Radon programme of the Czech Republic – New findings and challenges

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Radon program of the Czech Republic Overview

- Decree of Ministry of health on requirements of management of exposure from radon and other natural radionuclides issued on February 12, 1991
  - Radon commission
- Responsible organization and coordinator of all activities: State Office for Nuclear Safety (from 1995, atomic act 1997)
- Radon programme of the Czech Republic, 2000 – 2009
  - Identification of all dwellings with elevated radon concentration
  - Technical standards for protection of buildings and corrective actions
  - Scientific and technical support of the RnPrg, development of measurement protocols
- Radon programme of the Czech Republic - Action plan, 2010 – 2019
  - Targeted measurement campaigns
  - Communication campaigns
  - Radon prevention strategy, Regulation of existing exposure through support of house-owners and building sector
  - Scientific and technical support of the Action plan
- Development of new strategic plan for next decade has already started

Radon program of the Czech Republic Legislation

- New atomic law and supportive documents (decrees, methodologies) implementing the Directive 2013/59/Euratom
  - RL for radon concentration 300 Bq/m^3 for both, new and existing buildings, measured in habitable room
  - RL for maximum dose equivalent 1 µSv/h, measured in habitable room 0.5 m from the wall, 1 m above ground
- ČSN 73 0601 Protection of buildings against radon from the soil (Czech Technical Standard)
- ČSN 73 0602 Protection of Buildings against radon and gamma radiation from building materials (Czech Technical Standard)
- Methodologies issued by the State Office for Nuclear Safety
  - for indoor radon measurement
  - for radon in soil gas measurement and building site characterization
  - for measurement and assessment of personal doses for workers in NORM industry
  - for measurement and assessment of effective dose for workers on radon workplaces
  - clearance of materials from NORM workplaces
- Guidelines for building professionals
  - developed by the Faculty of civil engineering, Czech Technical University in Prague

Radon program of the Czech Republic Findings

- Increasing energy efficiency of buildings and related health hazards
  - Issue for dwellings as well as for buildings of public interest
  - Thermal retrofitting of existing (old) buildings and new construction technologies
- Issues connected to mitigations of elevated radon levels
  - System of subsidies is not that attractive as one might think
  - Limited information on radon levels in formerly mitigated houses
- Buildings with elevated activity concentration of ^{226}Ra – reloaded
  - 3000 factory-made family houses built from slag concrete panels (^{226}Ra mass activity 1-10 kBq/kg)
  - Dose rates up to 2 µGy/h 0.5 m from the wall

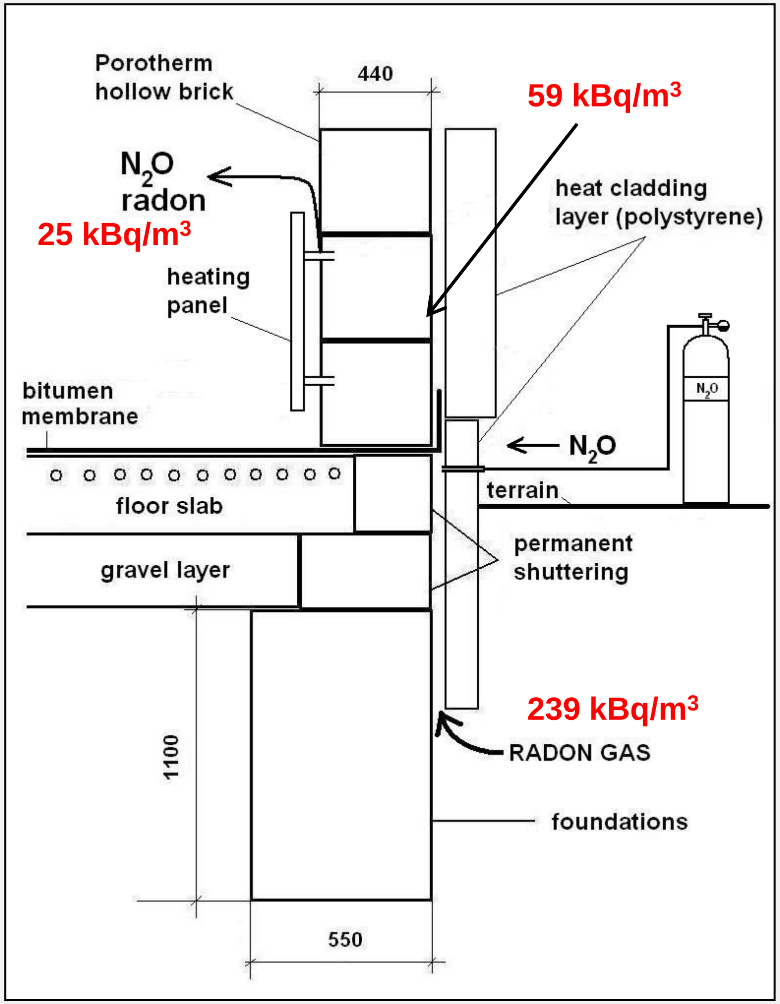
Increasing energy efficiency of buildings and related health hazards

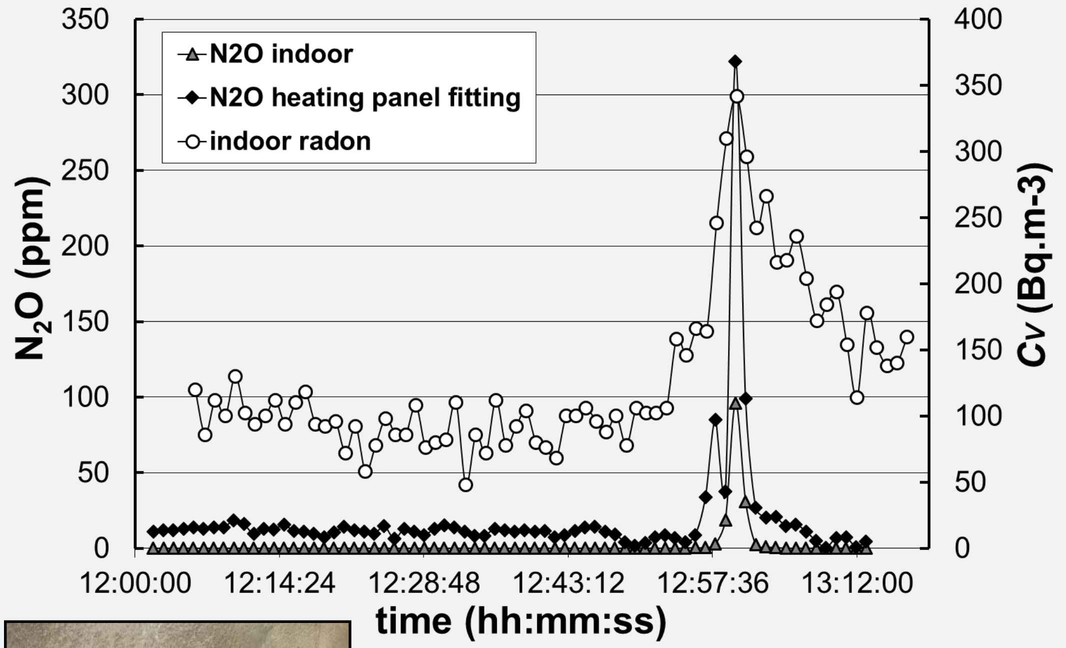
- Housing stock categories
  - new buildings – design and construction practice is primarily focused on **energy performance of buildings** (air-tightness of the building envelope is the dominant goal)
  - existing dwellings – **renovation and energy retrofitting**; frequently non-balanced design ignoring the IAQ requirements linked to the air-exchange rate reduction
- General human health hazards associated with home energy retrofits
  - CO, CO_2, radon concentration, asbestos, formaldehyde and other VOC, moisture accumulation leading to mold growth and structural decay.
- Energy savings technologies
  - ETICS (External Thermal Insulation Composite System)
  - Reduction in overall ventilation rates caused by air sealing

