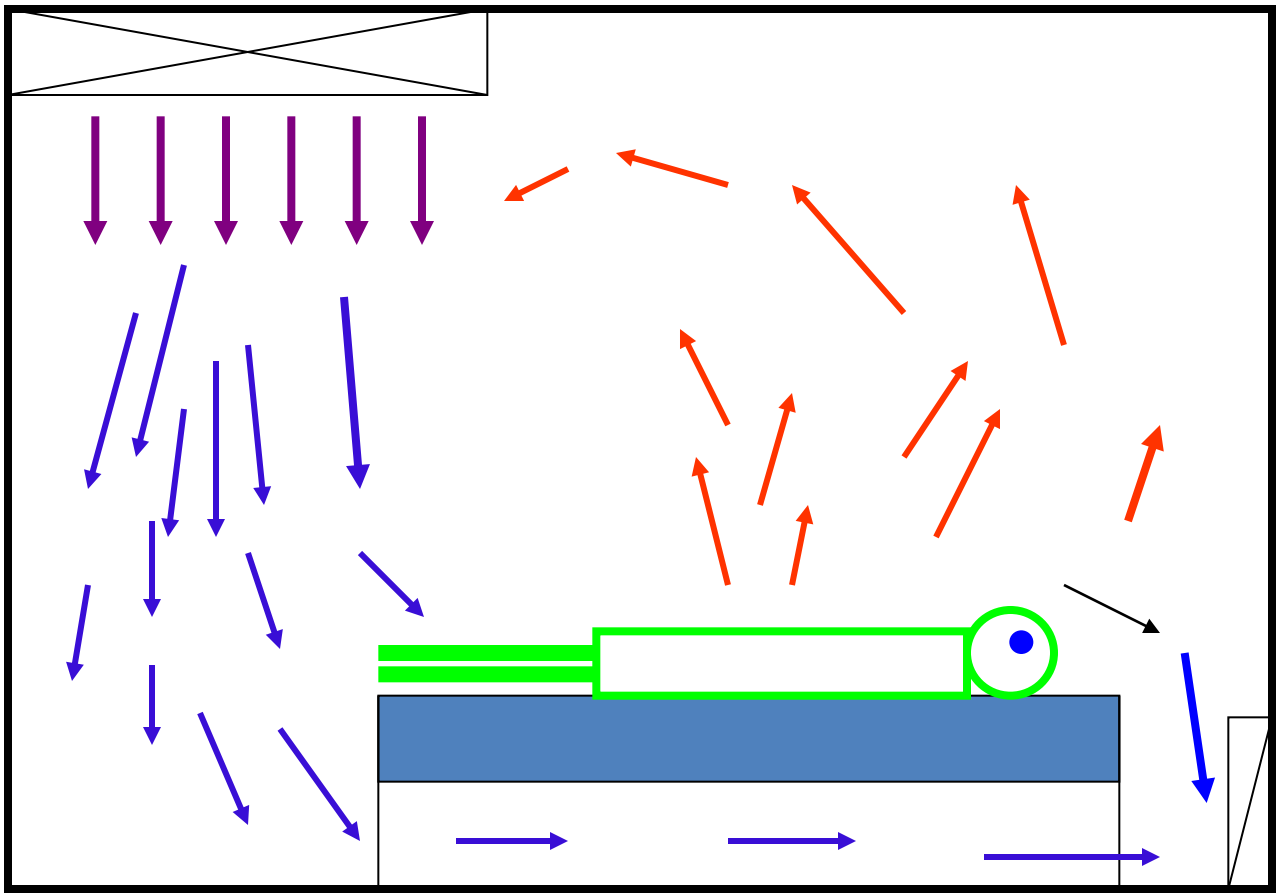
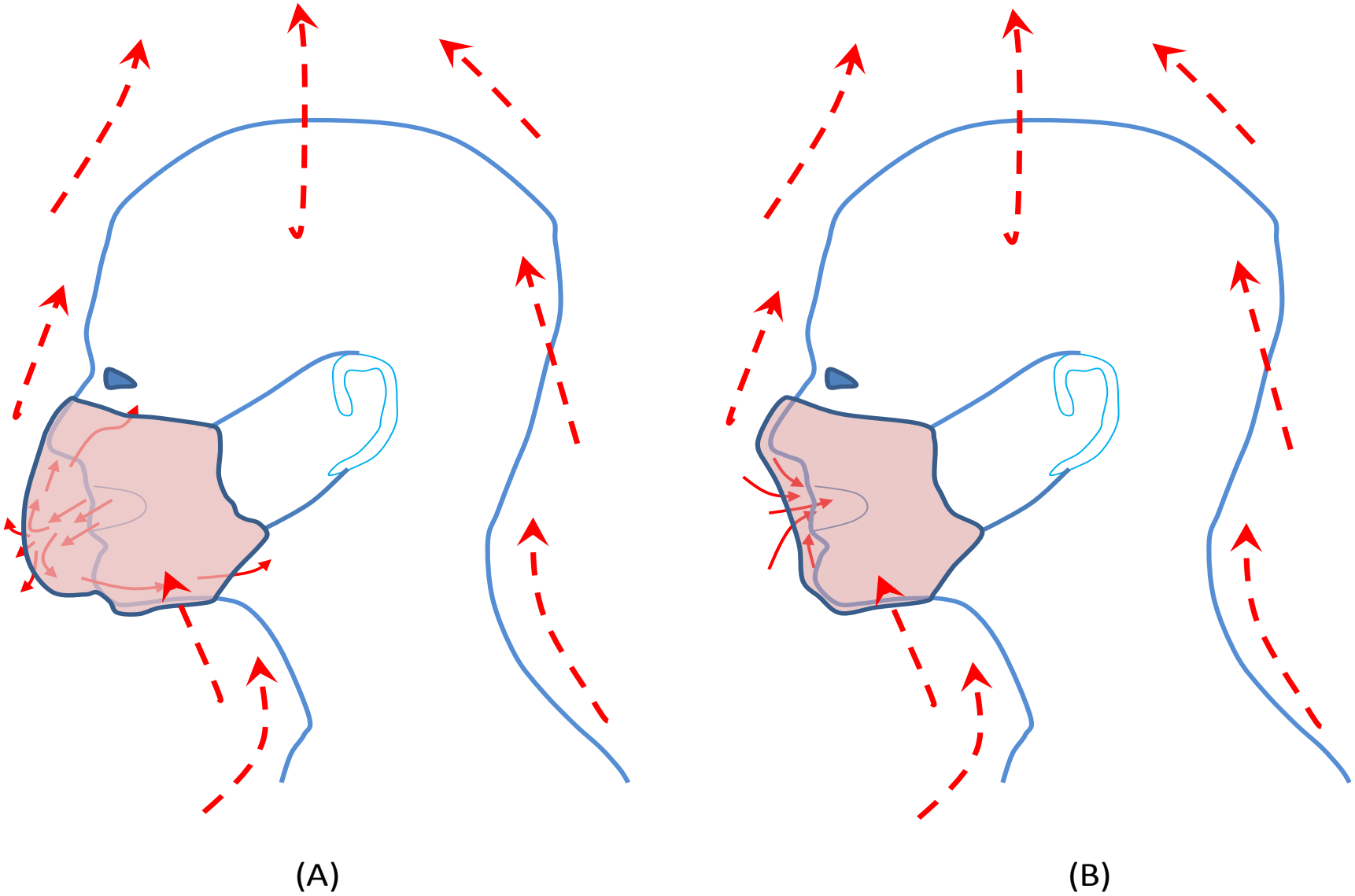
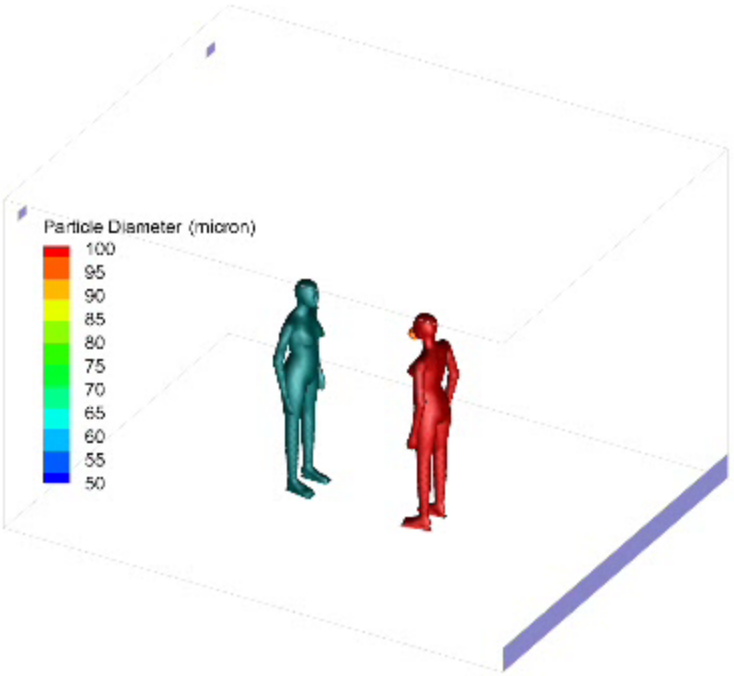
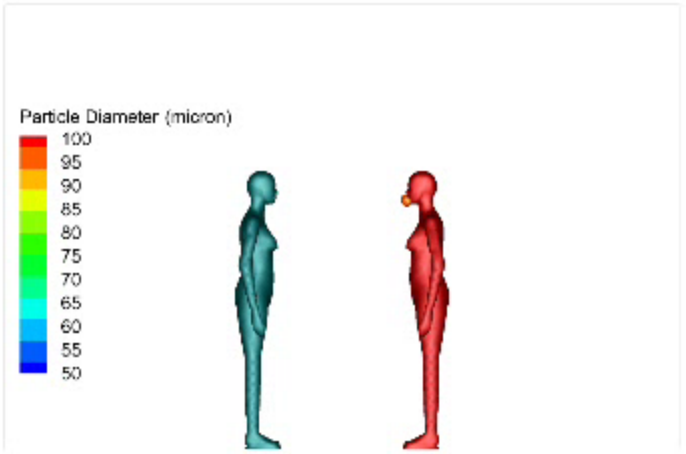
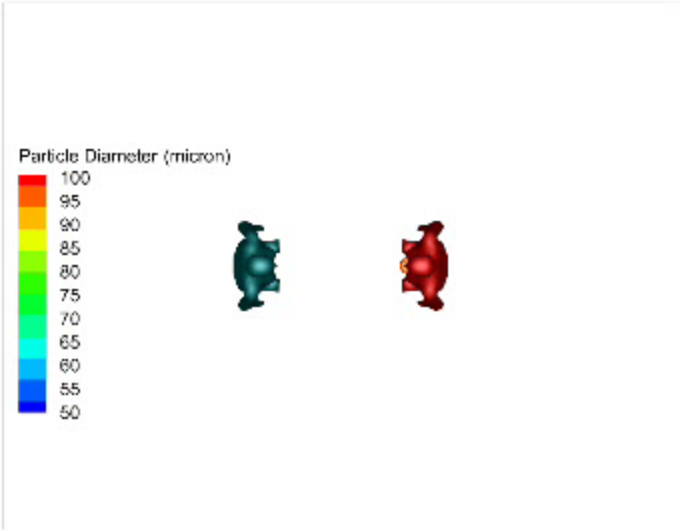


