ASSESSING RADON EXPOSURE IN SWEDISH WORKPLACES AND SCHOOLS: DISPARITIES, CRITERIA AND RECOMMENDATIONS

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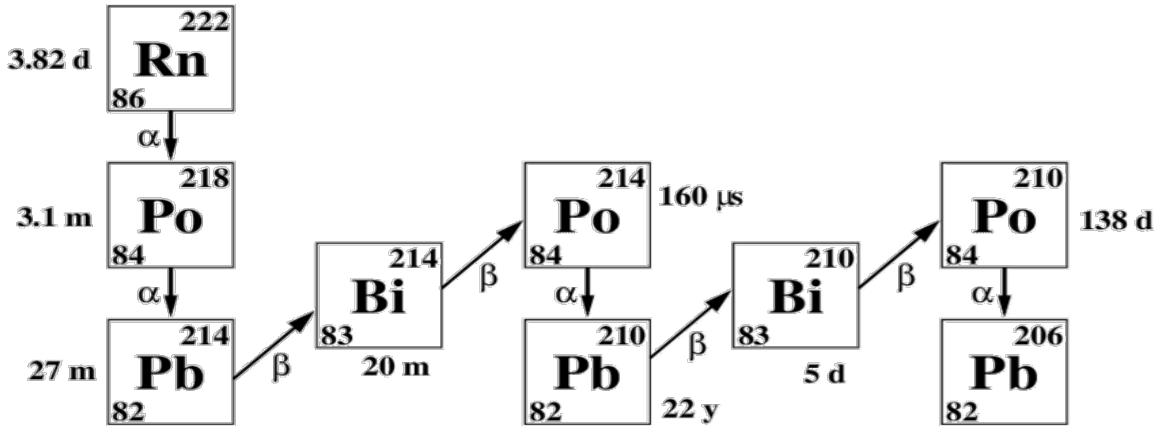
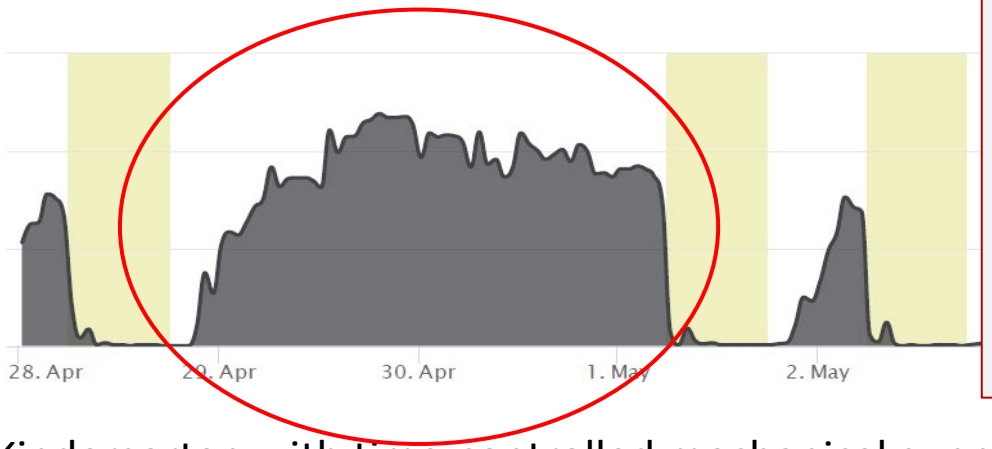


Time-resolved workplace measurements - examples



The radon levels during **weekends are often higher** than during nights in the working week since the ventilation has been OFF for a longer time.