Radon entry path tracking in newly built house

- Building built in 2012
  - high radon potential building site (RC 5.3 – 137.6 kBq/m^3), double layer damp proof bitumen membrane, floor heating system
  - indoor radon concentration raged from 1300 to 6900 Bq/m^3
  - low ventilation rate identified by tracer gas measurement campaign
- Detailed radon diagnosis was done to identify radon paths (the only radon source was the subsoil)
  - Diagnosis indicated the radon transport from the subsoil within the air gap between the walls and exterior thermal insulation layer into the indoor environment
- Entry path tracking experiment was carried out
  - Blower door test - depressurization of the building (-20Pa)
  - Constant tracer gas injection (N_2O) into the air gap between the cavity wall and thermal insulation (XPS board) or into the soil gas probe in the vicinity of buildings. Indoor measurement of tracer gas concentration.
  - Indoor radon concentration measurement – continuous radon monitors (Radonic – airflow ionization chamber operating in current mode, fast response ~ 1 min)
- Tracer gas concentration measurement – indoor vs. identified leakage areas (wall-floor joints; heating panel fittings)
  - time response estimate – time elapsed since BD test commencement till tracer gas detection 1 min. 48s

Infiltration experiment – tracer gas application – radon entry path tracking

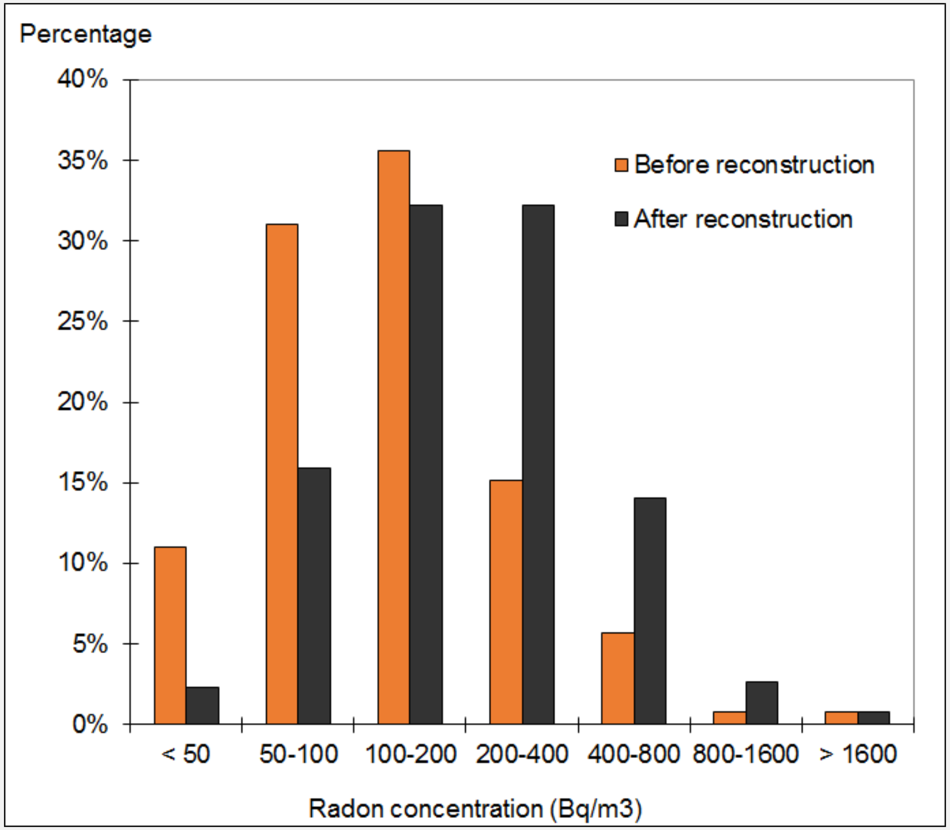




Thermal retrofitting of existing buildings

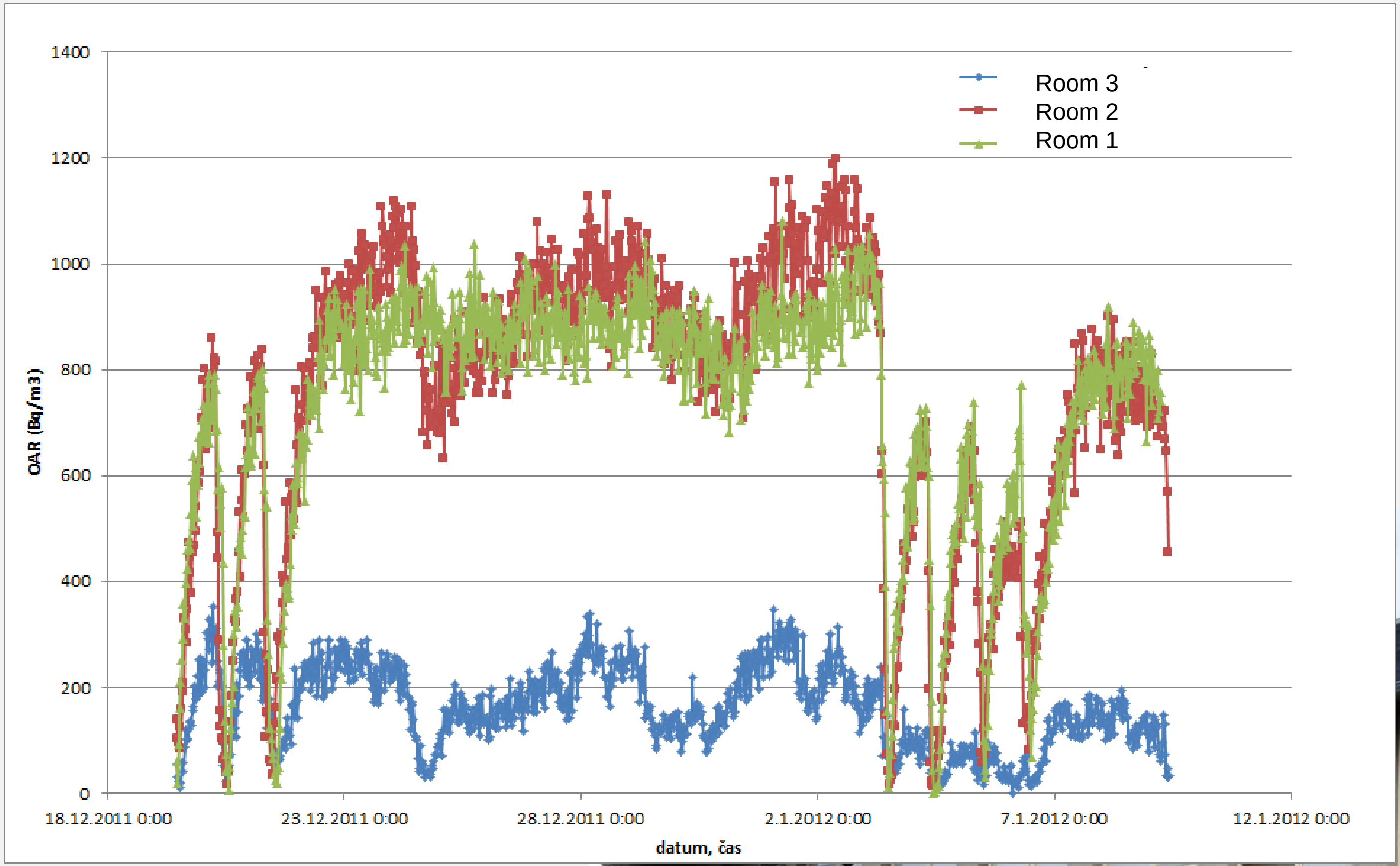
- Two measurement campaigns in schools and kindergartens were organized in 1990s and from 2011 to 2018.
  - Passive radon detector based on LR-115 II, first campaign used bare detectors, second campaign detectors enclosed in diffusion chamber.
  - Exposure time 1 year for the first campaign, academic year (Sept – Jun) only for the second campaign.
- Some of the buildings underwent reconstruction in the mean time.
  - Type of reconstruction work was asked in the questionnaire accompanying detectors
- 2 groups of buildings with Rn measurement available from both measurement campaigns were formed – with new tight plastic windows, with original windows.