Interaction of body micro-environment plays an role in exposure to fine droplets.



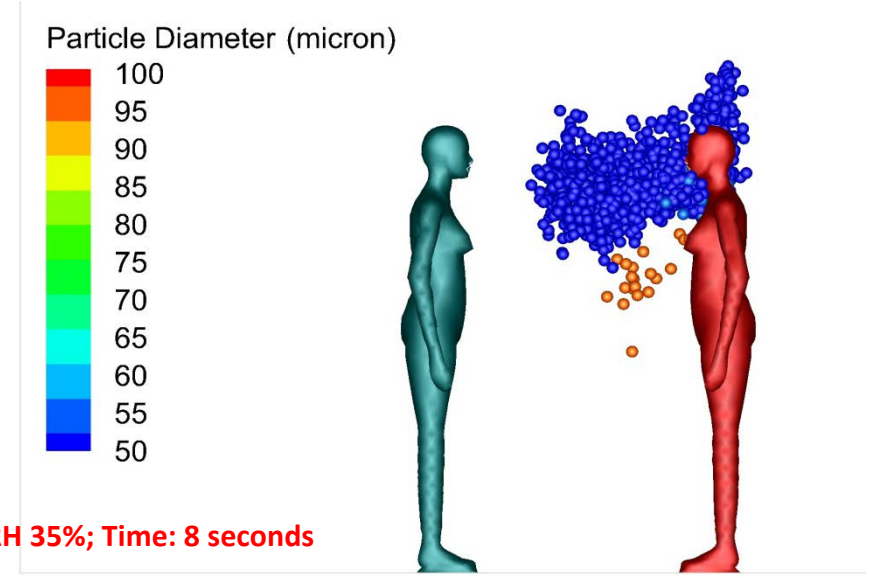




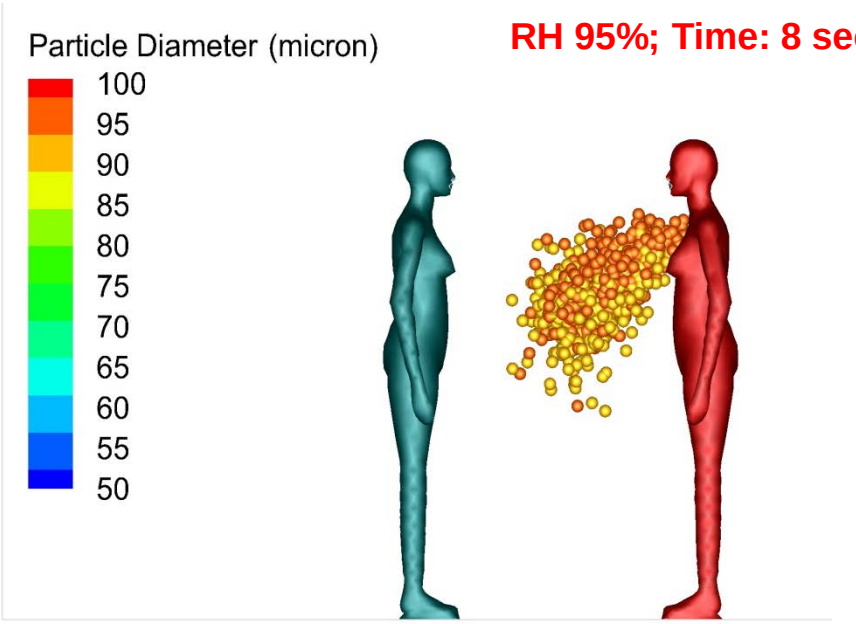


Time = 4.1 second

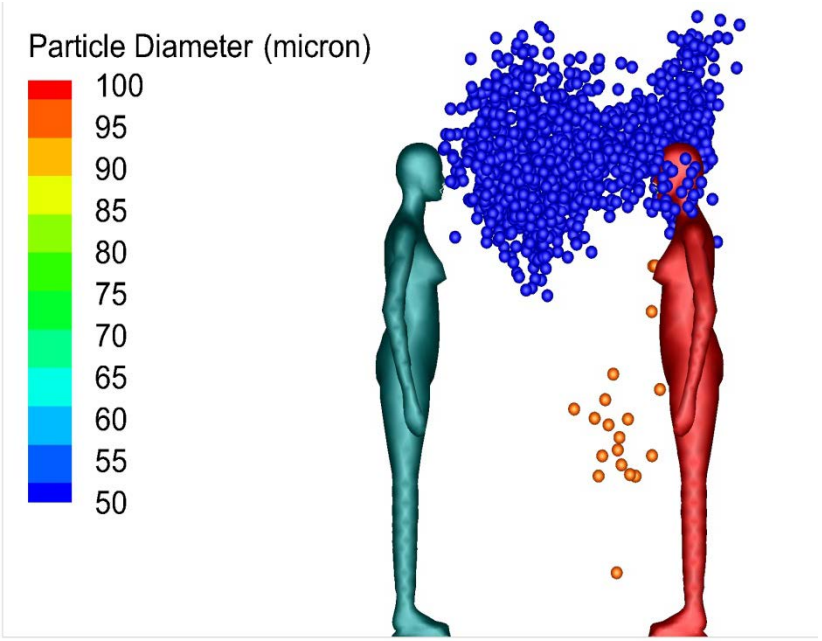
Displacement ventilation	**5.5 ACH**
Distance between people	**0.8 m**
Normal breathing	**synchronized**
Initial droplet diameter	**100 micron**
Ambient relative humidity	**35%**
Droplet composition	**NaCl 0.9%, Solids 1.8%**



