RADON DIAGNOSTICS USING LOW-COST CONTINUOUS MONITORS AND AIR EXCHANGE RATE MEASUREMENT – A CASE STUDY IN A RESIDENTIAL BUILDING

Katerina Navratilova Rovenska; National Radiation Protection Institute, Prague, Czech Republic; katerina.rovenska@suro.cz;

on behalf of co-authors

17.9.2025, 17th GARRM, Prague, Czech Republic

CO-AUTHORS

- Miroslav Vanek; Technical University in Zvolen, Zvolen, Slovakia
- Radim Moznar; National Radiation Protection Institute, Prague, Czech Republic;
- Martin Kaschner; Czech Technical Unversity in Prague, Faculty for Nuclear Sciences and Physical Engineering, Prague, Czech Republic;
- Elena Castaño Casco; Radiation Physics and Environment Group (FRYMA), Centre for Natural Resources, Health and Environment (RENSMA), University of Huelva, Huelva, Spain;
- Shahed Khan; School of Mathematics and Physics, University of Surrey, Guildford, Surrey, UK;
- Esther Osei Akuo-ko; University of Pannonia, Department of Radiochemistry and Radioecology, Veszprem, Hungary;
- Ilaria Rocchetti ; Università degli studi Roma Tre, Roma, Italy;
- Ondřej Pařízek; National Radiation Protection Institute, Prague, Czech Republic;
- Jan Lenk; National Radiation Protection Institute, Prague, Czech Republic;
- Marcela Adamova; State office for Nuclear Safety, Prague, Czech Republic;
- Oana Elena Peneoasu; S.C. DOZIMED S.R.L., Bucharest, Romania;
- Lukáš Mareda; Licon s.r.o. , Stráž nad Nisou;

MOTIVATION

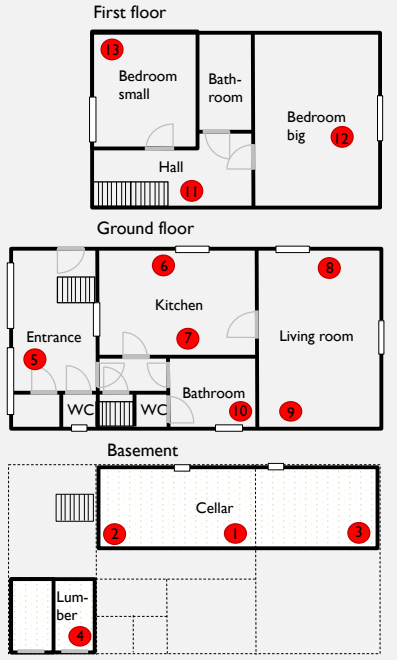
- Radon measurement is crucial for identifying high-risk environments and also for validating the effectiveness of both mitigation and preventive measures.
- Traditionally relied on solid-state nuclear track detectors (SSNTDs) and electret ion chambers (EICs), in the US also charcoal canisters are used for short-term measurements. All provide single average value for the measurement period.
- For identification of radon pathways and analysis of temporal radon behaviour electronic continuous radon monitors (CRMs) should be used.
- For years, CRMs were quite expensive and research-grade therefore reserved for scientific applications or available in limited numbers.
- Recent advances in sensor miniaturisation and digital electronics have enabled the production of affordable, low-cost CRMs.
- Radon diagnostics requires the use of multiple continuous monitors simultaneously, lower-cost devices would enable more frequent use in practice.

TRAINING COURSE

- Training course "From radon measurement to optimized mitigation" organized in the frame of RadoNorm project.
- Aim of the training course – to contribute to capacity building in the field of radon measurement and design of remedial and preventive measures.
- Course was jointly organized by the National Radiation Protection Institute (SURO) and Faculty of Civil Engineering of the Czech Technical University in Prague in May 2025.
- 2 weeks full of lectures, practical lessons and site visits.
- Participants carried out a practical demonstration of radon diagnostics in a single-family home previously identified as having potentially elevated radon concentrations.

