Control of Infectious Aerosols for Primary & Secondary Schools

Occupational Health Clinics for Ontario Workers

Centre de santé des travailleurs et travailleuses de l'Ontario

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Research to Practice, Offering Practical Evidence-Based Solutions

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OUTLINE

1 Air Quality and Schools – The Compelling Case for Good IAQ

2 Natural versus Mechanical Ventilation

3 AIRAH Schools Brochure Ventilation Optimisation for Infection Control

4 Various Strategies for Improvement

5 ASHRAE 241-2023 framework

BACKGROUND

1 Air quality has long been neglected in both primary & secondary schools

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Evaluation of ventilation in Australian school classrooms using long-term

with median over 1000 ppm in 70% of classrooms. All 10 classrooms in the study exceeded the Australian recommended limit of 850 ppm. Using average peak CO_2 concentrations from year-long measurements, estimated ventilation rate (VR) of 4.08 Ls^{-1} per person show under-performing classrooms where 60% had VRs 35–40% lower than the 10-12 Ls^{-1} per person Australian recommendation. Estimated VR range of 1.24–2.07 Ls^{-1} per person using peak maximum CO_2 levels were 19–30% lower than ASHRAE recommendation of 6.7 Ls^{-1} per person. These VRs translate to a range of air change rates on average between 0.52 and 0.88 $h^{-1} \pm$ 0.26–0.59, well below the 6.0 h^{-1} recommendation for good indoor ventilation by the World Health Organisation in the context of COVID-19 pandemic. Characterisation of ventilation and indoor air quality in current Australian

recommended limit of 850 ppm. Using average peak CO_2 concentrations from year-long measurements, estimated ventilation rate (VR) of 4.08 Ls^{-1} per person show under-performing classrooms where 60% had VRs 35–40% lower than the 10-12 Ls^{-1} per person Australian recommendation. Estimated VR range of 1.24–2.07 Ls^{-1} per person using peak maximum CO_2 levels were 19–30% lower than ASHRAE recommendation of 6.7 Ls^{-1} per person. These VRs translate to a range of air change rates on average between 0.52 and 0.88 $h^{-1} \pm$ 0.26–0.59, well below the 6.0 h^{-1} recommendation for good indoor ventilation by the World Health Organisation in the context of COVID-19 pandemic. Characterisation of ventilation and indoor air quality in current Australian classroom stock is critical for the improvement of classroom design, induction on room operating practices, understanding of the school community on the relevance of building ventilation on school performance and health, and development of appropriate ventilation and indoor air quality guidelines for schools.

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BACKGROUND

1 Air quality has long been neglected in both primary & secondary schools

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Indoor air quality in French schools: a nationwide study (2013-2017)

Claire Dassonville[1*], Anthony Grégoire[1], Sutharsini Sivanantham[1], Bruno Berthineau[1], Mickaël Derbez[1], Olivier Ramalho[1], Jacques Riberon[1], Corinne Mandin[1]

preliminary results focusing on $PM_{2.5}$ showed that indoor concentrations measured during teaching hours (median value: 18 $\mu g/m^3$) were lower than those previously observed in European studies. Most of the concentrations (>90%) exceeded the 10 $\mu g/m^3$ WHO long-term guideline value.

to assess air quality in [illegible] classrooms of [illegible] randomly selected schools across France. All pollutant concentrations and comfort parameters were measured in each studied classroom over one school week from Monday morning (8:00 am) to Friday afternoon (5:00 pm). The preliminary results focusing on $PM_{2.5}$ showed that indoor concentrations measured during teaching hours (median value: 18 $\mu g/m^3$) were lower than those previously observed in European studies. Most of the concentrations (>90%) exceeded the 10 $\mu g/m^3$ WHO long-term guideline value.

BACKGROUND

1 Air quality has long been neglected in both primary & secondary schools

Journal of Building Engineering

8.3 CiteScore | 6.4 Impact Factor

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Indoor Environmental quality and Health in School Buildings

Edited by
- Prashant Kumar
- Wei Yu
- Sasan Sadrizadeh

Last update 6 March 2023

Children are a particularly vulnerable group in society. They are more susceptible to exposure to heat/cold stress and air pollution than adults and they are less able to communicate concerns in response to pollutant levels. The main aim of this Special Issue is to focus on the indoor environmental quality of school buildings. We welcome the up-to-date research outcomes to be shared internationally. The topics are expected to be focused on:

BACKGROUND

1 Air quality has long been neglected in both primary & secondary schools – *making the cost-benefit case*

Benefit/Cost Analysis of Ventilation Strategies to Reduce Airborne Infectious Disease Transmission in Schools

Sangeetha Kumar[1], Leigh A. Lesnick[1], Richard Corsi[1], Atila Novoselac[1*]

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doors. A preliminary analysis of a singular portable classroom for a two month school period suggests a 10% chance of contracting the flu or nearly three flu cases per class period equivalent to a $270 loss of state funding per infector. Under normal ventilation conditions for the same time period, the total conditioning costs are $24. Ventilation strategies, including maintaining

doors. A preliminary analysis of a singular portable classroom for a two month school period suggests a 10% chance of contracting the flu or nearly three flu cases per class period equivalent to a $270 loss of state funding per infector. Under normal ventilation conditions for the same time period, the total conditioning costs are $24. Ventilation strategies, including maintaining minimum ASHRAE standards for fresh air requirements and eliminating secondary infections, result in similarly high benefit-to-cost ratios due to the relatively low cost of energy.

