Utilization of integral ventilation rate measurement in practice

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Motivation

- The air exchange rate (ACH) between indoor and outdoor air is the key physical process affecting among others also behavior of all types of aerosol and gaseous contaminants, including radon /thoron gas and their decay products in buildings and mediates their transport from the outside air in to interiors of buildings.
- Air exchange rate is air flow rate through the building (house) normalized by its volume.
- Objectification of results of radon measurement to the minimum hygienic air exchange rate (0.3 1/h).
- Tool of the radon diagnostics for identification radon pathways and radon entry rate.

Theoretical background

- Perfluorocarbon tracer (PFT) technique allows calculation of average air exchange rate and interzonal airflows in multizonal buildings.
- Number of compartments equals to number of tracer gases used. SURO is capable to measure with 7 different tracer gases.
- Tracer gas ***i*** (Ci) is constantly injected into the compartment (i.e. room (s) or storey) with defined and well know entry rate driven just by diffusion.
- Tracer gas is absorbed in the detection tubes filled with proper sorbent.
- Gas chromatograph GS Agilent equipped with a proper chromatographic column to distinguish mixture of used tracer gases and electron capture (EC) and flame ionization (FI) detector is used as the evaluation unit. As a carrier gas we use helium.

In principle Dietz PFT multi- zonal approach based on continuous constant injection of a tracer gas(es) and its(their) long term diffusion sampling was adopted.

$$\frac{dC_i}{dt} Vi = \boldsymbol{Rs_i} - \sum_{j=1}^{N+1} (R_{ji}\, C_i) + \sum_{j=1}^{N+1} (R_{ij}\, C_j) \qquad (1)$$

$$0 = \boldsymbol{Rs_i} - \sum_{j=1}^{N+1} (\hat{R}_{ji}\, \hat{C}_i) + \sum_{j=1}^{N+1} (\hat{R}_{ij}\, \hat{C}_j) \qquad (2)$$

$$R_{\boldsymbol{I}i} = R_{\boldsymbol{Ei}} - \sum_{j=1}^{N} (R_{\,ij} - Rji) \qquad (3)$$

Eq.(1) represents mass balance equation for a some type used tracer gas in the i-the zone inside a investigated building (house) divided into N- zones. When N+1 zone is outdoor air.

Eq. (2) represents steady state situation within measured time T

Eq (3) represents analogy of the 1th Kirhofs law for airflows in a one zone (el. node = zone)

Rsi means known average and constant tracer gas entry rate into i-th zone in (mg/h)

Rij, $\hat{R}_{ij}$ means air flow and average air flow, respectively from zone j-th into zone i-th in (m^3/h)

Rji, $\hat{R}_{ji}$ means air flow and average air flow, respectively from zone i-th into zone j-th in (m^3/h)

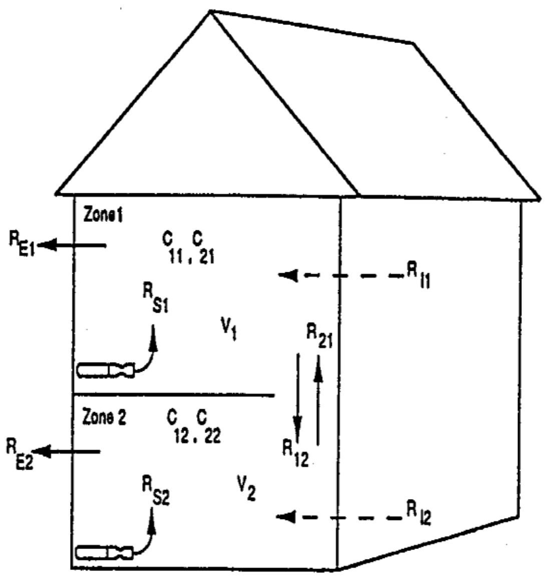
C_i, $\hat{C}_i$ means mass concentration and an average mass concentration, respectively of the tracer gas in the i-th zone in (mg/m^3)

C_j, $\hat{C}_j$ means mass concentration and an average mass concentration, respectively of the same tracer gas in the j-th zone in (mg/m^3)

R_{Ei}, R_{Ii} means air infiltration and (exfiltration), respectively to (from) the i- th zone in (m^3/h)

Vi means effective mixing volume of i-th zone in (m^3).