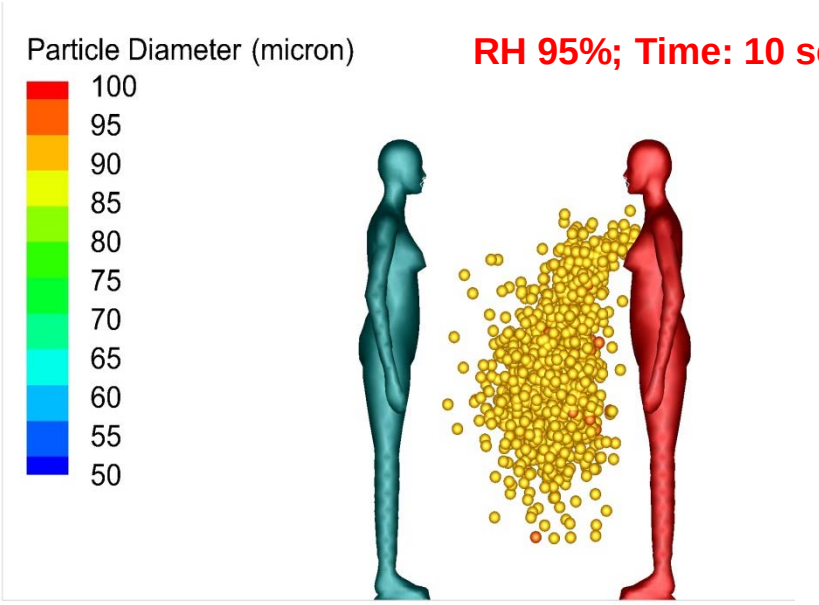
RH 35%; Time: 8 seconds



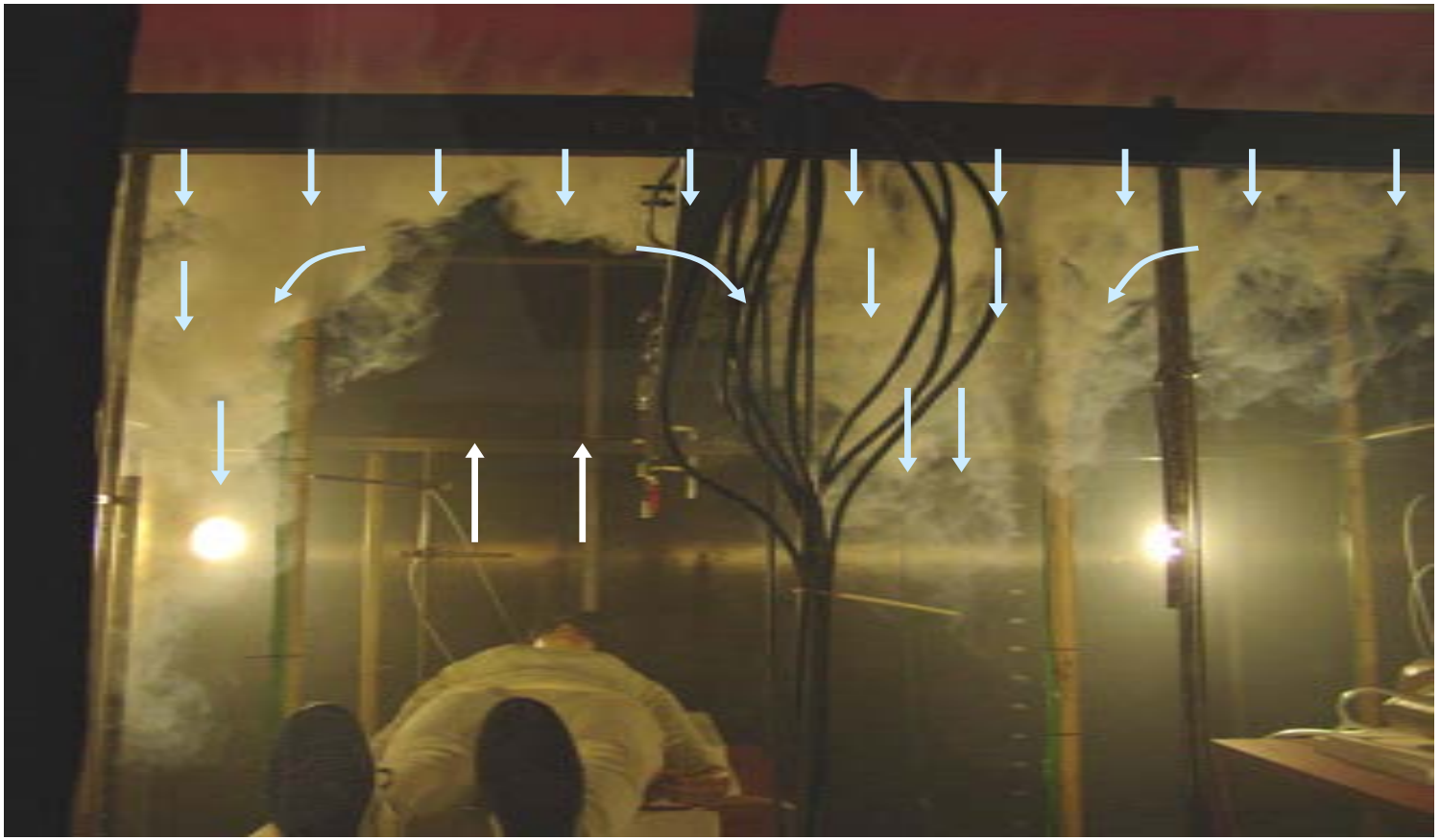
RH 95%; Time: 8 seconds



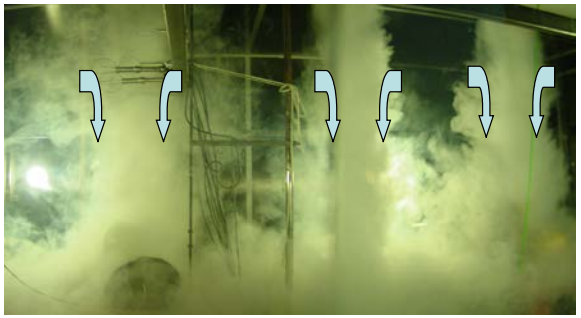
RH 35%; Time: 10 seconds



RH 95%; Time: 10 seconds

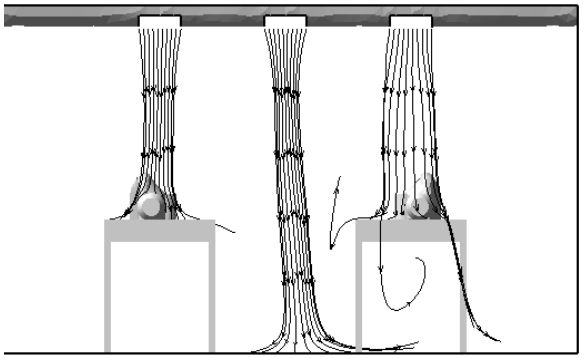


Airflow pattern in the isolation room is not unidirectional, but mixed!

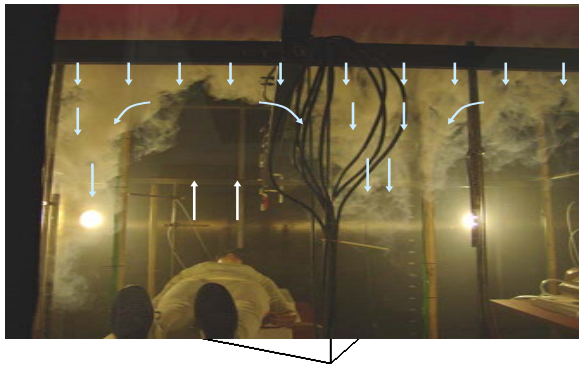


(a)

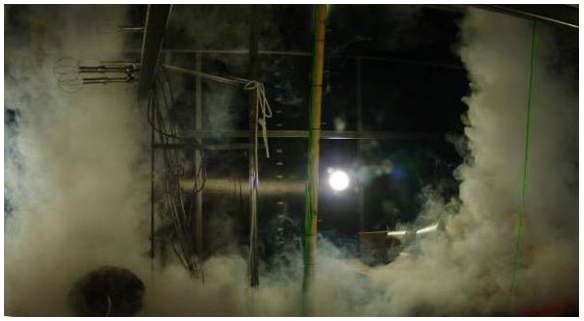
(b)



(c)



(d)



(e)

(f)

Qian et al., Building and Environment 2008;43:344-354

Differences between ventilation & air conditioning

- **The purpose of ventilation is to achieve good air quality** which means freedom from unwanted odours, and restriction of air contaminant concentrations below the levels at which irritation or toxic effects manifest themselves.