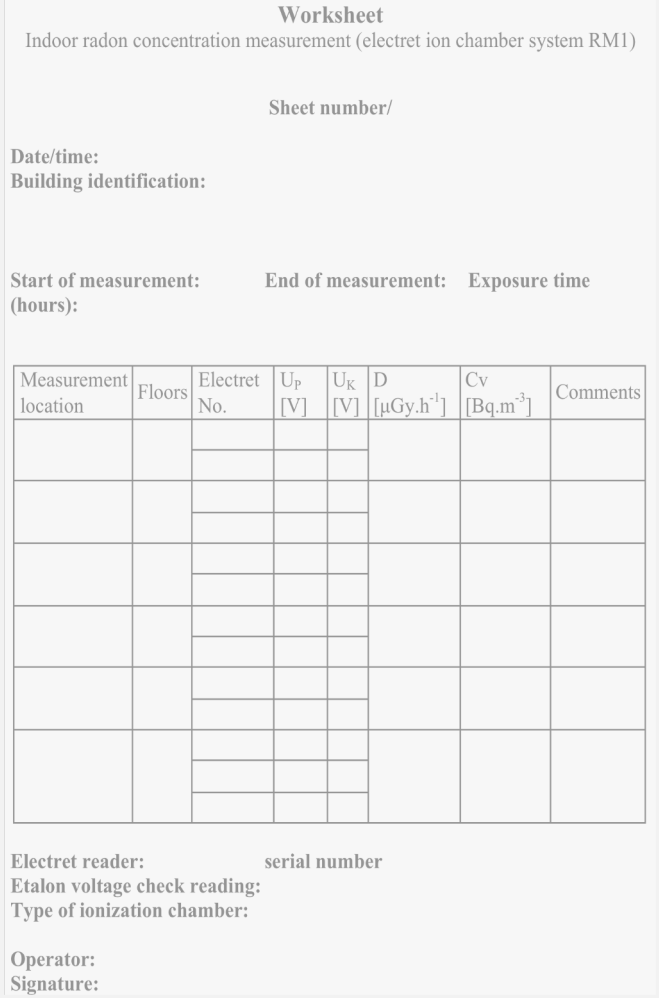
OVERVIEW OF THE MEASUREMENT SITE

- Built around 1939 from bricks, wood, concrete.
- Small reconstructions between 1960-1980.
- Around 1970 hallway and entrance was added as an extension to the original house.
- Complete reconstruction 2010-2014 – new tight windows, new floor in part of the ground floor, newly built rooms in the first floor, new roof, thermal insulation.
- 2 above ground floors, the first floor is accessible via staircase.
- Cellar located partially beneath the kitchen and living room
  - 2 small windows,
  - recess in the middle,
  - accessible from the entry hallway through wooden hatch.
- Simple bituminous waterproofing, water from public water system, no floor heating.



MEASUREMENT CAMPAIGNS

- 3 measurement campaigns
- **initial** measurement campaign, 2 weeks, end of May – beginning of June 2021
  - RadonEye+2 monitors in habitable rooms on the ground floor (kitchen and living room), in the entrance, and in the large bedroom on the first floor,
  - Radim3AT monitor in the cellar,
  - for most of this period, the building was occupied by at least two adults and two children.
- **second** measurement campaign, 1 week (within the RadoNorm training course)
  - several RadonEye+2 and Corentium Pro monitors,
  - the building was unoccupied.
- **third** measurement campaign, 2 weeks, end of May – beginning of June 2025,
  - several RadonEye+2 and Corentium Pro monitors,
  - the building was unoccupied.



Worksheet

Indoor radon concentration measurement (electret ion chamber system RM1)

Sheet number/

Date/time:
Building identification:

Start of measurement: **End of measurement:** **Exposure time (hours):**

Measurement location	Floors	Electret No.	U_P [V]	U_K [V]	D [μGy.h^{-1}]	Cv [Bq.m^{-3}]	Comments

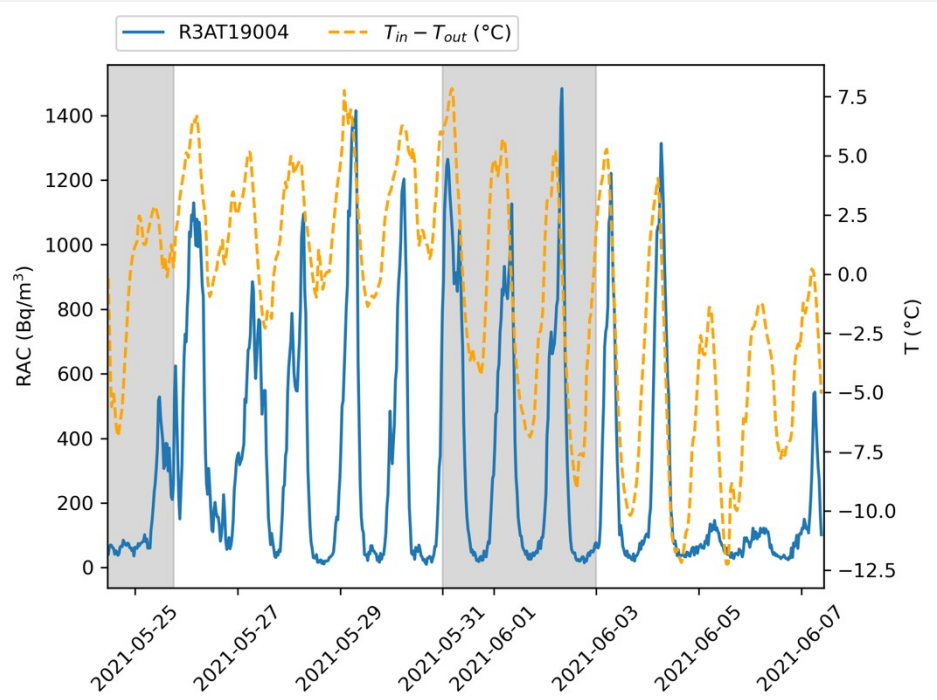
Electret reader: **serial number**
Etalon voltage check reading:
Type of ionization chamber:

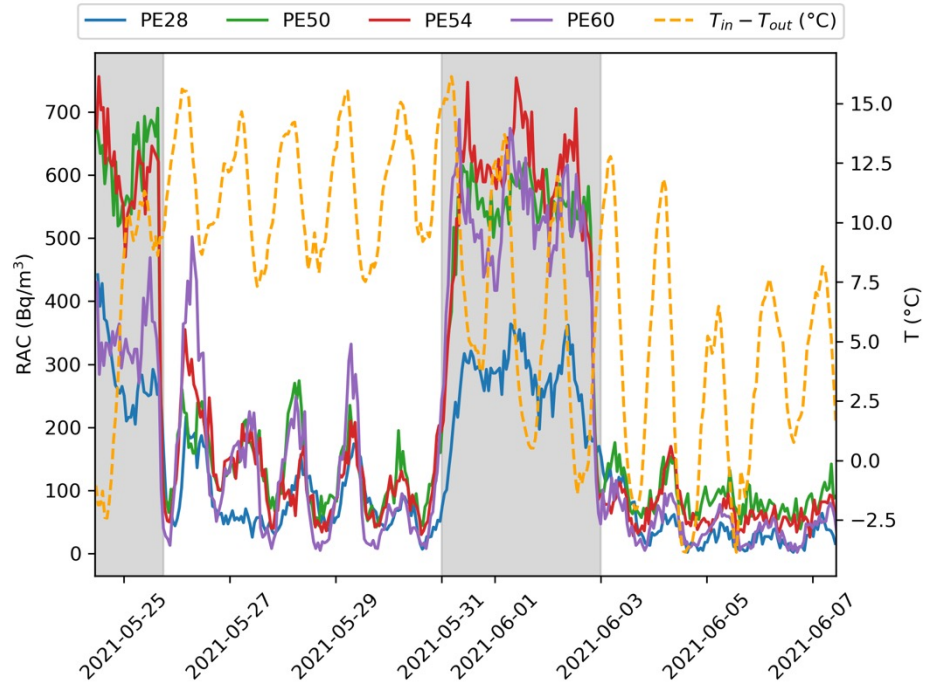
Operator:
Signature:

INITIAL MEASUREMENT

- 2 weeks
- continuous radon monitors – RadonEye+2, Radim3AT
- air exchange rate measurement
- building occupied for most of the time

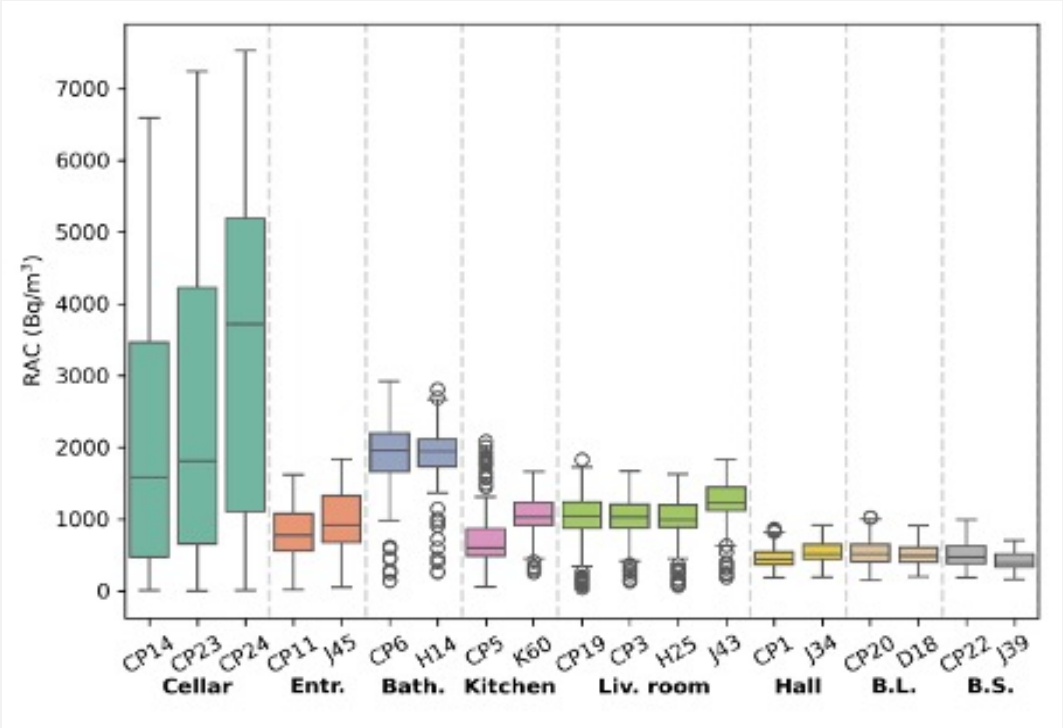
floor	room	device	average RAC (Bq/m^3)
-1	Cellar, front	Radim3AT (R3AT 19004)	310 ± 47
1	Entrance	RadonEye+2 (PE60)	199 ± 30
1	Kitchen	RadonEye+2 (PE50)	245 ± 37
1	Living room	RadonEye+2 (PE54)	243 ± 36
2	Big bedroom	RadonEye+2 (PE28)	126 ± 19