Reconstruction	Number of buildings	Mean radon level in the 1990s (Bq/m^3)	Mean radon level after 2011 (Bq/m^3)
YES	264	125 (GSD = 2.15)	204 (GSD = 2.15)
NO	247	136 (GSD = 2.14)	149 (GSD = 2.27)



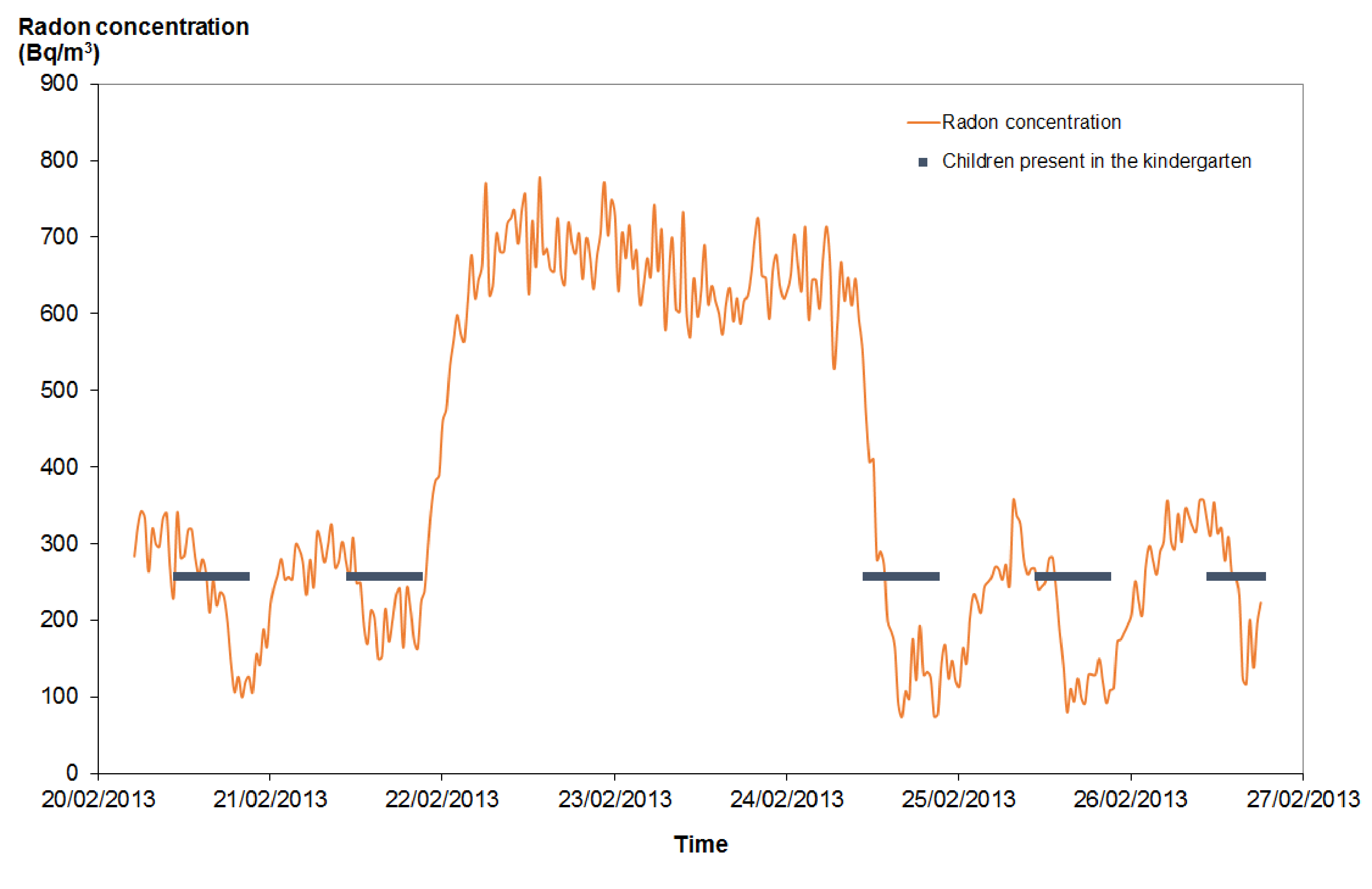
Mean increase of radon concentration is 63 % for the group with new windows compared to the group of buildings with original windows where the increase is negligible.

The difference between the two groups was tested using Analysis of Variance, and was found to be statistically significant.



Comparison of indoor radon concentration in 3 rooms on the same floor a single building, the only difference were windows.

