ELFT SUGÁRVÉDELMI SZAKOSZTÁLY

IRPA ÖVS

L. Sugárvédelmi Továbbképző Tanfolyam, Hajdúszoboszló, 2025. április 7-9

A new method for estimating the radon situation indoors

TU WIEN

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BOKU UNIVERSITY

Motivation

In principle or by law (Annex 2 to §5 Austrian Radon Protection Ordinance):

Determination of the average annual radon concentration indoors:

- Long-term measurement of the activity concentration, at least six months
- Half of the measuring time in the winter season

Special cases require a quicker estimation of the annual average radon value:

e.g.

- Possible health consequences in the event of greatly increased radon activity concentrations
- Assessing the effectiveness of radon remediation at property transactions

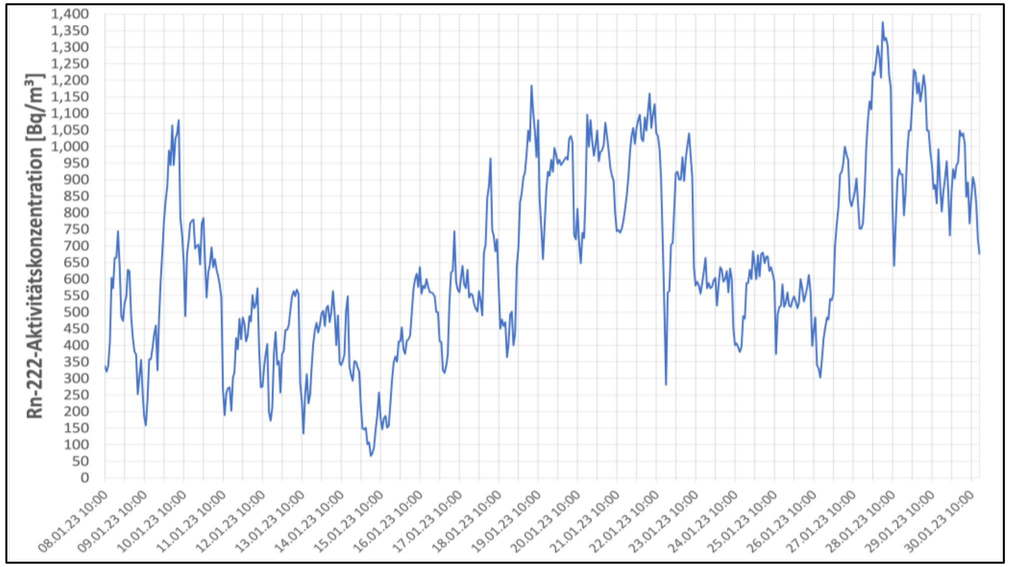
→ *Target*

Development of a method with which <u>the annual average radon-222 activity concentration (IRC)</u> in indoor spaces can be realistically estimated by means of <u>three-weeks short-term radon-222 measurements</u>.