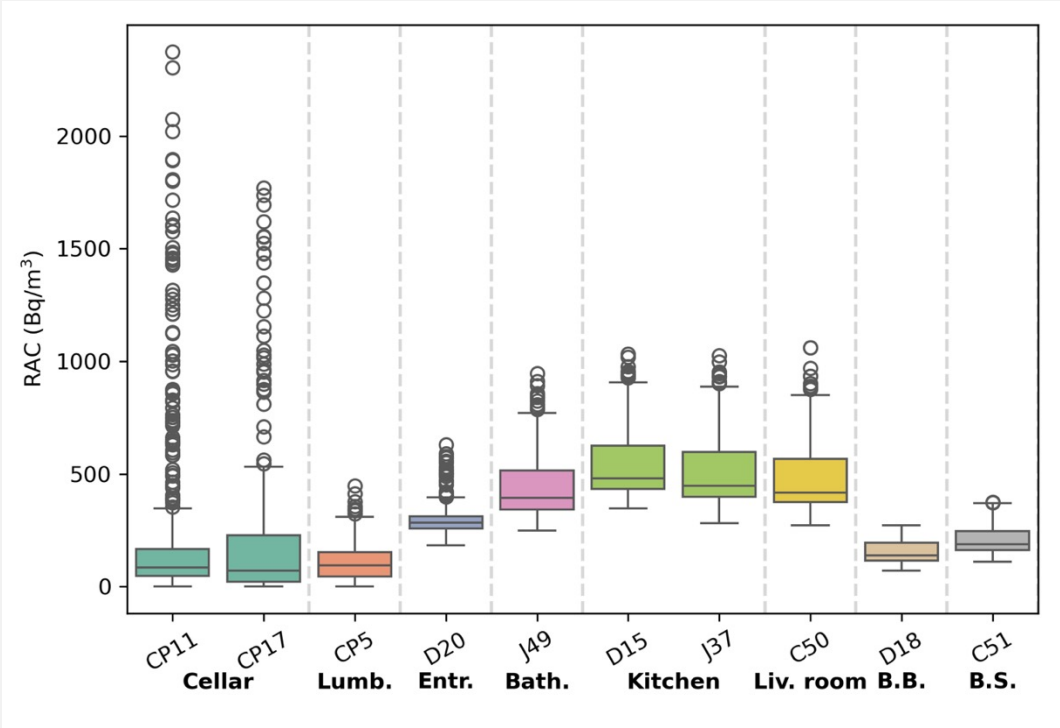


MEASUREMENT CAMPAIGN

SECOND



THIRD

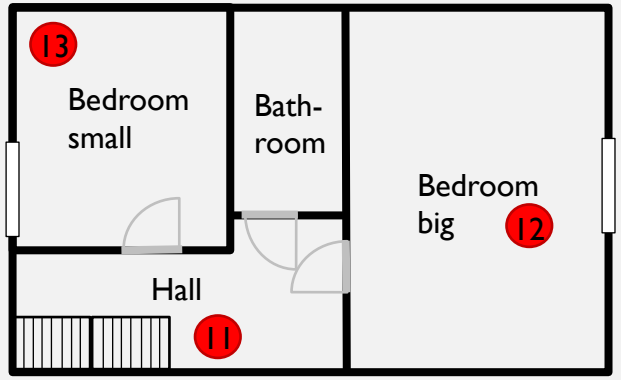


B.L. - Bedroom large, B.S. - Bedroom small

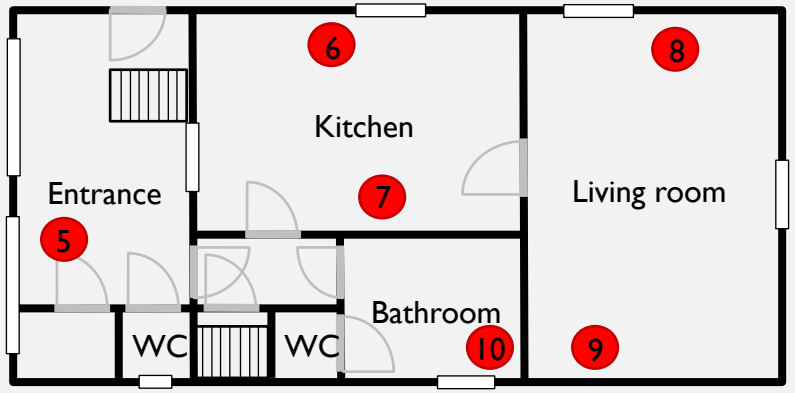
Legend

Room	Point	Measurement 2		Measurement 3	
		Device	Type	Device	Type
Cellar	1	CP24	CP	CP17	CP
	2	CP14	CP	CP11	CP
	3	CP23	CP	-	-
Lumber room	4	-	-	CP5	CP
Entrance	5	CP11	CP	D20	RnE
		J45	RnE		
Kitchen	6	CP5	CP	D15	RnE
		K60	RE		
	7	-	-	J37	RnE
Living room	8	CP19	CP	C50	RnE
		H25	RnE		
	9	CP3	CP	-	-
		J43	RnE		
Bathroom	10	CP6	CP	J49	RnE
		H14	RnE		
Hall	11	CP1	CP	-	-
		J34	RnE		
Bedroom big	12	CP20	CP	D18	RnE
		D18	RnE		
Bedroom small	13	CP22	CP	C51	RnE
		J39	RnE		