2 ZONES - AIR EXCHANGE RATE (ACH) CALCULATION



$$\mathrm{ACH} = \frac{\boldsymbol{R_{E1}} + \boldsymbol{R_{E2}}}{\boldsymbol{V_1} + \boldsymbol{V_2}}$$

Infiltrations:

$$R_{11} = R_{E1} + R_{12} - R_{21}$$
$$R_{12} = R_{E2} + R_{21} - R_{12}$$

Zone 1

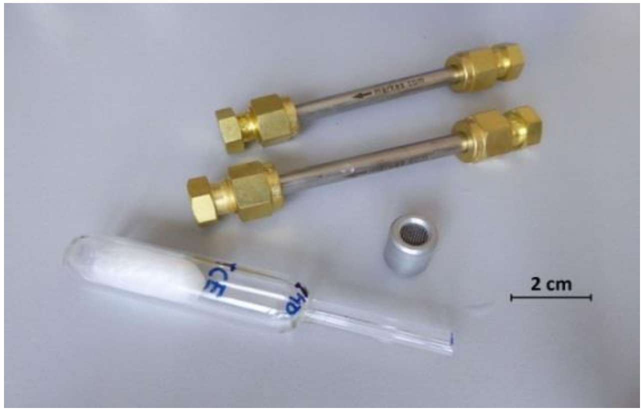
$$R_{21}C_{12} - R_{12}C_{11} - R_{E1}C_{11} = -R_{s1}$$
$$R_{21}C_{22} - R_{12}C_{21} - R_{E1}C_{21} = 0$$

Zone 2

$$R_{12}C_{11} - R_{21}C_{12} - R_{E2}C_{12} = 0$$
$$R_{12}C_{21} - R_{21}C_{22} - R_{E2}C_{22} = -Rs2$$

R_{Ei} exfiltration air flow from i - th zone (m^3/h)
V_i volume i- th zone (m^3)
R_{Ii} infiltration of outdoor air flow into i-th zone (m^3/h)
C_{ij} i-th tracer gas concentration in j-th zone (mg/m^3)
R_{si} tracer source in i- th zone (mg/h)
R_{ij} air flow from i- th zone to j-th (m^3/h)

$$R_{21} = (R_{s1}C_{21)/}(C_{11}C_{22} - C_{12}C_{21})$$
$$R_{12} = (R_{s2}C_{12})/(C_{11}C_{22} - C_{12}C_{21})$$
$$R_{E1} = R_{21}(C_{11/C21)} - R_{12}$$
$$R_{E2} = R12(C11/C12) - R_{21}$$


2 cm


TD100-xr

Capabilities of the system

- Dynamic measuring range of ACH (0.05 - 3) h^{-1}
- Exposition duration from one day up to approx. 3 months
- Measurement in occupied buildings (apartments, schools, multi-storey family houses etc.)
- Assessment of inter-zonal flows between 7 different zones-compartments (storey, rooms)
- Measurement and estimation of ACH with overall uncertainty 15 % (K= 1) having in mind:
  - instrumentation errors (due to calibration, influence of ambient conditions upon source emission rate and uptake rate of TD detection tubes, actual size of mixing volume of measurement zone etc.)
  - model errors (homogeneity of the mixture tracer gas-air in the zone, transient changes of measured tracer gas concentration can be neglected within whole exposure).