- **The purpose of air conditioning is to achieve thermally comfortable air environment**, as indicated by the combined effect of air temperature, relative humidity, air speed and mean radiant temperature.

The commonly found ventilation problems

- Ventilation rate is not met due to pressure imbalance – regular check and re-commissioning is needed
- Ventilation supply air is polluted in the air ducts – faulty filters
- Exhaust fans do not function well
- Poor air distribution such as short-circuiting

We measured SARS wards in the following major hospitals Jun- Nov, 2005

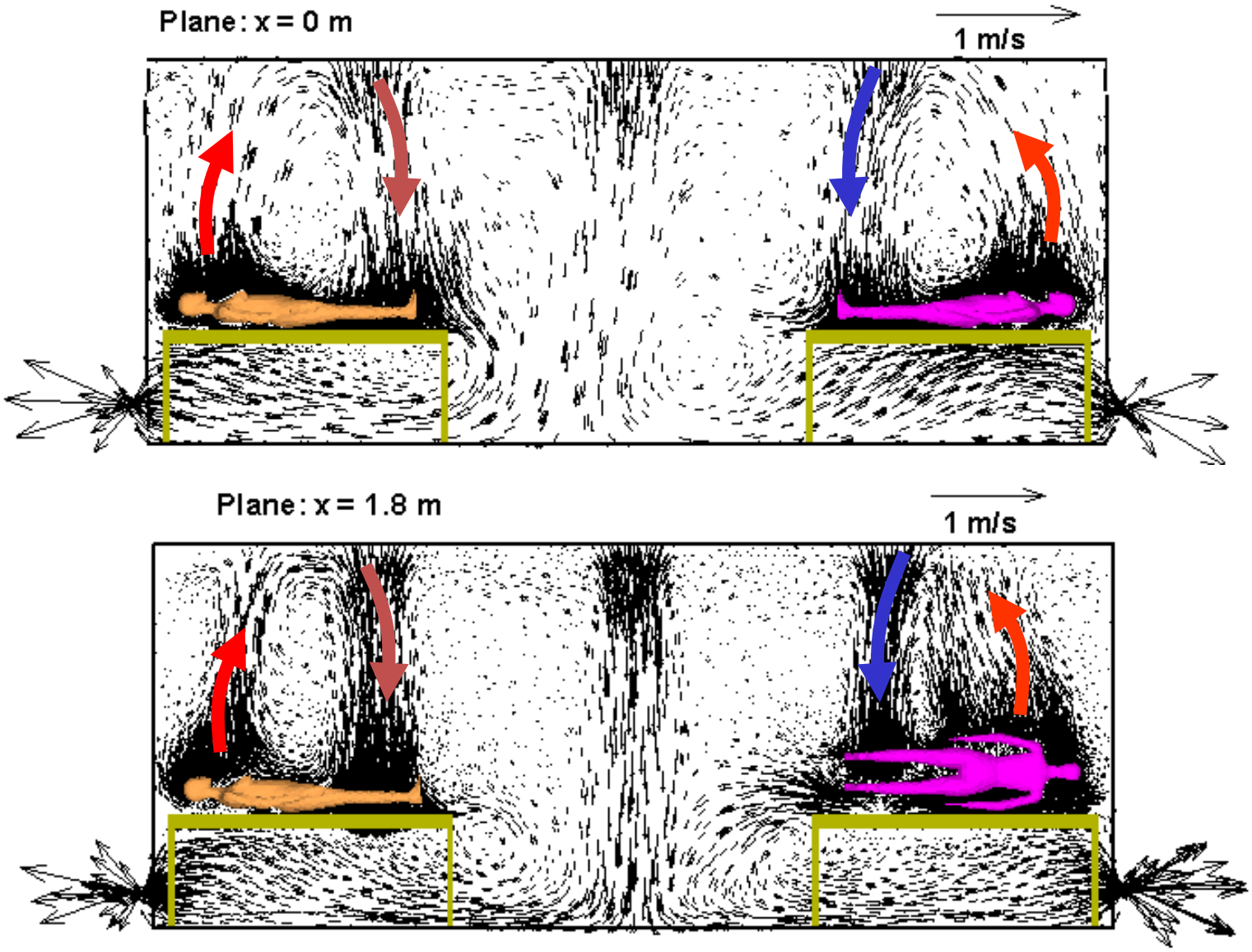
Hospital Name		Measurement Period	Ward
Grantham Hospital	GH	9-10 Nov 2005	2/F & 6/F
Kwong Wah Hospital	KWH	14-21 July 2005	E3
Pamela Youde Nethersole Hospital	PYNH	7-21 June 2005	B11
Prince of Wales Hospital	PWH	22-23 August 2005	11B
Princess Margaret Hospital	PMH	25-27 July, 29 to 31 August 2005	4F
Queen Elizabeth Hospital	QEH	5-11 July 2005	E10
Queen Mary Hospital	QMH	9-14 May 2005	C6
Tseung Kwan O Hospital	TKOH	15-19 August 2005	2A
Tuen Mun Hospital	TMH	23-28 June 2005	T8
United Christian Hospital	UCH	30 June to 1 July 2005	13B
香港皇后大道西134號西營盤賽馬會診療所	SYP	5-6 Nov 2005	1/F

Field study of SARS wards in 9 hospitals (2005)

- The overall performance of Hong Kong SARS isolation rooms are reasonably good.
- Air flows all from corridor to cubicle, better than all existing reported performance in the literature
- 8 out of 36 (22.2%) tested rooms had ACH of less than 12.
- 34.5% cubicles tested had airflow from toilet to cubicle.
- There is an air leakage problem in the suspended ceiling.
- Effectiveness of air flow pattern may not be ideal.

Airflow pattern

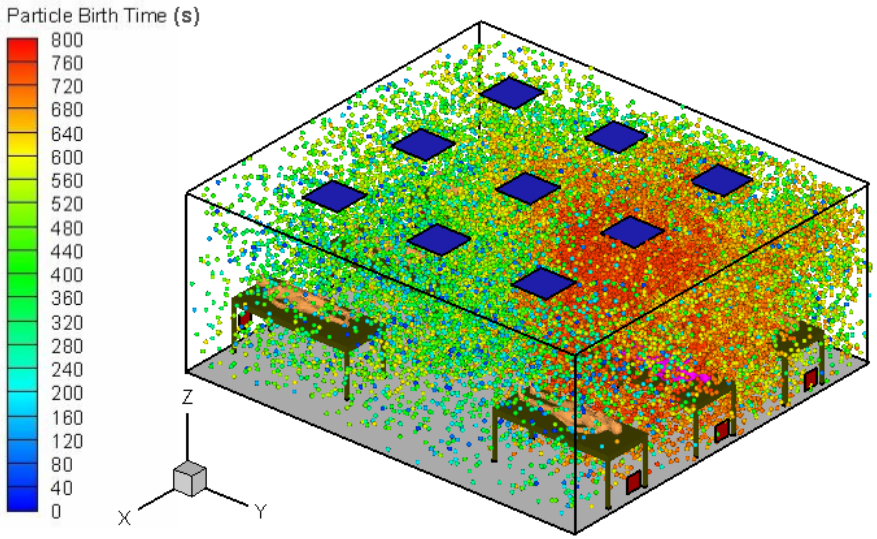
Xie Xiaojian, PhD thesis, HKU, 2008



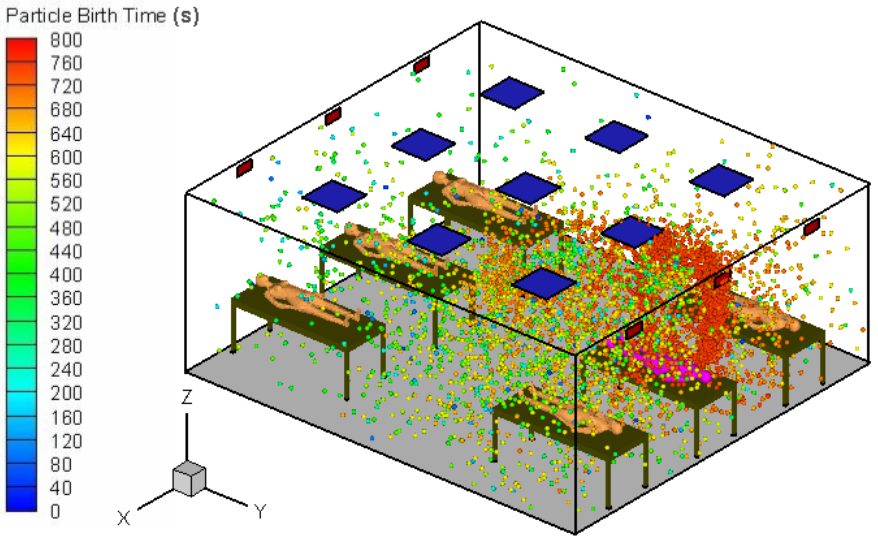
CDC downward ventilation when only the floor level exhaust outlets used