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BACKGROUND

2 Research indicates reduced COVID-19 transmission in well-ventilated schools

2 "Each additional ACH reduced COVID-19 infection risk 12% to 15%"

frontiers | Frontiers in Public Health

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Check for updates

OPEN ACCESS

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Increasing ventilation reduces SARS-CoV-2 airborne transmission in schools: A retrospective cohort study in Italy's Marche region

Giorgio Buonanno[1,2], Luca Ricolfi[3,4], Lidia Morawska[2] and Luca Stabile[1]*

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BACKGROUND

3 Additional benefits of performance

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3 Additional benefits of performance

Ventilation Rates in Schools and Learning Performance

Zs. Bakó-Biró[1], N. Kochhar[1], D.J. Clements-Croome[1], H.B. Awbi[1] and M. Williams[2]

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scales. The present paper shows preliminary results obtained for one primary school out of eight being studied. Due to the intervention the fresh air supply increased from 0.3-05 to 13-16 L/s per person that increased pupils' work rate by ~7% in addition ($p<0.036$) and subtraction ($p<0.052$).

Associations between classroom ventilation and pupils' performance were investigated in primary schools in the United Kingdom. The concentration of carbon dioxide and other parameters were monitored for three weeks in two selected classrooms in each school. A direct air supply system through the windows was used to alter the ventilation rates in the classrooms. The system was set either to provide outdoor air or to re-circulate the classroom air while all other physical parameters were left unchanged. Computerised Assessment Tests and Paper-based Tasks were used to evaluate pupils' performance. Pupils' perceptions about the classroom environment, comfort, general mood and hunger were assessed on subjective scales. The present paper shows preliminary results obtained for one primary school out of eight being studied. Due to the intervention the fresh air supply increased from 0.3-05 to 13-16 L/s per person that increased pupils' work rate by ~7% in addition ($p<0.036$) and subtraction ($p<0.052$).

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BACKGROUND

3 Additional benefits of performance – ***2005 review article***

Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature

Abstract To assess whether school environments can adversely affect academic performance, we review scientific evidence relating indoor pollutants and ther-

tions, which in turn have been related to reduced performance and attendance. Also, much evidence links poor IEQ (e.g. low ventilation rate, excess moisture, or formaldehyde) with adverse health effects in children and adults and documents dampness problems and inadequate ventilation as common in schools. Overall, evidence suggests that poor IEQ in schools is common and adversely influences the performance and attendance of students, primarily through health effects from indoor pollutants. Evidence is available to justify (i) immediate actions to assess and improve IEQ in schools and (ii) focused research to guide IEQ improvements in schools.

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COMPELLING CASE

1. Air quality has long been neglected in both primary & secondary schools
2. Improved ventilation ↓ infectious disease transmission schools
3. Improved ventilation ↑ performance
4. Existing code language is insufficient regarding operation (as well as design)
5. Improvements do not necessarily contradict sustainability

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NATURAL OR MECHANICAL VENTILATION

1 Many school designs rely on operable windows for ventilation

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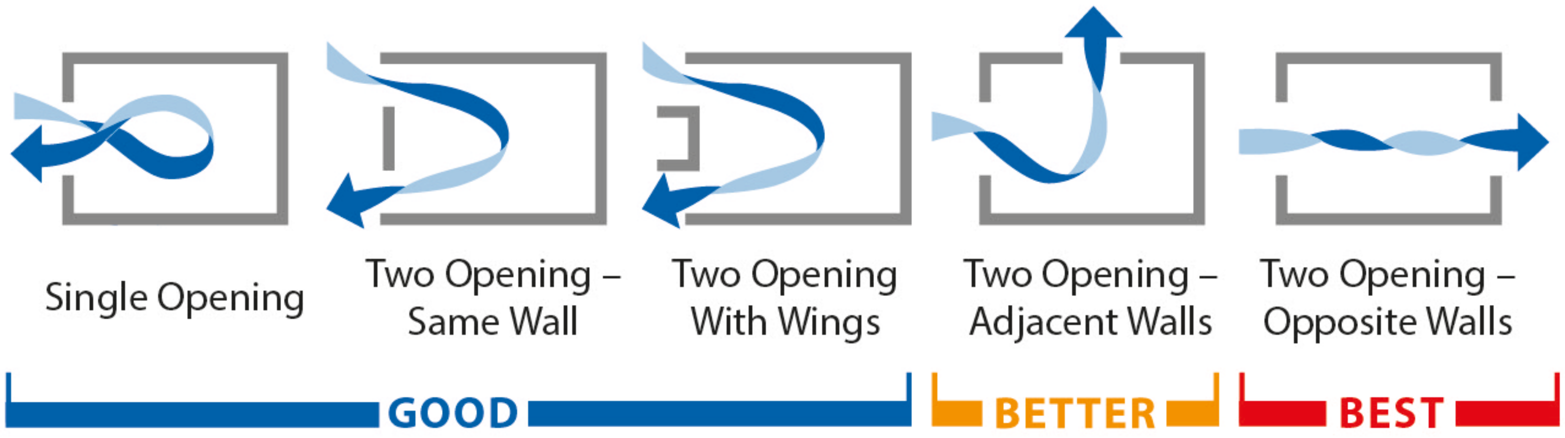
NATURAL VENTILATION SIMPLE SOLUTIONS