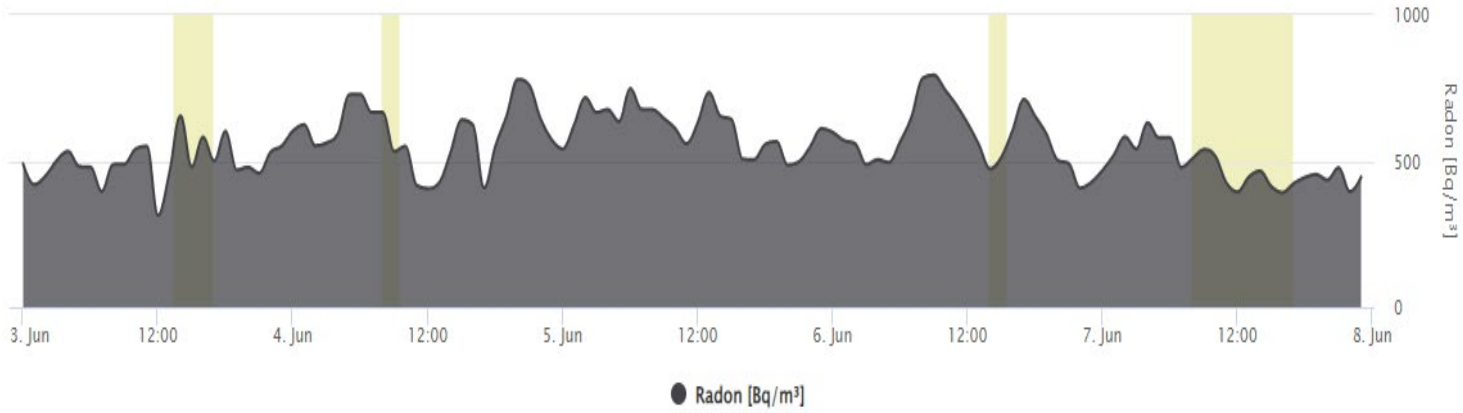
- 7-day average:
  - 810 Bq/m³ (**22 pCi/L**)
- Average during occupied hours:

  35 Bq/m³ (**<1 pCi/L**)

Kindergarten with <u>time-controlled mechanical supply and exhaust ventilation.</u>

- 7-day average:
  - ~500 Bq/m³ (**14 pCi/L**)
- Average during occupied hours:

  ~500 Bq/m³ (**14 pCi/L**)



Church with purely <u>natural ventilation.</u>

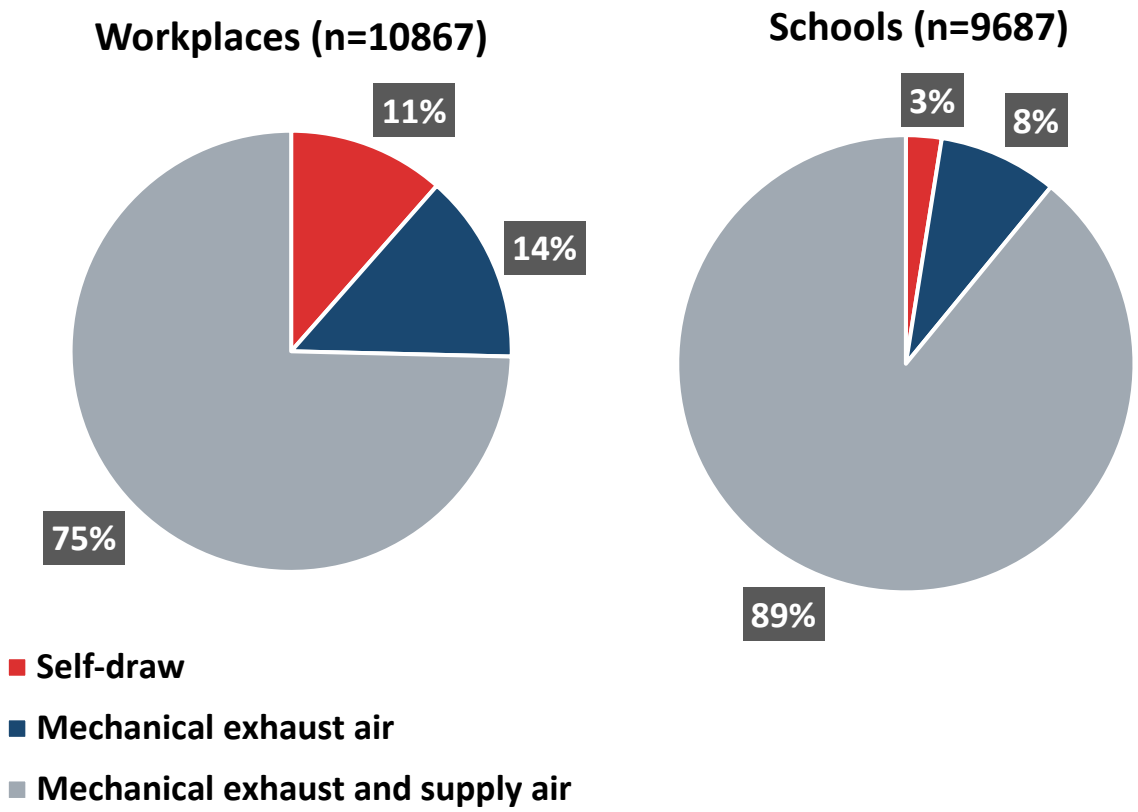
Spatial distribution of radon levels - long-term measurement

