Radon Diagnosis Procedures Focused on Energy Efficient Buildings

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Technology Agency of the Czech Republic

Radon Program of the Czech Republic 2010 ï 2019 Action Plan

Increasing energy efficiency of buildings and related health hazards

- **New requirements on evaluation of energy performance of buildings in the Czech Republic (EU) ï** implementation of the revised European Union Directive 2010/31/EU on the energy performance of buildings ï changes associated with energy certification of buildings
  - amended legislation needs to be applied on all types of buildings, including new build houses and existing dwellings (graded approach is defined)
  - Ąlack of harmonizationñ with public health care programs focused on IAQ requirements, including Radon Program ï Action Plan (2010-2019) coordinated by State Office for Nuclear Safety
- Apparent conflicts between professional experience and recommendations on air-exchange rate in residential buildings (issued by National Institute of Public Health) and Czech standards requirements given in ĻSN 73 0540 ï Part 2 (Thermal Protection of Buildings) **12-25$m^3.h^{-1}$; 0.4-0.6h^{-1} (occupied rooms); 0.1h^{-1} (minimal value for unoccupied rooms)**
- **Housing stock categories**
  - new buildings ï design and construction practice is primarily focused on energy performance of buildings (air-tightness of the building envelope is the dominant goal)
  - existing dwellings ï 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**
  - carbon monoxide and other combustion products from combustion appliances, **radon concentration**, asbestos, formaldehyde and other VOC, moisture accumulation leading to mold growth and structural decay

Common relevant energy saving technologies in civil engineering

Å Changes in building envelope materials and construction

- energy efficiency in housing is augmented by use of exterior slab and basement insulation (e.g. XPS boards application); keeping the foundation wall system warm and dry; expensive due to excavations and backfilling works
- interior thermo insulation layers application ï less expensive; risk of mold growth between the wall system and the interior insulation resulting from insufficient sealing (external load-bearing walls; roofs and attics etc.) ï XPS boards; mineral wool
- windows and exterior doors replacement

ETICS (**E**xternal **T**hermal **I**nsulation **C**omposite **S**ystem)

- improve the energy efficiency of both new and existing buildings
- set of construction elements consisting of certain (specified) prefabricated components being applied directly to the façade (adhesive; insulation material; anchors; base coat; reinforcement; top coat + painting; accessories)

Å The reduction in overall ventilation rates caused by air sealing

- application of flexible sealing compounds to close up gaps in buildings
- installing direct vent appliances
- ducts and pipes sealing (utility penetrations)
- joints sealing (wall-floor; window frames; door frames etc.)

Purpose of indoor radon measurement

- **Preventive measures or corrective actions failure identification vs. dose estimate procedures**
  - short-term indoor radon screening measurement (passive detectors; continuous monitors; minimal period of measurement 1 week) spot measurement not recommended
  - long-term mean indoor radon assessment (passive integral detectors; SSNTD, EIC)
  - methods of radon diagnosis (combination of radiometric and non-radiometric measuring procedures)
- Graded approach methodology (short-term screening measurement followed by long-term measurement in case of mean indoor radon exceeding the reference level; radon diagnosis)

- **Main influencing factors**

- building and building site related factors (radon potential of building site; type of house and construction materials; building geometry and location, thermal mass effect and thermal performance etc.)
- **residential habits** (occupancy factor; lifestyle; technical building systems operation - HVAC)
- weather conditions
- **diffusive vs. advective radon entry mechanism** (the effect of indoor-outdoor pressure difference induced by wind, stack effect and HVAC systems operation on indoor radon variations

Type of ventilation

- **Mechanically ventilated buildings** ï forced type of ventilation (specific modes of **HVAC** systems operation)
  - passive and low energy consumption houses
  - well defined and controlled pressure field conditions (over pressurizing, under pressurizing, balanced (equal pressure) systems
  - homogeneous pressure field within the single pressure zone building
- **Naturally ventilated buildings**
  stack effect (buoyancy driven ventilation)
  airflow caused by pressure difference due to air density differences ï magnitude of the airflow is determined by the pressure difference and building opening characteristics
  - building layout ï pressure zones distribution ï different radon entry rate pattern
  - neutral pressure level position ï internal and external pressures balanced
  interior heat sources distribution ï role of **floor heating** systems; local and central heating systems; solar radiation effects; glazing
- wind driven ventilation
  - two important factors - wind speed and wind direction
  - the pressure difference dramatically varies with building geometry and location of the building (highly protected vs. highly exposed buildings)
- Combined buoyancy-wind driven ventilation
  - very complex evaluation ï not many simplified methods available

Methods of radon diagnosis focused on energy efficient buildings

Å **Radon sources** identification and quantification (subsoil, building materials, water supply etc.)

- building material as a main source of indoor radon ï gamma dose rate mapping; in-situ gamma spectrometry or building materials samples laboratory analysis
  - different radon entry rate behavior (relatively stable radon exhalation rate from building materials; no significant pressure field effect regarding the radon supply)
  - constant radon entry rate approximation can be assumed

Å Radon entry rate analysis (simultaneous **continuous indoor and soil gas radon measurement**, **blower door tests, infrared imagery** etc.)

Å A radon potential quantification of building site (radon concentration and soil permeability measurement)

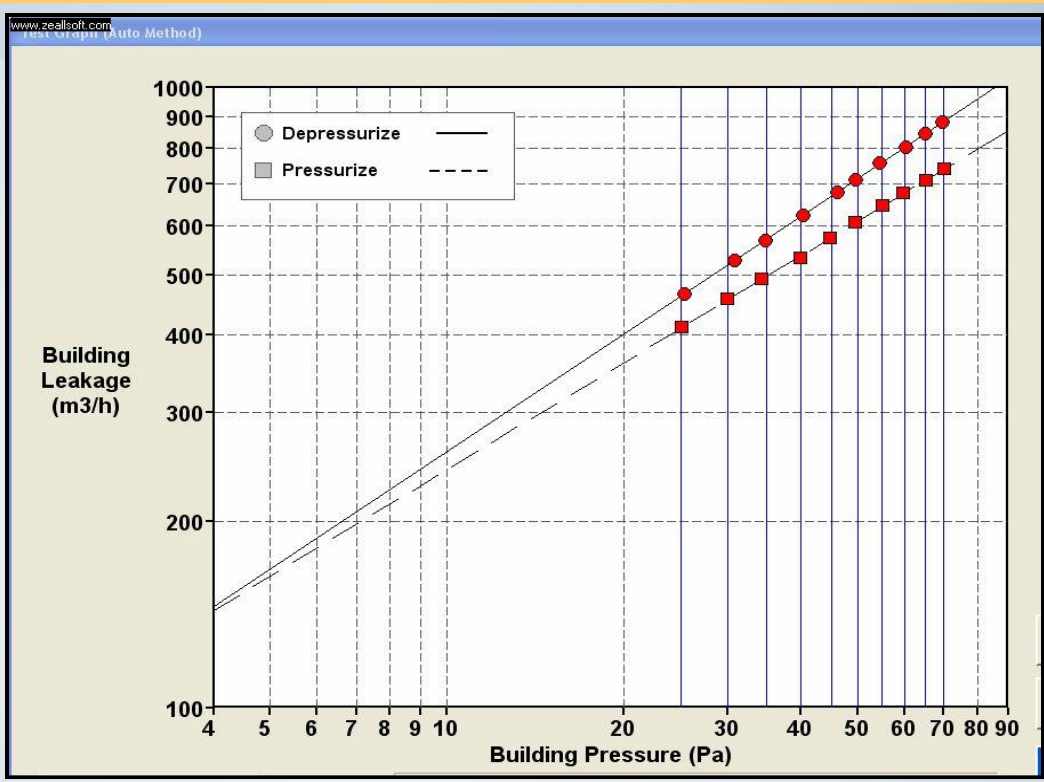
Å **Independent air exchange rate** assessment using tracer gas application (air infiltration, exfiltration evaluation, weather conditions monitoring)

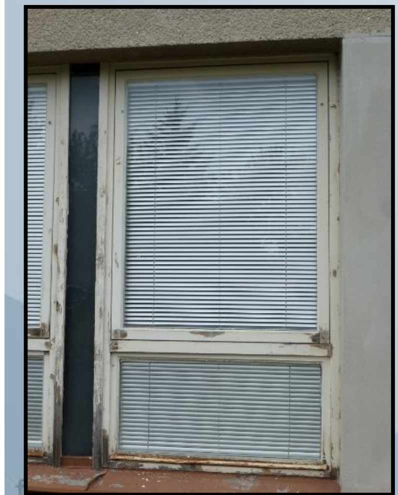
Å Interior spot air sampling from leakage areas (wall-floor joints; concrete slab cracks, utilities penetrations etc.)

