Improving Ventilation Performance for Energy-Efficient Buildings using Tracer Gas Measurements

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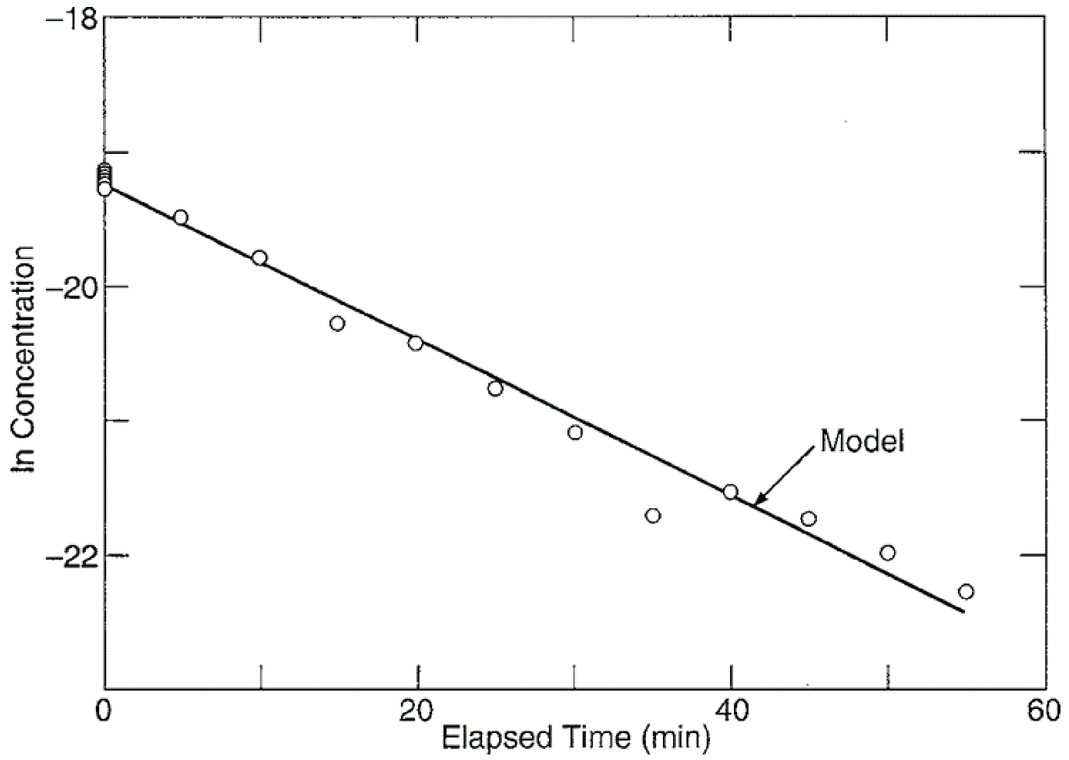
Research Problem!

Decay method assumptions:

- Stable and inert tracer.
- No adsorption processes.
- Single zone.
- Constant ventilation rate.
- **Well-mixed space.**

To what extent
Well-mixed space
is real?

$$\lambda = \boxed{?} \frac{\ln C(t2) - \ln C(t1)}{t2 - t1}$$



Regression method of estimating air change rates using decay method [ASTM E741].

Limitations of existing Solutions!

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Existing mixing models and effectiveness factors (e.g., K or E_z) are limited in addressing this gap since their reported data are **subjective, roughly estimated,** and **inconsistent across different standards** (ASHRAE and AIHA).