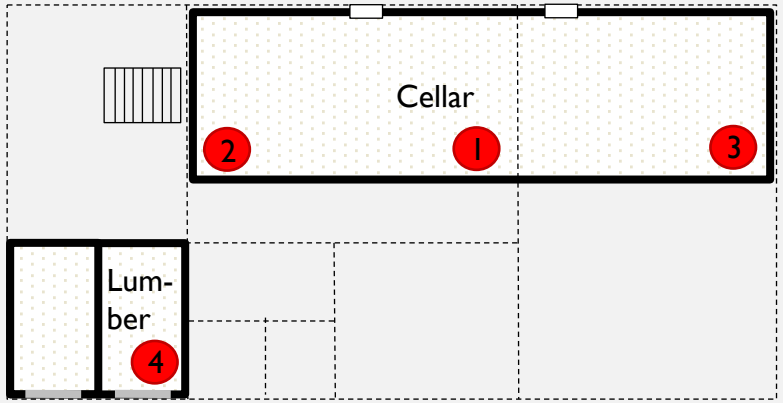
First floor

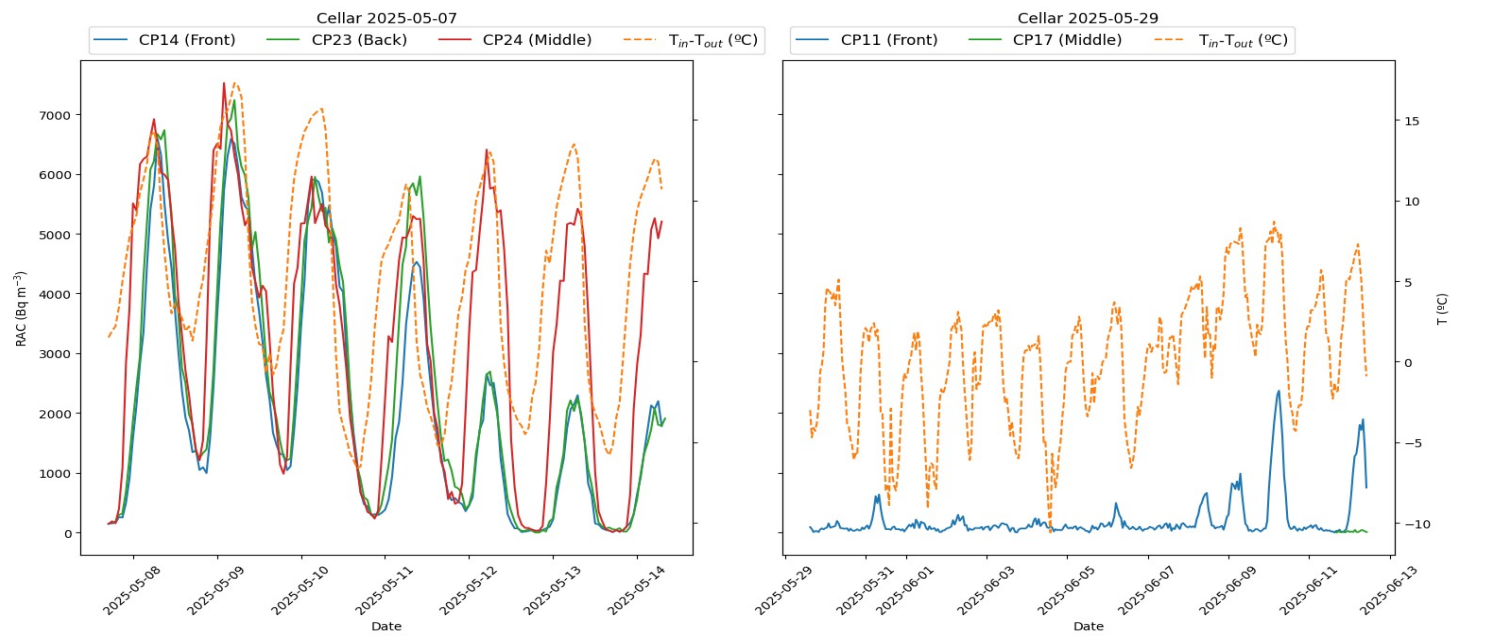


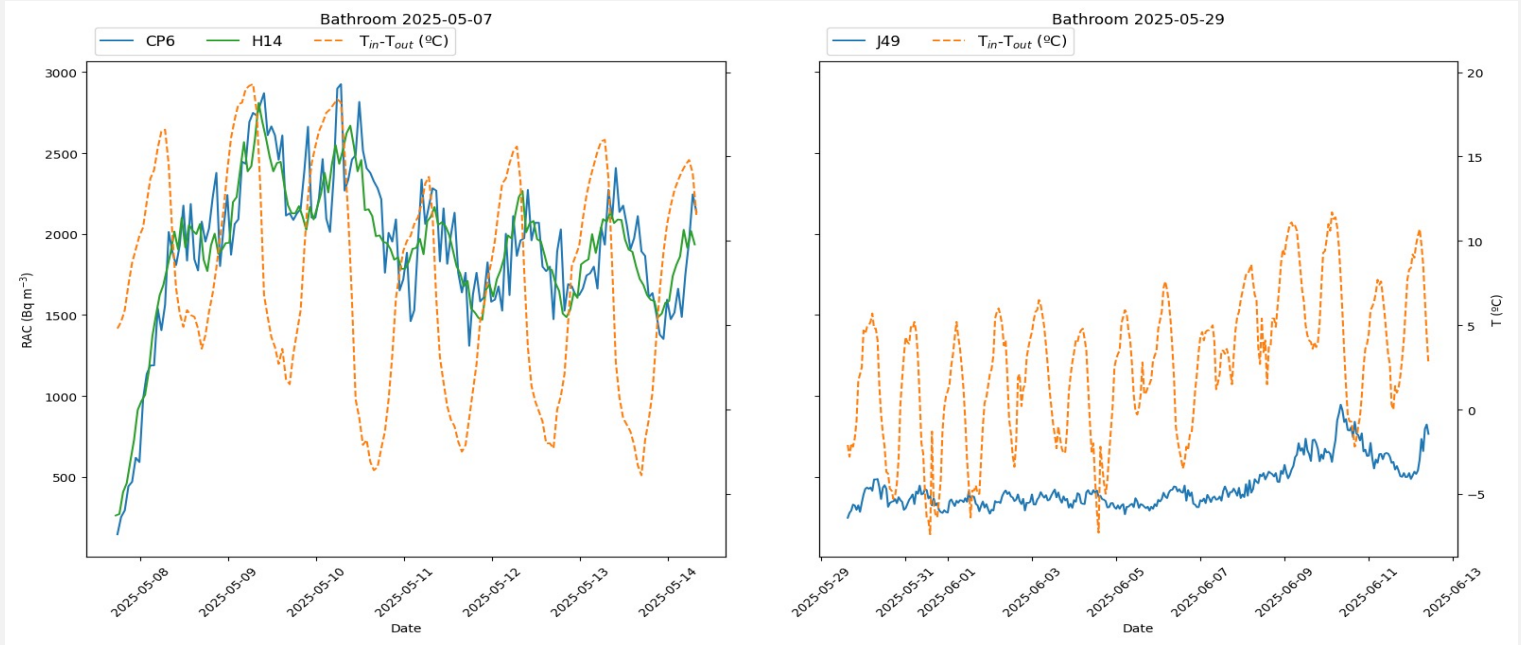
Ground floor

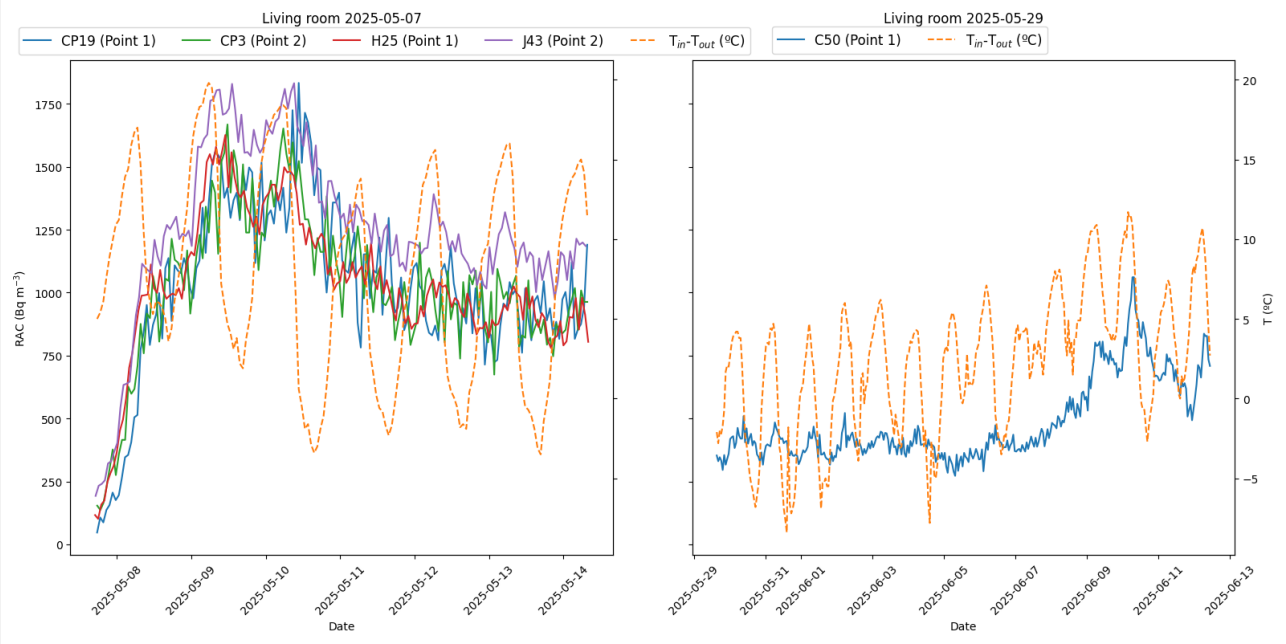


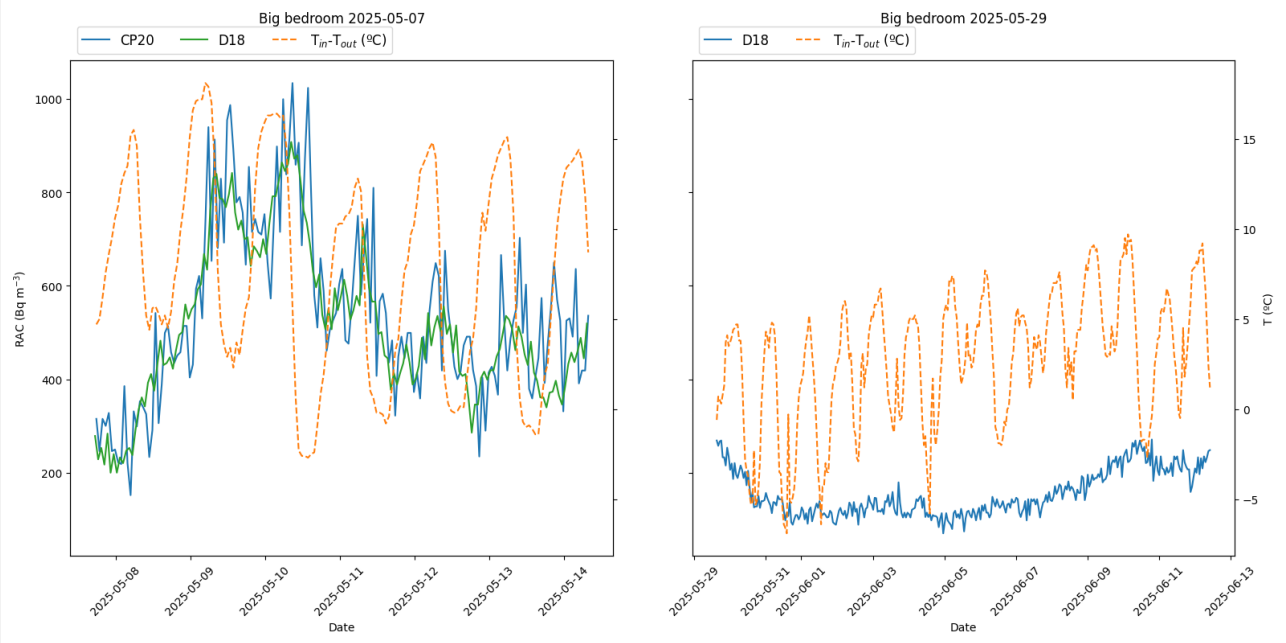
Basement




Cellar 2025-05-07
CP14 (Front)
CP23 (Back)
CP24 (Middle)
T_{in}-T_{out} (ºC)
RAC (Bq m^{-3})
Date
Cellar 2025-05-29
CP11 (Front)
CP17 (Middle)
T_{in}-T_{out} (ºC)
T (ºC)
Date

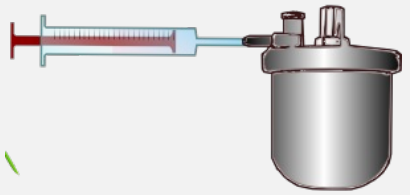

Bathroom 2025-05-07
CP6
H14
T_{in}-T_{out} (ºC)
RAC (Bq m^{-3})
Date
Bathroom 2025-05-29
J49
T_{in}-T_{out} (ºC)
T (ºC)
Date


Living room 2025-05-07
CP19 (Point 1)
CP3 (Point 2)
H25 (Point 1)
J43 (Point 2)
T_{in}-T_{out} (ºC)