Effect of tight windows

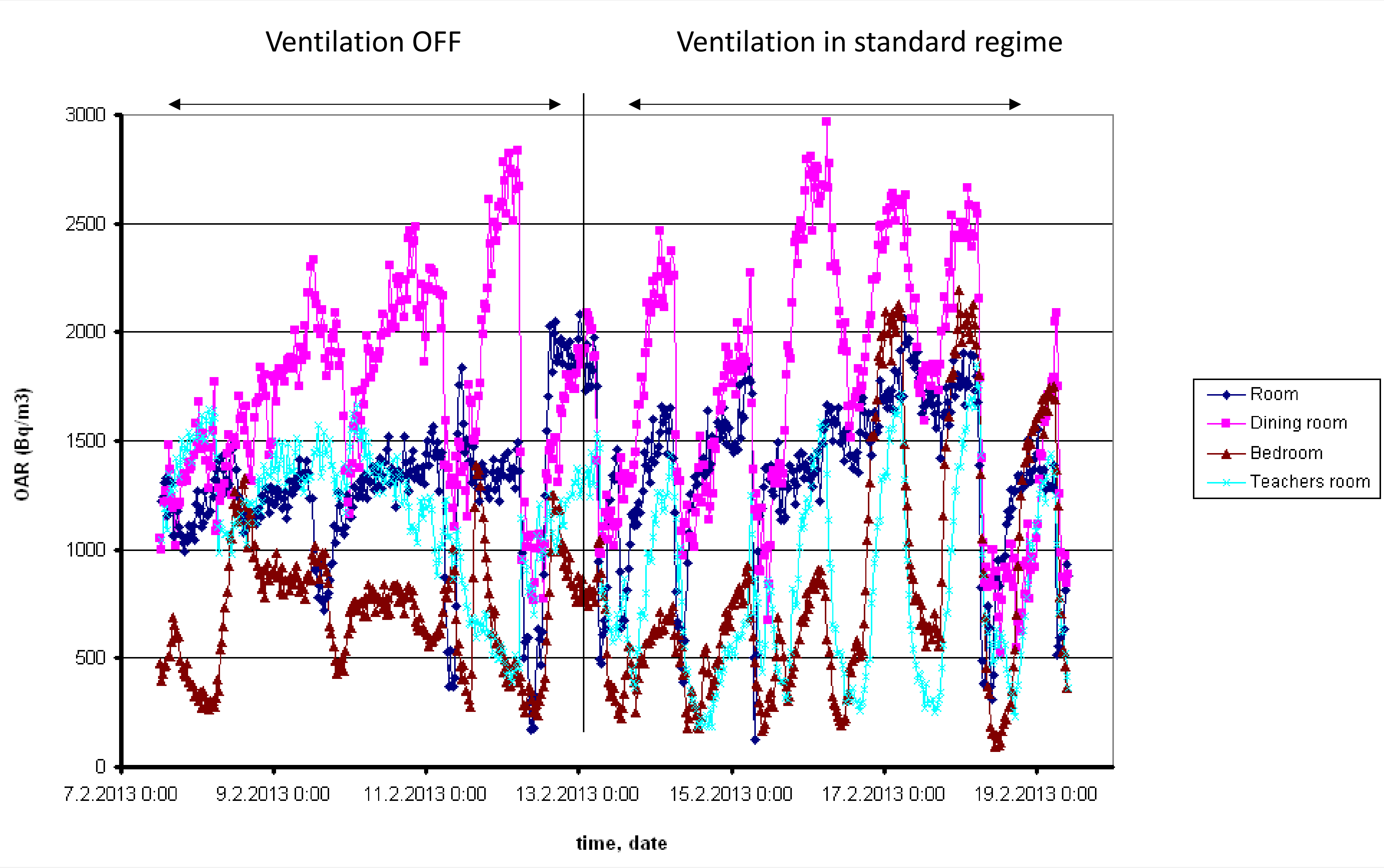


Sustainability of low radon levels reached by mitigation

- Experience from mitigated buildings (family houses, kindergartens)
  - Some of the house owners switched off the forced ventilation (too noisy, too expensive, too difficult to maintain, …) → not all of the mitigation systems are suitable for all buildings
  - Some of the house owners took care about the system, but never checked its efficiency again →lack of communication towards the house owner
  - Some of the house owners reconstructed the building, the mitigation system was not reflected, and the efficiency of mitigation was not measured again →lack of communication towards the house owner

- Long term sustainability of low radon values reached by the mitigation should be one of the tasks of radon programme.
  - Through targeted communication (and support of measurement)

Ventilation system / not effective /



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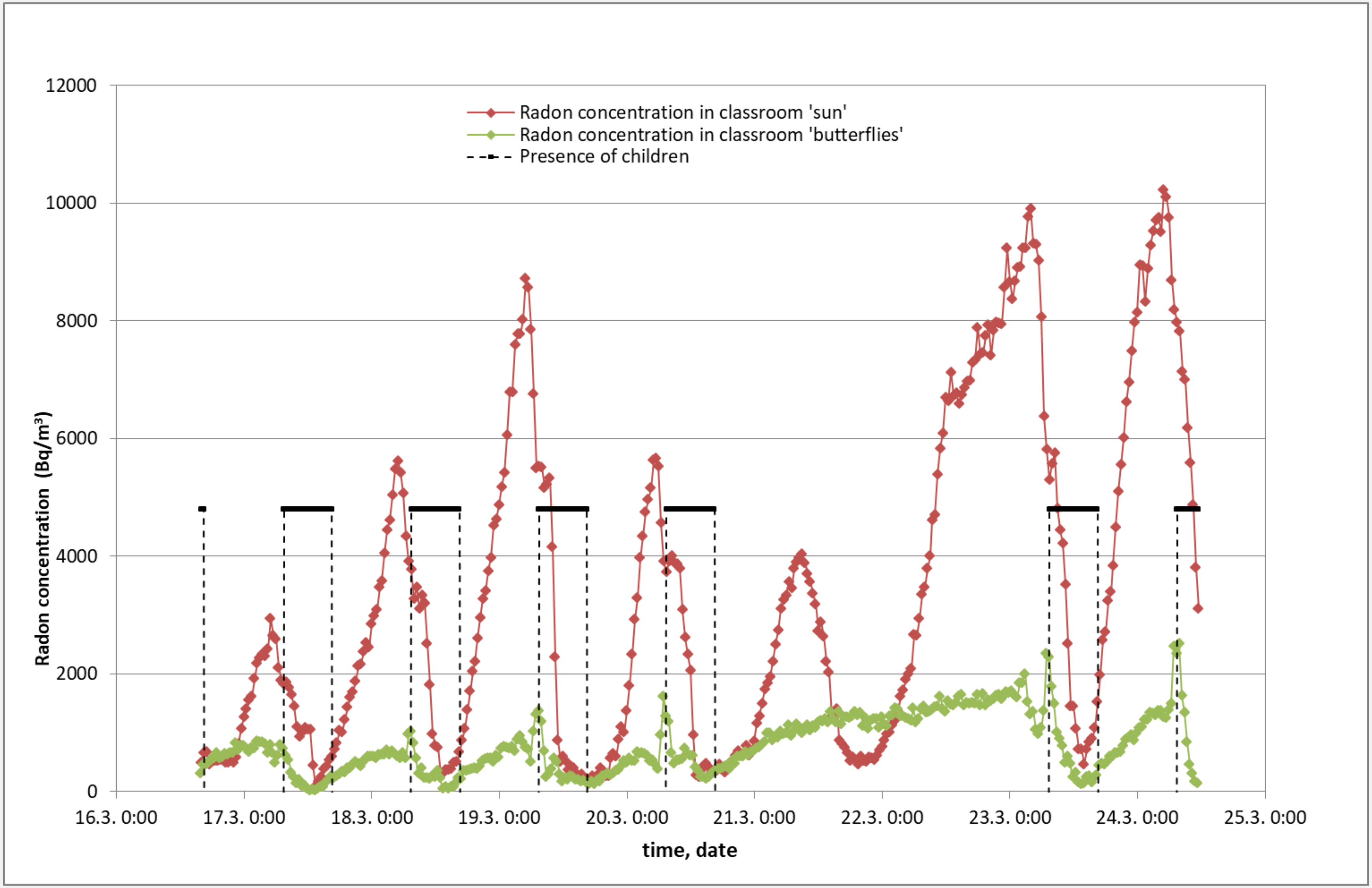

