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Corrigendum: Covid 19 and beyond: a procedure for HVAC systems to address infectious aerosol illness transmission

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KEYWORDS

respiratory infections, HVAC filtration, infectious aerosols, Wells-Riley, COVID-19, infection reproduction rate, energy, ventilation standards

A Corrigendum on
Covid 19 and beyond: a procedure for HVAC systems to address infectious aerosol illness transmission

by Walkinshaw DS and Horstman RH (2023) Front. Built Environ. 9:999126. doi: 10.3389/fbuil.2023.999126

In the published article, there were several errors made in the text:

Two definitions were not properly spaced.

A correction has been made to **Inhalation equations**, Paragraph 3. The definition sentences previously stated:

"N_T = number of occupants in the space t = occupancy time after the exposed group including the infector enter the space"

The corrected definition sentences appear below:

"N_T = number of occupants in the space

t = occupancy time after the exposed group including the infector enter the space"

The definitions of r_o and P are not provided.

A correction has been made to the **Infection Equations** following Equation 14.

$r_o = \left(1 - \frac{P}{P}\left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right)\right)$

The definitions to be added after Equation 14 appear below:

$$r_o = \left(1 - \frac{P}{P}\left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right)\right) \quad (14)$$

where

r_o = reproduction rate, the average number of secondary transmissions per infectious person

P = disease prevalence, the fraction of the population that is shedding infectious aerosols at the rate used in calculating dose, D

Missing words, small p and wrong equation number.

A correction has been made to **Designing HVAC Systems**, Paragraph 1, missing phrase introducing the equation; variable p should be cap P; Equation 14 should be Equation 15. This sentence and the following equation previously stated:

. . . for the average infectious period of the index.

p = 1/NT

The corrected variable name and equation number appear below:

"for the average infectious period of the index, the disease prevalence at the beginning then is"

$P = 1/N_T$

A variable definition missing.

A correction has been made to **Designing HVAC systems**, Paragraph 5. This sentence previously stated:

". . .maximum reproduction number either in the setting. . ."

The corrected sentence appears below:

". . .maximum reproduction number r_o either in the setting. . ."

The caption of **Table 2** requires more information. The caption previously was: **Table 2** Outdoor air exposure estimates"

The corrected **Table 2** caption appears below:

"**Table 2** Occupancy experience example input data for four settings"

There was an error in the below factor, which originally stated: "then by a factor (i.e. 1.127) to obtain." The corrected factor appears below

"then by a factor (i.e. 0.898) to obtain."

The below sub-section name should have been a higher level:

A correction has been made to **Design of HVAC systems**, *Equal reproduction and Equal reproduction and local prevalence*.

The equation number in text is incorrect

A correction has been made to **Designing HVAC systems**, Equal reproduction, Paragraph 8. This sentence previously stated:

". . .using Equation 15 where $n_o = 1$."

The corrected sentence appears below:

". . .using Equation 14 where:

$$n_o = PN_T$$

$$r_o = \frac{n}{n_o} \sim \left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right)P$$

$$\mathrm{D} = \frac{D_G}{N_S} \sim \frac{Q_B P q_G}{(VE)Q_p}\left[t + \frac{v_o}{(VE)Q_p}\left(e^{-\left(\frac{(VE)Q_p}{v_o}\right)t}\right) - 1\right]$$

The equation number and lack of capitalization for p is incorrect.

A correction has been made to **Designing HVAC systems** *Occupancy experience example*. The equation number previously and variable P was:

$$r_o \sim \left[1 - e^{-\left(\frac{Q_B P q n t}{Q_p + Q_f}\right)}\right] \Big/ \mathrm{p} \qquad (15)$$

The corrected equation number and variable P appears below:

$$r_o \sim \left[1 - e^{-\left(\frac{Q_B P q n t}{Q_p + Q_f}\right)}\right] \Big/ \mathrm{P} \qquad (16)$$

The sub-sub-section title for Recirculation and filter flow was place on too high a level and should have been downsized.

The equation number was incorrect:

TABLE 3 Determining the filter efficiency and flow required.