QA/QC

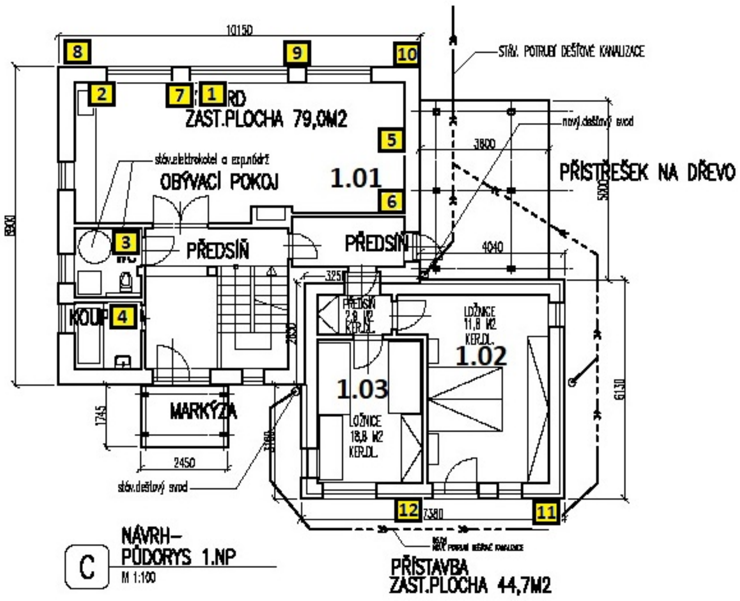
- Interlaboratory comparison (up to 10%) between the National Brookhaven Lab. NY (USA) and SURO carried out in 15 different houses located in the CR comprising apartments 3+1, 5 multi-storey family houses)
- State Office for Nuclear Safety has certified the measurement protocol for assessment of average ACH in buildings under reference number: SÚJB/RCHK/4581/2017
- SURO periodically runs tests in the big climatic radon chamber allowing independently adjust the ACH within wide range of ACH
- Average ACH can be compared to the average value obtained from the continuous measurement of ACH based on use of N_2O and SF_6 as tracers.