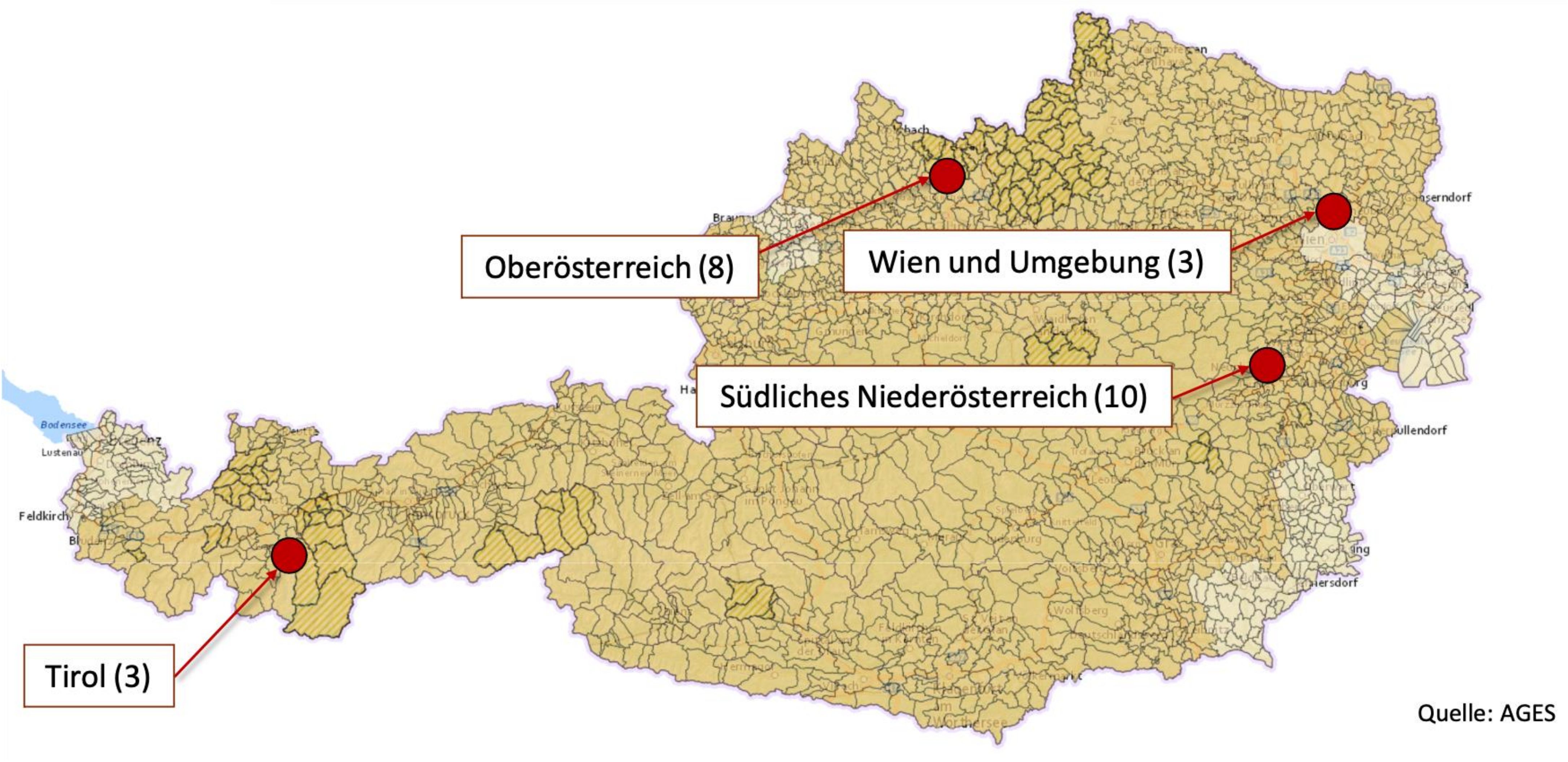
Rn-222 measurements in the period from October 2022 to July 2023 in private homes in four Austrian federal states:

→ **24** long-term measurement locations, 6 months = 3 month in winter + 3 month in summer, with Rn-222 nuclear track detectors

→ **50** short-term measurements, hourly averages, 3 weeks, with Rn-222 measuring devices