Å Analysis of indoor radon transport and distribution for the different parts of the buildings

Å **Visual inspection** of buildings with regard to relevant physical properties of individual elements of building structures (fabric and components air tightness classification, individual locations selection for subsequent detailed radon entry analysis)

Blower door test (depressurization vs. pressurization)



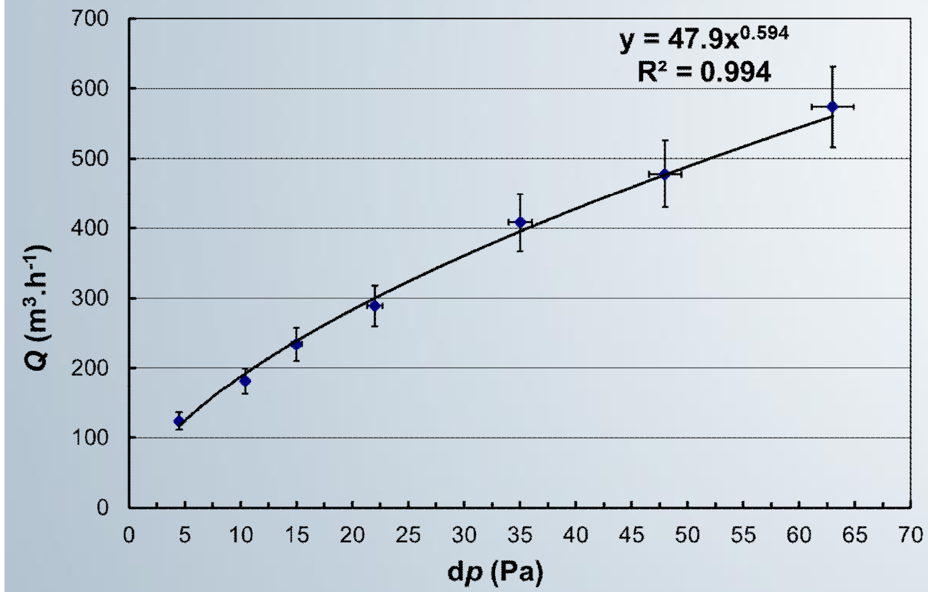


Measurement location	BD test n_{50} (h-1) depressurization	Annual mean indoor radon ($Bq.m^{-3}$) 2011-2012 I. Measurement campaign ï long-term (SSNTD)
Playroom I	2.3 +/- 7%	626
Playroom II	8.4 +/- 14%	124
n_{50} ratio	3.7	5.0

Blower door tests statistical analysis

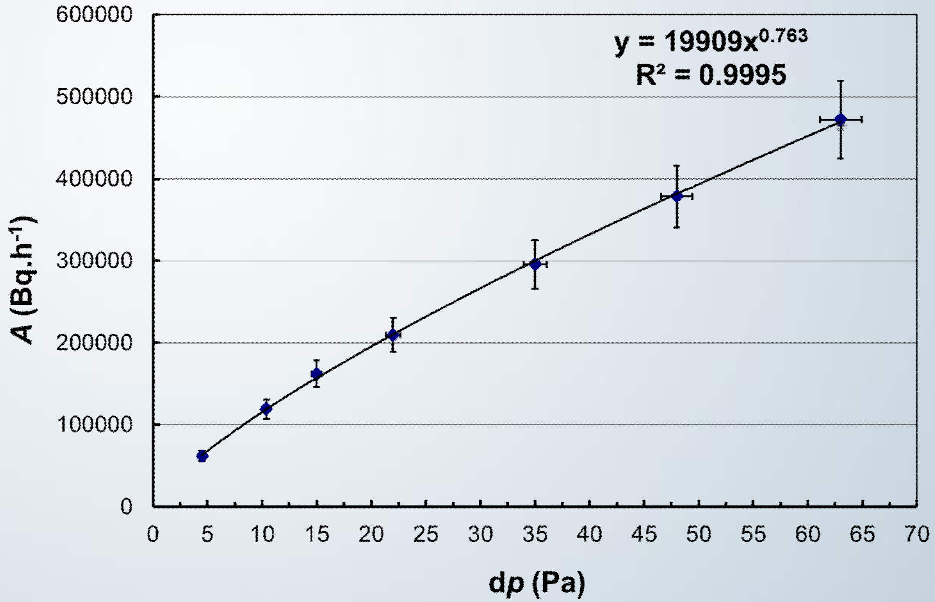
Effective air leakage area assessment

$$_{BD}Q(\Delta p) = f_{BD} \cdot (\Delta p)^{n_{BD}}$$



Radon entry rate BD characteristic

$$_{BD}A_{Rn} = f_{Rn} \cdot (\Delta p)^{n_{Rn}}$$



f_{BD}é ..flow coefficient

n_{BD}é .flow exponent
(turbulent or laminar flow)

Independent assessment of air-exchange rate (ACH) and radon entry rate (RER)

Simultaneous indoor radon a tracer gas concentration measurement ï single zone approximation:

$$\frac{\mathrm{d}c(t)}{\mathrm{d}t} = G - k(t)\cdot[c(t) - c_{EXT}(t)] \qquad \frac{\mathrm{da}(t)}{\mathrm{d}t} = Q_{\mathrm{Rn}}(t) - [\lambda + k(t)]\cdot(a(t) - a_{EXT}(t))$$

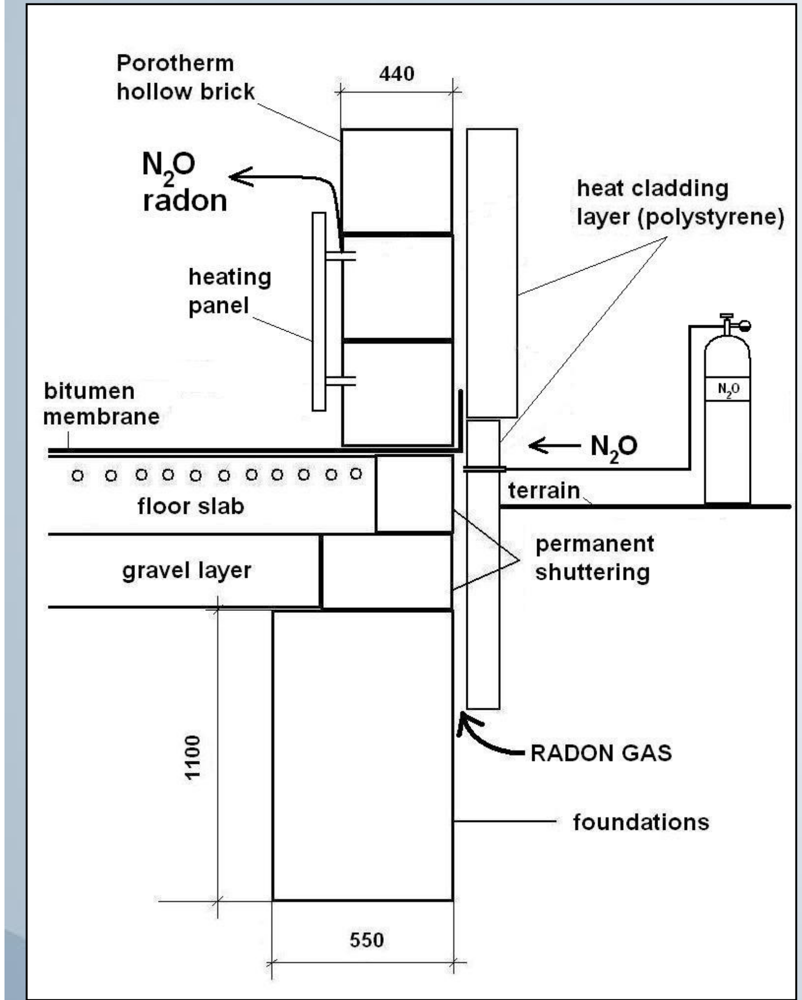
General assumptions: ACH(radon) = ACH (tracer gas) then the radon entry rate Q_{Rn}(t) can be expressed as follows:

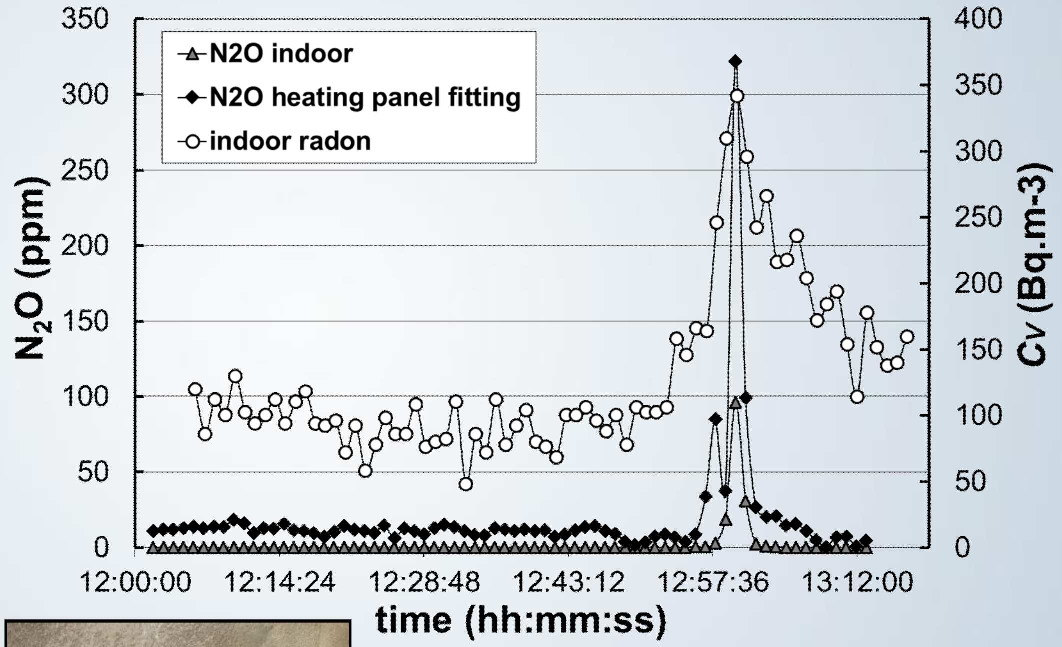
$c(t)$ $\frac{\mathrm{d}c(t)}{\mathrm{d}t}$ is time varying tracer gas concentration (in kg/m^3) and its time-derivative

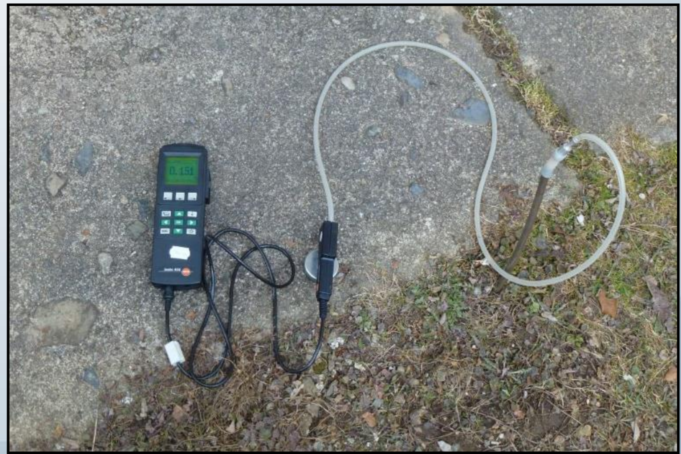
- c_{EXT} (t), a_{vEXT} (t) is time varying outdoor concentration of tracer gas and radon gas, respectively.
- λ is radon decay constant (0.00756 h^{-1}).
- *k(t)* is air exchange rate, ACH (in h^{-1}). It is assumed to be the same for both tracer gas and radon gas.
- *G* is a tracer gas entry rate into a house (in kg/ m^3 h). It is artificially injected into a house and generally is well-known.
- Q_{Rn}(t) is sum of radon entry rate into a house, RER (in Bq/m^3 h)

$$Q_{\mathrm{Rn}}(t) = V\left\{\frac{\mathrm{d}c_{\mathrm{Rn}}(t)}{\mathrm{d}t} + \left[\frac{G}{V} - \left(\frac{\Delta c(t)}{\Delta t}\right)\right].\frac{c_{\mathrm{Rn}}(t)}{c(t)}\right\}$$

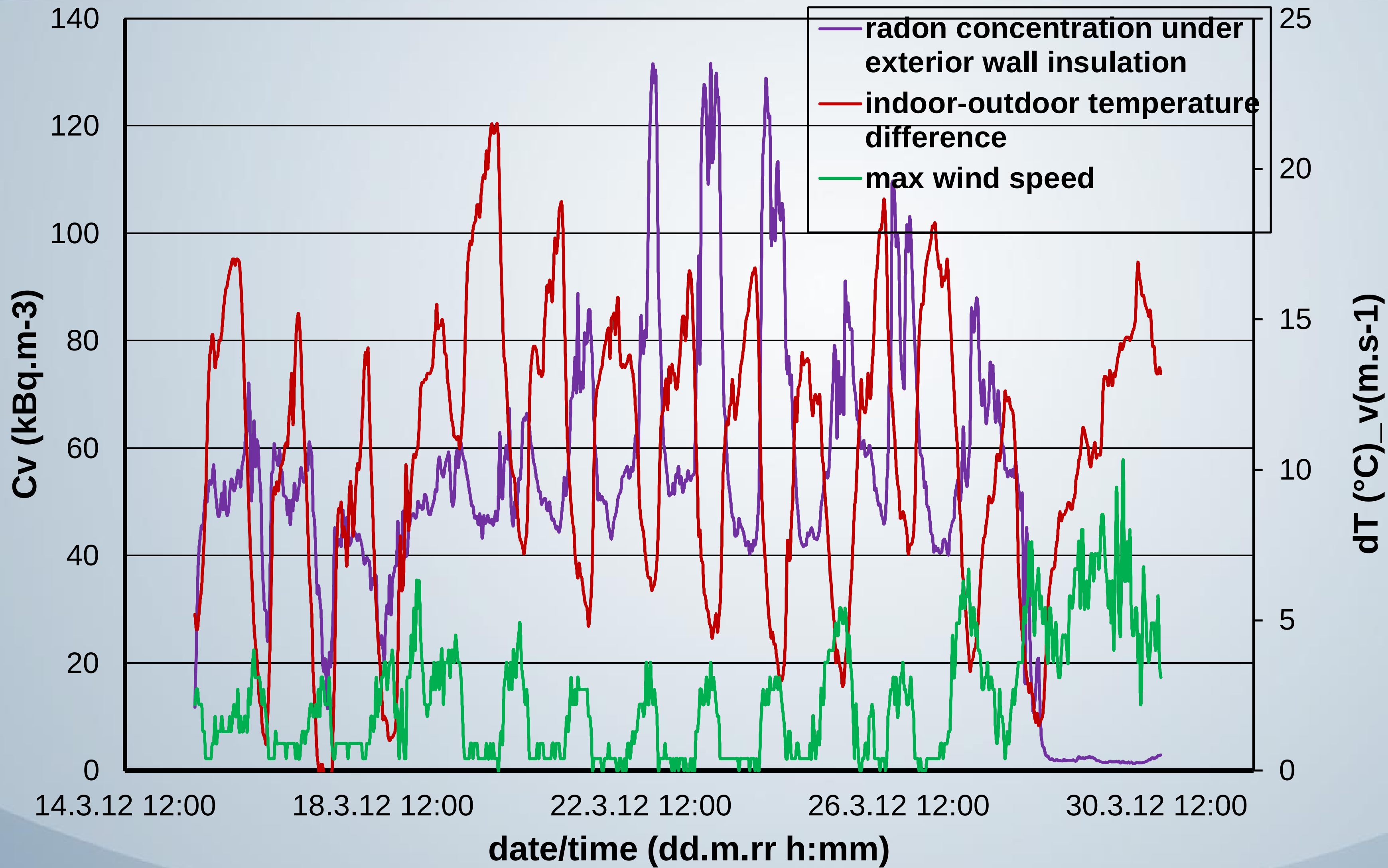
Infiltration experiment ï tracer gas application ï radon entry path tracking