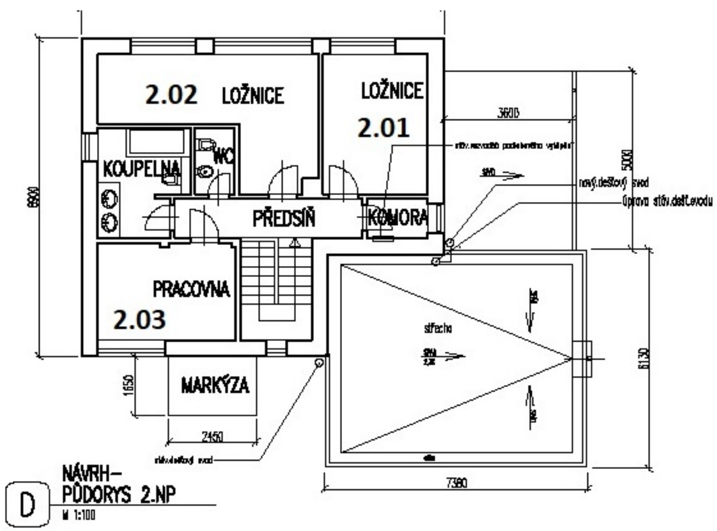
Case study 1

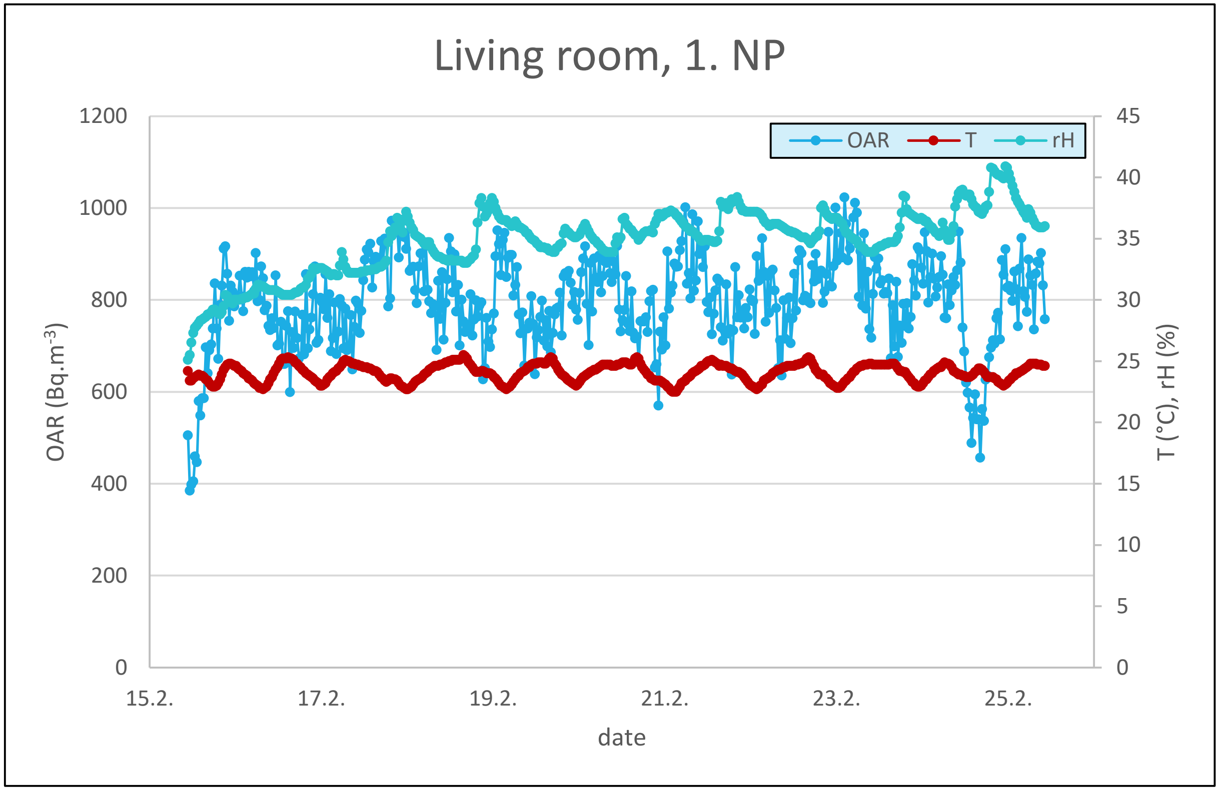
- Family house, 2 storey building build in 2010, single storey extension added in 2013.
- 1 Week measurement done by electret detectors showed radon concentration of 900 Bq/m^3 in the large kitchen+living room located in the 1^{st} floor and 40 Bq/m^3 in the bedroom located in the building extension. Heating season, building occupied.
- Radon diagnostics was done in unoccupied heated building. Doors to the extension were closed for the whole period.