24 measurement locations in Austria



Survey of relevant influencing factors

→ **Building data**

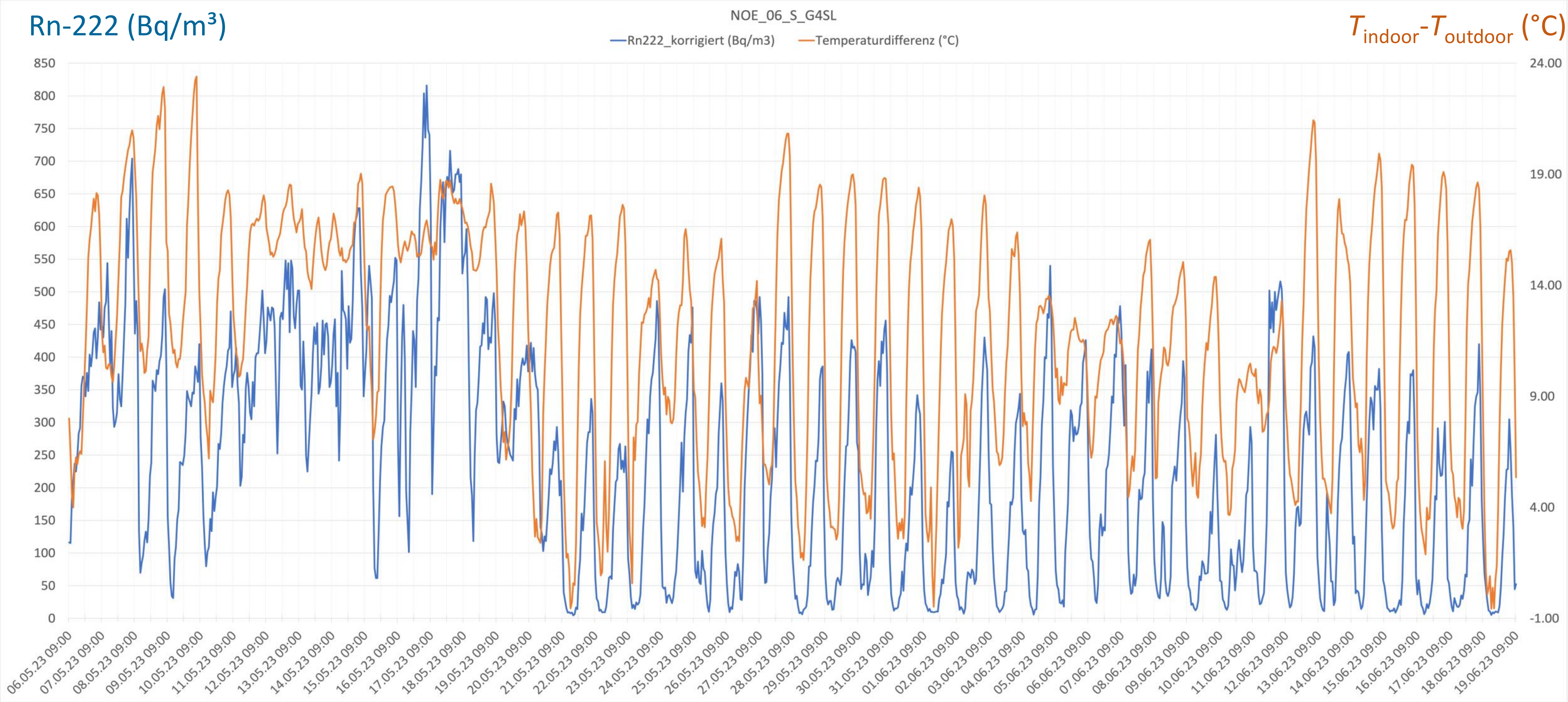
Year of construction, foundation type, basement, slope, etc.

→ **Ventilation and room utilisation behaviour**

→ **Meteorological parameters**

Outdoor and indoor temperature, indoor & outdoor air pressure, indoor & outdoor humidity, wind speed, wind direction, amount of precipitation

Example: Temperature difference → Rn-222



Number of significant correlations *IRC* ↔ meteorological data

	Air pressure indoor	Temperature indoor	Relative air humidity indoor	Air pressure outdoor	Temperature outdoor	Relative air humidity outdoor	Precipi-tation	Wind speed	Wind direction	Air pressure difference (indoor - outdoor)	Temperarture difference (indoor - outdoor)
	Number of correlations										
with ρ > 0.2	3	7	**16**	5	3	**25**	1	2	3	**10**	**23**
with ρ > 0.3	3	3	**9**	4	3	**20**	1	1	0	4	**17**
with ρ > 0.5	1	1	**5**	2	1	**5**	0	0	0	2	**5**
	Number of anti-correlations										
with ρ < -0.2	7	**18**	5	**10**	**26**	1	2	**16**	4	6	3
with ρ < -0.3	5	**10**	3	6	**17**	1	0	**8**	1	1	2
with ρ < -0.5	1	0	0	1	**7**	0	0	2	0	0	1
Total number of measurements	**35**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**35**	**50**

=> Complex influences on the IRC short time measurement!