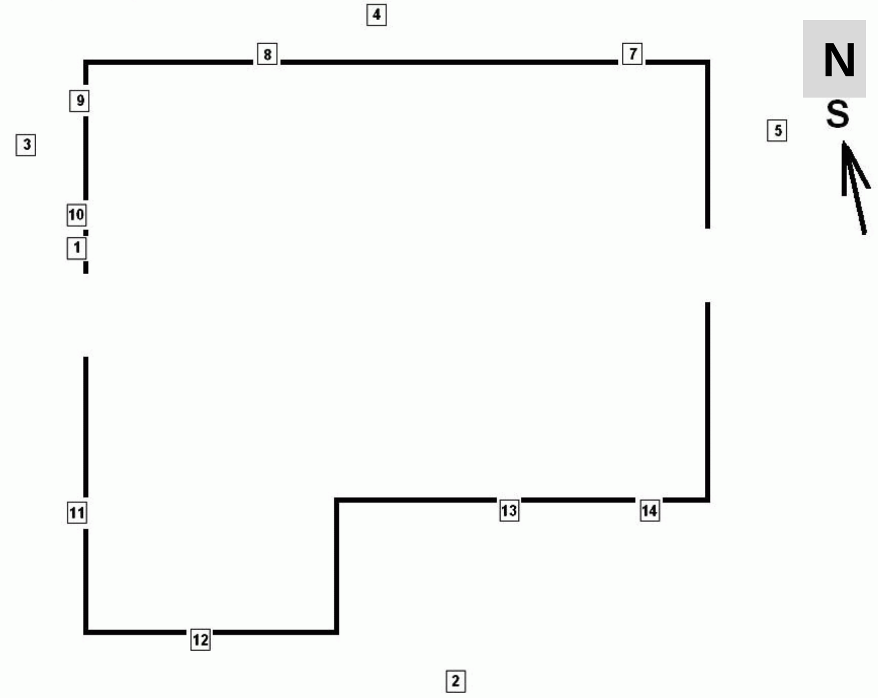
Radon concentration measurement ï influencing factors analysis



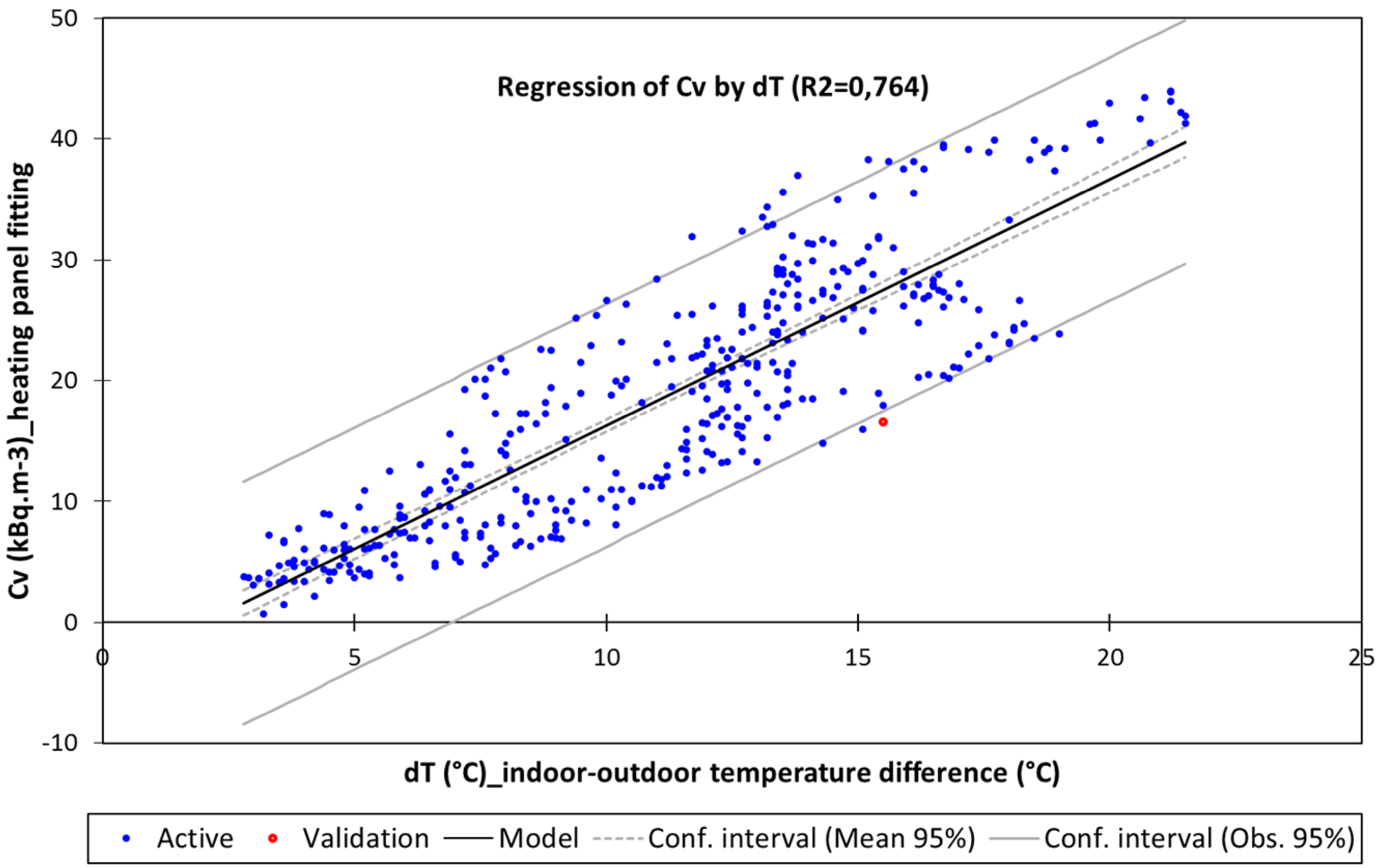
Results of soil gas radon measurement ï spot sampling

Soil gas radon concentration measurement in the vicinity of the building and in building structures and leakage areas		
	Sampling points	C_V (kBq.m^{-3})
2	Soil probe	239
3	Soil probe	27.3
4	Soil probe	204
5	Soil probe	300
6	Heating panel fittings (bedroom)	Before BD test 1.1 After BD test 10.8
7	Under exterior insulation	36.4
8	Under exterior insulation	59.4
9	Under exterior insulation	13.0
10	Under exterior insulation	30.2
11	Under exterior insulation	6.5
12	Under exterior insulation	39.8
13	Under exterior insulation	10.5
14	Under exterior insulation	7.1