- Grab sampling from suspicious places confirmed high radon concentration in cracks in the technical room and living room (~7 kBq/m^3).
- Grab sampling taken from space between external wall and heat cladding showed higher radon conc. on the building extension (~14 kBq/m^3).

10 days radon concentration average, electret detectors, heated unoccupied building

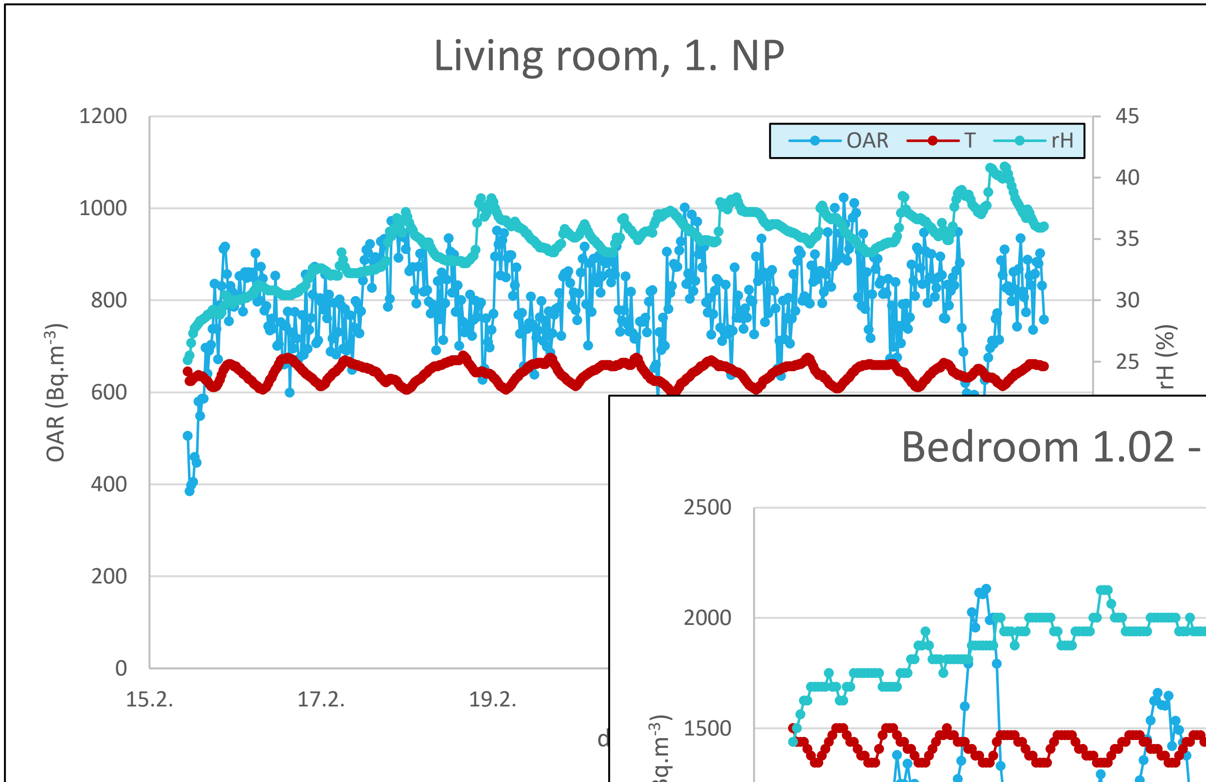
Room	Floor	Radon conc. (Bq.m^{-3})	Ambient dose eq. rate (mikroSv.h^{-1})
Living room	1. NP	795	0,08
Bedroom 1.02 - extension	1. NP	1112	0,07
Bedroom kids 1.03 – extension	1. NP	1344	0,09
Technical room	1. NP	710	0,07
Bedroom 2.02	2. NP	840	0,07