In any case, this must be taken into account:

- Measurement date (season)
- Ventilation behaviour
- Foundation type and floor
- Outdoor temperature

→ Starting point for creating the radioecological-statistical model

$$EIRC = SIRC \cdot \prod_i p_i = SIRC \cdot p_{TDJ} \cdot p_{TTX} \cdot p_{MON} \cdot p_{FFX} \cdot p_{VVX} \cdot p_{TIA} \cdot p_{s(cRn)} \cdot p_{PPX'} \cdot p_{TIA'} \cdot p_{sym}$$

$p_{TDJ} = 0{,}905 - 0{,}1992 \cdot \cos(TDJ)$

$p_{TTX} = 0{,}875 + 0{,}0227 \cdot TTX^*$

p_{MON} = wenn (MON>5 und MON<9) dann 1,589 sonst 0,959

$p_{FFX} = 0{,}512 + 6{,}24 \cdot 10^{-3} \cdot FFX^*$

$p_{VVX} = 1{,}053 - 0{,}0342 \cdot VVX^*$

$p_{TIA} = 0{,}978 + 1{,}683 \cdot 10^{-3} \cdot TIA^*$

$p_{s(cRn)} = 1{,}111 - 0{,}225 \cdot s(c_{Rn})$

$p_{PPX'} = 0{,}881 - 0{,}339 \cdot PPX'_{<0}{}^*$

$p_{TIA'} = 0{,}674 + 0{,}405 \cdot TIA'_{>0}{}^*$

$p_{sym} = 0{,}962$

p_{TDJ} seasonal influence - winter / spring / summer / autumn

p_{TTX} outdoor temperature

p_{MON} strong ventilation during the 'hot' summer months of June to August

p_{FFX} relative outdoor humidity

p_{VVX} wind force at the building

p_{TIA} temperature difference inside-outside

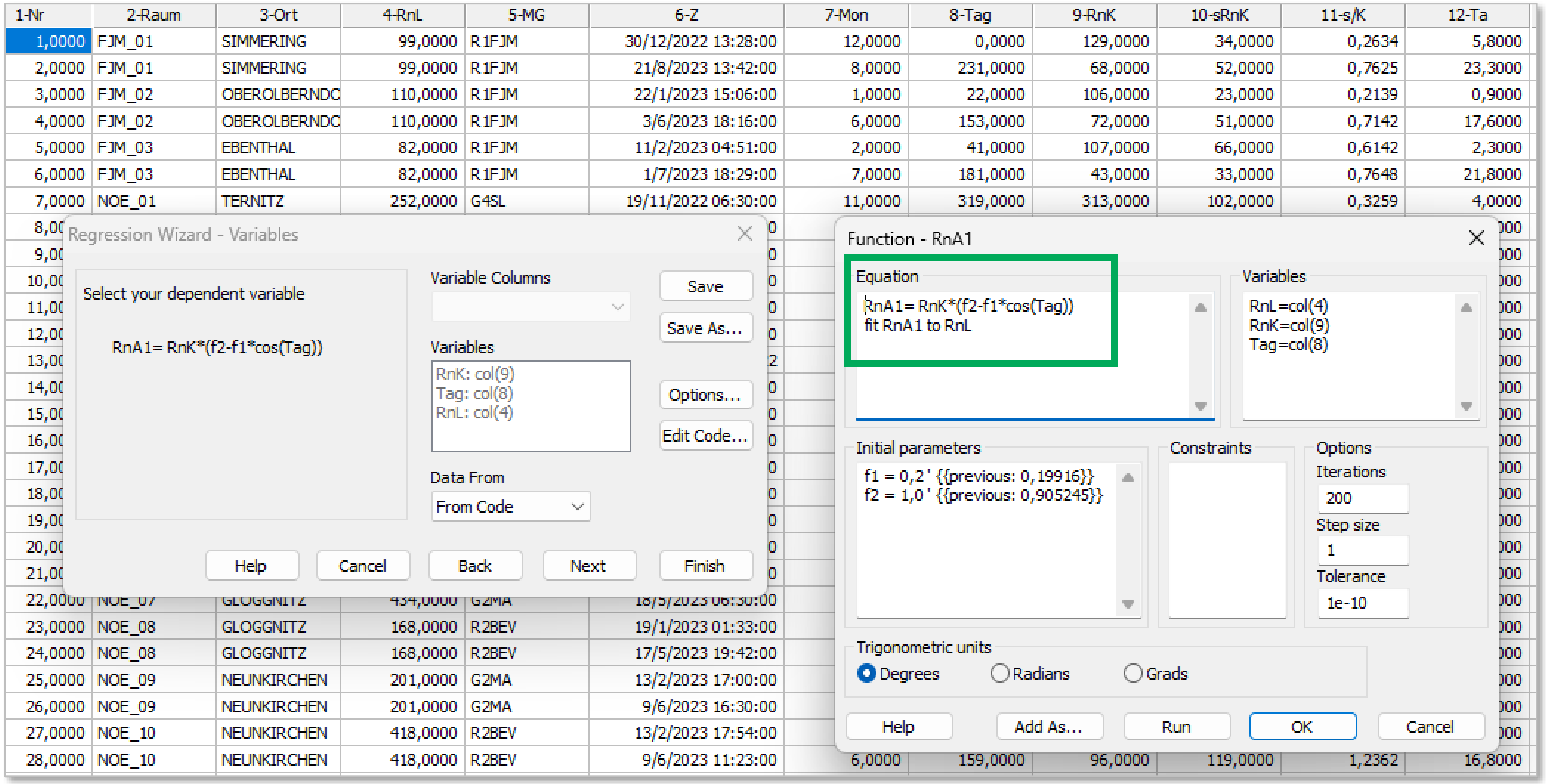
$p_{s(cRn)}$ variability of the radon activity concentration during the short-term measurement