Xie Xiaojian, PhD thesis, HKU, 2008

D_{po}=10μm

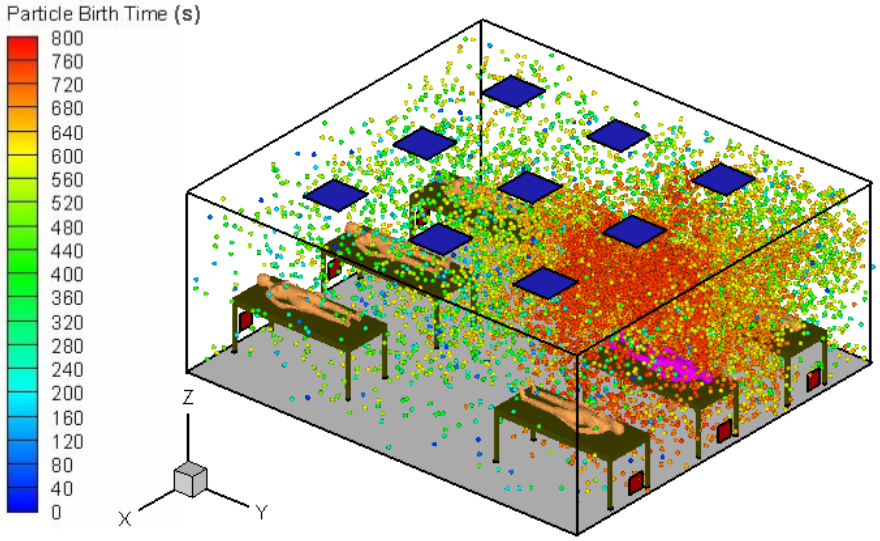


D_{po}=10μm



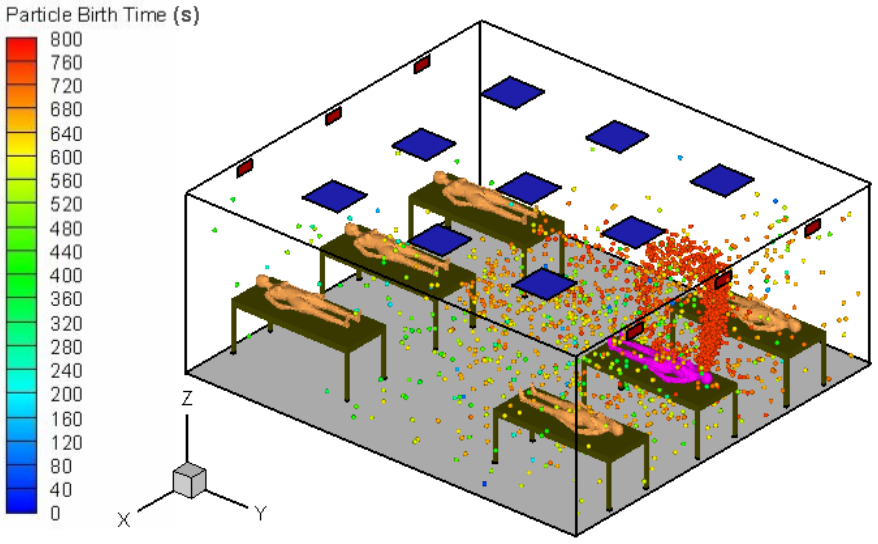
D_{po}=50μm

CDC-Low



D_{po}=50μm

HKU-New

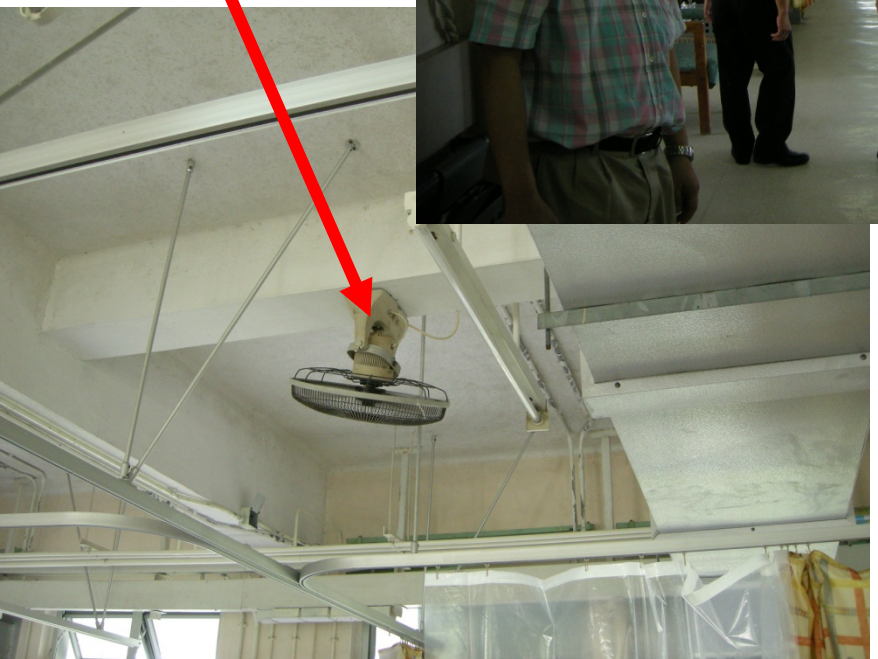


Grantham Hospital -A TB hospital that has been naturally ventilated since 1950s

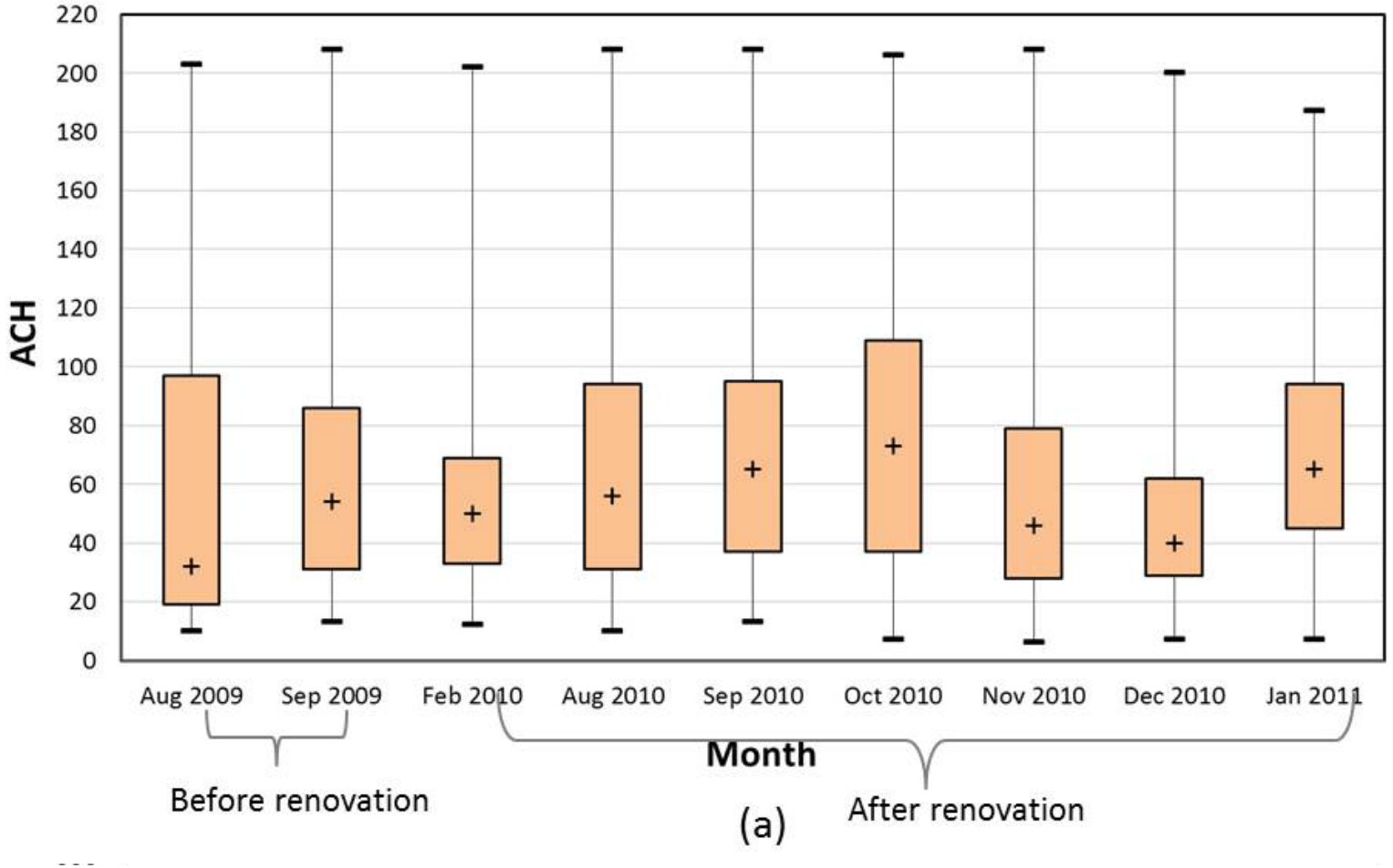
Spot cooling

Ceiling fans

Open windows for 24 hrs a day and 365 days a year



Measured air change rate in Grantham hospital by using INNOVA analyzer in Cubicle A