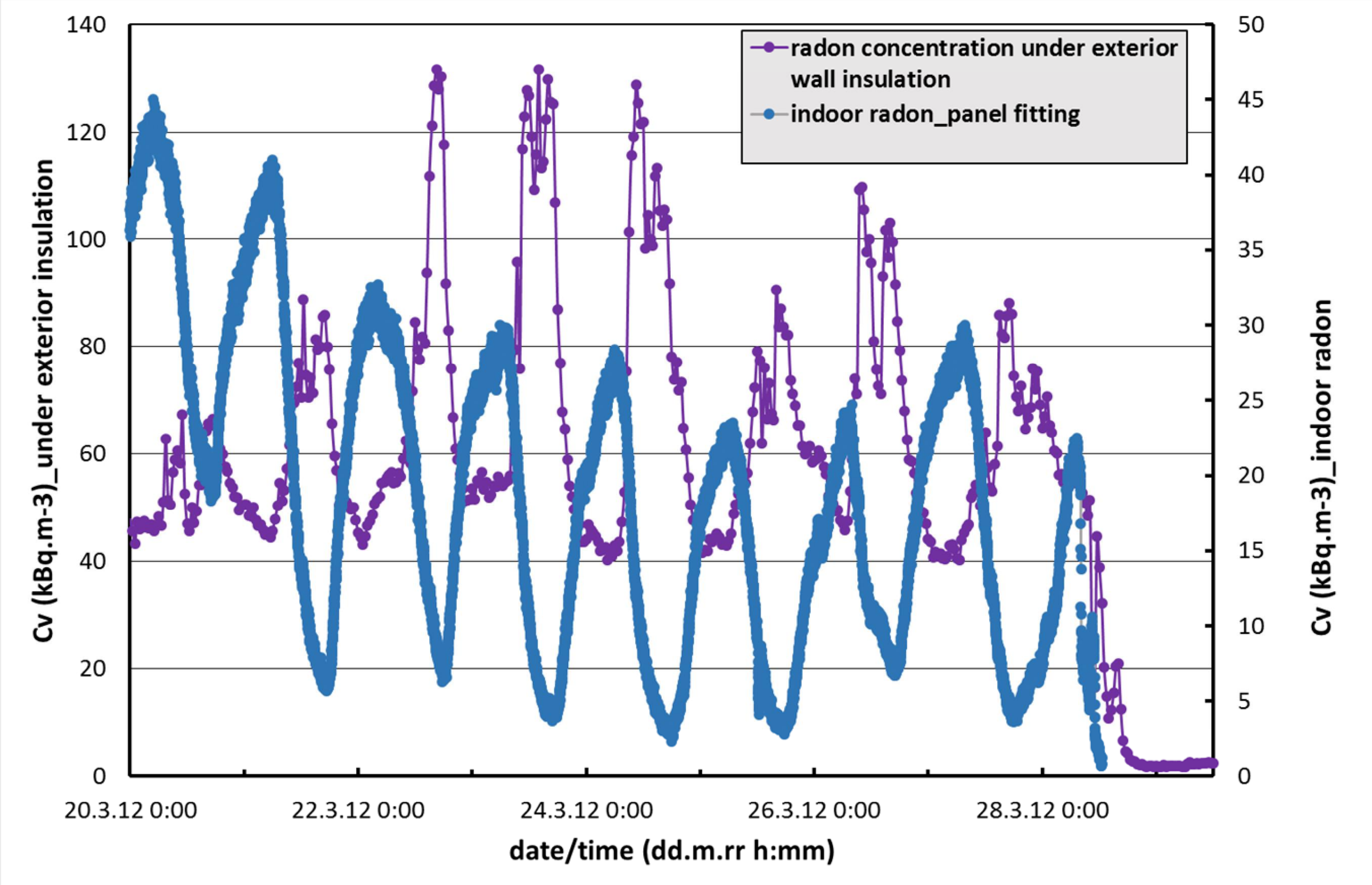
Sampling points distribution



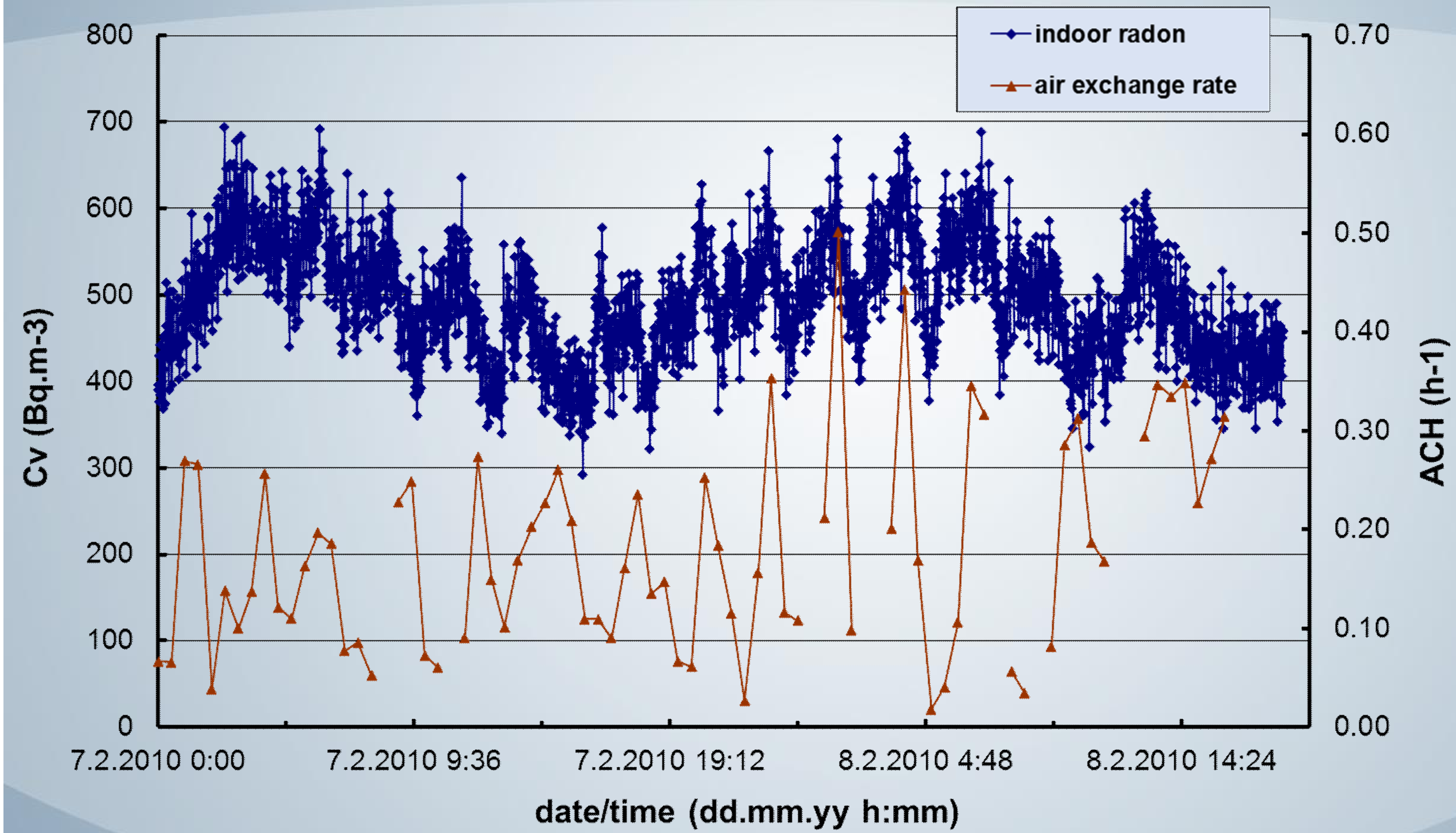
Radon concentration measurement ï influencing factors analysis



Radon entry pathways tracking



Indoor radon in low-energy consumption building



Impact of home energy retrofits on indoor radon concentration in family houses with contaminated building materials

Houses were built in period of 1972-1983 and distributed over the whole country (mostly around Prague), high levels of indoor natural radioactivity identified in 1987 in walls construction material (slag concrete panels with high concentration of **Ra-226**)

(slag origin: the small coal burning power plant - local high radioactive coal from Rynholec near Prague, radioactive slag known from the fifties, the changes in the factory ownership in 1968 Ÿ the new management took no care of this danger

3000 factory-made family houses from slag concrete panels (Ra-226 specific activity **1-10 kBq/kg**).