Many school designs rely on operable windows for ventilation



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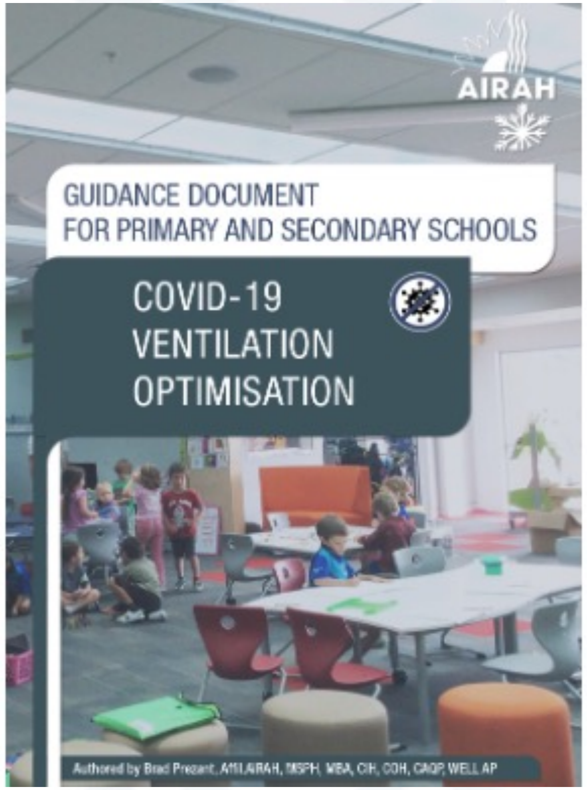
MECHANICAL VENTILATION SIMPLE SOLUTIONS

1. Increase outdoor air percentage by opening damper
2. Operate VAV systems in more constant volume mode
3. Program BMS to conduct flush cycles

RESOURCES

AIRAH COVID-19 Ventilation Optimisation Guide for Schools



AIRAH COVID-19 Ventilation Optimisation Guide for Schools

This document is intended to identify factors in typical Australian facilities that relate to transmission of COVID-19, in order to form a framework for understanding and choosing appropriate interventions that will:

- Reduce the risk of respiratory infections (including but not limited to COVID-19);
- Optimise resource allocation for maximum benefit;
- Address stakeholder concerns;
- Minimise liability;
- Create a more healthful building environment for occupants beyond avoiding infection.

chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.airahfiles.org.au/Resources/COVID19/2021_AIRAH_COVID-19_Ventilation_Optimisation_Guide_for_Schools.pdf

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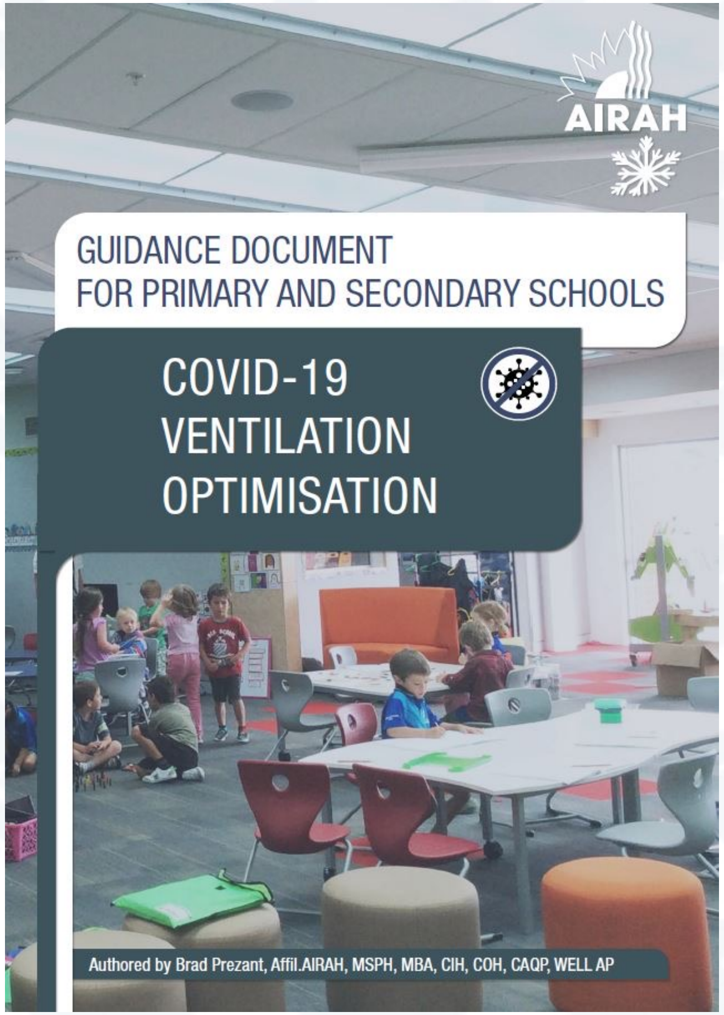
AIRAH COVID-19 Guide for Schools

1 Understanding Airborne Transmission

2 Building Ventilation Systems

3 Air Cleaning Technologies

4 Building a Strategy for Your Facility



chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.airahfiles.org.au/Resources/COVID19/2021_AIRAH_COVID-19_Ventilation_Optimisation_Guide_for_Schools.pdf

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DEFINING A FRAMEWORK FOR IMPROVEMENT