RAC (Bq m^{-3})
Date
Living room 2025-05-29
C50 (Point 1)
T_{in}-T_{out} (ºC)
T (ºC)
Date


Big bedroom 2025-05-07
CP20
D18
T_{in}-T_{out} (ºC)
RAC (Bq m^{-3})
Date
Big bedroom 2025-05-29
D18
T_{in}-T_{out} (ºC)
T (ºC)
Date

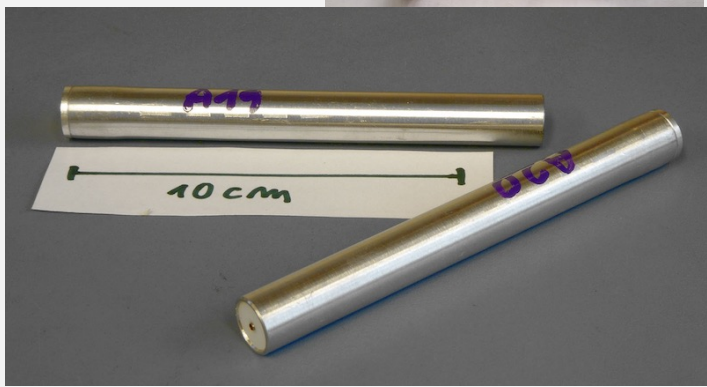
ACCOMPANYING MEASUREMENTS

- Grab sampling from suspicious places
  - 8 grab samples from floor-wall joints in bathroom, kitchen and living room, and joint floor-staircase,
  - radon concentration between 3 and 7 kBq/m^3.
- Radon in soil gas
  - 7 measurement points in the vicinity of building,
  - average radon concentration wass 46.2 ± 3.2 kBq/m^3.
- Gamma dose rate indoors
  - at none of the measurement points exceeded 80 nGy/h (50 cm from wall, 1 m above ground).
- Meteorological data
  - measured during training course measurement campaign using Davis Vantage Pro weather station,
  - obtained from the Open-Meteo project.



AIR EXCHANGE MEASUREMENT (ACH)

- Tracer gas method
  - building is divided into compartments,
  - a number of tracer gas generators in each compartment and at least one detection point is established per compartment,
  - volume of each compartment must be measured,
  - the weight loss of tracer gas generators is determined,
  - chromatographic evaluation of the integral detectors is performed,
  - total ACH, compartment-specific ACH, and inter-compartmental airflows are calculated.