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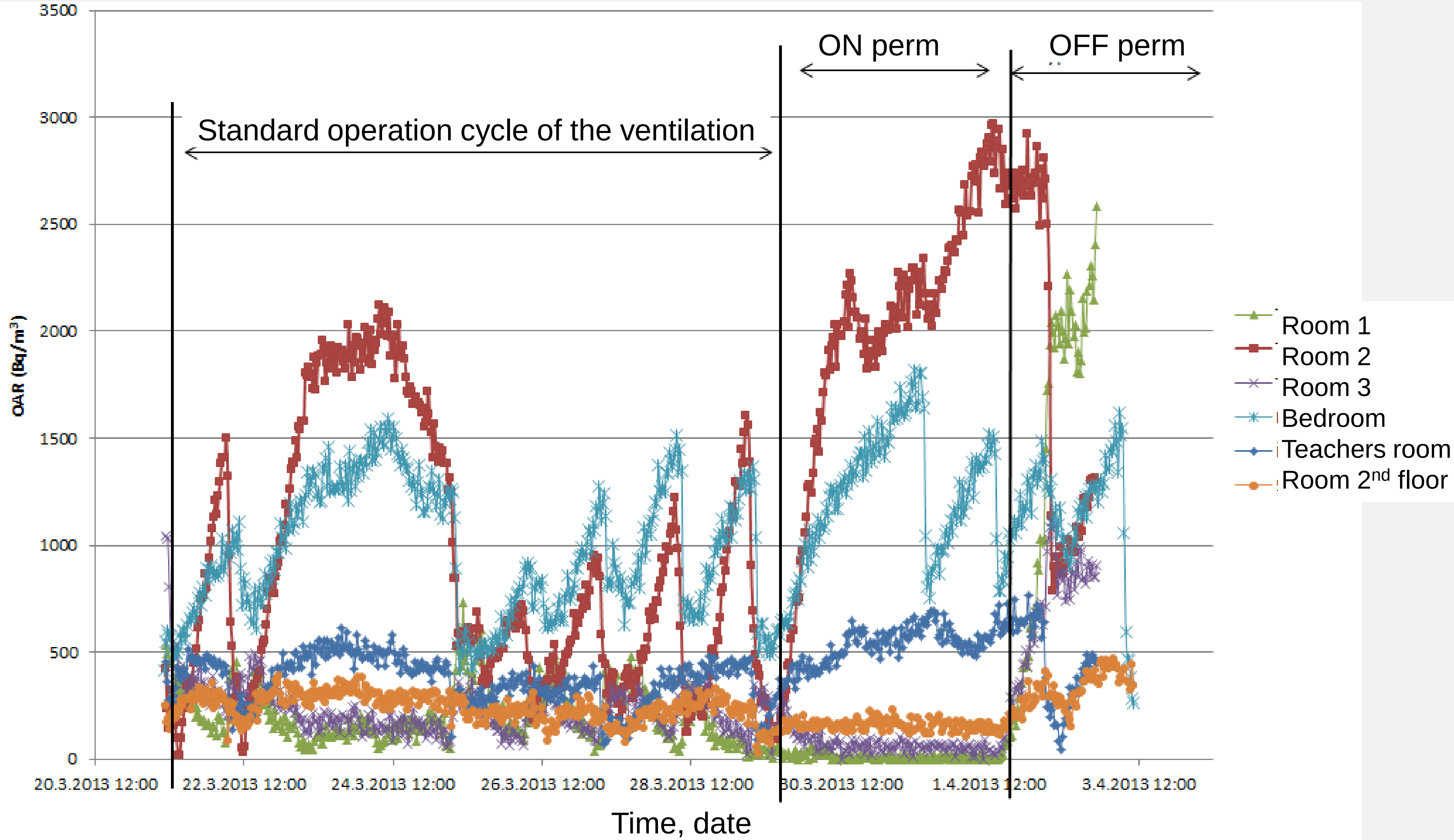
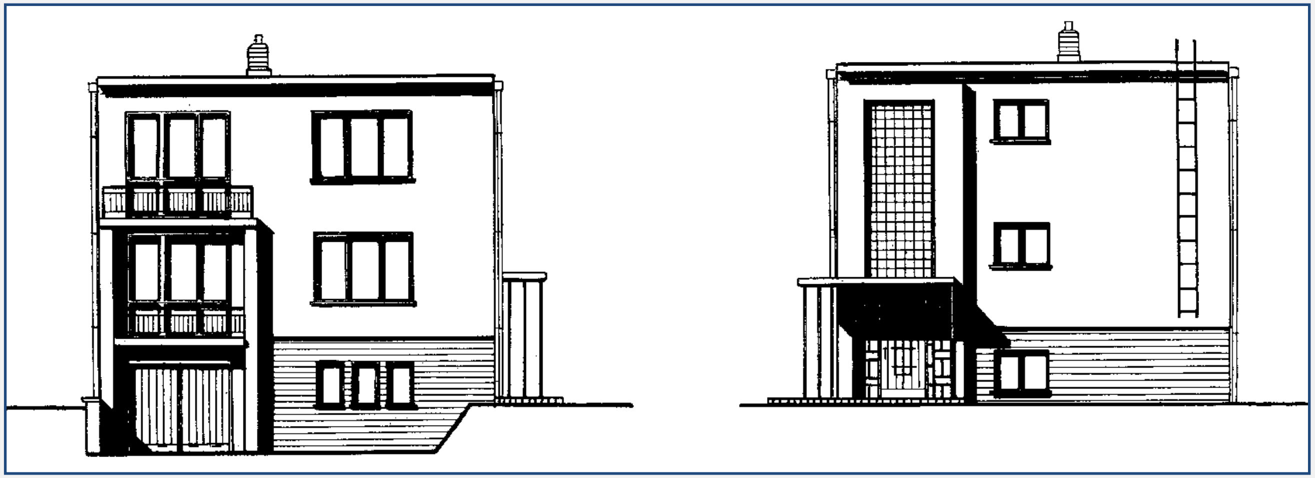


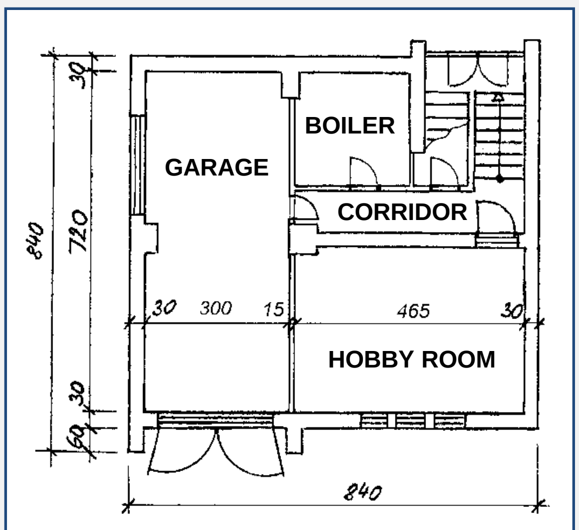
Buildings with elevated activity concentration of ^{226}Ra – reloaded

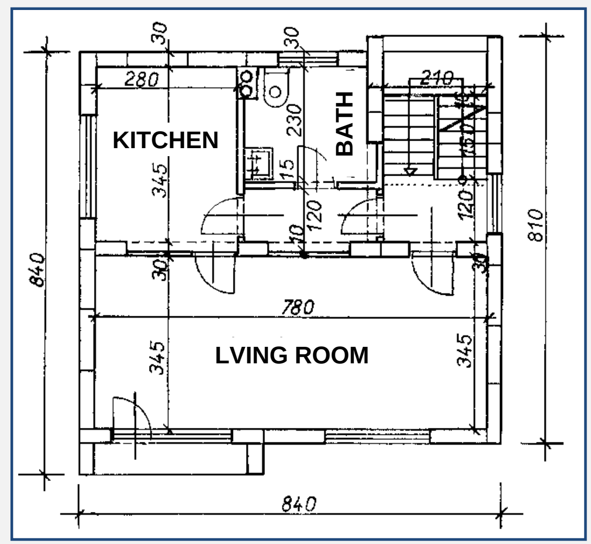
- State enterprise Prefa Hyskov produced slag concrete panels for apartment houses at the beginning of 1960. High dose rate was found in these houses and the use of the slag was banned.
- Slag origin: the small power plant burning local high radioactive coal from Rynholec near Prague. Due to the changes in the factory ownership in 1968 the information on the high radium content was lost. And the slag was used again for slag concrete panels.
- Around 3 000 of 'START' houses are distributed across the Czech Republic.
- 1988 Measurement campaign to determine the situation in each of the houses.