Floor	Measurement points	Average (Bq/m³)	Highest value (Bq/m³)	> 200 Bq/m³	< 50 Bq/m³
Cellar	31	130	1350	10 %	77 %
1st floor	61	120	510	18 %	40 %
2nd floor	99	80	590	6 %	55 %
3rd floor	84	90	2350	5 %	55 %
4th floor	67	80	970	3 %	45 %
5th floor	40	70	330	5 %	52 %
6th floor	20	70	250	5 %	50 %
7th floor	16	90	170	0 %	19 %
8th floor	5	130	210	17 %	0 %

- On almost all floors there are values above the reference value of 200 Bq/m³
- A significant proportion of the measured values on each floor are relatively low

Large Swedish workplace (measurement in almost every workroom).

Ventilation patterns in Swedish workplaces and schools



In countries with colder climates:

- Low energy consumption through time-controlled mechanical ventilation with heat recovery.
- Ventilation through window opening, only outside the heating period.
- Natural ventilation through ventilation valves.

Types of ventilation in workplaces and schools from the Radonova radon database (2014-2023) with a minimum of 5 measurements per building.

Radon measurements at Swedish workplaces - measurement protocol

Reference value: 200 Bq/m^3 (5.4 pCi/L)

The first step, the “annual” average value measurement, takes place over a period of at least 2 months:

- Measurement during the heating period October-April.

- Floors with floor contact: Measurement in at least every fifth room and at least one measuring point per 200 m^2.

- Upper floor: At least one measuring point per 200 m^2.

If the first long-term radon measurement in a building with time-controlled ventilation exceeds the reference value, further investigations can be carried out with time-resolved radon measuring devices in a so-called follow-up measurement.

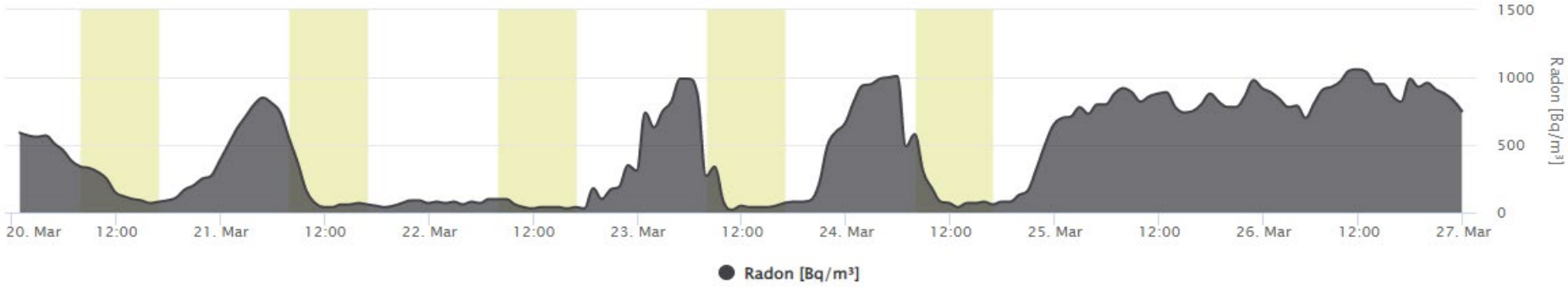
Estimated long-term average during working hours

The follow-up measurement **must**:

- be carried out during the **same measurement conditions**
- provide **two different radon results**, the average radon value during the working day and the average radon value during the entire measurement period (7 days)*.

