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Comparison of PFT and CO_2 Estimates of Air Exchange Rates in an Apartment

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SUMMARY
Estimates of air exchange rates (AER) in buildings are important when ventilation systems are evaluated. Many methods may be used, but here the focus lies on the PFT and CO_2- methods. Traditionally, perfluorocarbon tracers (PFT) together with passive sampling has been used. However, the rise of low cost CO_2- sensors has opened a relatively inexpensive route to estimating AER using the CO_2 emitted by the occupants as tracer gas. The two methods have their different strengths and weaknesses, but are typically separated by measuring in different time periods. Longer periods for PFT and shorter periods for CO_2.

The aim here is to simultaneously measure and compare the two estimates of AER in a well-ventilated apartment during the same (short) time period. The homogeneous emission tracer technique is used for PFT, i.e. the tracer is homogeneously emitted in all rooms of the apartment. CO_2 uses the tracer emission of the occupants and usually focus on measuring the night AER in the bedroom, but placing CO_2 sensors in other positions the general AER of the apartment may be estimated. In this study the estimates of AER in the bedroom and for the whole apartment are compared for three different bedroom door states: totally open; 1 cm open; and closed.

The PFT estimates of AER vary less with the state of the bedroom door, whereas the CO_2 estimates are lower (than PFT) when the door is open and progressively higher (than PFT) when the door is more closed.

KEYWORDS
Air change rate, perfluorocarbon tracers, CO_2-sensors, open or closed door

1 INTRODUCTION
The aim of this study is to compare the air exchange rate (AER) estimates of two different tracer gas methods: the CO_2 method using the occupants as tracer sources and the PFT method using PFT tracers. In this particular study, the bedroom AER and the total AER (of the whole apartment) are estimated by both methods in a field measurement where the state of the bedroom door is varied. The two methods are suited to different lengths of the measurement period, but in this study the aim is use comparable periods.

2 MATERIALS/METHODS

The field measurements were performed at winter conditions in an apartment occupied by two individuals of known height, weight and gender. The apartment consist of a bedroom, a living room, a kitchen, a hallway and a bathroom. The bedroom has two doors, but one of them was sealed with duct tape for this experiment. The other bedroom door, opening into the living room, was stipulated to remain either fully opened, fully closed or 1 cm open during the three night-time measurement periods. For comparison, one extra measurement period was conducted during day-time with a fully opened bedroom door. Thus, four cases were examined. During each measurement period, CO_2 concentrations in all rooms and outdoors were measured at 1-minute intervals by CO_2-monitors (Rotronic CL11, Rotronic Instruments, Switzerland). The procedures for calculation of AERs by mass balance using occupant generated CO_2 are described in detail by Hou et al. (2018). For night-time AERs, CO_2 concentrations obtained in the time period of 00:00-7:00 were extracted for the calculations. Two routes for estimating the AERs are used, where either the whole apartment or the bedroom is treated as a single zone in the mass balance equations. The apartment (total) AERs are calculated based on the volume weighted averages of the CO_2 concentrations in the rooms, whereas the bedroom AERs are based only on the CO_2 concentrations in the bedroom.

The average local mean ages of air (τ) were simultaneously measured in all rooms using the homogeneous emission tracer gas technique described in NORDTEST Standard VVS 118 (1997) and ISO 16000-8 (2007). The local AERs are then estimated by $1/\tau$ and the total apartment AER is estimated by the volume weighted average. The underlying multi-zone approximation of buildings is described in Etheridge and Sandberg (1996). One type of PFT tracer (A, polyfluorobenzene) is homogeneously emitted in the whole apartment and another type of tracer (B, polyfluorotoluene) is emitted only in the bedroom. Passive collection onto charcoal tubes were used to sample the average tracer concentration in the sampling points (Dietz et al, 1986; Säteri, 1991; Stymne and Boman, 1994; Øie et al., 1998). Captured amounts of tracers were measured using liquid extraction and subsequent GC/ECD analysis.