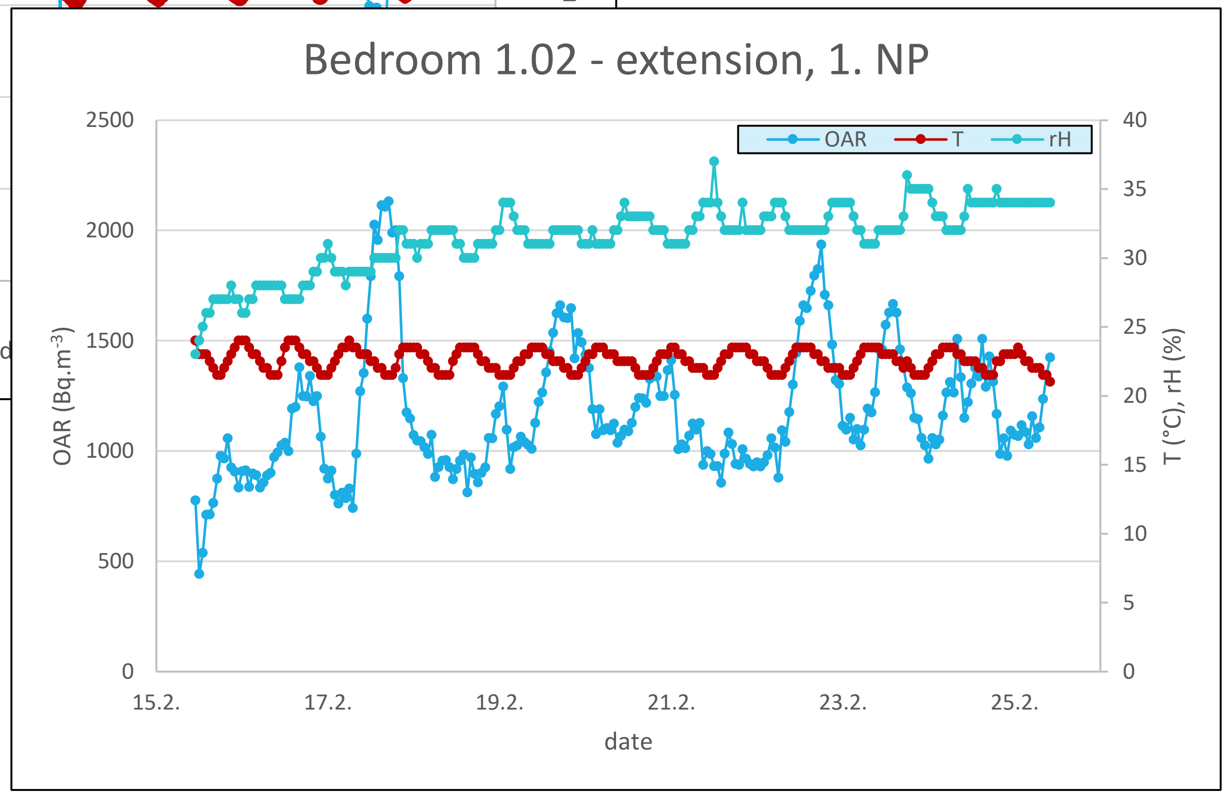


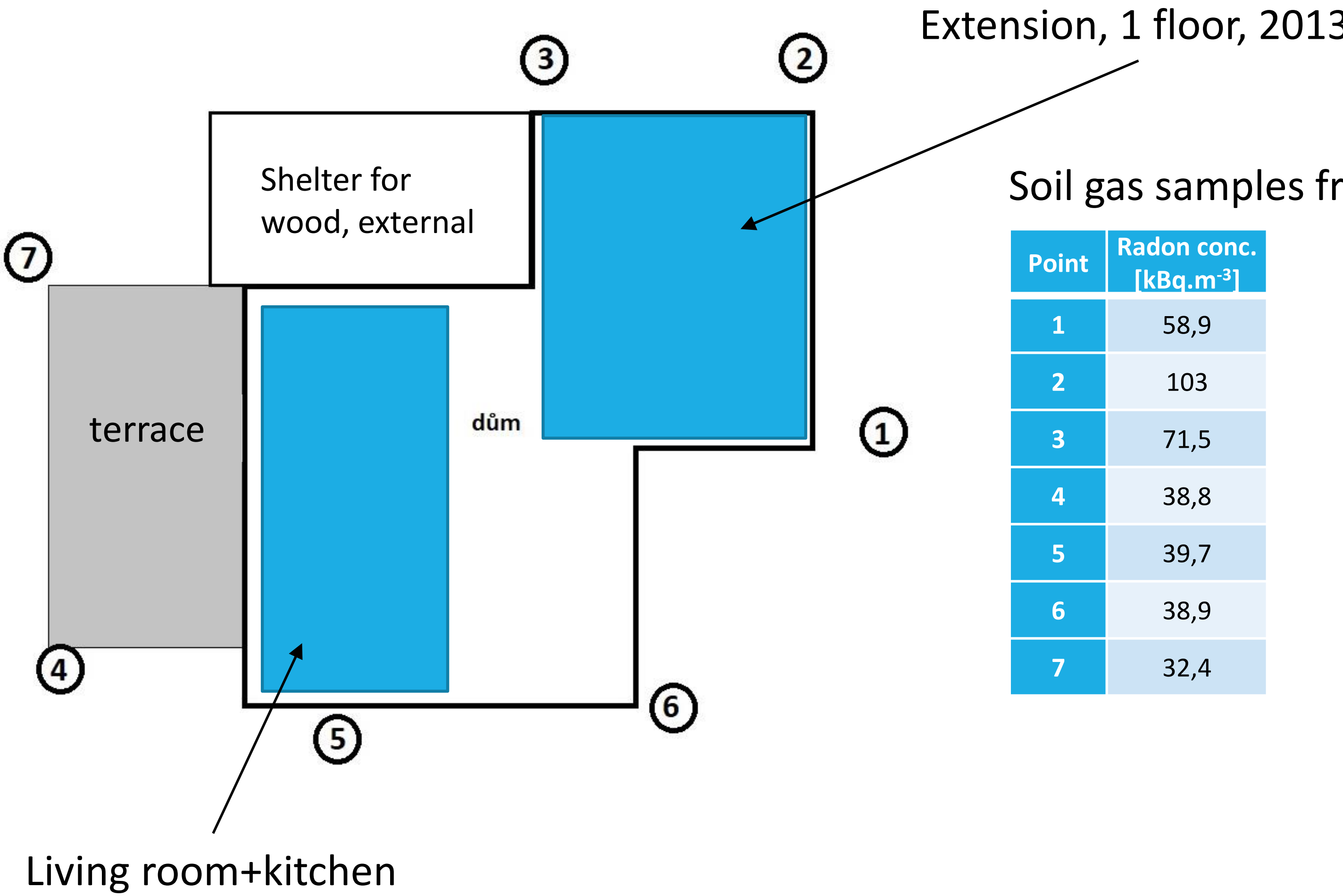




Living room, 1. NP
OAR
T
rH
1200
1000
800
600
400
200
0
OAR (Bq.m-3)
45
40
35
30
25
20
15
10
5
0
T (°C), rH (%)
15.2.
17.2.
19.2.
21.2.
23.2.
25.2.
date