1 Operational recommendations

2 Minimum ACH recommendations

3 ASHRAE 241-2023

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ASHRAE 241-2023 BACKGROUND

1 COVID 19 Preparedness Plan White House Mandate (Ashish Jha)

2 December 2022 - Develop and publish a standard in 6 months

3 Public Review 11 May 2023
Over 1,000 comments received

4 Final Publication 4 July 2023

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QUOTING & CLARIFYING

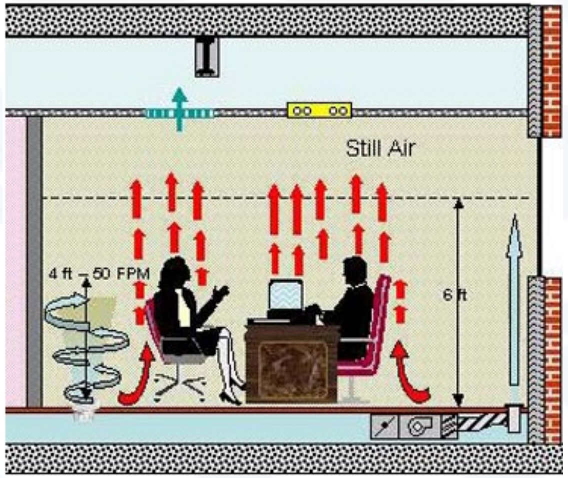
Green writing is quoted from the standard

[Blue and black writing is interpretation]

ASHRAE 241 CONTROL OF INFECTIOUS AEROSOLS – JUNE 2023

GOAL

Establish minimum requirements (equivalent clean airflow) for control of infectious aerosols to reduce risk of disease transmission including requirements for both outdoor air system and air cleaning system design, installation, commissioning, O and M



New & Existing Buildings

Doesn't

Maintain Acceptable Air Quality

Work for all Infective Agents

Only Addresses Long Range

Determine When to go into infection control mode

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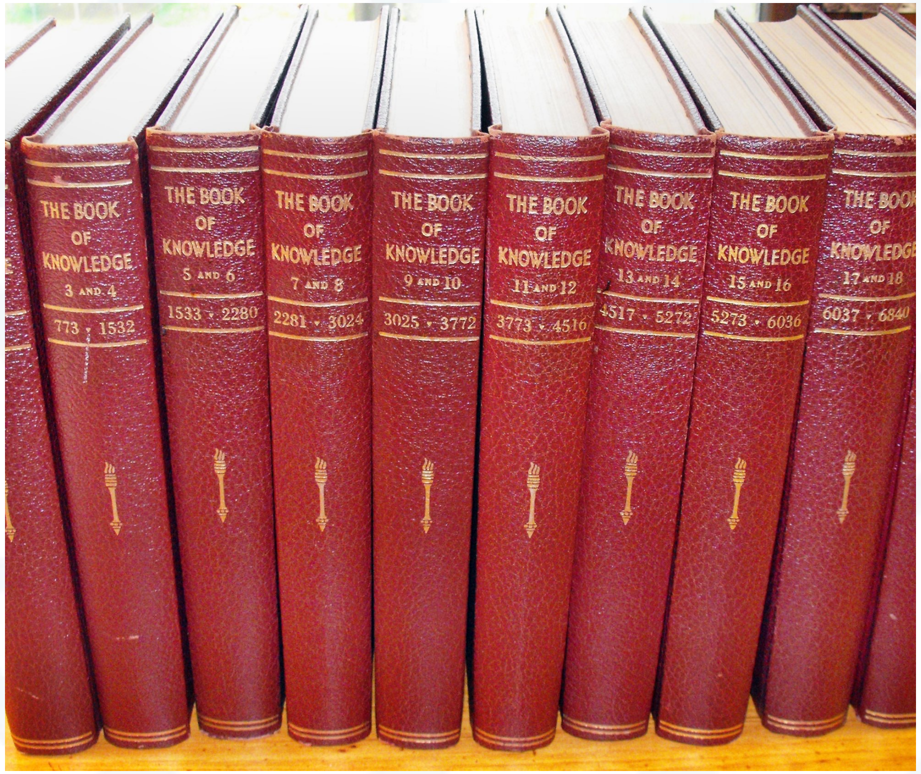
DEFINITIONS

Infection risk management mode (*IRMM*): the mode of operation in which measures to reduce infectious aerosol exposure documented in a building readiness plan are active

Equivalent clean airflow (V_{ECAi}) the theoretical flow rate of pathogen-free air that, if distributed uniformly within the breathing zone, would have the same effect on infectious aerosol concentration as the sum of actual outdoor airflow, filtered airflow, and inactivation of infectious aerosols

Building readiness plan (BRP) a plan documenting the engineering and non-engineering controls that the facility systems will use for the facility to achieve its goals.



EQUIVALENT CLEAN AIRFLOW FOR INFECTION RISK MITIGATION Equation 5-1

Total “clean” flow to space in L/s = Per person table 5-1 value for the space x number of persons

Minimum equivalent clean airflow rate required in the breathing zone for each occupiable space to mitigate long-range transmission risk in *IRMM* (V_{ECAi}) shall be determined in accordance with Equation 5-1.

$$V_{ECAi} = ECA_i \times P_{Z,IRMM} \qquad \text{Equation 5-1}$$

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TABLE 5-1

Table 5-1 Minimum Equivalent Clean Airflow per Person in Breathing Zone in IRMM

Occupancy Category	ECAi cfm/person	ECAi L/s/person
Correctional Facilities		
Cell	30	15
Dayroom	40	20
Commercial/Retail		
Food and beverage facilities	60	30
Gym	80	40
Office	30	15
Retail	40	20
Transportation waiting	60	30
Educational Facilities		
Classroom	40	20
Lecture hall	50	25
Industrial		
Manufacturing	50	25
Sorting, packing, light assembly	20	10
Warehouse	20	10
Health Care		
Exam room	40	20
Group treatment area	70	35
Patient room	70	35
Resident room	50	25
Waiting room	90	45