3 RESULTS

The measurements were performed during winter conditions with outside temperatures ranging from -3 to 2 °C. The indoor average temperatures during the measurement periods range from 20.2 to 22.5 °C. The bedroom average temperatures was approximately 1 °C cooler than the rest of the apartment. Measurements were started as late as possible in the evening, but it did not necessarily coincide with the time when the inhabitants went to bed. The inhabitants stopped the measurements in the morning. The first measurement was from 21:25 to 09:35 and the second measurement during daytime was from 09:15 to 17:55 with a fully opened bedroom door. The third measurement was from 23:00 to 07:15 with the bedroom door only 1 cm open. The fourth measurement was from 22:15 to 07:15 with fully closed bedroom door. The estimated AERs from the PFT and CO_2 methods are presented in Figure 1. Error bars for the PFT estimates mainly arises from measurement errors of the samplers loads (roughly 10 %) and the same relative errors are assumed for the CO_2 method. The left figure show the estimates of the total volume weighted AER for the whole apartment for the four cases. The right figure shows the estimates for the AER in the bedroom only. Note that the PFT values refer to the whole measurement period, whereas the CO_2 values, at night, are based on data only from 00:00 to 07:00. The PFT values are based on the averages of four samplers in the bedroom, two samplers in the living room and one sampler in the kitchen. The four PFT samplers in the bedroom do not show exactly the same sampler loads indicating that the bedroom is not fully mixed during the measurement period. On the other

hand, the observed variations of less than 10% are comparable to the estimated measurement relative errors of less than 5 %.

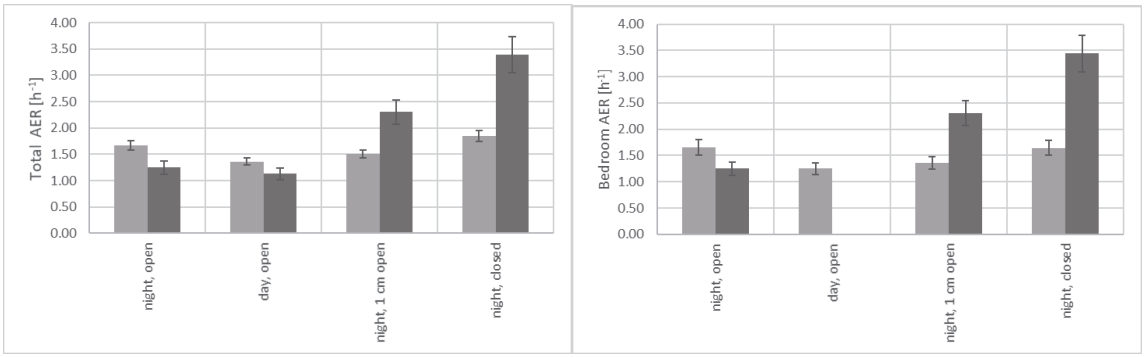

Figure 1. The total AERs and bedroom AERs estimated by PFT (light grey) and by CO_2 (dark grey) with estimated error bars.

From the PFT mass balance equations for the bedroom, in the chosen setup and with one sampler just outside the bedroom door, it is possible to calculate estimates of the air flows into the bedroom. Those are presented in Table 1. Propagation of errors in the mass balance equations is the major contribution to the errors reported. One flow contribution comes from the direct inflow of unmarked air (i.e. outside air) into the bedroom and the other contribution comes from air flow through the doorway of the bedroom. Note this latter air flow is non-zero for a closed door and similar to nearly closed door (1 cm open). However, it is markedly smaller than the air flow through an open bedroom door as expected. The direct air flows of unmarked air into the bedroom during the nights are higher than during the day.

Table 1. PFT mass balance estimates of air flows into the bedroom either through the bedroom door or by direct infiltration of unmarked (outdoor) air.

Time, door condition	Airflow in through bedroom door [m^3/h]	Error [m^3/h]	Direct flow of outside air into bedroom [m^3/h]	Error [m^3/h]
Night, door fully open	284	±72	48	±34
Day, door fully open	235	±63	22	±26
Night, door open 1 cm	97	±18	41	±13
Night, door closed	98	±19	50	±15

4 DISCUSSION

The higher direct inflow of outside air into the bedroom during nights, as compared to the day, in Table 1 indicate that the inhabitants prefer to sleep with an open window in the bedroom. During the day, when the inhabitants are not home, the bedroom window is probably closed. While the PFT and CO_2 AER estimates in Figure 1 are similar for both the night and day measurements with a fully open bedroom door, they clearly differ at night with the door closed or nearly closed. One reason for this is the fairly high overall AERs that are observed in Figure 1, but the main reasons can be found in the methods themselves. As discussed by Nazaroff (2009) and Björling et al (2018), a drawback of the PFT samplers is that they collect tracers proportionally to the concentration. This means that periods of high concentration dominate periods of very low concentration. For the PFT method, this means that periods with high local mean age of air (τ) dominate over periods with very low mean age of air. While the time average $<\tau>$ correctly reflects the relative proportions, the corresponding average $<1/\tau>$ that estimates <AER> does not. Since low τ means high AER, periods with high AER are simply not given proper weights in the PFT method. Thus, the PFT method underestimates the