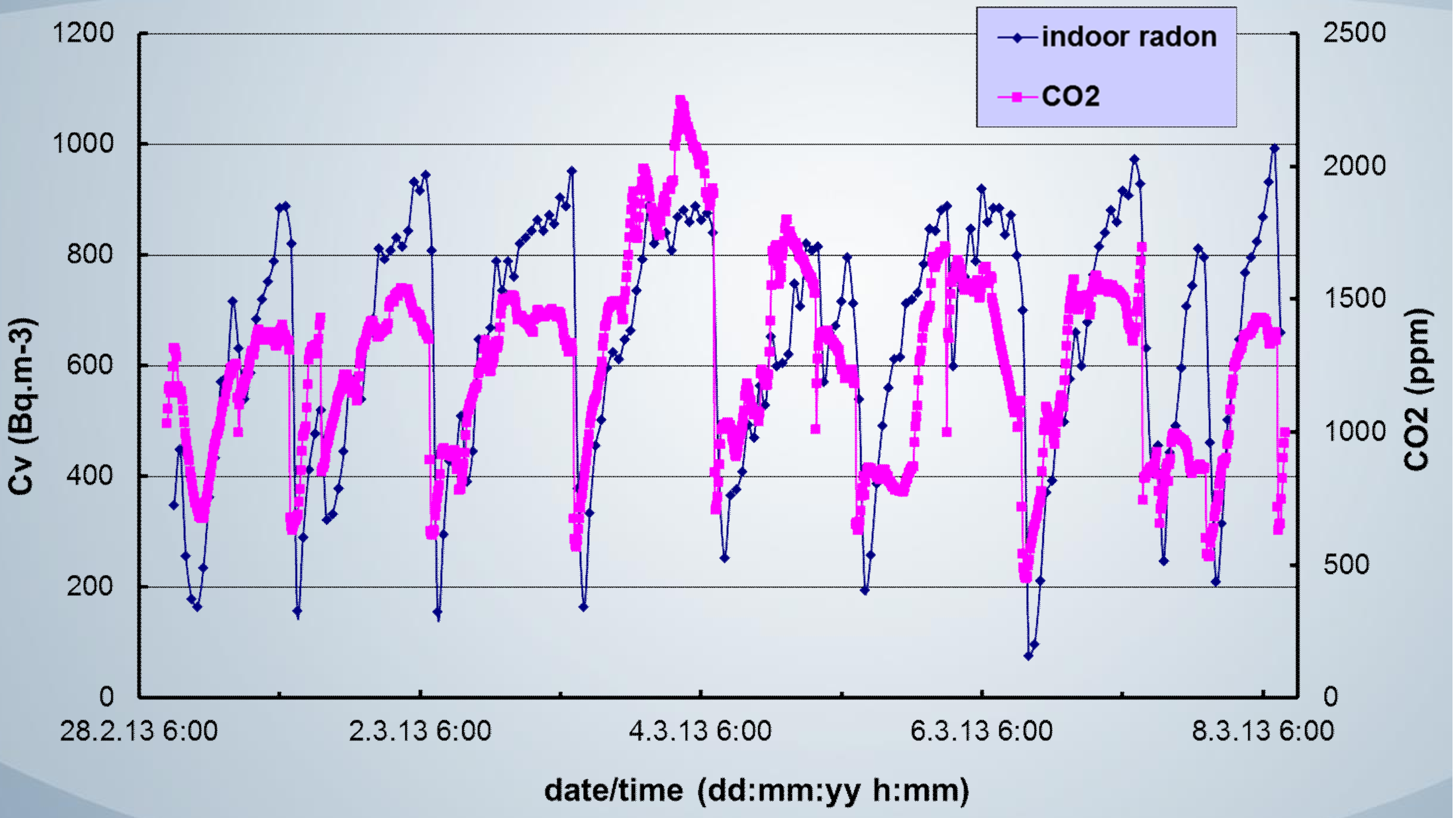
The indoor gamma dose rates (**0.5-2 μGy/h**);

All peripheral and load-bearing walls were made from this material, while some partition walls were from bricks Ÿ the spatial variation in rooms was characterized by a factor of 2, with highest values in the corner of peripheral walls.

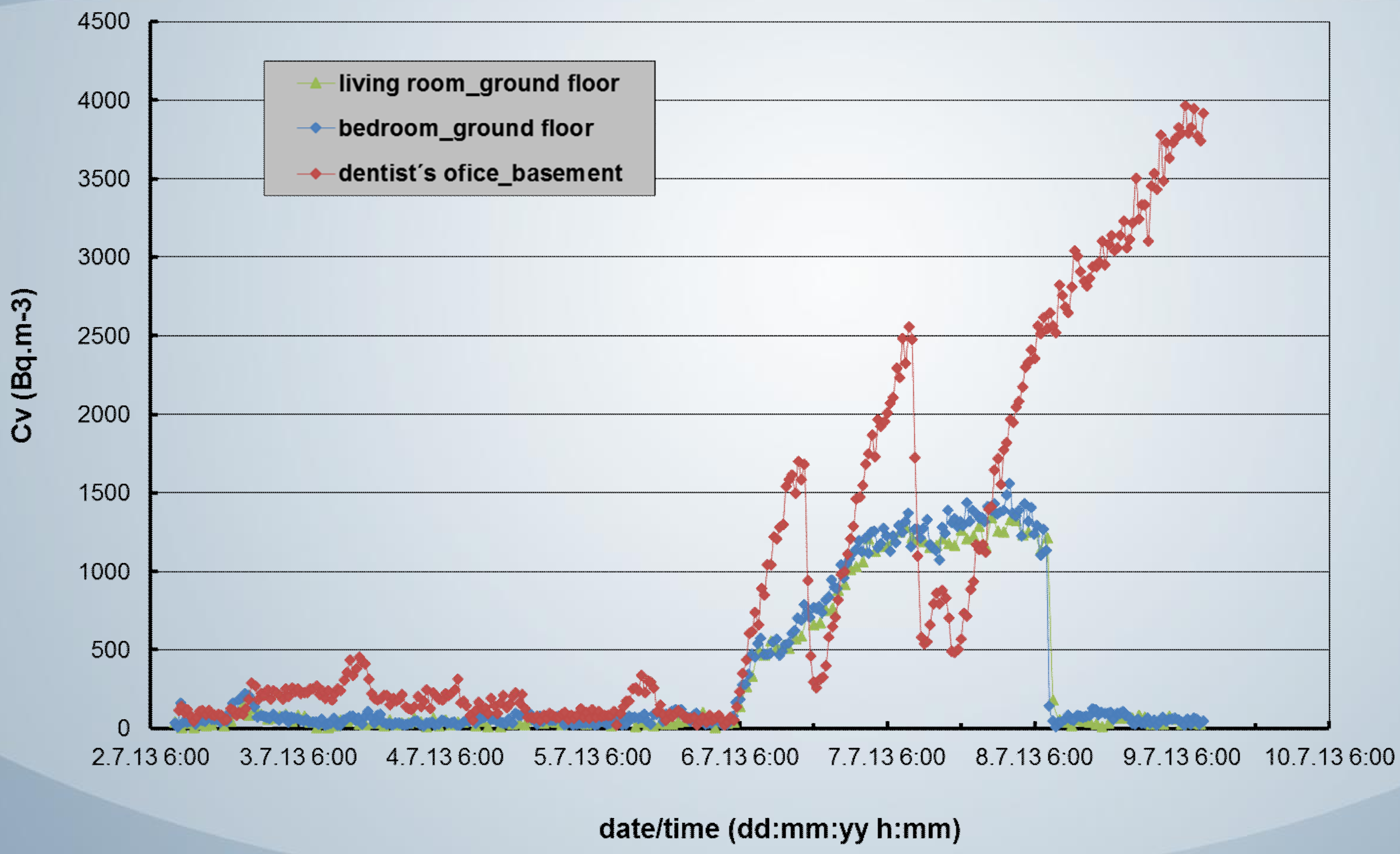
small emanation coefficient of the material (only 1-5%) Ÿ the indoor radon concentration was fortunately only in the range of 200-800 Bq/m3