TABLE 5-1 (CONTINUED)

Table 5-1 Minimum Equivalent Clean Airflow per Person in Breathing Zone in IRMM

	ECAi	
Occupancy Category	**cfm/person**	**L/s/person**
Public Assembly/Sports and Entertainment		
Auditorium	50	25
Place of religious worship	50	25
Museum	60	30
Convention	60	30
Spectator area	50	25
Lobbies	50	25
Residential		
Common space	50	25
Dwelling unit	30	15

TABLE 5-1

Table 5-1 Minimum Equivalent Clean Airflow per Person in Breathing Zone in IRMM

Occupancy Category	ECAi cfm/person	ECAi L/s/person
Correctional Facilities		
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Commercial/Retail		
Food and beverage facilities	60	30
Gym	80	40
Office	30	15
Retail	40	20
Transportation waiting	60	30
Educational Facilities		
Classroom	40	20
Lecture hall	50	25
Industrial		
Manufacturing	50	25
Sorting, packing, light assembly	20	10
Warehouse	20	10
Health Care		
Exam room	40	20
Group treatment area	70	35
Patient room	70	35
Resident room	50	25
Waiting room	90	45

$$V_{ECAi} = ECA_i \times P_{Z,IRMM}$$

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TABLE 5-1 (CONTINUED)

Default occupancy is based on persons per 100 m^2

Occupancy Category	ECAi	62.1
	L/s/person	occupancy
Correctional Facilities		
Cell	15	25
Dayroom	20	30
Commercial/Retail		
Food and Beverage Facilities	30	70
Gym	40	7-40
Office	15	5
Retail	20	15
Transportation Waiting	30	100
Educational Facilities		
Classroom	20	25-35
Lecture Hall	30	150

Default occupancy is based on persons per 100 m^2

Occupancy Category	ECAi	62.1
	L/s/person	occupancy
Industrial		
Manufacturing	25	7
Sorting, packing, light assembly	10	7
Warehouse	10	n/a
Healthcare		
Exam room	20	-
Group treatment area	35	-
Patient room	35	-
Resident room	25	-
Waiting room	45	-

Default occupancy is based on persons per 100 m^2

Occupancy Category	ECAi	62.1
	L/s/person	occupancy
Public Assembly/Sports & Entertainment		
Auditorium	25	150
Place of Religious Worship	25	120
Museum	30	40
Convention	30	
Spectator Area	25	150
Residential		
Common Space	5	n/a
Dwelling unit	15	1/bedroom

5.1.3 Where the occupancy category for a proposed space or zone involves group vocalization above a conversational level, the *equivalent clean airflow* rate required per person in *IRMM* shall be multiplied by a factor of 2.

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TABLE 5-1 (CONTINUED)

Input assumptions from 62.1

	OA L/s/person	OA L/m²	Occupant Density (#/93m²)
Office	2.4	0.3	5
Classroom	5	0.6	35
Restaurant	3.5	0.9	70

ECA_i derived ACH

	ASHRAE 62.1 default L/s/person	ASHRAE 241 ECA_i L/s/person	ASHRAE 241 ACH with 2.7 m. ceiling
Office	8.0	15	1.1
Classroom	6.1	20	10.5
Restaurant	4.7	30	31.5

- Compared with 62.1, 241 rates are higher, particularly for densely occupied spaces
- Keeping a constant risk across occupancies results in very different ACH values for different space types