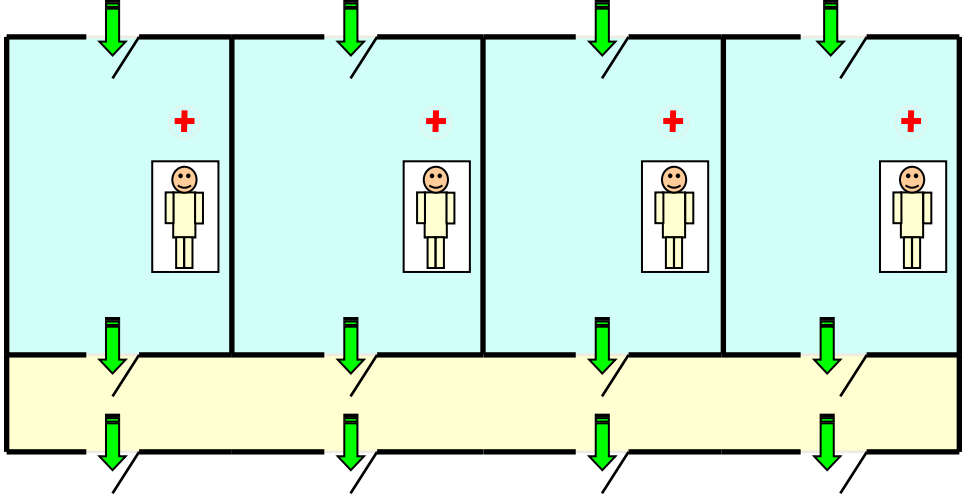


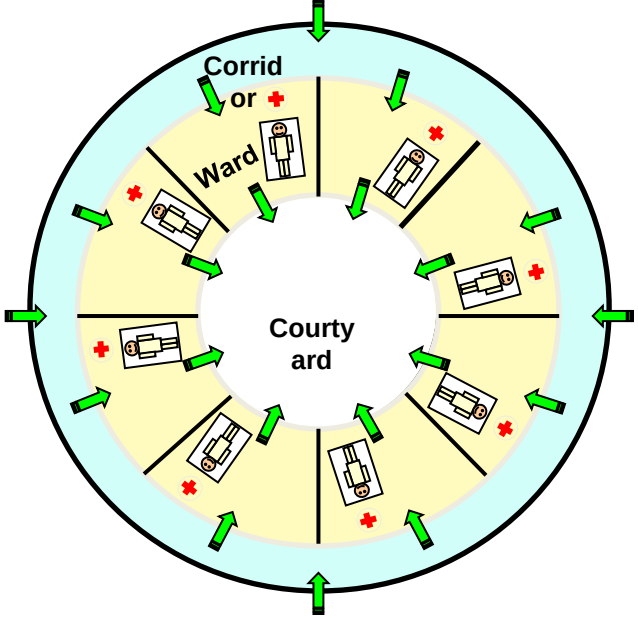
We obtained more than 8000 hourly air change rates.

WHO (2009) specified the minimum hourly averaged natural ventilation rate of 160 l/s per patient.

With 10 patients in each Cubicle, the required minimum hourly averaged ventilation rate is 1600l/s, that is 3.8 ACH at Grantham Hospital due to its relative large volume.

The measured hourly air change rates all satisfy the WHO requirement in all 4 cubicles, except some hours in August 2010 in one of the cubicles (not shown).