Single family house of the ‘START’ type built in 1975



UNDERGROUND FLOOR

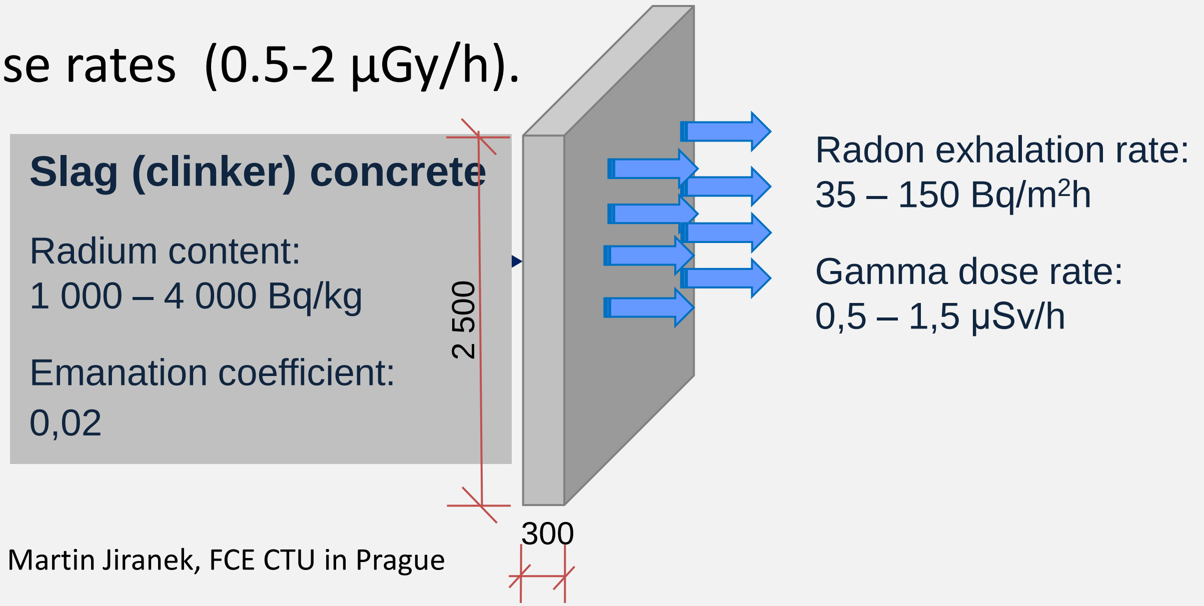




FIRST FLOOR

Courtesy of Prof. Martin Jiranek, FCE CTU in Prague

- All the peripheral and supporting walls were made from this material, while some partition walls were from bricks → the spatial variation in rooms was characterized by a factor of 2, with highest values in the corner of peripheral walls.
- Content of radionuclides was highly variable in the slag → resulting dose rate and radon concentration in buildings built of this material is highly variable.
- Small emanation coefficient of the material (only 1-5%) → the indoor radon concentration was fortunately only in the range of 200-800 Bq/m^3.
- The indoor gamma dose rates (0.5-2 µGy/h).