Adapted from Bahnfleth, BS Summer Camp 2023

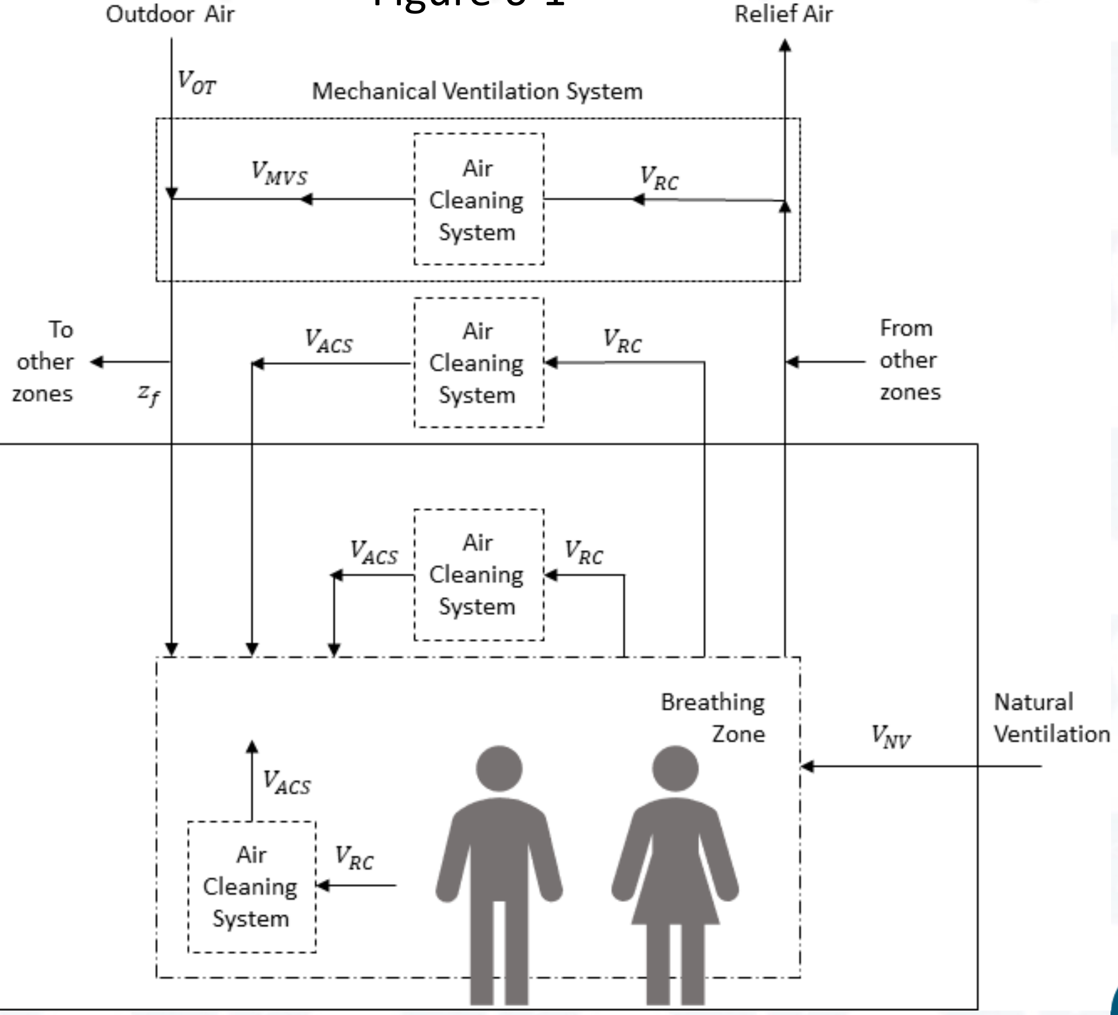
SUM OF ALL CLEANING DEVICES MUST EQUAL OR EXCEED V_{ECAi} EQUATION 6-1 & Figure 6-1

Add up the contribution of all the cleaning devices and ensure that they exceed the target V_{ECAi} value

The clean airflow rate to each zone, as shown in Figure 6-1, shall be greater than or equal to the minimum equivalent clean airflow required, as expressed by Equation 6-1

V_{ECAi} = minimum equivalent clean airflow rate required in the breathing zone to mitigate long-range transmission risk in IRMM, cfm (L/s)

Figure 6-1



EQUIVALENT CLEAN AIRFLOW FOR INFECTION RISK MITIGATION Equation 6-1

Add up all the outdoor air + cleaning sources to exceed V_{ECAi}

$$\sum [z_f \times (V_{OT} + V_{MVS})] + \sum V_{ACS} + V_{NV} \geq V_{ECAi}$$ Equation 6-1

PROVIDED CALCULATOR

https://docs.google.com/spreadsheets/d/1WjR2CE8OpWwAK5D2Hk4HCrX-2AAhmysp53_Ay5TwGQ0/edit?usp=sharing

1	Phase of the Process		Assessment	Planning	Planning	Planning	Planning	Implement
2	Name of Space / AHU / Building	Units	EXISTING	Option 1	Option 2	Option 3	Option 4	FINAL SYSTEM
3	Description of system or Option		AHU with X,Y,Z	Description	Description	Description	Description	Description
4	Space Type from Standard 241	Type	Office	Office	Office	Office	Office	Office
5	Target ECAi from Standard 241 (See Instructions for Table)	CFM / Person	30	30	30	30	30	40.0
6	Area	Sq Ft	2,000	2,000	2,000	2,000	2,000	2,400
7	Average Ceiling Height	Ft	9	9	9	9	9	9
8	Volume	Cu Ft	18,000	18,000	18,000	18,000	18,000	21600
9	Total Supply Air	CFM	1,800	1,800	1,800	1,800	1,800	1800
10	Total Outdoor Air	CFM	240	240	240	240	240	272
11	Occupancy - Design (Pz)	Quantity	12	12	12	12	12	12
12	Occupancy - IRMM Target (Pz,IRMM)	Quantity	8	8	8	8	8	12
13	VECAi,t,Des Airflow Target - Design Occupan	CFM	360	360	360	360	360	480
14	VECAi,t,IRMM Airflow Target - IRMM Target Oc	CFM	240	240	240	240	240	480
15	Central AHU Filter MERV Rating	MERV	12	13	13	13	13	13
16	Method for Rating Filter	241 or DNFE	241	241	DNFE	241	241	241
17	Filter Pathogen Removal Efficiency	εPR	71.0%	77.0%	67.0%	77.0%	77.0%	77.0%
18	UV in HVAC - Single Pass Inactivation	%	0.0%	35.00%	50.00%	0.00%	0.00%	0.00%
19	Air Treatment in HVAC (Impacts Space)	CFM	400	100	0	0	0	0
20	Air Treatment Device in Space	CADR	0	4	0	0	0	0
21	Number of Air Treatment Devices in Space	Quantity	0	1	0	0	0	0
22	In Room UV	CFM	0	150	0	200	0	200
23	Number of In Room UV Type	Quantity	0	2	0	1	0	1
24	In Room Air Cleaner (Fan Filter Type)	CADR	0	300	0	0	0	0
25	Number of In Room Air Cleaners (Fan Filter ty	Quantity	0	3	0	0	0	0
26	Equivalent Clean Air per Technology							
27	Outdoor Air	CFM	240.0	240.0	240.0	240.0	240.0	272.0
28	VECAi,filter	CFM	1107.6	1201.2	1045.2	1201.2	1201.2	1176.6
29	VECAi,uv,hvac	CFM	0	126	257	0	0	0
30	VECAi,rac,hvac	CFM	400	100	0	0	0	0
31	VECAi,rac,space	CFM	0	4.0	0.0	0.0	0.0	0.0
32	VECAi,irac,uv	CFM	0	300.0	0.0	200.0	0.0	200.0
33	VECAi,irac,fanfilter	CFM	0	900.0	0.0	0.0	0.0	0.0
34	Total Equivalent Clean Air	CFM	1748	2871	1543	1641	1441	1649
35	Occupancy Count Method (Design or IRMM)	Method	IRMM	IRMM	IRMM	IRMM	IRMM	IRMM
36	**ECAi Provided by the Option**	**CFM / person**	**218.5**	**358.8**	**192.8**	**205.2**	**180.2**	**137.4**
37	DOES THIS SYSTEM MEET ECAi TARGET	Pass / Fail	PASS	PASS	PASS	PASS	PASS	PASS