Long-term measurements with nuclear track detectors

Time-resolved measuring device for follow-up measurements



Average in selection
100 ± 20 Bq/m³

Average level for all points
450 ± 60 Bq/m³

Factor
0.22

X

Previous long term measurement
550 Bq/m³

=

Corrected result from previous long term measurement
130 Bq/m³

Corrected result of the previous long-term measurement

=

Previous long-term measurement (**LT**)

X

Average level during occupation (ST_{OH})

Average level during the measurement period (**ST**)

**Turtiainen et al. (2021) Improving the assessment of occupational exposure to radon in above-ground workplaces. Radiation Protection Dosimetry Vol. 196. No. 1-2, pp. 44-52.*

Follow-up measurement - How long should we really measure for?

Data and results from internal testing conducted in 2023

Average factor	Full week	5 days (Without weekend)	2 days (Mo & Tu)	2 days (Th & Fr)
ST_{OH}/ST	0.33 ± 0.23	0.44 ± 0.23	0.42 ± 0.25	0.46 ± 0.22

'For non-residential buildings, **occupied/unoccupied evaluation is recommended'** in the ANSI/AARST standard MA-MFLB-2023 if results are ≥4.0 pCi/L.

A full 7-days measurement is not motivated since no factor-multiplication with a previous long-term result is made.

But if used in a calculation:

Follow-up measurement periods **not** in whole weeks might lead to an overestimation of the estimated long-term radon concentration during occupied hours.

Follow-up measurements at Swedish workplaces

Follow-up measurements from Radonova's radon database between 2022-2024.

Measuring devices "rented" and returned to Radonova.

The measuring method is accredited according to ISO 17025.

- **332** measurements (216 schools/kindergartens, 100 offices/industry, 16 others) with **time-controlled mechanical supply and exhaust ventilation** (with or without heat recovery):
  - Mean factor ‘office’ **0.51 ±0.23**
  - Mean factor ‘industry’ **0.66 ±0.28**
  - Mean factor ‘school’ **0.38 ±0.31**
  - Mean factor ‘daycare’ **0.28 ±0.22**
- 197 measurements during the heating period (Oct-Apr): mean factor **0.44 ± 0.31**
- 135 measurements outside the heating period (May-Sep): mean factor **0.37 ± 0.27**
- **31%** of the measurements have a factor **<0.2** whilst **13%** of the measurements have a factor **<0.1**