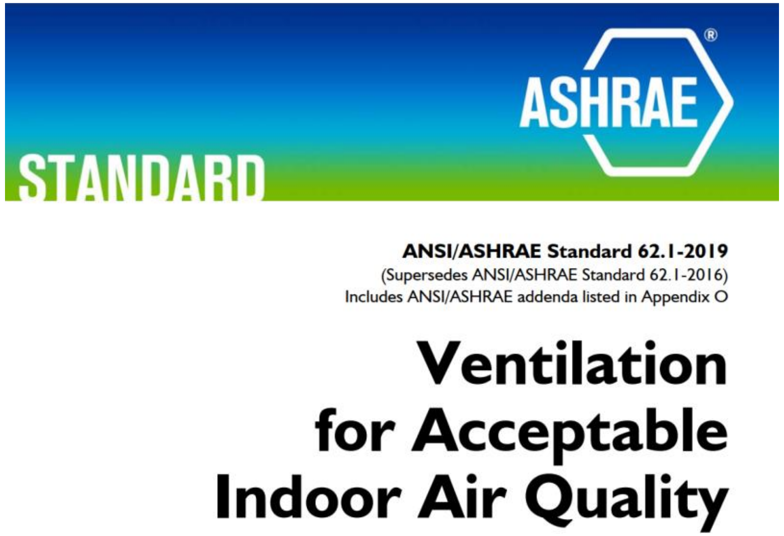

Table 6-4 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Well-Mixed Air Distribution Systems	
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is less than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is equal to or greater than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	1.0
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply outlet located more than half the length of the space from the exhaust, return, or both	0.8
Makeup supply outlet located less than half the length of the space from the exhaust, return, or both	0.5
Stratified Air Distribution Systems (Section 6.2.1.2.1)	
Floor supply of cool air where the vertical throw is greater than or equal to 60 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor and ceiling return at a height less than or equal to 18 ft (5.5 m) above the floor	1.05
Floor supply of cool air where the vertical throw is less than or equal to 60 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor and ceiling return at a height less than or equal to 18 ft (5.5 m) above the floor	1.2
Floor supply of cool air where the vertical throw is less than or equal to 60 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor and ceiling return at a height greater than 18 ft (5.5 m) above the floor	1.5

Solution

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Original decay method (ODM) for uniform mixed space

$$\lambda = \frac{\ln C(t2) - \ln C(t1)}{t2 - t1}$$

Modified decay method (MDM) for non-uniform mixed space

$$\lambda(U_i) = \begin{cases} \lambda_{wm} = \frac{1}{(t - t_0)} \ln \frac{(C - C_{bg})}{(C_0 - C_{bg})}, & \text{Well-mixed if } \lambda_{wm} = \lambda_m \\ \lambda_{sc} = \frac{1}{U_i(t - t_0)} \ln \frac{(C - C_{bg})}{(C_0 - C_{bg})}, & \text{Short-circuiting if } \lambda_{wm} < \lambda_m \\ \lambda_{sr} = \frac{U_i}{(t - t_0)} \ln \frac{(C - C_{bg})}{(C_0 - C_{bg})}, & \text{Stagnant region if } \lambda_{wm} > \lambda_m \end{cases}$$

Calculations of Uniformity Index (U_i) using tracer gas tests

- $L \times W \times H$
- Sampling factor (S_f), where $S_f = \frac{L_e \times W_e}{H_e (L_e + W_e)}$
- Grid sampling
- CO_2 test
- U_i, where $U_i = \frac{C_{min}}{C_{avg}}$

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A modified decay method based on a proposed uniformity index for measuring air change rates in non-uniform air mixed spaces