Setting	ASHRAE 62 ventilation	Disease			Occupant metabolic			Exposure/ week	ro = 3.29 infections for ASHRAE 62 ventilation		Ventilation with filtered recirculation added for ro =2.52 infections					
	outside air	Prevalence	quanta/				Breathing	hrs/p	infections	%	Same	virion-free	outside air	recirc air		
	Qp	for 4 days	hour			Met	QB				percent	air req'd	saving	H = 0.62		
	cfm/p	p	qn	btu/hr			cfm/p				infections	cfm/P	cfm/p	cfm/p		
School	22.3	3%	12	323	0.83	0.25		17.1	2.22	67.3%	1.49	33.5			18.1	
Restaurant	13.1	3%	12	485	1.24	0.37		2.3	0.77	23.4%	0.70	14.5			2.3	
Supermarket	64.5	3%	12	460	1.18	0.35		1.7	0.11	3.4%	0.12	59.9	4.6			
Gym	39.8	3%	12	740	1.9	0.57		1.1	0.20	5.9%	0.21	37.9	1.9			

TABLE 4 Compilation of Figure 5 using Equation 18 and national prevalence P = 0.03.

$r_o = \left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right)/P$	Typical	Outside air ventilation & occupancy - ASHRAE Standard 62				Infection parameters in typical setting & exposure time					Ventilation required ro=2.5	
		Nd				NT	Infection				Qp	Qf
	Ceiling	occupants	Rp	Ra	Qpo	number	prevalence	Ventilation	η	occupancy	Qpo+hQf	unfiltered
	height	per	cfm per	cfm/ ft2	L/s-p	of	*P*	Effectiveness	filter	time	clean air	recirc air
	ft	1000 ft2	person		outdoor air	occupants	%	VE	eff	hours	L/s-p	L/s-p
Aircraft cabin, narrow body	5.8	190	7.5	0	3.5	150	3%	0.8	0.995	3	9.9	6.4
Aircraft cabin, wide body	6.7	136	10	0	4.7	320	3%	1	0.995	10	26.7	22.1
Auditorium, theater	20	150	5	0.06	2.6	100	3%	0.8	0.5	3	9.6	14.0
Bar, cocktail lounge	9	100	7.5	0.18	4.4	60	3%	0.8	0.5	3	9.7	10.6
Classroom 5-8	12	25	10	0.12	7.0	30	3%	1	0.5	6	15.4	16.8
Classroom 9+	12	35	10	0.12	6.3	30	3%	1	0.5	6	15.6	18.5
Day care (through age 4)- residence setting	8	25	10	0.18	8.1	10	3%	1	0.5	8	21.1	25.9
Gambling casino	9	120	7.5	0.18	4.3	400	3%	0.8	0.5	6	20.0	31.4
Lecture classroom	12	65	10	0.06	5.2	30	3%	0.8	0.5	6	19.8	29.2
Lecture hall	20	150	7.5	0.06	3.7	100	3%	0.8	0.5	2	5.9	4.4
Mall, common areas	18	40	7.5	0.06	4.3	150	3%	1	0.5	3	6.6	4.7
Music/theater/dance	12	35	10	0.06	5.5	50	3%	1	0.5	3	7.0	2.9
Office	9	5	5	0.06	8.0	80	3%	1	0.5	8	19.4	22.8
Restaurant	9	70	7.5	0.18	4.8	50	3%	1	0.5	2	4.8	0.0
Retail sales store	18	15	7.5	0.12	7.3	25	3%	0.8	0.5	2	7.3	0.0
Spectator area (Maple Leaf Gardens)	55	150	10	0.06	4.9	5,000	3%	1	0.5	4	9.9	10.0

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TABLE 5 Compilation of Figure 6 using Equation 19 and a national prevalence P = 0.03.