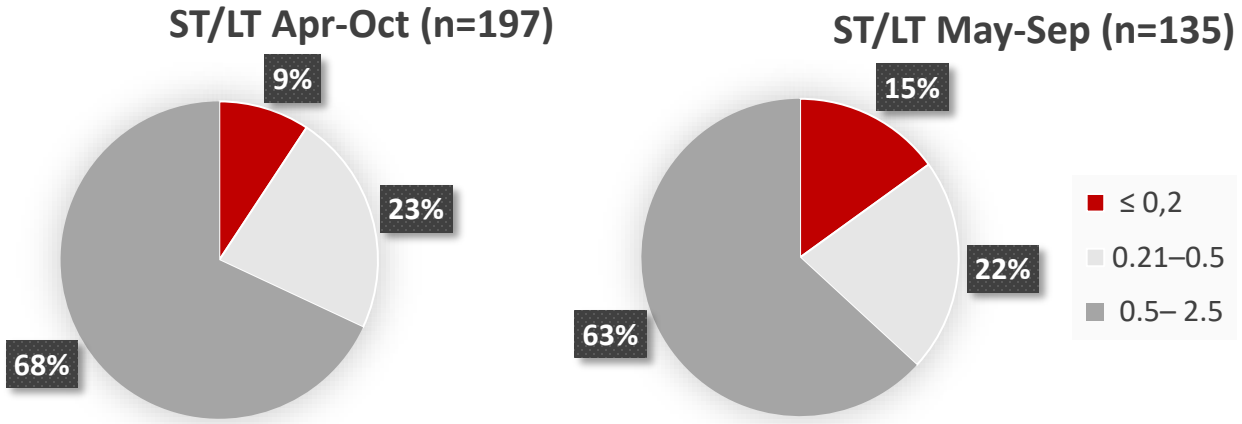
Result validation ST/LT

Radonova uses the following rules to determine if a follow-up measurement is representative by looking at the value over the entire measurement period (ST) divided by the value from the long-term measurement (LT):

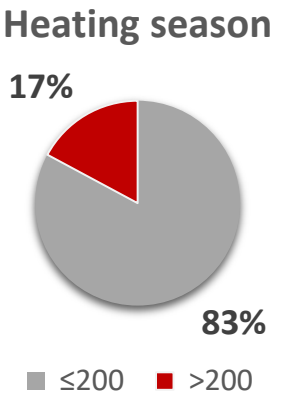
- ≤ 0.2 - No corrected annual average during working hours is calculated
- 0.2-0.5 – Corrected value is calculated but with report comments
- 0.5-2.5 – Considered OK
- 2.5-5.0 – Corrected value is calculated but with report comments
- > 5.0 - No corrected value is calculated

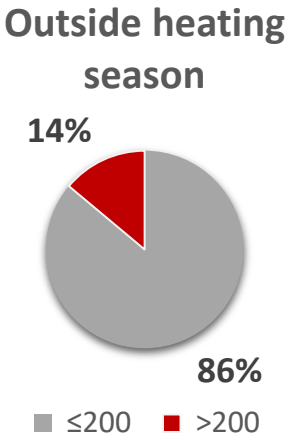
When the average value during **the follow-up measurement is clearly lower** than the value during the long-term measurement, **the "factor" is usually larger,** which **leads to an overestimation of the annual average** value during working hours.

No measurements with ST/LT >2.5 in this dataset



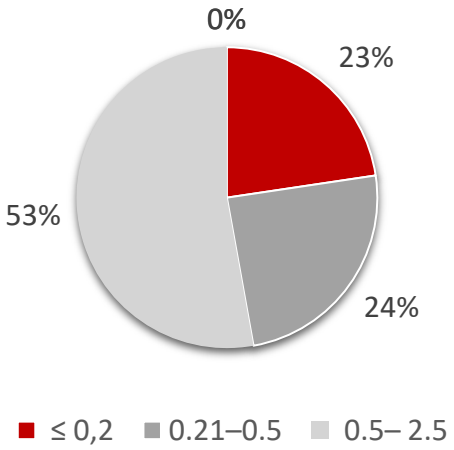
% of the annual average value (Bq/m³) during working hours above or below the reference level **after the follow-up measurement**

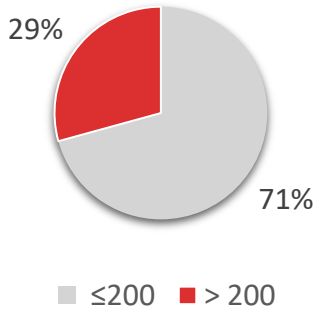




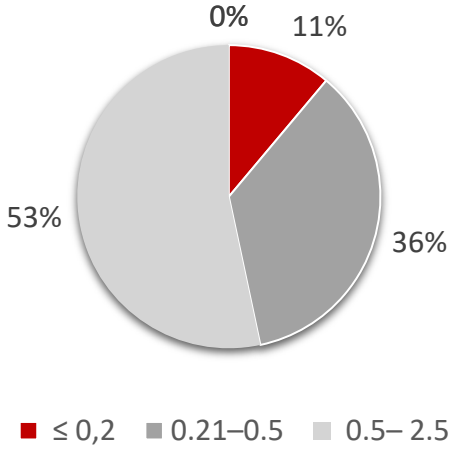
The result after follow-up measurement ST/LT