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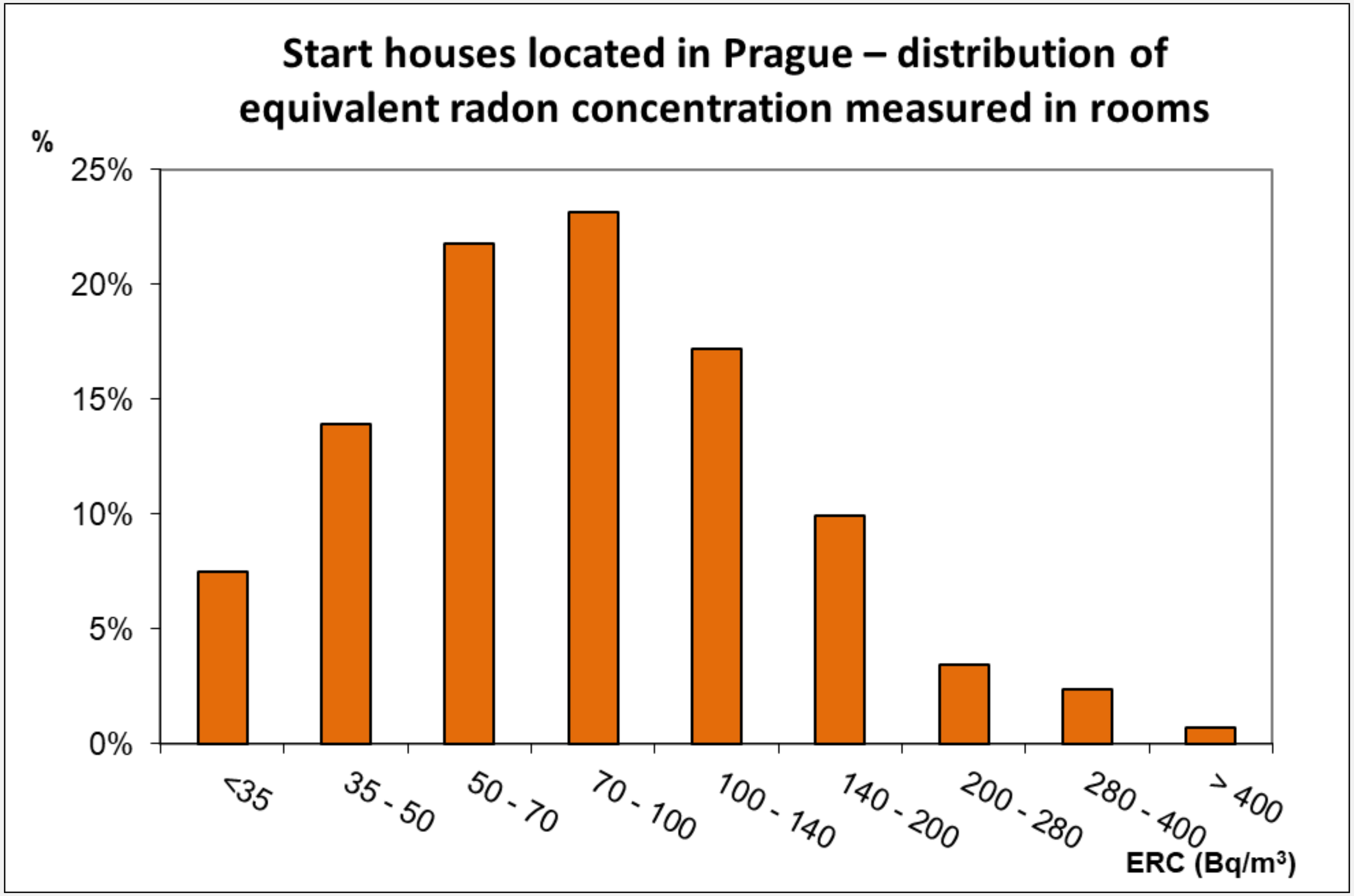
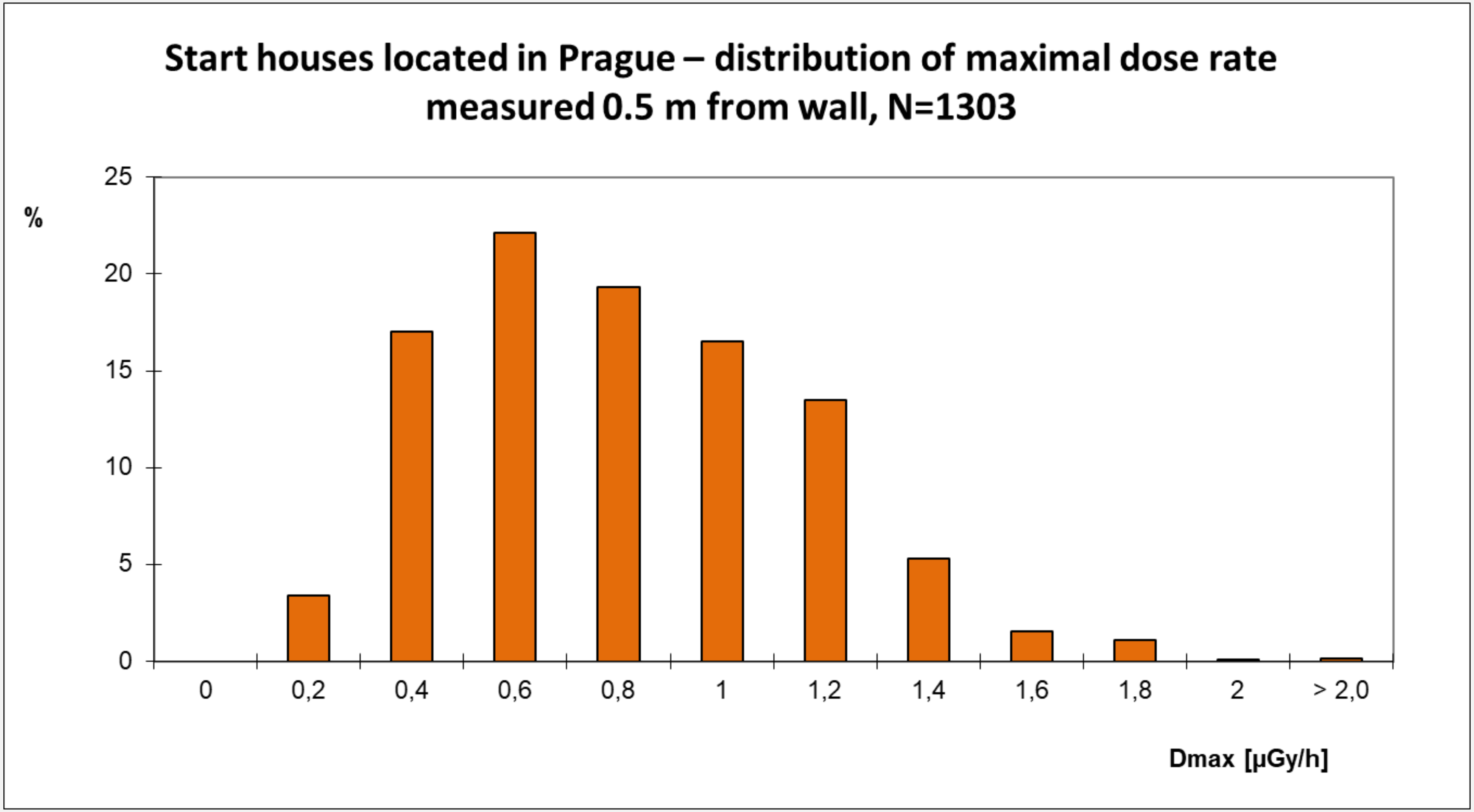
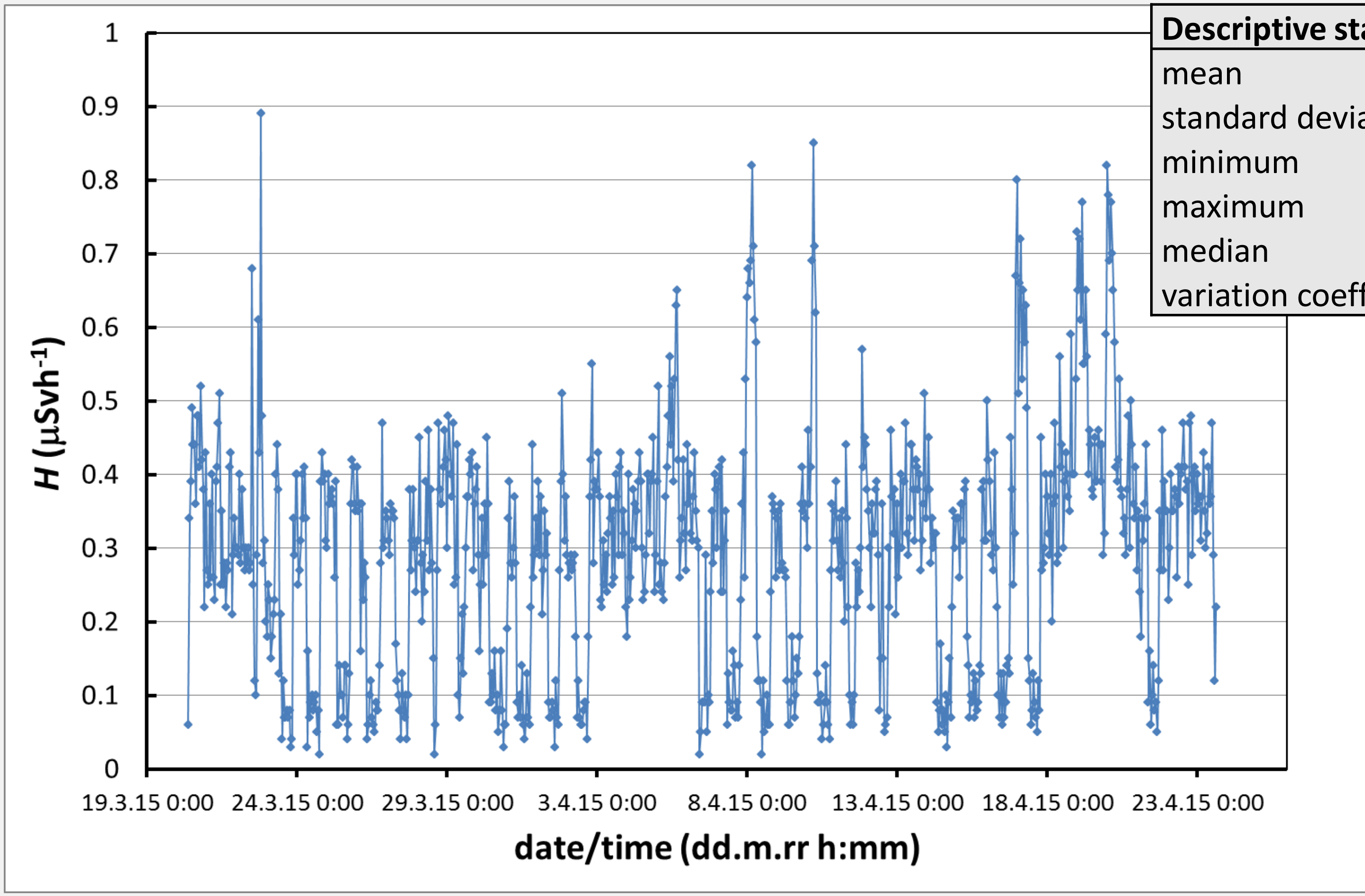
ERC > 140 Bq/m^3	16,5 %
ERC > 200 Bq/m^3	6,5 %



Dmax > 0,5 µGy/h	80 %
Dmax > 1 µGy/h	21 %



Personal dose equivalent rate continuous measurement



Descriptive statistics *H* ($\mu Sv.h^{-1}$)	
mean	**0.29**
standard deviation	**0.16**
minimum	**0.02**
maximum	**0.89**
median	**0.30**
variation coefficient	**0.54**

Intervention level for existing houses

- Recommended values (1987)
  - indoor radon (existing houses): 400 Bq/m^3
  - indoor gamma dose-rate: 2 µGy/h
- Having in mind both radon and gamma exposures, the intervention level that summed both exposures was defined by index S:

$$S = \frac{D}{2\mu Gy/h} + \frac{C_{Rn}}{400Bq/m3}$$

D is the gamma dose rate (µGy/h)

C_{Rn} is the long-term radon concentration (Bq/m^3).

- This sum rule (used only if D > 0.5 µGy/h) and value S = 1 were used for decision making on remedial measures with governmental support .

Public awareness

- The owners of these houses were aware of the **cause of their trouble** and called for remedial measures or to redeem these houses by the government.
- The government has agreed in 1991 (after great struggle) .
- Most of the owners have accepted remedial measures (approx. 10 000 E per house for mitigation) ; only 4 % owners have sold their house (approx. 40 000 E per house).
- Mitigation
  - **radon removal** by forced ventilation was the only effective and reasonable mitigation (ventilation system with heat recovery, controlled by a central computer, was found to be most effective countermeasure and was used in practice). Radon level was reduced to 30 % of the former values in average.
  - Other remedial measures (gamma shielding, removal of building material, wall covering by special radon proof materials, etc.) were tested in some cases but were rejected as non-effective.