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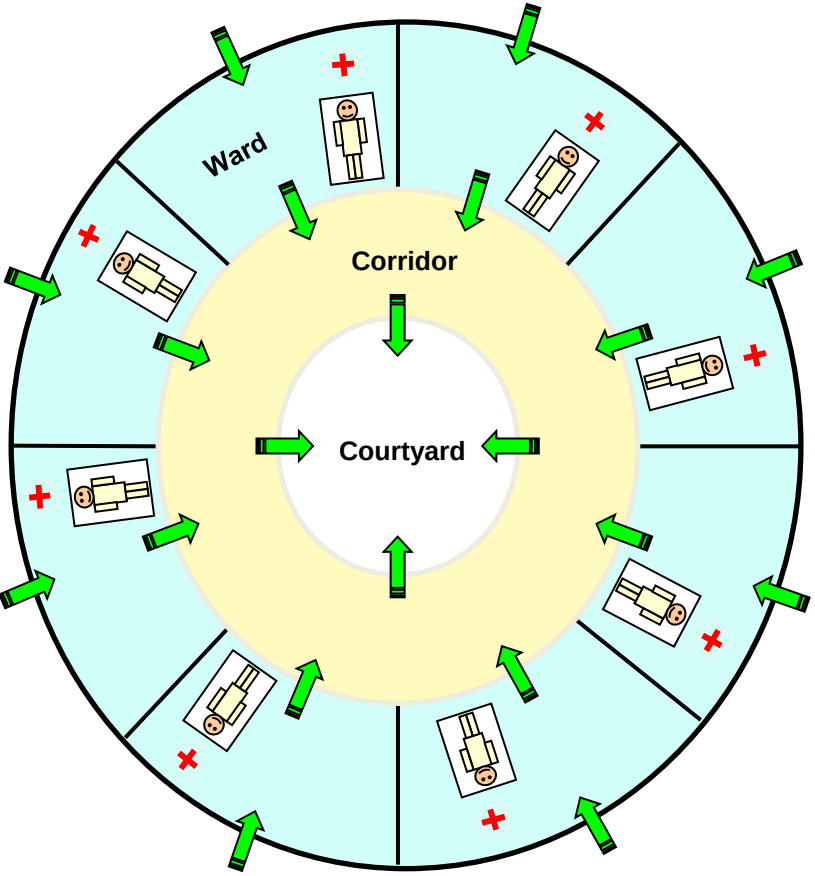
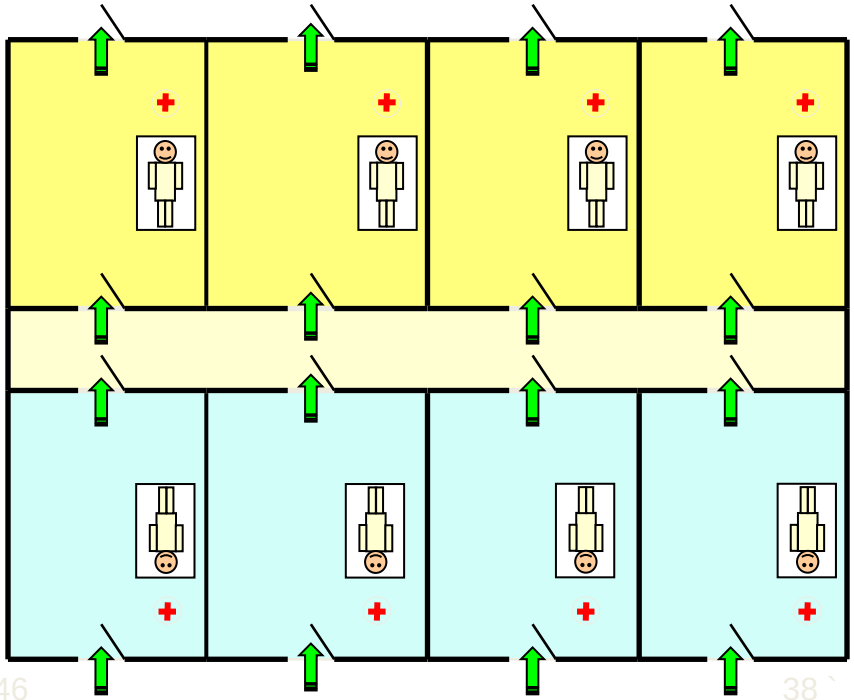
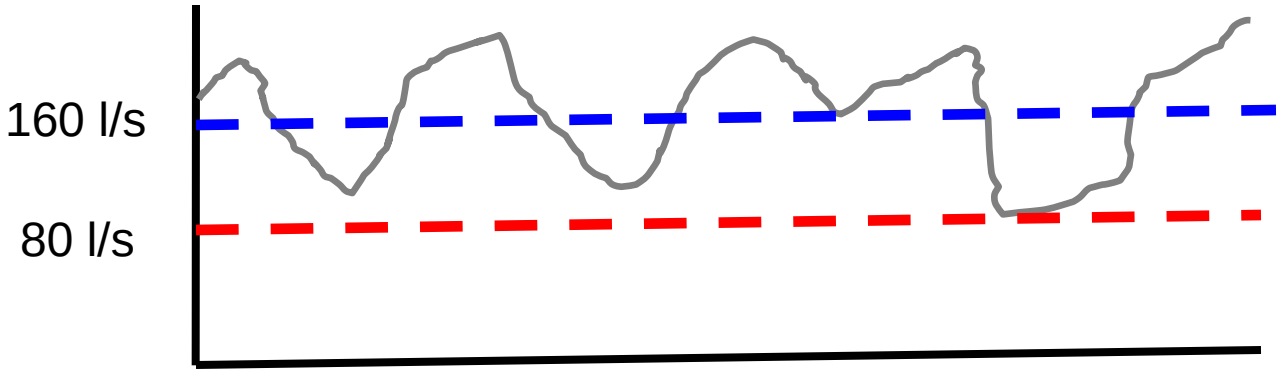

Ward
Corridor
Courtyard



WHO 2009 NatVent Guideline – key ideas

- **For natural ventilation, a minimum hourly averaged ventilation rate of 160 L/s/patient for airborne precaution rooms (with a minimum of 80 L/s/patient).**

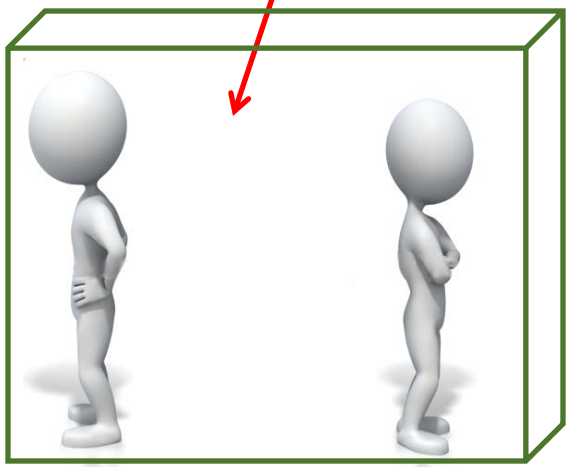


- When natural ventilation alone cannot satisfy the requirements, mechanically assisted natural ventilation system should be used.
- **Overall airflow should bring the air from the agent sources to areas where there is sufficient dilution, and preferably to the outdoors.**

What happens when airborne transmission is not the only transmission route ?

Relative importance ?

Airborne transmission

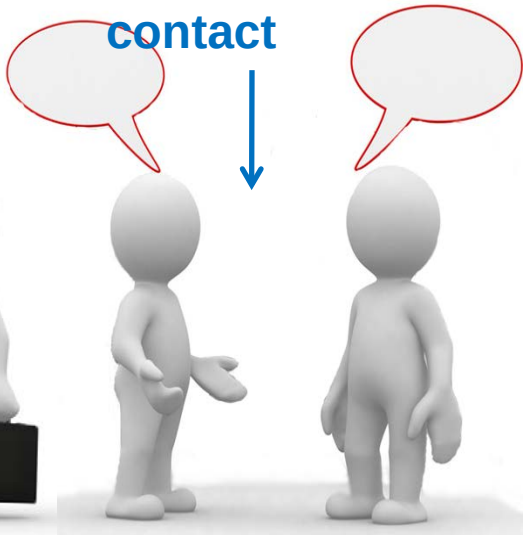


Close-contact transmission

Surface contact

Physical contact

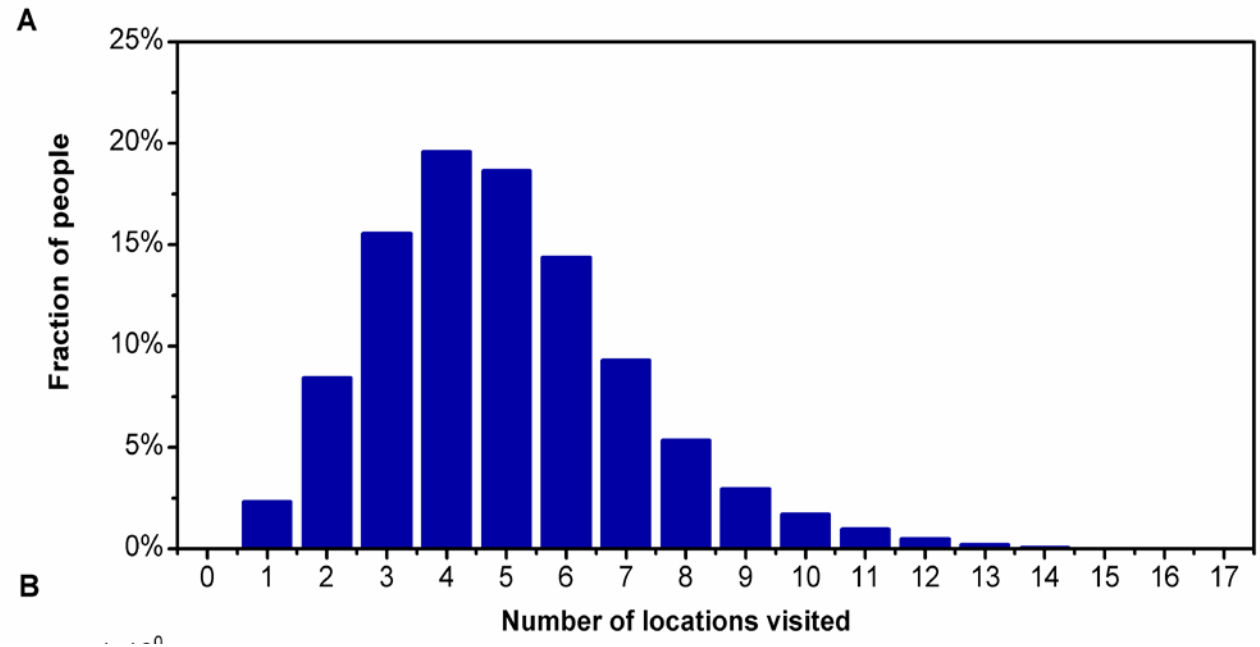
Conversational contact



What is the probability of any two individuals meeting in any of the indoor spaces in Hong Kong, and how long?