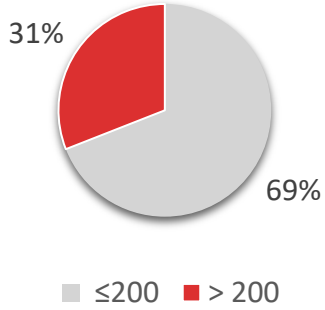
Office (n=53)



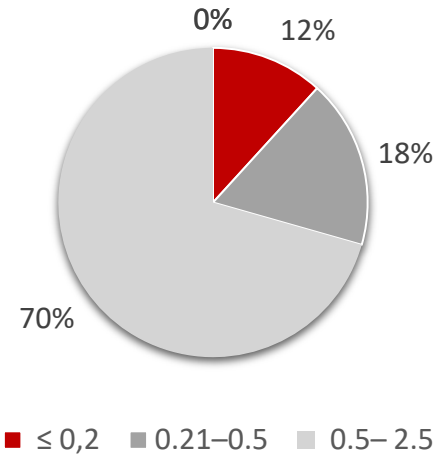


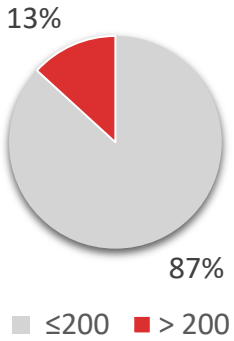
Industry (n=47)



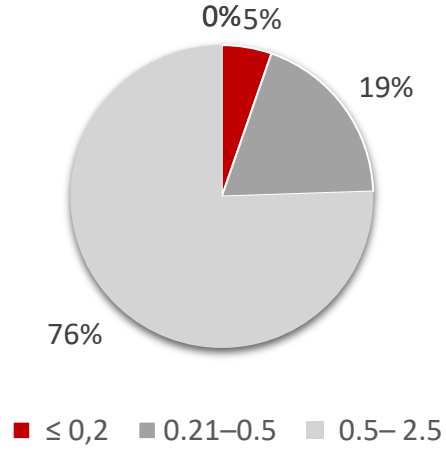


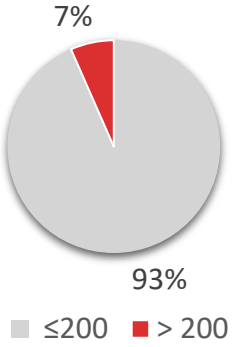
School (n=120)