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AND THAT'S STANDARD 241……in a nutshell (Equation 5-1 & Equation 6-1)

$$V_{ECAi} = ECA_i \times P_{Z,IRMM}$$

Equation 5-1

$$\sum [z_f \times (V_{OT} + V_{MVS})] + \sum V_{ACS} + V_{NV} \geq V_{ECAi}$$

Equation 6-1

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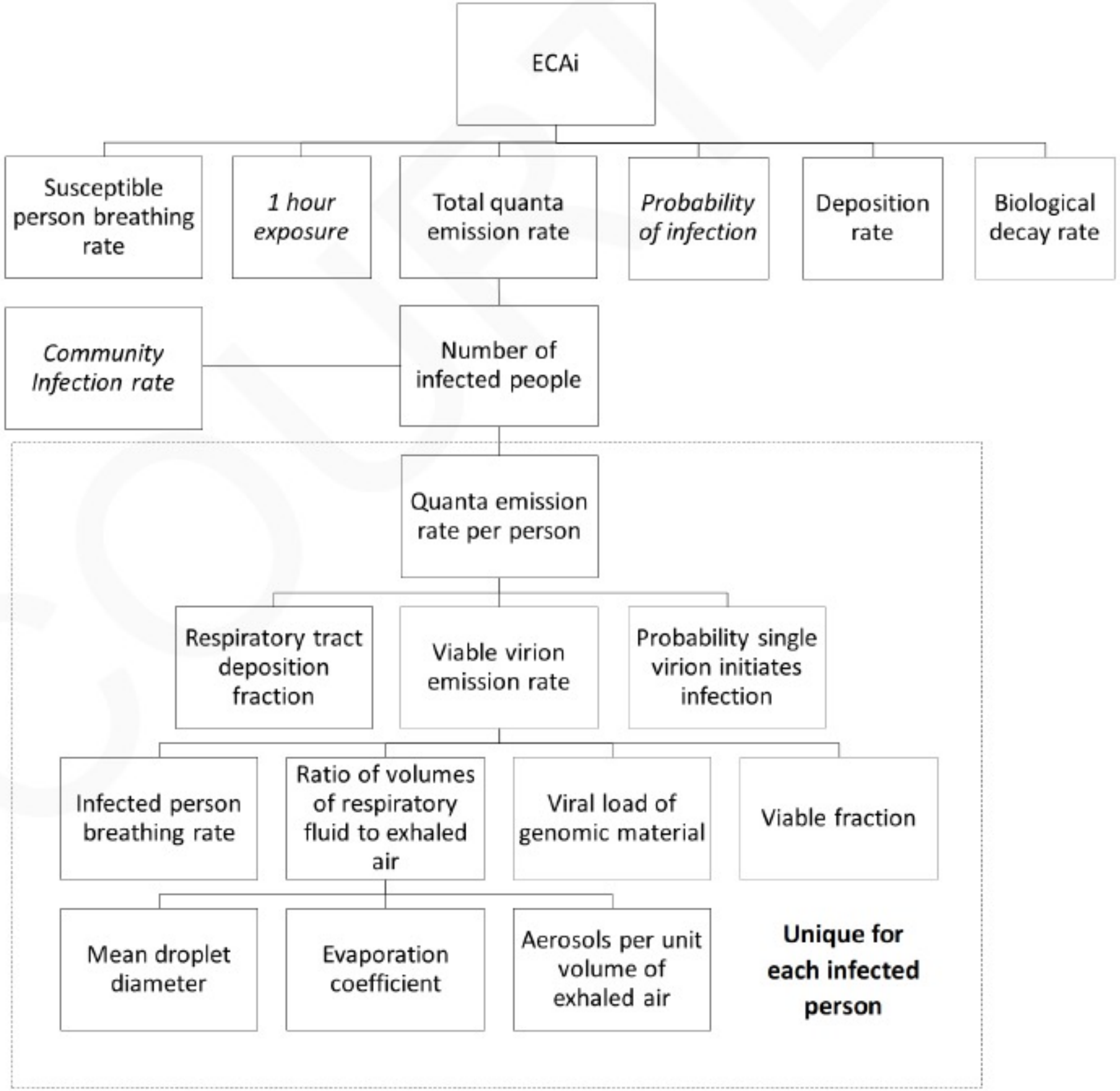
ADDITIONAL REQUIREMENTS 241-2023