Current situation corresponds to trends in civil engineering ï impact of renovation and refurbishment on indoor radon concentration has been identified and can be considered as general issue for further investigation

Tracer gas and indoor radon concentration measurement



Indoor radon concentration measurement ï effect of occupancy



Home energy retrofits of START houses

LIVING ROOM	CO2 (ppm)
MEAN	1256
STANDARD DEVIATION	354
MAXIMUM	2246
MINIMUM	450
MEDIAN	1309

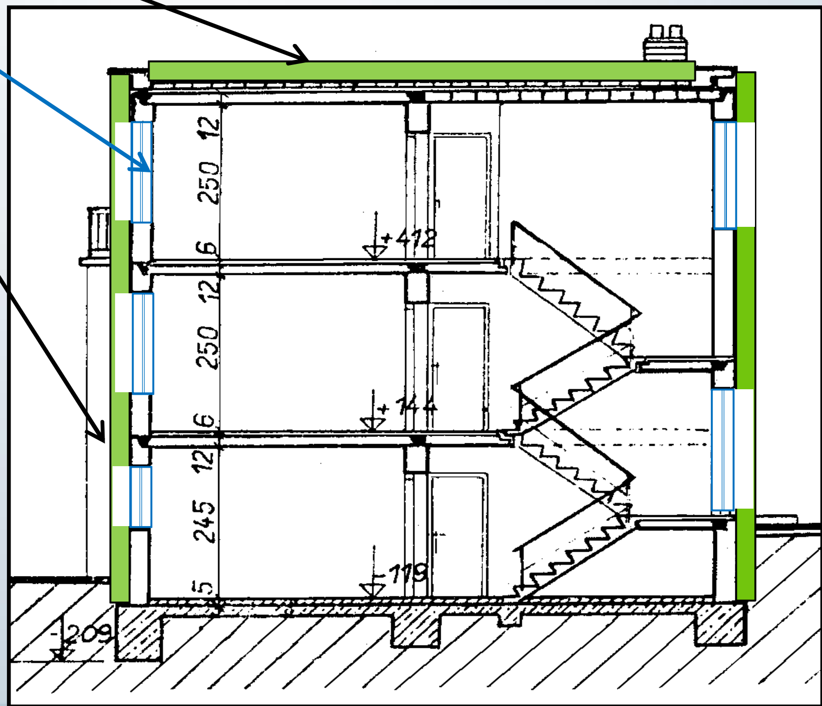
LIVING ROOM	INDOOR RADON (Bq.m-3)	ATM.PRESSURE (hPa)	TEMPERATURE (°C)	HUMIDITY (%)
MEAN	642	988.2	21.1	45.3
STANDARD DEVIATION	218	7.7	0.6	2.7
MAXIMUM	992	998.0	22.0	50.0
MINIMUM	77	975.0	18.1	31.4
MEDIAN	676	992.0	21.3	46.0

ROOF thermal insulation ï 100 mm XPS boards

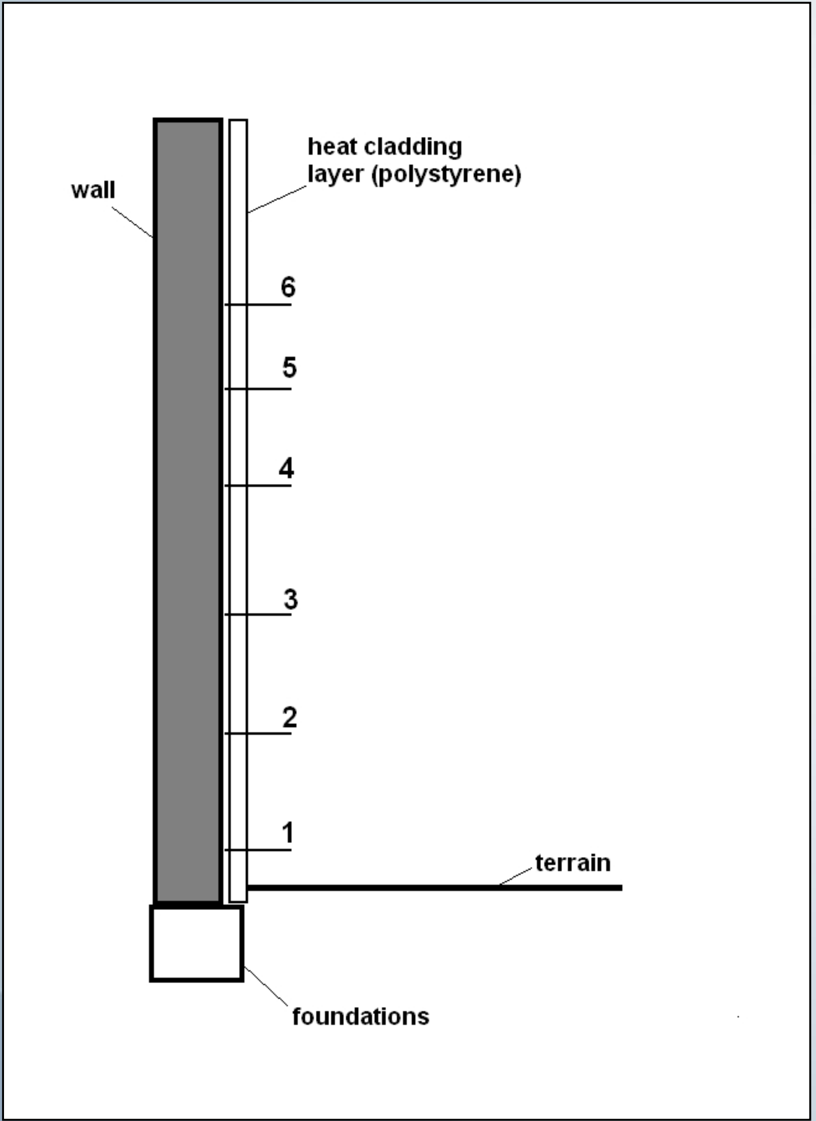
New air-tight plastic windows

Exterior thermal insulation ï 100 mm XPS boards

Indoor radon before home energy retrofits ï 337Bq.m-3
After ï 1117 Bq.m-3



High level of radon concentration within the air gap between thermal insulation layer and external wall