$r_o = \frac{\left(1-e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right)}{p} \sim \frac{D_G}{1.443HID_{50}}$	Typical	Outside air ventilation from ASHRAE Standard 62				Infection parameters in typical setting & exposure time					Ventilation required ro=2.5		occupant experience	
	Ceiling height	Nd occupants per 1000 ft2	Rp cfm per person	Ra cfm/ ft2	Qpo L/s-p outdoor air	NT number of occupants	Infection prevalence P %	Ventilation Effectiveness VE	η filter eff	occupancy time hours	Qp Qpo+hQf clean air L/s-p	Qf unfiltered recirc air L/s-p	Qoe additional clean air L/s-p	Qp Qpo+hQf+Qoe clean air L/s-p
Aircraft cabin, narrow body	5.8	190	7.5	0	3.5	150	0.03	0.8	0.995	3	10.3	6.8	0.03	10.4
Aircraft cabin, wide body	6.7	136	10	0	4.7	320	0.03	1	0.995	10	27.7	23.1	0.03	27.7
Auditorium, theater	20	150	5	0.06	2.6	100	0.03	0.8	0.5	3	10.0	14.8	0.003	10.0
Bar, cocktail lounge	9	100	7.5	0.18	4.4	60	0.03	0.8	0.5	3	10.1	11.5		
Classroom 5-8	12	25	10	0.12	7	30	0.03	1	0.5	6	16.0	18.1	8.5	24.5
Classroom 9+	12	35	10	0.12	6.3	30	0.03	1	0.5	6	16.2	19.7	8.5	24.7
Day care (through age 4)- residence setting	8	25	10	0.18	8.1	10	0.03	1	0.5	8	21.9	27.6		
Gambling casino	9	120	7.5	0.18	4.3	400	0.03	0.8	0.5	6	20.7	32.9		
Lecture classroom	12	65	10	0.06	5.2	30	0.03	0.8	0.5	6	20.6	30.8		
Lecture hall	20	150	7.5	0.06	3.7	100	0.03	0.8	0.5	2	6.2	5.0		
Mall, common areas	18	40	7.5	0.06	4.3	150	0.03	1	0.5	3	6.9	5.3		
Music/theater/dance	12	35	10	0.06	5.5	50	0.03	1	0.5	3	7.3	3.6		
Office	9	5	5	0.06	8	80	0.03	1	0.5	8	20.3	24.6	0.11	20.4
Restaurant	9	70	7.5	0.18	4.8	50	0.03	1	0.5	2	5.0	0.5	6.4	11.4
Retail sales store	18	15	7.5	0.12	7.3	25	0.03	0.8	0.5	2	7.3	0.0		
Spectator area (Maple Leaf Gardens)	55	150	10	0.06	4.9	5000	0.03	1	0.5	4	10.4	10.9		

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TABLE 6 Compilation of Figure 7 using Equation 20 and local prevalence $P = 1/N_T$ for various settings for a reproduction rate $r_o = 2.5$

$r_o = N_s\left(1-e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right)$	Typical	Outdoor air and occupancy from ASHRAE Standard 62					Infection parameters				Ventilation required ro=2.5	
		Nd				NT					Qp	Qf
	Ceiling	occupants	Rp	Ra	Qpo	number	Infection	Ventilation	η	occupancy	Qpo+hQf	unfiltered
	height	per	cfm per	cfm/ ft2	L/s-p	of	prevalence	Effectiveness	filter	time	clean air	recirc air
	ft	1000 ft2	person		outdoor air	occupants	*P*	VE	eff	hours	L/s-p	L/s-p
Aircraft cabin, narrow body	5.8	190	7.5	0	3.5	150	0.67%	0.8	0.995	3	10.1	6.6
Aircraft cabin, wide body	6.7	136	10	0	4.7	320	0.31%	1	0.995	10	27.5	22.9
Auditorium, theater	20	150	5	0.06	2.6	100	1.00%	0.8	0.5	3	9.7	14.3
Bar, cocktail lounge	9	100	7.5	0.18	4.4	60	1.67%	0.8	0.5	3	9.7	10.6
Classroom 5-8	12	25	10	0.12	7	30	3.33%	1	0.5	6	14.7	15.5
Classroom 9+	12	35	10	0.12	6.3	30	3.33%	1	0.5	6	14.9	17.2
Day care (through age 4)- residence setting	8	25	10	0.18	8.1	10	10.00%	1	0.5	8	16.8	17.3
Gambling casino	9	120	7.5	0.18	4.3	400	0.25%	0.8	0.5	6	20.6	32.7
Lecture classroom	12	65	10	0.06	5.2	30	3.33%	0.8	0.5	6	19.0	27.6
Lecture hall	20	150	7.5	0.06	3.7	100	1.00%	0.8	0.5	2	6.0	4.6
Mall, common areas	18	40	7.5	0.06	4.3	150	0.67%	1	0.5	3	6.8	5.1
Music/theater/dance	12	35	10	0.06	5.5	50	2.00%	1	0.5	3	6.9	2.8
Office	9	5	5	0.06	8	80	1.25%	1	0.5	8	19.6	23.2
Restaurant	9	70	7.5	0.18	4.8	50	2.00%	1	0.5	2	4.8	0.0
Retail sales store	18	15	7.5	0.12	7.3	25	4.00%	0.8	0.5	2	7.3	0.0
Spectator area (Maple Leaf Gardens)	55	150	10	0.06	4.9	5000	0.02%	1	0.5	4	10.3	10.8