$p_{PPX'}$ change in outside air pressure - negative outside air pressure gradient (air pressure gradient 'radon pump')

$p_{TIA'}$ change in indoor-outdoor differential temperature – positive temperature difference gradient (temperature gradient 'radon pump')

p_{sym} to the symmetry of the ratios *EIRC/LIRC* around the optimum value 1.0 (*EIRC* = *LIRC*)

Non-linear regression for fitting $(SIRC, f_i) \rightarrow LIRC$ using SigmaPlot 15



$$SS = \sum_{i=0}^{n} w_i (SIRC_i - LIRC_i)^2$$

$$SS \rightarrow min$$

$RnL = LIRC$

$RnK = SIRC$

$TAG = TDJ$

$p_{\mathrm{TDJ}} = f2 - f1 \cdot cos(TDJ) =$

$= 0.905 - 0.1992 \cdot \cos(TDJ)$

Marquardt, D.W. (1963). An Algorithm for Least Squares Estimation of Parameters. *Journal of the Society of Industrial and Applied Mathematics*, 11, 431-441.

Fit result (SigmaPlot 15)

Nonlinear Regression **Sonntag, 3. März 2024 21:29:54**

Data Source: Data 2 in NotebookRadon final.JNB
Equation: User-Defined; RnA1 in Radonprojekt final.jfl
RnA1= RnK*(f2-f1*cos(Tag))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0,934	0,872	0,869	189,396

	Coefficient	Std. Error	t	P
f1	0,199	0,053	3,772	0,0004
f2	0,905	0,042	21,547	<0,0001

Analysis of Variance:

	DF	SS	MS	F	P
Regression	2	21254510,714	10627255,357	296,264	<0,0001
Residual	48	1721804,286	35870,923		
Total	50	22976315,000	459526,300		

The F-test compares the regression model to the zero model.

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	1	11684198,214	11684198,214	325,729	<0,0001
Residual	48	1721804,286	35870,923		
Total	49	13406002,500	273591,888		

The F-test compares the regression model to the zero model.

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	DF	SS	MS	F	P
Regression	1	11684198,214	11684198,214	325,729	<0,0001
Residual	48	1721804,286	35870,923		
Total	49	13406002,500	273591,888		

The F-test compares the regression model to a constant model whose value is the mean of the observations.