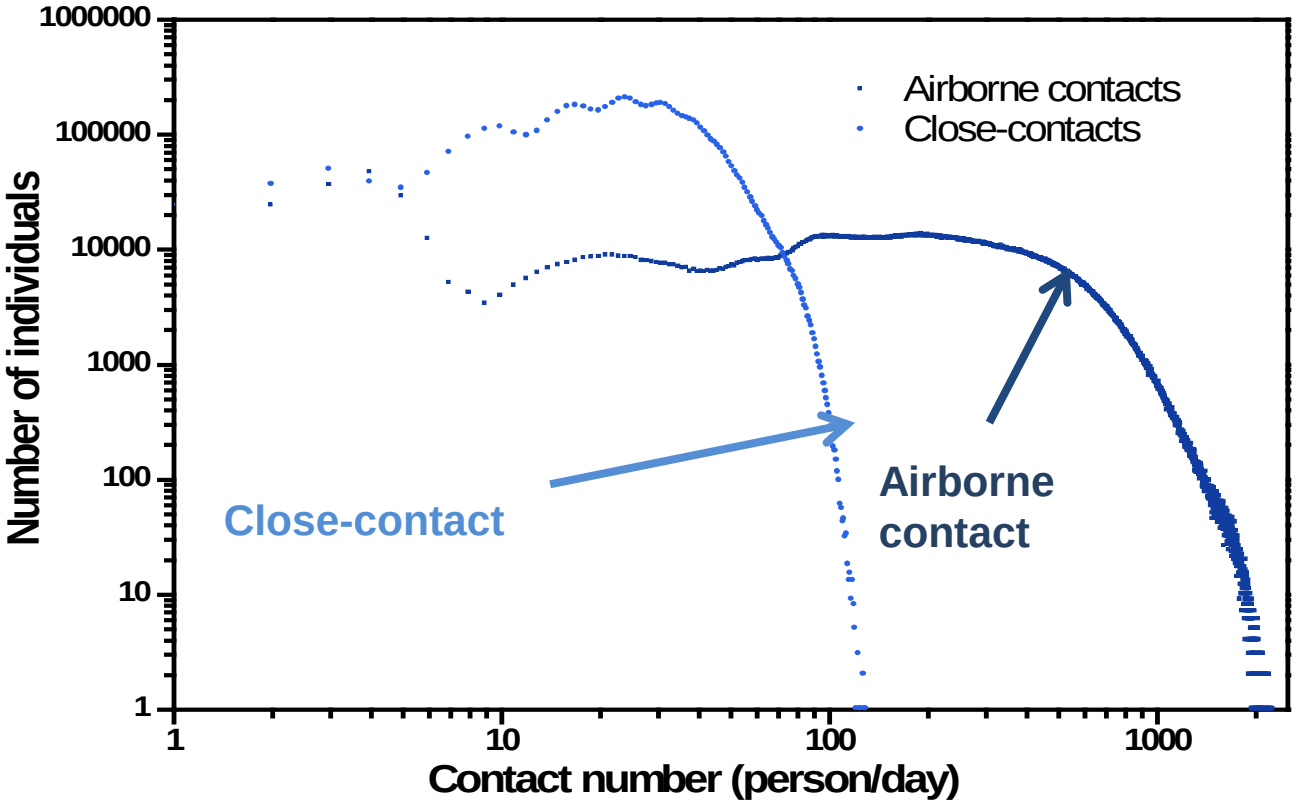
Individual nodes : 6,857,100

location nodes : 2,923,035



Degree distribution of individuals having different numbers of daily visiting locations

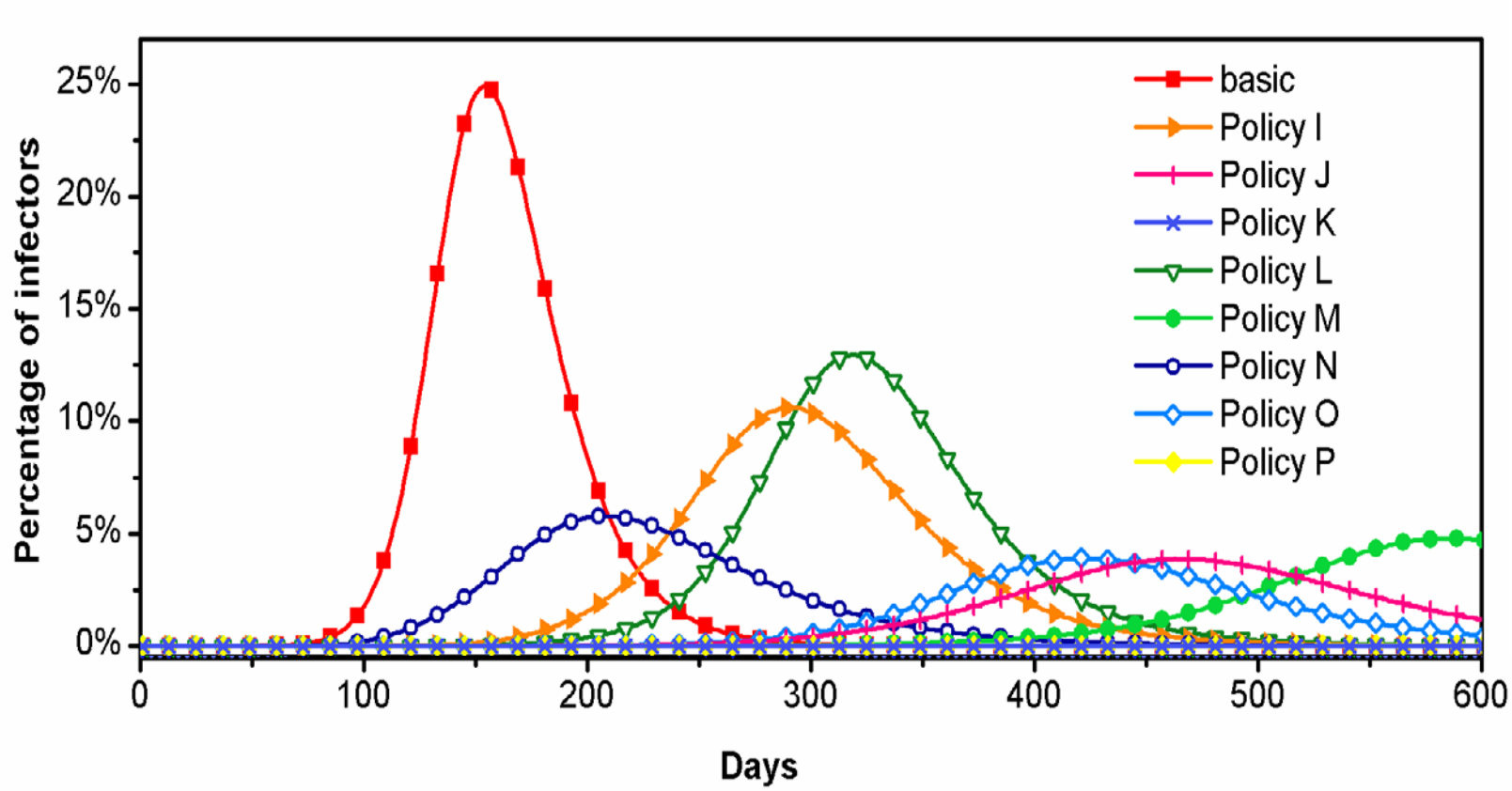
The social contact pattern of Hong Kong population as estimated using our model



A vast majority of the population is found with the close-contact number around 10 to 30 person/ day. The degree distribution also has a small tail, which indicates that few individuals in society have daily close-contacts larger than 100 person/ day.

Control effect of increasing ventilation rates in Hong Kong

Policy I	Double ventilation rates in all locations
Policy J	3 ACH (All locations)
Policy K	5 ACH (All locations)
Policy L	8 l/s•person (All locations)
Policy M	12 l/s•person (All locations)
Policy N	5 ACH (Homes and classrooms)
Policy O	5 ACH (Homes and offices)
Policy P	5 ACH (Homes, classrooms and offices)



New opportunities and challenges

- Greater expectation of hospitals users and workers
- Energy costs and energy efficiency.
- Larger and more complex hospitals and health care settings.
- Better understanding of disease transmission
- Impact of advanced manufacturing technologies and smart sensor/control.
- The trend of hybrid ventilation.


Thank you