The NRPI multi-tracer gas PFT method as a new radon diagnostic tool

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Introduction

- **Motivation**: locating radon sources
- perfluorocarbon tracers method
- radon concentration measurement (TESLA TERA and CANARY detectors), volume measurement (laser measure)
- radon flow sources define known radon entry rates
- calculation of radon entry rates into compartments
- verification of the calculation model on measured data
- three experiments were realized

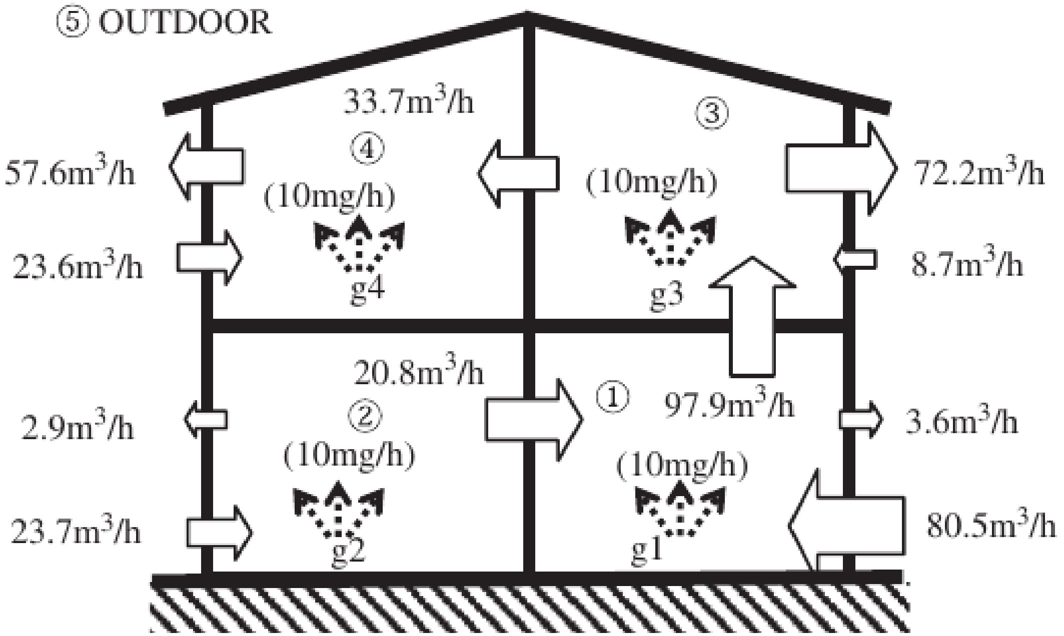

Fig. 0: Partition of a building to compartments, https://doi.org/10.1016/j.buildenv.2008.04.014

Fig. 1: Tracers sources and TD detectors

Fig. 2: CANARY continuous detector

Fig. 4: Radon flow source

Multi-tracer gas PFT method

- measurement usually lasts from 14 to 31 days
- number of gases ≥ number of compartments
- also measurements of temperature and pressure have to be done
- evaluation by gas chromatography with thermal desorption
- output: weight of gases absorbed in TD detectors
- intrazonal airflows and exfiltrations can be calculated

Fig. 4: Chromatograph

Radon entry rates calculation

- $$\dot{a}_i = \frac{1}{V_i}\left(\sum_{j=1}^{N+1} a_j k_{ji} - \sum_{j=1}^{N+1} a_i k_{ij}\right) - \lambda a_i + Q_i\,, \quad i \in \{1, 2, \ldots, N\}$$

  or

  $$0 = \frac{1}{V_i}\left(\sum_{j=1}^{N+1} \overline{a_j}\,\overline{k_{ji}} - \sum_{j=1}^{N+1} \overline{a_i}\,\overline{k_{ij}}\right) - \lambda \overline{a_i} + \overline{Q_i}\,, \quad i \in \{1, 2, \ldots, N\}$$

- $$k_{i_I} = k_{i_E} + \sum_{j=1}^{N} (k_{ij} - k_{ji})$$
- implementation in python (including uncertainty propagation handling)

Example experiment

- typical object
- measurement duration=14 days
- three compartments (floors)
- 14 tracers sources, 12 TD detectors and 3 thermometers were deployed
- six types of tracers were used, in each zone two
- two radon sources were emplaced in basement and in kitchen)
- eight radon monitors were used (4x TESLA TSR, 4x CANARY)