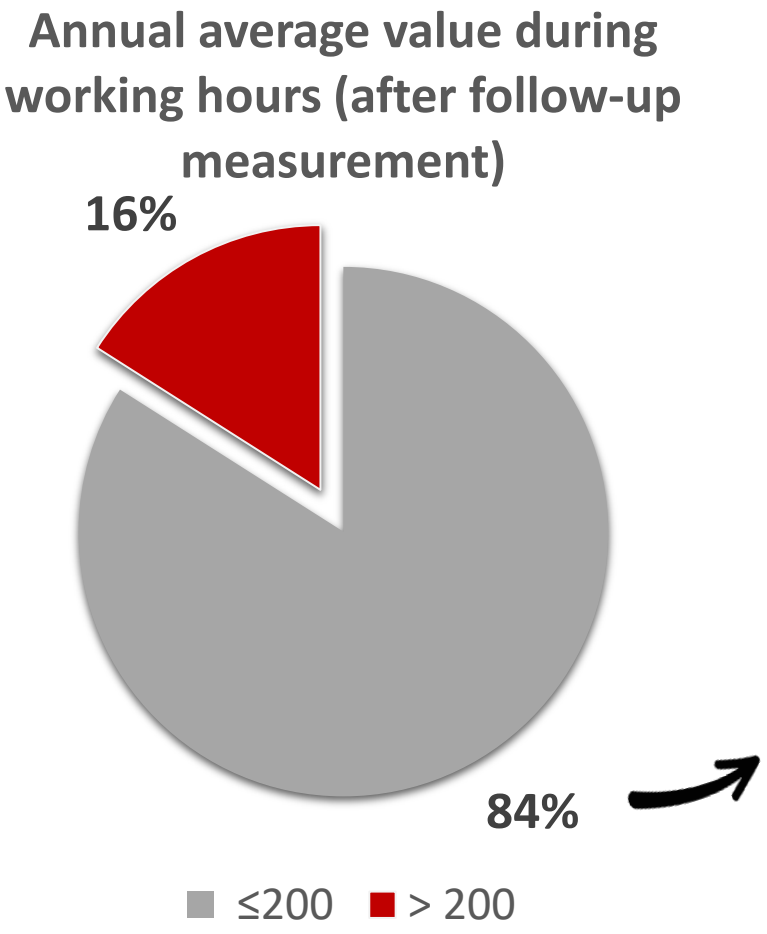


Daycare (n=96)





The result after follow-up measurement



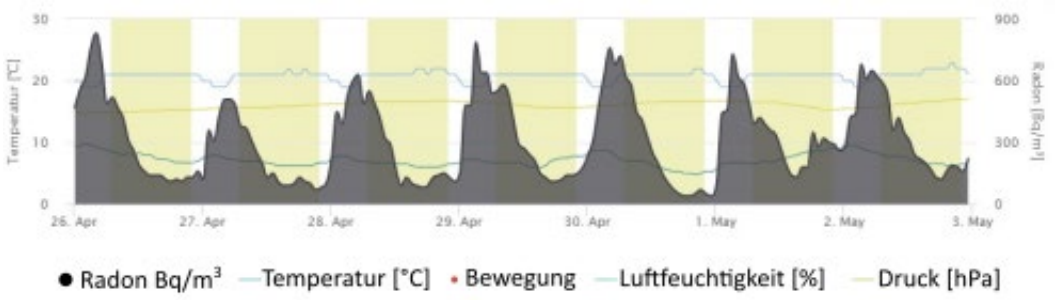
Within the acceptance criteria: **294** out of 332

Above the reference value: **47** cases

84% of the cases where the first long-term radon measurement exceeded the reference value of 200 Bq/m^3 (5.4 pCi/L) **are below this threshold after the follow-up measurement.**

Conclusions and thoughts

- In Sweden, radon levels in buildings with time-controlled ventilation during working hours are on average about **one third** of the levels over the entire measurement period, although this factor varies greatly.
  - Is the building also used outside of normal opening hours?
- **The time** at which ventilation begins after nights and weekends could have a major impact on the radon exposure of people in the building.



- **How close to a previous** long-term measurement should follow-up measurements be taken?
  - **Not stated in** ANSI/AARST MA-MFLB-2023.
  - However, we observe **LOW seasonal variations** in buildings with time-controlled ventilation.
- **Applicable** in all workplaces **with time-controlled mechanical supply and exhaust ventilation** (with or without heat recovery).
  - **Caution** with Stack effect and resulting pressure differences in the building.
  - **Caution** in School/Daycares during the summer break.

Conclusions and **thoughts**

How much can the average value of the follow-up measurement (ST) deviate from the long-term measurement (LT)?

Challenge: Estimating deviation between ST and LT is complex.

- Different measurement periods (2 months vs. 1 week).
- Different measurement methods (passive detector vs. Continuous Radon Monitor).
- Each method has its own uncertainties.
- Difficulty in determining if results come from the same statistical distribution.

Potential Solution: LT with Continuous Radon Monitor (CRM).

Challenge: Expensive to implement.

Alternative Approach: Combine ST in a LT

- Perform 1-week ST measurement during the first month of LT measurement.
- Repeat 1-week ST measurement during the second month of LT measurement.
- Follow up with the usual ST measurement.

Benefits:

- Generates 3 population distributions.
- Easier to compare using statistical tools.
- Facilitates better assessment of measurement variations.

Thank you for your attention

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