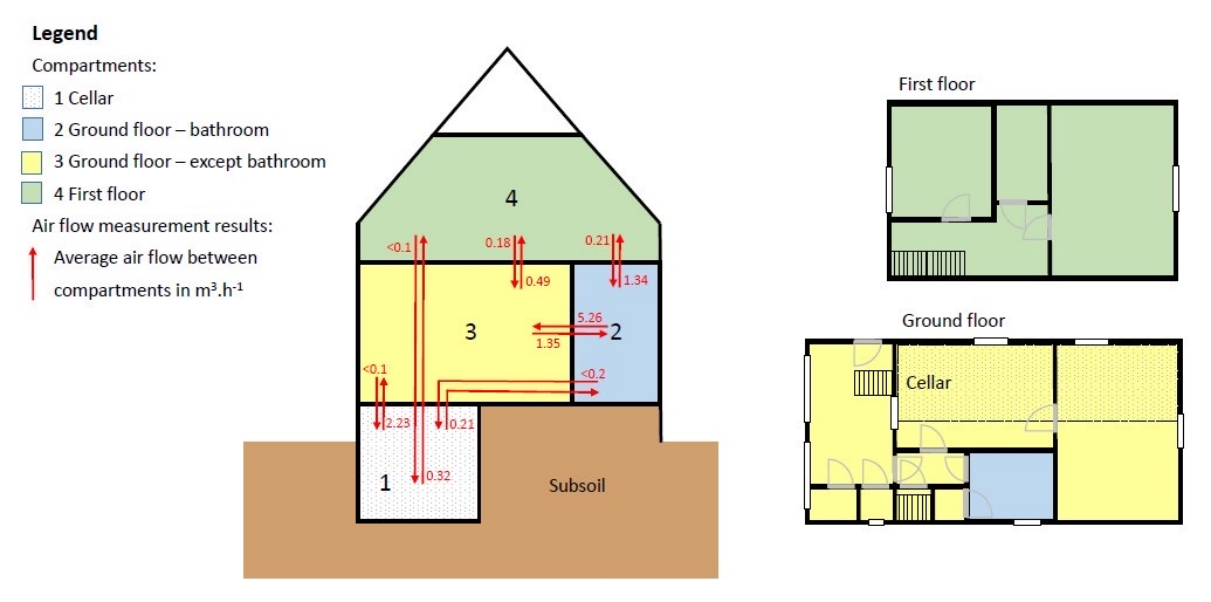
AIR EXCHANGE MEASUREMENT

Measurements results:

- dominant air flow from lower to higher floors,
- very good homogeneity within the first floor,
- no analytes from the upper floors were detected in the cellar.

Significant amount of air from the basement and the bathroom enters the rooms of the ground and first floors.

measurement period	2021	2025
duration [days]	14	14
occupancy	mostly occupied	empty
compartment	average ACH [h-1]	
cellar	0.7 ± 0.1	0.72 ± 0.05
ground floor – hallway	0.2 ± 0.1	-
ground floor – bathroom	-	0.05 ± 0.01
ground floor	0.16 ± 0.04	0.05 ± 0.02
first floor	0.24 ± 0.03	0.09 ± 0.01
average (whole building)	**0.25 ± 0.03**	**0.13 ± 0.05**

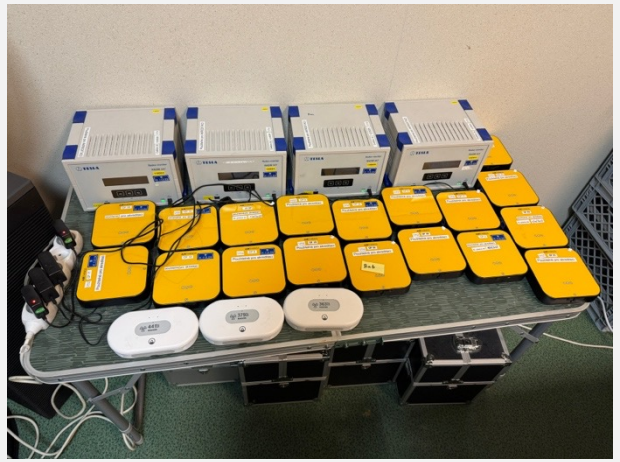


LESSONS LEARNED

- Training course received high overall rating, highly appreciated was the experience from field measurements.
- Participants encountered typical real-world challenges – missing data for analysis, lost pliers for electret chamber components, and forgotten parts of the soil permeability measurement device, processing large data set from all monitors and detectors placed across the building, writing measurement report, etc.
- Air exchange rate was (again) found as a key component of radon diagnostics.
- Utilization of low- and medium-cost CRMs enabled monitoring of radon concentration over time in both living and technical rooms.
- Cost also influences the capabilities of CRMs (single device can't serve all applications anymore).

CONCLUSION

- Low-cost CRMs represent a transformative development in accessible, convenient radon diagnostics, particularly for residential settings and citizen science applications.
- However, integration of low-cost CRMS into regulatory frameworks requires caution due to possible decline of performance and calibration shift over time.
- This case study utilized only those low- and mid-cost CRMs that undergo periodic testing in SURO's radon chamber and, specifically, devices that are type-approved and subject to regular metrological verification.
- Training course provided opportunity for its participants to carry out real radon diagnostics of a single family house.
- Main source of radon in a habitable rooms was not the cellar as was in the original idea but rather radon infiltration from the subsoil beneath the bathroom and part of the living room.
- The most cost-effective mitigation strategy for this particular building is sub-slab depressurization.



FUNDING

This research was funded by the European **RadoNorm** project – Euratom Research and Training Programme 2019–2020 under grant agreement No 900009.

This work has been partially supported by the **PIANOFORTE** project that has received funding from the H2020-EURATOM research and innovation program under the 101061037 grant agreement.

This work was supported by the **Grant Agency of the Czech Technical University in Prague**, grant No. SGS24/149/OHK4/3T/14.

This work has been co-funded by the **Erasmus+** programme of the European Union.

This work has been partially supported by the Spanish **Nuclear Safety Council** (CSN)-funded project "Radon exhalation from Building Materials: Radiological Impact and Corrective Measures (EXRADON)" (PR-047-2021).

THANK YOU FOR YOUR ATTENTION