Living room, 1. NP
OAR
T
rH
OAR (Bq.m-3)
rH (%)
1200
1000
800
600
400
200
0
45
40
35
30
25
15.2.
17.2.
19.2.


Bedroom 1.02 - extension, 1. NP
OAR
T
rH
OAR (Bq.m-3)
T (°C), rH (%)
2500
2000
1500
1000
500
0
40
35
30
25
20
15
10
5
0
15.2.
17.2.
19.2.
21.2.
23.2.
25.2.
date



Soil gas samples from 80 cm depth

Point	Radon conc. [kBq.m^{-3}]
1	58,9
2	103
3	71,5
4	38,8
5	39,7
6	38,9
7	32,4

ACH measurement

- 3 compartments – compartment 1: 2nd floor, compartment 2: extension, compartment 3: 1st floor living room, kitchen, technical room
- Compartment 1 - 2nd floor
  - Low average air exchange rate 0.14 1/h
- Compartment 2 – extension
  - Low average air exchange rate 0.04 1/h
  - Main air flow pathway to compartment 3 living room etc., 20 times stronger than to compartment 1
- Compartment 3 – 1st floor living room etc.
  - Surprisingly large average air exchange rate 0.42 1/h
  - 2 time stronger air flow to compartment 1 compared to compartment 2

Results

- Radon concentration in occupied building will be much lower compared to measured values (~1200 Bq/m^3 in the extension recalculated to 0.3 1/h -> 160 Bq/m^3).

- 3 radon pathways identified
  - Cracks in the contact floor of the 1st floor
  - Joint between the external wall and heat cladding which continues bellow the foundation slab
  - Joint between the walls of original and new parts of the building.
- Main transport route for radon to 2nd floor is the staircase.

Case study 2

- Large 4 storey administrative building
- Built during 2nd WW originally as a block of flats
- Reconstructed few years ago
- Cellar with gym, technical rooms
- Lid covering entrance to small technical tunnel to somewhere outside the building is located in the gym
- 4 floors of offices, meeting rooms
- Central staircase connecting all of the floors, lift

	Heating season Avg. radon conc. Bq/m^3	Non-heating season Avg. radon conc. Bq/m^3
Space under stairs, cellar	10838	
Room 004, cellar	92	1225
Lift engine room, cellar	95	48
Room 005, cellar	7192	8906
Room 014, cellar	781	1547
Room 101, 1.NP	317	279
Room 102, 1. NP	582	400
Room 201, 2. NP	441	276
Room 203, 2. NP	119	770
Room 301, 3. NP	595	211
Room 303, 3. NP	1231	771
Room 401, 4. NP	1019	683
Room 403, 4. NP	972	723

ACH measurement

- 5 compartments per each of the floor
- ***R*** exfiltration air flow rate, ***n*** average air exchange rate

	Non-heating season		Heating season	
Compartment	R (m^3/h)	n (h^{-1})	R (m^3/h)	n (h^{-1})
1. PP / cellar	326	0.73	413	0.92
1. NP	56	0.12	100	0.21
2. NP	84	0.17	119	0.24
3. NP	94	0.20	46	0.10
4. NP	107	0.26	150	0.36

- Air exchange rate is higher during heating season in the 4th floor
- Radon ingress from the cellar is also higher
- Staircase was identified as a main radon pathway in this case

What can be average exchange rate used for?

- Air exchange rate is air flow rate through the building (house) normalized by its volume.

- Objectification of results of radon measurement to the minimum hygienic air exchange rate (0.3 1/h).
- Tool of the radon diagnostics for identification radon pathways and radon entry rate.
- Assessment of exfiltration-infiltration from the outside – improvement in dose assessment in case of plume contamination.