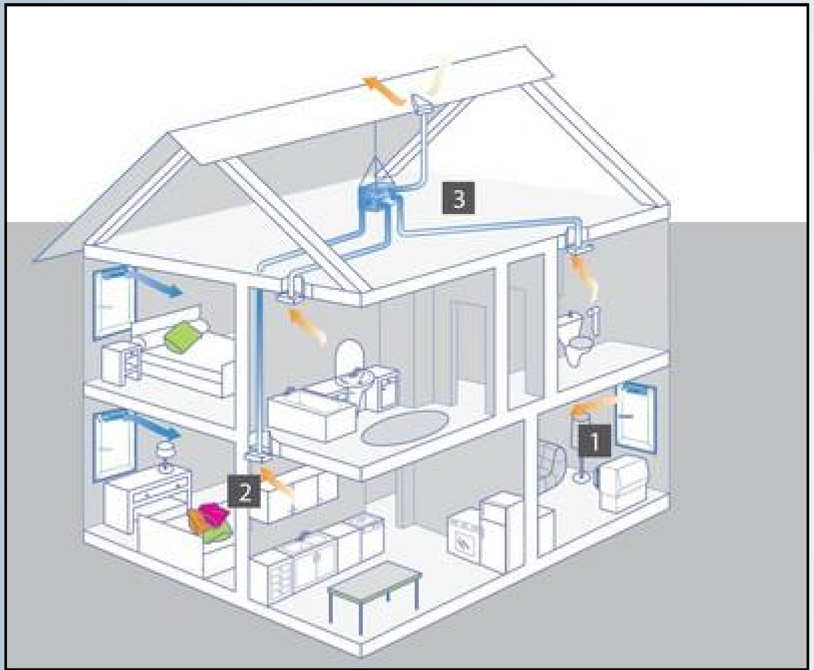
Spot sampling

-distance between the sampling points approximately 100cm
- vertical radon distribution (5m profile)
- radon concentration ranging from 1 to **5.7 kBq.m-3**
-the highest value of radon concentration identified at the highest sampling point (see figure No.6)
- source of radon identified as a building material (slag concrete panels) ï the gamma dose rate in air ranging from **0.20 to 0.85 microGy.h-1**
- **Radon exhalation rate** into the indoor environment can be altered as a consequence of energy saving technology application

Balanced approach needs to be considered

Details regarding energy performance of this building in contrast to indoor radon levels alteration after refurbishment of the house was published in special Issue of RPD in 2014 ï author Dr.**Martin Jiránek**

Radon corrective measures ï hybrid ventilation system



Local ventilation units

- installed in the bathroom (lavatory) on each floor (individual flats)
- low power consumption (5.5 ï 13W)
- max air flow @ 100 Pa (**80 m3.h-1**)
- ventilation aperture distribution (5 ï 35 m3.h-1)
  - air humidity based controlled ventilation system
  - heating season ï dominancy of naturally driven ventilation due to the stack effect
  - summer period ï active system contribution prevails due to temperature balanced conditions

Mean indoor radon concentration measurement

(short-term continuous monitoring ï 10days)

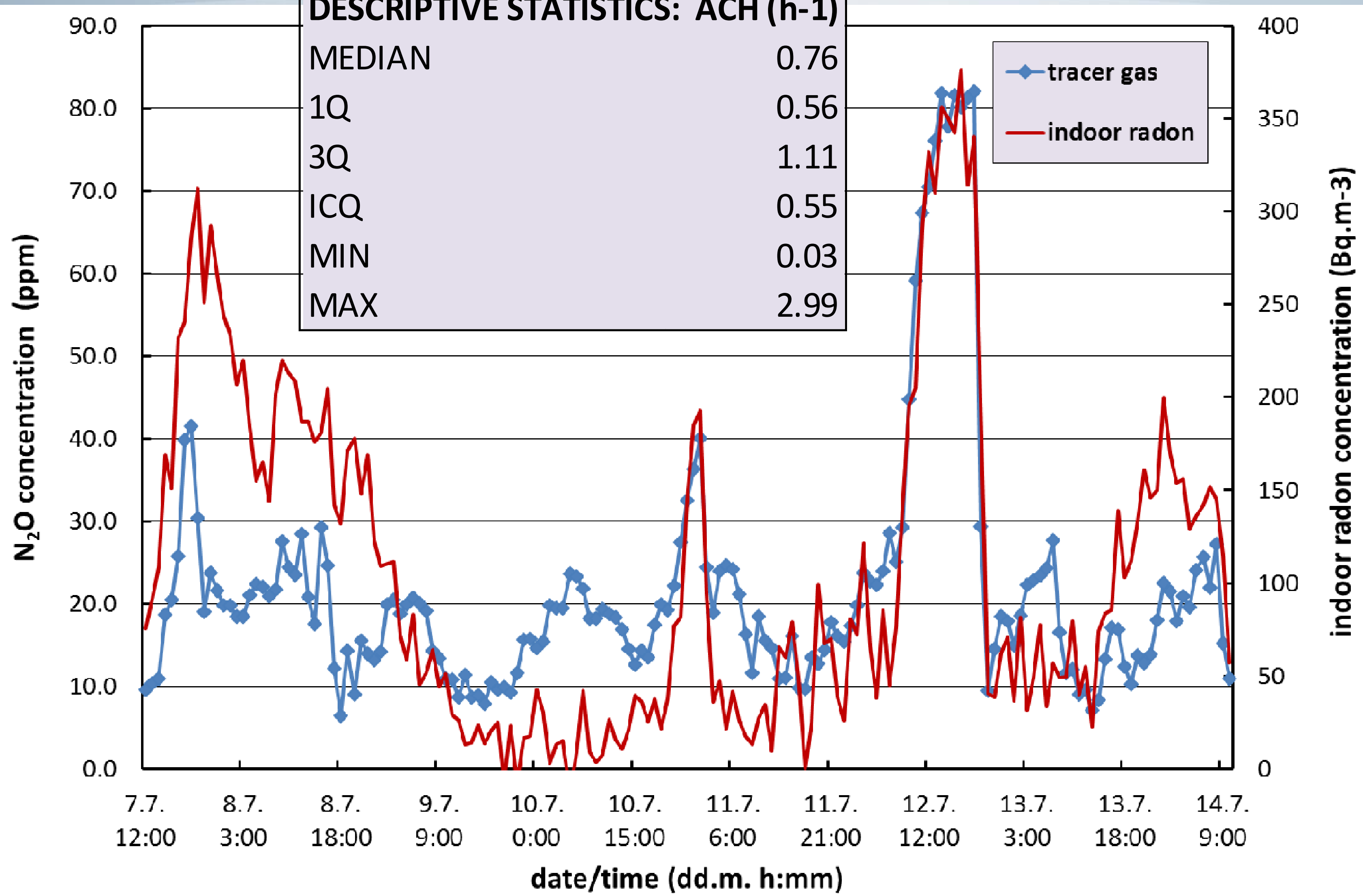
March 2014

- ventilation system OFF ï 440 Bq.m-3
- ventilation system ON ï 370 Bq.m-3

June/july 2014 (one month continous measurement)

- ventilation system ON ï 161Bq.m-3 (significant effect of residnetial habits)

Tracer gas and indoor radon concentration measurement



DESCRIPTIVE STATISTICS: ACH (h-1)	
MEDIAN	0.76
1Q	0.56
3Q	1.11
ICQ	0.55
MIN	0.03
MAX	2.99

Main outputs of radon diagnosis focused investigation

- **In-situ tracer gas application is absolutely essential for correct analysis of air-exchange rate dynamics and air movement and distribution within the building**
- tracking of radon entry pathways
- validation of short-term screening measurement in case of disputes (inconsistent results due to variable measurement conditions)
- multiple compartment task can be solved using variable tracer gases with similar physical properties and natural low background concentration (active or passive detection technique can be employed)
- **In general the results of air-exchange rate** estimates for the closed building condition were less than **$0.1h^{-1}$** (frequently lower than $0.05h^{-1}$)
- Refurbishment of existing buildings focused on energy saving technologies **has to be harmonized** with indoor air quality requirements - explanation on deterioration of IAQ (increasing of indoor radon levels) after the energy saving technologies application can not be simplified to reducing of air exchange rate; radon entry rate dynamics has to be considered and involved accordingly in overall evaluation
- Technical rooms grouping the equipment for centralized services in buildings like HVAC systems, water, and gas and electricity supplies were often recognized as the main radon entry area

Thank you for your attention!

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