Development of regulatory framework

- The experiences from the past lead to strict regulation of natural radioactivity:
  - indoor radon a gamma exposure in existing buildings
  - natural radioactivity in building materials
- Screening - exemption level (EU recommendation)… „activity index“ I (based on gama dose-rate estimation 0.3 mSv)

$$I = \frac{C_{Ra}}{300 Bq.kg^{-1}} + \frac{C_{Th}}{200 Bq.kg^{-1}} + \frac{C_{K}}{3000 Bq.kg^{-1}}$$

< 0.5 used in bulk amount

<1 raw material

< 2 „small“ amount (tiles)

- Limitation - ^{226}Ra content limitation to limit Rn entry rate

  < 150 Bq/kg for material used in bulk amount (brick, concrete, gypsum..

  < 300 Bq/kg for raw material (sand)

  <1000 Bq/kg for constructions without stay of persons

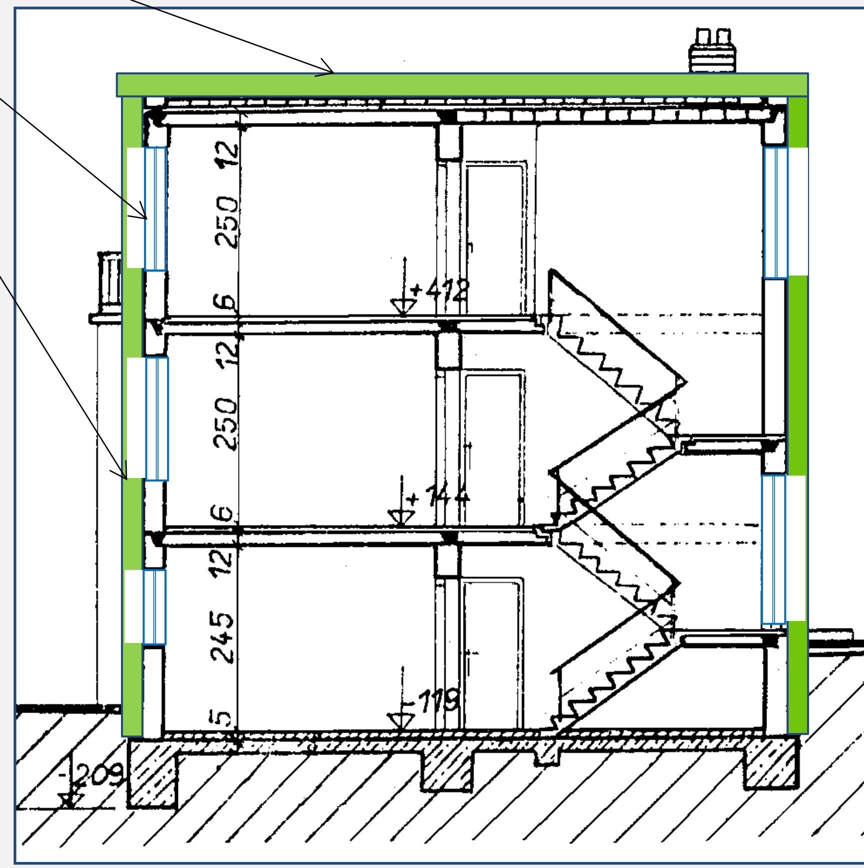
Example of thermally retrofitted START house

ROOF – 100 mm polystyrene

New air-tight plastic windows

ETICS – 100 mm polystyrene

2008 – energy-saving measures undertaken



Courtesy of Prof. Martin Jiranek, FCE CTU in Prague

Indoor radon concentration before and after adoption of energy – saving measures (track detectors exposed for 1 year)

Room	Radon concentration [Bq/m³]		Ratio [-]
	before C_{before}	after C_{after}	C_{before}/C_{after}
Living room + kitchen – 1st floor	302	753	2,5
Children`s bedroom -2nd floor	296	1 165	3,9
Main bedroom - 2nd floor	312	1 524	4,9
Kitchen - 2nd floor	438	1 025	2,3
Mean values	337	1 117	3,4

Possible reasons

- Decrease in the ventilation rate (higher air-tightness) – confirmed, air-exchange rate measured by the mean of tracer gas was 0.35 ± 0.11 h^{-1}
- Increase in the radon exhalation rate (ETICS) – not confirmed

Mitigation

- Improved natural ventilation
- Forced ventilation with energy recovery was rejected as too costly by the owner

How to: demolish the START building

- Who wants to demolish the START house (and is willing to comply with law) has 3 options:
  1. The house will be demolished and the material will be removed to the landfill by the owner him(her-) self.
  2. The house will be demolished by the owner and transport of material from a building site to the landfill will be done by a company
  3. The house will be demolished by a company as well as transport of material to the landfill

Is there any company involved?

- Measurement of mass activity concentration in building material and the dose rate should be done by a licensed laboratory.
  - Mass activity concentration of natural radionuclides is bellow clearance level and the dose rate is lower than 0.5 μ Sv/h → OK
  - Mass activity concentration of natural radionuclides is above clearance level

  (1 Bq/g for U/Th and 10 Bq/g for ^{40}K) and/or dose rate is equal/above 0.5 μSv/h then:

The building site becomes a NORM workplace

The building site becomes a NORM workplace → the house owner has to:

1. Inform the regulator about the commencement of the workplace with potentially increased exposure to natural source of radiation (with all information required by the decree and law)
2. Carry out measurements to determine personal doses at the workplace and report them to the regulator (or based on the description of situation and prior agreement with the regulator to assess the doses to the workers based on worst case scenario)
3. Assess the effective doses to the members of public caused by a discharge of the material (radioactive substance) from the workplace during a calendar year
    1. The resulting effective dose is < 0.3 mSv → discharge without license, inform the regulator 60 days prior the discharge
    2. The resulting effective dose is > 0.3 mSv → discharge with license
4. Provide all of the information required by the law and decree to the regulator and store the information next 30 years and inform the workers about the risk of radiation.

Summary

- Buildings built of building material with elevated natural radionuclide content:
  - Can be mitigated by increased ventilation of indoor air – radon removal
  - In case the radon source is **only** building material, the source term is stable - thermally retrofitted house can be mitigated by increased ventilation as well.
  - In case the radon source is not only the building material – the design of corrective action is much more complicated. Forced ventilation (underpressure) can make thigs even worse.
  - Removal of gamma radiation is almost impossible, lead shielding can be applied to the worst spots.
- Some of the issues went to the court
  - The court has never questioned the measurement which were carried out by the properly licensed measurement laboratory according to official methodologies.
  - Radon was considered as a consequence of elevated radium content which was considered as the main issue and undiscoverable defect.

Summary

- Not only energy needs, but also IAQ should be considered when planning the energy conversion of buildings.
- There is still very limited harmonisation between energy savings projects and programmes and IAQ projects and programmes, RnPrg included. Measured ventilation rates in new buildings are very low, often below the hygienic requirements.
- Once finished and verified to be effective enough, the mitigation should be followed in time by repeated verification measurements. We should keep the communication channel open also to the closed cases.

Thank you for your attention

- References:

  - Radiation Protection Dosimetry, Volume 160, Issue 1-3, 1 July 2014, Pages 149–153, https://doi.org/10.1093/rpd/ncu073
  - Radiation Protection Dosimetry, Volume 160, Issue 1-3, 1 July 2014, Pages 143–148, https://doi.org/10.1093/rpd/ncu074
  - Radiation Protection Dosimetry, Volume 160, Issue 1-3, 1 July 2014, Pages 43–47, https://doi.org/10.1093/rpd/ncu104

Save the date:
September 16 – 20, 2019, Prague, Czech Republic