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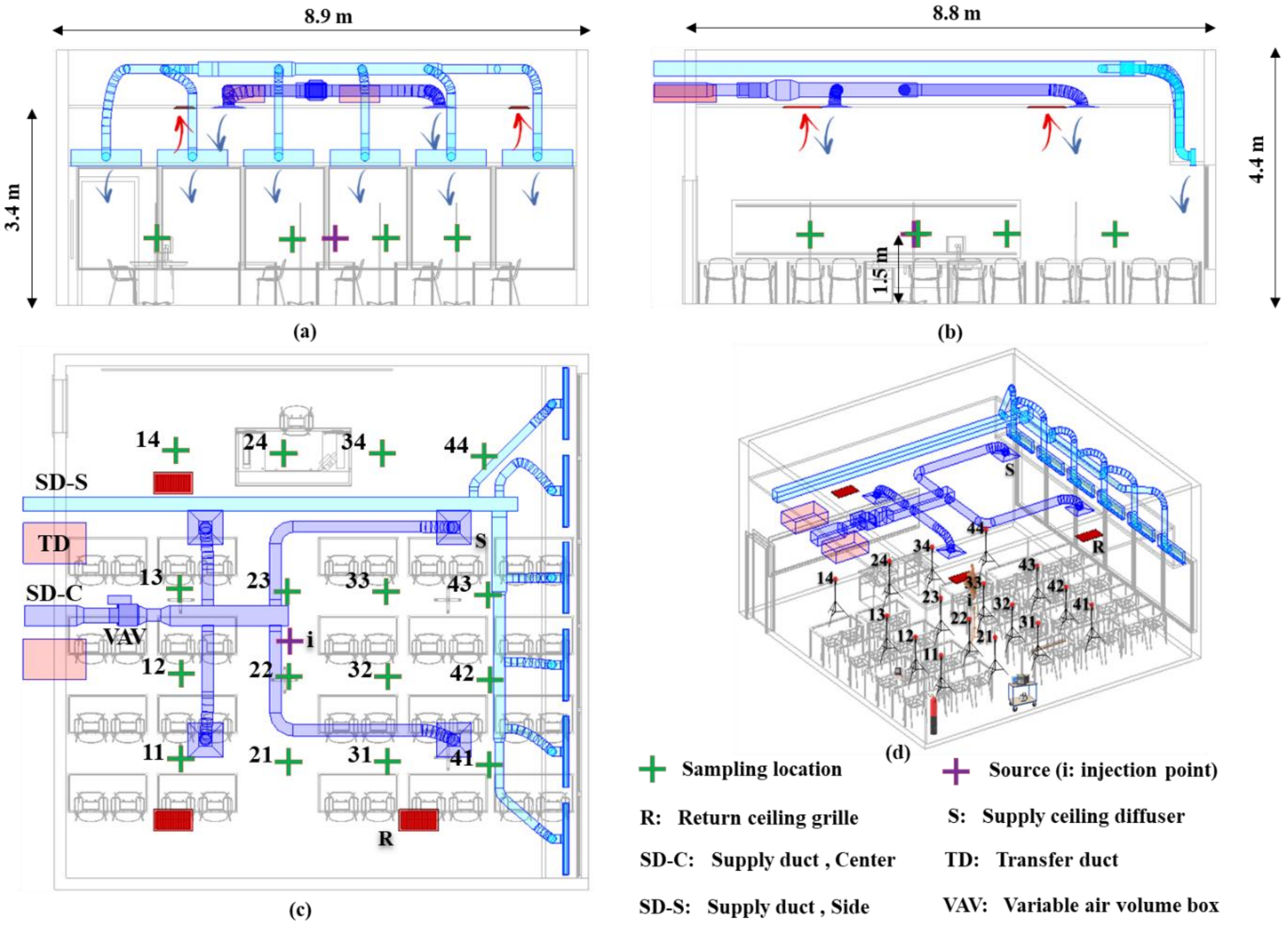
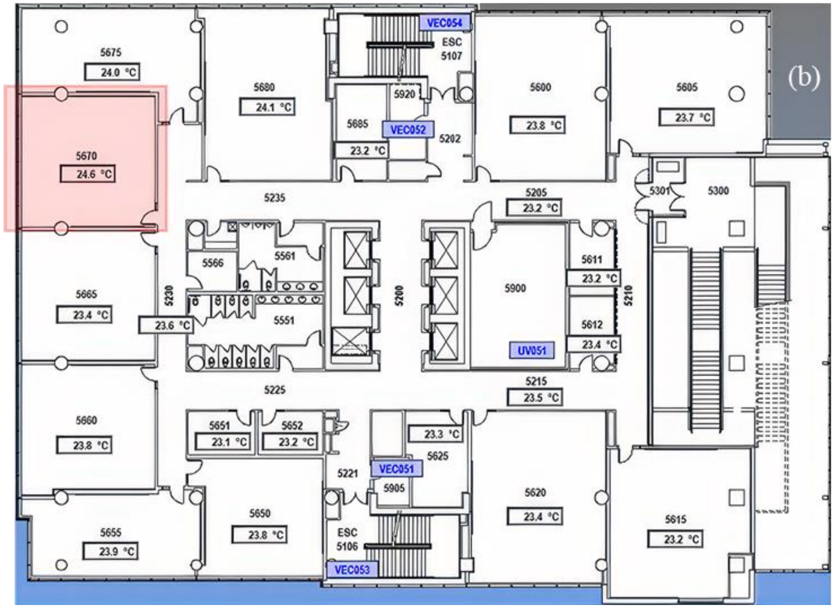
Application to classroom