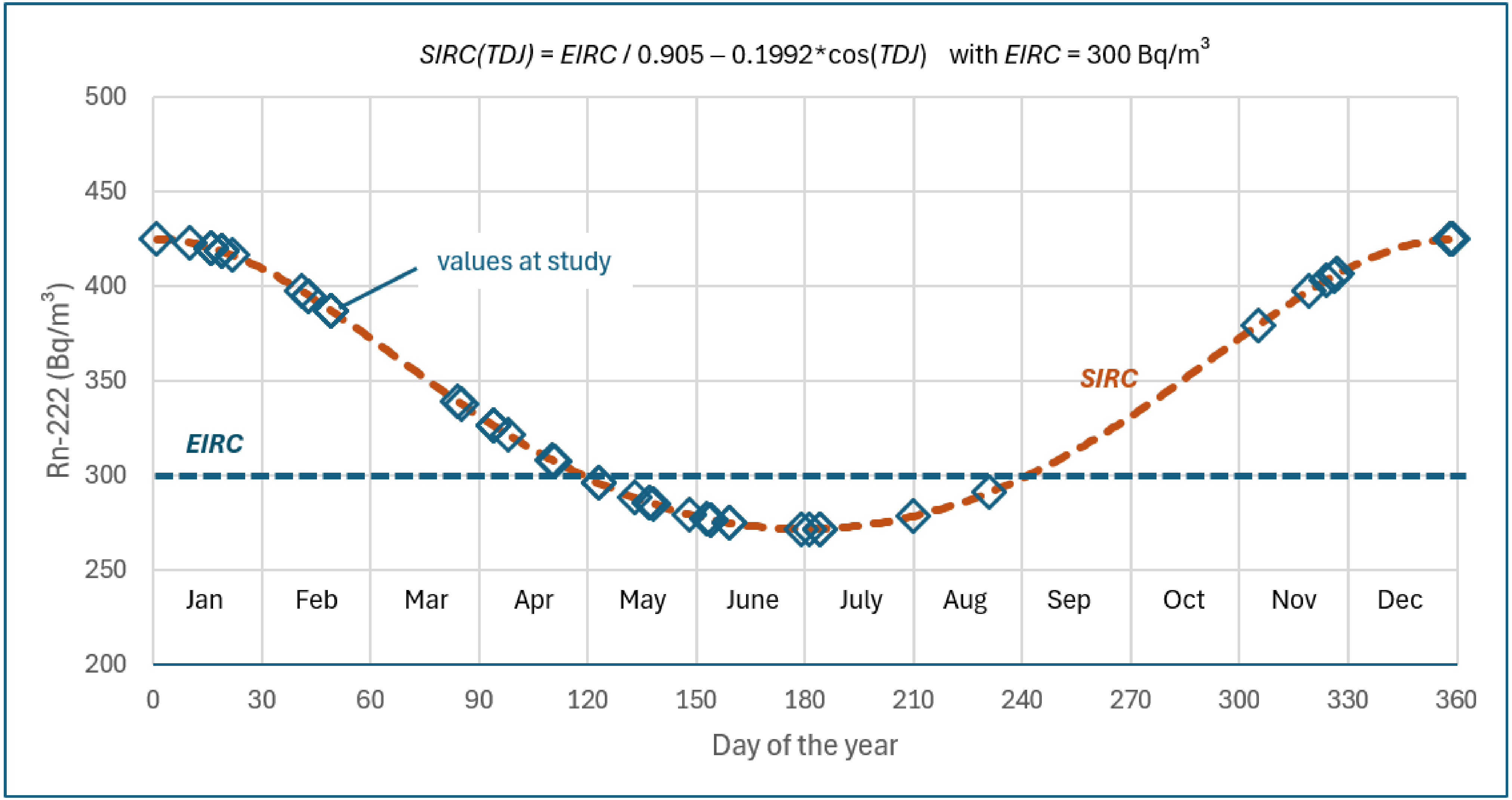
The results of an F-test should only be interpreted for nested models.