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A correction has been made to Occupancy experience example. The equation number previously was:

$Q_R = \frac{Q_f}{\eta}$ cfm/person

The corrected equation number appears below:

$$Q_R = \frac{Q_f}{\eta} \text{ cfm} \Big/ \text{person} \quad (17)$$

The caption for Table 3 needed clarification. The caption for Table 3 as published was: "Determining the filter efficiency and the flow required"

The Table 3 caption as corrected appears below:

"Table 3 Occupancy experience example recirculation flow requirements using Merv 13 filters $\eta = 0.62$ to achieve a combined reproduction rate r_o of 2.5 for the four settings."

Table 3 had too many decimal places and had to be expanded to include the metabolic and breathing rates that were used in the Occupancy experience example. The corrected Table 3 and it's caption appear below:

The caption of Table 4 needed more information, and some figure were incorrect. The corrected table caption appears below:

The caption of Table 5 required clarification and some values in the Filter Eff column were incorrect. The corrected table caption appears below:

A variable name was incorrect and the equation number is missing.

A correction has been made to **Designing HVAC systems,** *Equal reproduction example***,**

$$r_o = \left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right) \Big/ \text{P} \sim \frac{D_G}{1.443 HID_{50}}$$

The denominator variable should be cap P and the equation number is (19). The corrected equation appears below:

$$r_o = \left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right) \Big/ \text{P} \sim \frac{D_G}{1.443 HID_{50}} \quad (19)$$

There was an error missing equation number.

A correction has been made to **Designing HVAC systems,** *Equal reproduction and local prevalence example*

The equation as it now stands

$$\left[r_o = N_S\left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right)\right]$$

The equation corrected

$$\left[r_o = N_S\left(1 - e^{-D\left(\frac{QD_{50}}{HID_{50}}\right)}\right) \right] \quad (20)$$

The caption of Table 6 needed more information, and some of the figures presented were inaccurate. The corrected table caption appears below:

The caption of **Figure 5, 6 and 7** required additional detail. The corrected titles appear below:

Figure 5 Equal reproduction example using **Equation 18** and national prevalence P = 0.03 for ventilation designed for $r_o = 2.5$.

Figure 6 Equal reproduction example using the Wells-Riley approximation Equation 19 and national prevalence P = 0.03 for ventilation designed for reproduction $r_o = 2.5$.

Figure 7 Equal reproduction example ventilation requirements for various settings to achieve $r_o = 2.5$ using Equation 20, the data in Table 6 and local prevalence $P = 1/N_T$ (Equation 15).

The references to Tables 4, 5, **Figure 5** and **Figure 6** were missing. A corrections have been made to

The missing sentence below has been added to **Designing HVAC systems,** *Equal reproduction example***.** :

"**Equation 18** is used in calculating the recirculation flow requirements shown in Table 4 and **Figure 5** for the various settings."

And a correction has been made to the section **Occupancy experience example**. The figure and table reference previously was:

Figure 5; Table 4

The corrected reference appears below:

Figure 6; Table 5

The paragraph heading **Occupancy Experience was incorrectly located.**

A correction has been made to **Occupancy Experience**. The heading was previously before "This procedure sets a national. . .." and has been move to before "During COVID-19 Linka et al.