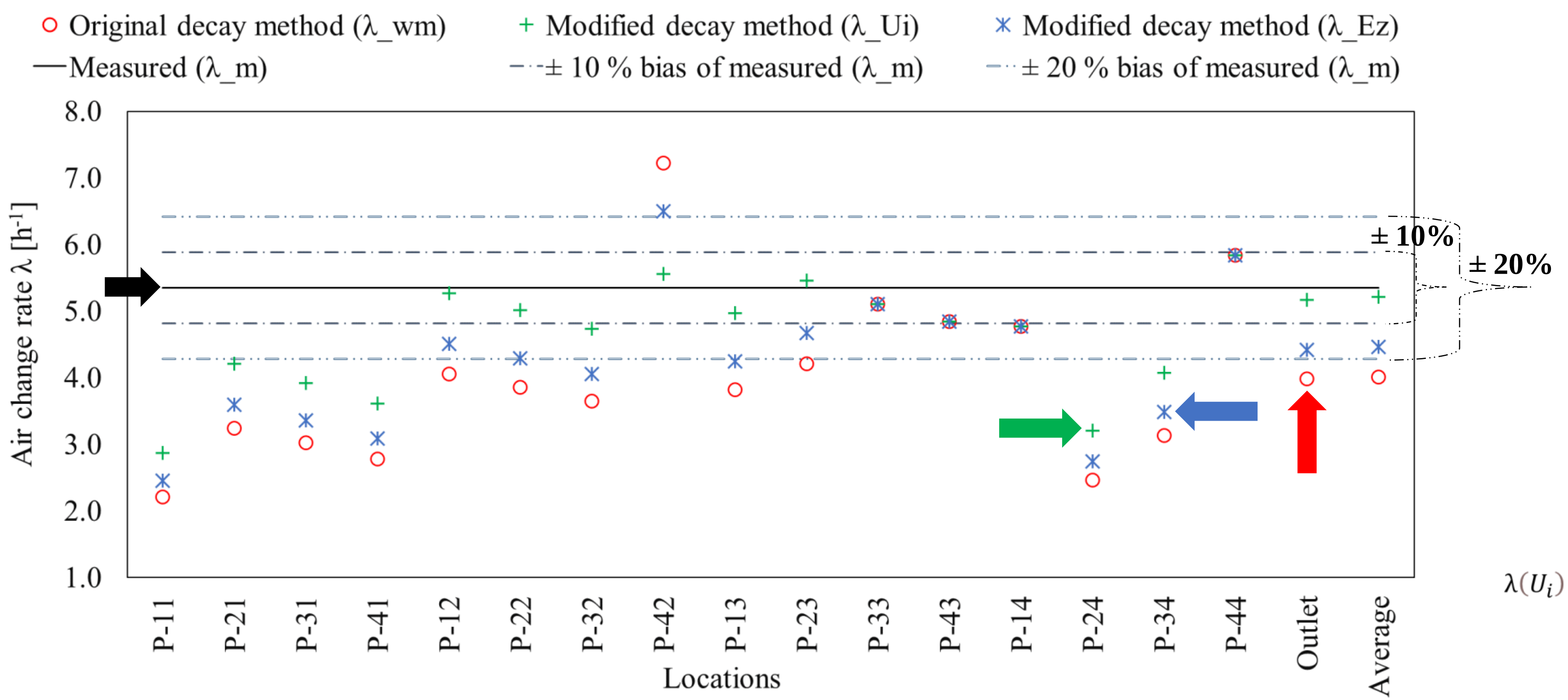
Tracer test setup

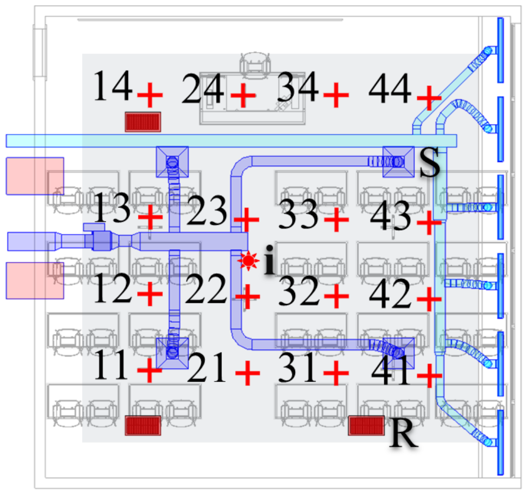


Zone description and test setup at Longueuil campus, University of Sherbrooke



Validation of the Modified Decay Method





$$
\lambda(U_i) = \begin{cases} \lambda_{wm} = \dfrac{1}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} = \lambda_m \\ \lambda_{sc} = \dfrac{1}{U_i(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} < \lambda_m \\ \lambda_{sr} = \dfrac{U_i}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} > \lambda_m \end{cases}
$$

$$
\lambda(E_z) = \begin{cases} \lambda_{wm} = \dfrac{1}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} = \lambda_m \\ \lambda_{zsc} = \dfrac{1}{E_z(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} < \lambda_m \\ \lambda_{zsr} = \dfrac{E_z}{(t-t_0)} \ln \dfrac{(C - C_{bg})}{(C_0 - C_{bg})}, & \lambda_{wm} > \lambda_m \end{cases}
$$

λ_{Ui}	Estimated air change rate using modified decay method and uniformity index [/h]		
λ_{wm}	Estimated air change rate using original decay method [/h]		
λ_{sc}	Estimated air change rate for a non-uniform mixed space with a short-circuiting of the inlet to outlet location [/h]		
λ_{sr}	Estimated air change rate for a non-uniform mixed space with stagnant regions [/h]		
U_i	Uniformity index	E_z	Zone distribution effectiveness
C	The indoor concentration of tracer gas [g/m^3]	C_{bg}	Background concentration [g/m^3]
C_o	The initial concentration of tracer gas [g/m^3]		

Conclusions

MDM

For the original decay method:

70% of sampling locations have underestimated λ (ε = 59%)

5% of sampling locations have overestimated λ (ε = 35%)

25% of sampling locations have acceptable λ (ε = 11%)

For the modified decay method:

ε decreased from 25.6% to 3.4% at the outlet

ε decreased from 25.0% to 2.5% at the average concentrations

For the proposed uniformity index (U_i):

U_i is more effective than ASHRAE Ez in enhancing the accuracy of λ measurements, with an improvement ranging from 7.8% to 17.5%.

Future needs

Generalizing the developed method (MDM)

CFD simulations and field tests for various geometrical and ventilation configurations will be performed to develop a referenced data (table) of uniformity index (U_i), which extend the applicability of the novel MDM.

Thanks!

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