AER, especially if AER is very high a large proportion of the time. On the other hand, this problem decreases considerably if AER is fairly stable. In the present measurement, the PFT AERs of the bedroom may differ from the CO_2 AERs, also because of the different time periods sampled. The PFT method measures the whole period, while the CO_2 AERs are based only on the data between 00:00 and 07:00. The probability that the window is open during the latter period is higher than for the whole period. On the other hand, the total AERs of the whole apartment are probably overestimated by the CO_2 method when the bedroom door is closed. In terms of the whole apartment, the total AER when the bedroom door is fully open should at least be comparable to when it is closed. In this case, the PFT method appear to perform better than CO_2 method, since the PFT total AERs are less sensitive to whether the bedroom door is closed or open. The disproportionate weight given to the bedroom AER in the estimation of the total AER, in the CO_2 method, may even indicate that the bedroom AER is in fact overestimated.

5 CONCLUSIONS

In these particular measurements, the PFT and CO_2 methods for estimating the bedroom AERs and the total AERs of the whole apartment are shown to differ considerably when the bedroom door is open or closed. The actual measurement conditions as well as the properties of the methods themselves have been discussed as probable causes of the discrepancies. Further studies are needed to compare the two methods more thoroughly.

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7 REFERENCES

Björling, M.; Boman, C.-A.; Stymne, H. (2009) “The Indoor Climate of a Naturally Ventilated Church.” In *Healthy Buildings 2009, Sept 13-18, Syracuse, NY USA, 2009*: *Conference Proceedings*.

Björling, M.; Akander, J.; Steen Englund, J. (2016) “On Measuring Air Infiltration Rates Using Tracer Gases in Buildings with Presence Controlled Mechanical Ventilation Systems” In *Indoor Air 2016: The 14th International Conference of Indoor Air Quality and Climate, July 3-8 2016, Ghent, Belgium: Conference Proceedings* / [ed] E. Van Kenhove, J. Laverge, P. De Vlieger, ISIAQ , 2016, 875.

Dietz R.N., Goodrich R.W., Cote E.A. and Wieser R.F. (1986) "Detailed description and performance of a passive perfluorocarbon tracer system for building ventilation and air change measurement." In *Measured Air Leakage in Buildings* (Edited by H R Treschel and P L Lagus), ASTM STP 904, pp 203-264.

Etheridge D. and Sandberg M. (1996) *Building Ventilation – Theory and Measurement*. John Wiley & Sons, Chichester, U.K.

Hou, J.; Zhang, Y.; Sun, Y.; Wang, P.; Zhang, Q.; Kong, X. and Sundell, J. (2018) “Air change rates at night in northeast Chinese homes.” *Build. Environ.* 132 (2018) 273–281.

ISO 16000-8. (2007, Revised 2016) “Indoor Air - Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions”, International Organization for Standardization.

Nazaroff W.H. (2009) “What does ‘average’ mean for time-varying air-change rates?” *Proceedings of Healthy Buildings 2009*, Syracuse, NY, U.S.A. 2009

NORDTEST (1997). “Ventilation: Local mean age of air – homogeneous emission technique”. *Nordtest Method: NT VVS 118*, Nordtest Finland.

Stavova, P. (2004) “A method for air change rate measurements in dwellings based on carbon dioxide produced by people”, *M. Sc. Thesis*, Technical University of Denmark, Denmark.

Stymne H. and Boman C.A. (1994) "Measurement of ventilation and air distribution using the homogeneous emission technique - A validation". *Healthy Buildings '94, Proc. of the 3rd International Conference*, Vol. 2, pp 539-544, Budapest, Hungary.

Stymne H. and Boman C.A. (1997) "Air distribution in an office building as measured with a passive tracer gas technique" *Proceedings of the 18th AIVC conference on Ventilation and Cooling*, Vol. 1, pp 379-388, Athens, Greece.

Säteri J. O. (editor), (1991) "Development of the PFT-method in the Nordic Countries" *Swedish Council for Building Research, Document D9:1991*.

Öie L., Stymne H., and Boman C.A. (1998) "The ventilation rate of 344 Oslo residences." *Indoor Air* 1998 (8) 190-196.