1. Air Distribution Categorisation & Permitted Air Cleaning Systems
2. Air Cleaning Systems Testing & Effectiveness (in duct, in room)
3. Planning & Documentation
4. Operations & Maintenance
5. Appendices A through I

APPENDIX D



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D Risk Assessment Model Explanation Monte Carlo Approach

APPENDIX D

1 Model considers many factors – aerosol size, emissions, deposition, deactivation, community prevalence, # of infectors

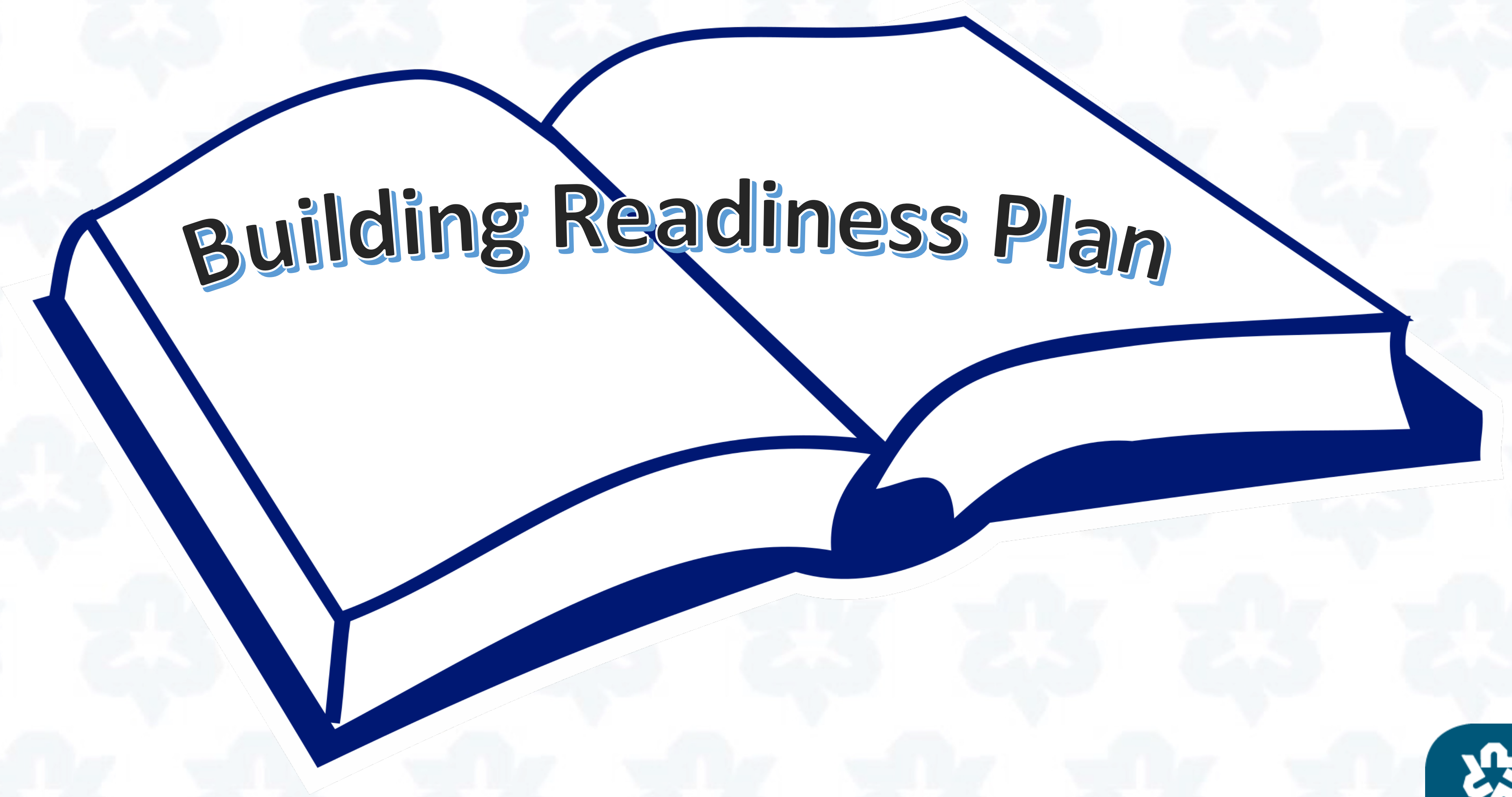
2 Monte Carlo simulation

3 Probability of infection chosen & standardised across 1-hour occupancies/space

4 Consider - CDC Alternative - based on ACH

- Doesn't adjust for community prevalence & # of infectors; prevents use of reduced occupancy as tool for reduced risk
- High ceilings are protective need less ACH; low ceilings are not protective; low ceilings need higher ACH to equalise risk

ASSESSMENT PLANNING & IMPLEMENTATION
BUILDING READINESS PLAN (BRP)



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SUMMARY

- ASHRAE Standard 241-2023 provides a comprehensive framework for managing infection control
- Invocation of IRMM is for owner/occupier or cognisant authority
- Multiple modes can be employed to achieve targets including reducing occupancy
- Calculated V_{ECAi} are based on reduction to acceptable risk level, equalised across spaces with 1 hour occupancy, after modelling known infection factors with a Monte Carlo approach
- Very feasible to implement but will require extensive assessment of current status and significant planning