The derivation of Equation 20 was not fully explained.

A correction has been made to missing equations to explain the derivation of Equation 20.

$\boldsymbol{r_o = N_s\left(1 - e^{-D\left(\frac{QD50}{HID50}\right)}\right)}$

The missing equations follow.

The possibility of zero infection follows a Poisson distribution:

$$Poisson = \frac{e^{-\lambda}\lambda^x}{x!}$$

For zero infection, x = 0

$$\lambda^x = \lambda^0 = 1$$
$$x! = 0! = 1$$

Probability of zero infections

$$Poisson = e^{-\lambda}$$

Probability of infection for susceptible individual:

$$r = 1 - e^{-\lambda}$$

Risk for occupant i:

$$r_i = 1 - e^{-\lambda_i}$$

Total risk for all occupants:

$$n = \sum_{i=1}^{N_s}\left(1 - e^{-\lambda_i}\right)$$

Total risk for all occupants assuming a perfectly mixed volume:

$$n = N_s\left(1 - e^{-\lambda}\right)$$

Lambda is the quantity of the statistical unit inhaled for i^{th} individual over time:

$$\lambda_i = \int_0^t Q_B C_i(t)\partial t$$

Q_B = cfh *breathing could vary with time and* individual

$C_i(t)$ = concentration *of quanta in air could vary with time and location quanta*/$ft3t$ = hours

λ_i = quanta *inhaled by occupant i over perion t at location i*

$$C_i(t) = C_{V,i}\left(\frac{QD50}{HID50}\right)$$

$C_{V,i}$ = concentration *of virus in air could vary with time and location virus*/$ft3$

$QD50$ = quanta *dose the causes disease in* 50% *of the group*, 0.693 *quanta*:

$$\frac{n}{N_s} = 0.5 = \left(1 - e^{-\lambda}\right) = \left(1 - e^{-0.693}\right)$$

$HID50$ = virus *dose that causes disease in* 50% *of the group*

$$\lambda_i = \int_0^t Q_B C_i(t)\partial t = \int_0^t Q_B C_{V,i}\left(\frac{QD50}{HID50}\right)\partial t$$

$$\int_0^t Q_B C_{V,i}\partial t = D$$

For the transient case, the virus dose is:

$$D = \frac{Q_B n_o q_n}{Q_T}\left[t + \frac{1}{ACH}\left(e^{-(ACH)t} - 1\right)\right]$$

The reproduction number shows the number of infections from an infector, no = 1:

$$D = \frac{Q_B q_n}{Q_T}\left[t + \frac{1}{ACH}\left(e^{-(ACH)t} - 1\right)\right]$$

$$q_n = \frac{virus}{hr}\, from\, infector$$

N_s = number *of susceptibles*

$$n = r_o = N_s\left(1 - e^{-\lambda}\right) = N_s\left(1 - e^{-D\left(\frac{QD50}{HID50}\right)}\right)$$

For steady state case t > 5 air changes:

$$D = \frac{Q_B q_n}{Q_T}\left[t + \frac{1}{ACH}\left(e^{-(ACH)t} - 1\right)\right] = \frac{Q_B q_n}{Q_T}t$$

$$r_o = N_s\left(1 - e^{-\frac{Q_B q_n}{Q_T}t\left(\frac{QD50}{HID50}\right)}\right)$$

$$\mathbf{r_o} = \mathbf{N_s}\left(1 - e^{-\mathbf{D}\left(\frac{\mathbf{QD50}}{\mathbf{HID50}}\right)}\right)$$

In terms of quanta:

$$q_G = \frac{QD50 q_n}{HID50}$$

You get the Wells-Riley equation:

$$r_o = N_s\left(1 - e^{-\frac{Q_B q_G t}{Q_T}}\right) \quad (20)$$

Extra clarification was need in the section Occupancy experience, following "...in that setting.

The additional sentence is: "Steady state occupancies only are considered "

Clarification was needed in the section Equal reproduction, following "and transient"

The below was added: "(leaving or entering)".

Publisher's note