Fig. 5: House in which the experiment took place

Radon concentrations in compartments

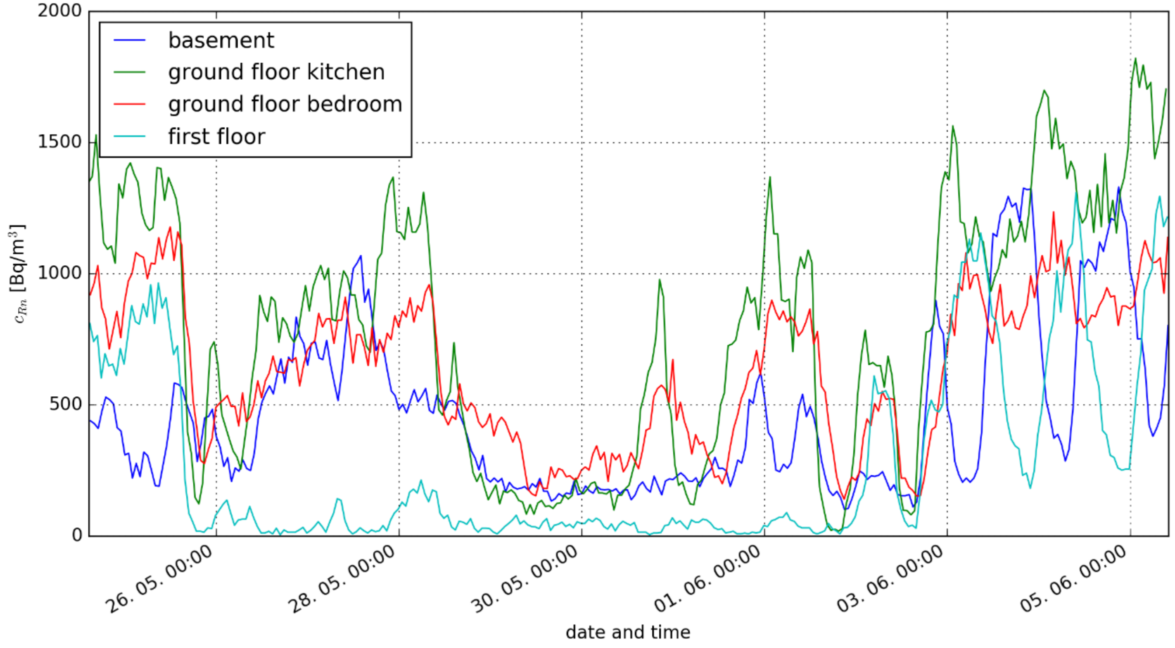

Fig. 6: Radon concentrations measured by TESLA TERA detectors

Fig. 7: Radon concentrations measured by CANARY detectors

Tab. 1: Average radon concentrations measured by TERA and CANARY detectors

floor	TESLA TERA	CANARY
basement	458 ± 33	381 ± 38
ground kitchen	789 ± 43	419 ± 42
ground bedroom	633 ± 37	465 ± 47
first	276 ± 31	156 ± 16

Airflows between compartments (m^3/hour)

Tab. 2: The airflows between compartments for two selected combinations of tracers, the last line cointains air exchage rates (1/hour)

	(TMH, MDC, PCH)	(TCE, MCH, PCE)
k_{12}	11.759±3.078	6.544±1.094
k_{13}	3.372±1.013	0.927±0.162
k_{21}	3.507±0.847	1.049±0.182
k_{23}	4.889±0.724	1.023±0.159
k_{31}	3.524±0.958	-0.020±0.004
k_{32}	5.967±0.967	0.767±0.116
k_{1_E}	19.770±5.057	3.713±1.256
k_{2_E}	41.624±4.833	38.543±4.268
k_{3_E}	24.294±3.199	7.815±0.852
k_{1_I}	27.869±6.140	10.155±1.683
k_{2_I}	32.294±5.917	33.303±4.414
k_{3_I}	25.525±3.693	6.613±0.889
n	0.363±0.042	0.212±0.025

Radon entry rates (Bq/m^3/hour)

- TMH, MCH, PCH and MDC are perfluorocarbons
- TCE and PCE are chlorinated hydrocarbons

Tab. 3: Calculated radon entry rates from RAC measured by CANARY detectors, in the last line there are known radon entry rates from the radon sources

	Q_1	Q_2	Q_3
(TMH, MDC, PCE)	294 ± 78	137 ± 28	8 ± 4
(TMH, MDC, PCH)	289 ± 77	135 ± 28	27 ± 14
(TMH, MCH, PCE)	301 ± 78	115 ± 24	9 ± 3
(TMH, MCH, PCH)	295 ± 76	113 ± 24	31 ± 14
(TCE, MDC, PCE)	98 ± 24	149 ± 27	8 ± 3
(TCE, MDC, PCH)	96 ± 25	146 ± 27	26 ± 13
(TCE, MCH, PCE)	100 ± 23	124 ± 23	9 ± 3
(TCE, MCH, PCH)	98 ± 24	122 ± 23	31 ± 13
source	400 ± 51	114 ± 13	0 ± 0

Tab. 3: Calculated radon entry rates from RAC measured by TESLA TSR, in the last line there are known radon entry rates from the radon sources

	Q_1	Q_2	Q_3
(TMH, MDC, PCE)	335 ± 90	236 ± 42	18 ± 6
(TMH, MDC, PCH)	323 ± 88	231 ± 42	63 ± 24
(TMH, MCH, PCE)	347 ± 89	197 ± 36	19 ± 6
(TMH, MCH, PCH)	334 ± 87	192 ± 35	70 ± 24
(TCE, MDC, PCE)	111 ± 28	249 ± 41	17 ± 6
(TCE, MDC, PCH)	108 ± 28	243 ± 41	62 ± 23
(TCE, MCH, PCE)	115 ± 26	208 ± 35	19 ± 6
(TCE, MCH, PCH)	111 ± 27	203 ± 35	70 ± 23
source	400 ± 51	114 ± 13	0 ± 0

Problems

- saturation of TD detectors (due to the use of many tracers sources and unrealistic conditions)
- reliability of continuous radon monitors (TESLA TSR3D)
- unknown natural radon concentrations

Tab. 4: Radon entry rates to the zones of Object 2 (flat), the unit is Bq/m³/hour

	Q_1	Q_2	Q_3	Q_4
(MDC, PCE, TCE, TMH)	444 ± 253	-25 ± 104	44 ± 86	-152 ± 368
(MDC, MCH, TCE, TMH)	445 ± 241	-86 ± 104	38 ± 84	-152 ± 351
source	332 ± 64	0 ± 0	0 ± 0	0 ± 0

Tab. 5: Radon entry rates to the zones of Object 3 (family house), the unit is Bq/m³/hour

	Q_1	Q_2	Q_3
(MCH, MDC, PCH)	1057 ± 245	-31 ± 13	21 ± 7
source	455 ± 90	0 ± 0	0 ± 0

Conclusion

- one experiment was inaccurate
- more experiments need to be done
- multi-tracer gas PFT method have to be done more carefully
- otherwise this method gives good results