Statistical Tests:

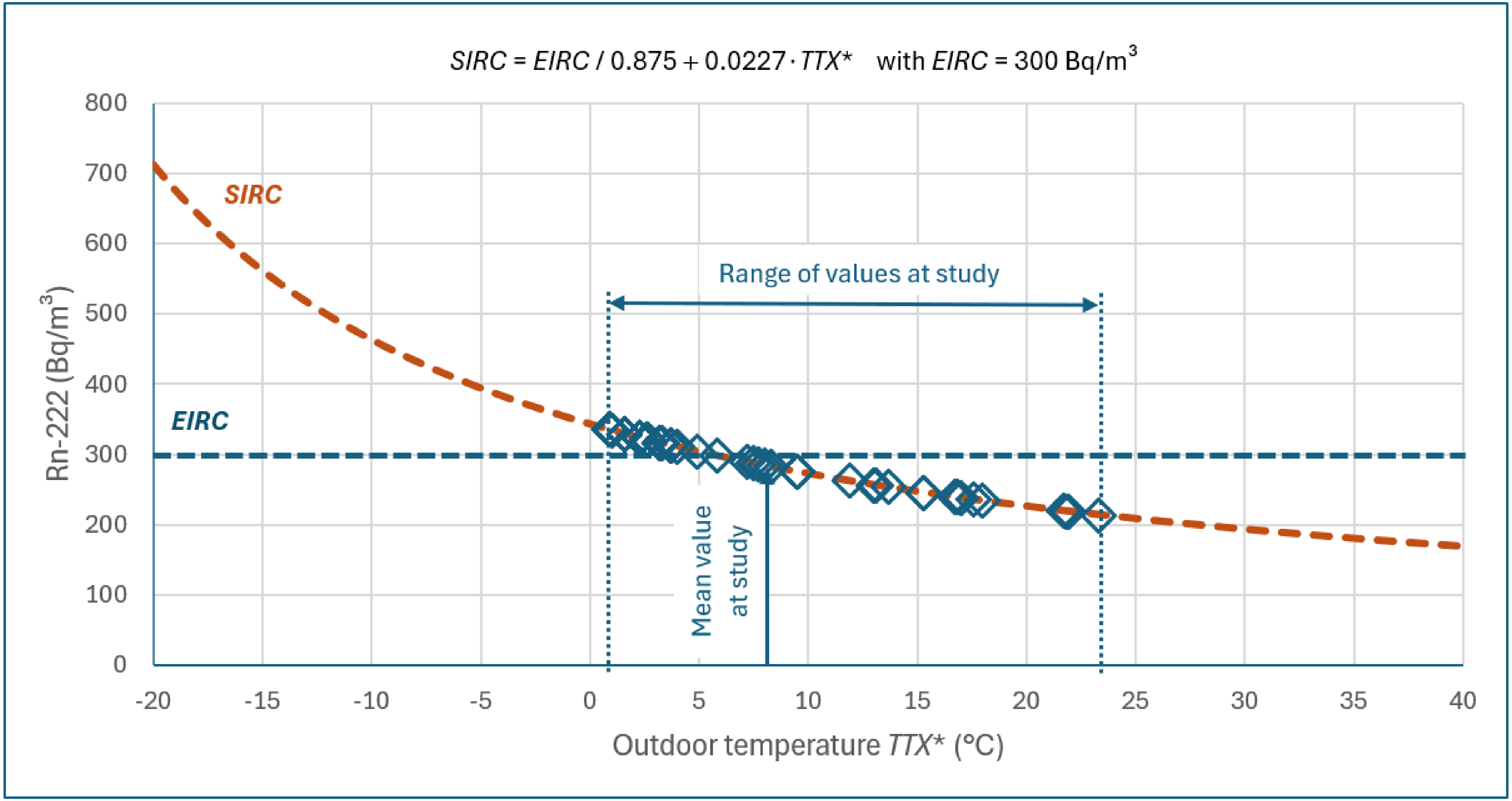
Normality Test (Shapiro-Wilk) Passed (P = <0,0001)
W Statistic= 0,7394 Significance Level = <0,0001

Constant Variance Test (Spearman Rank Correlation) Passed (P = 0,0100)

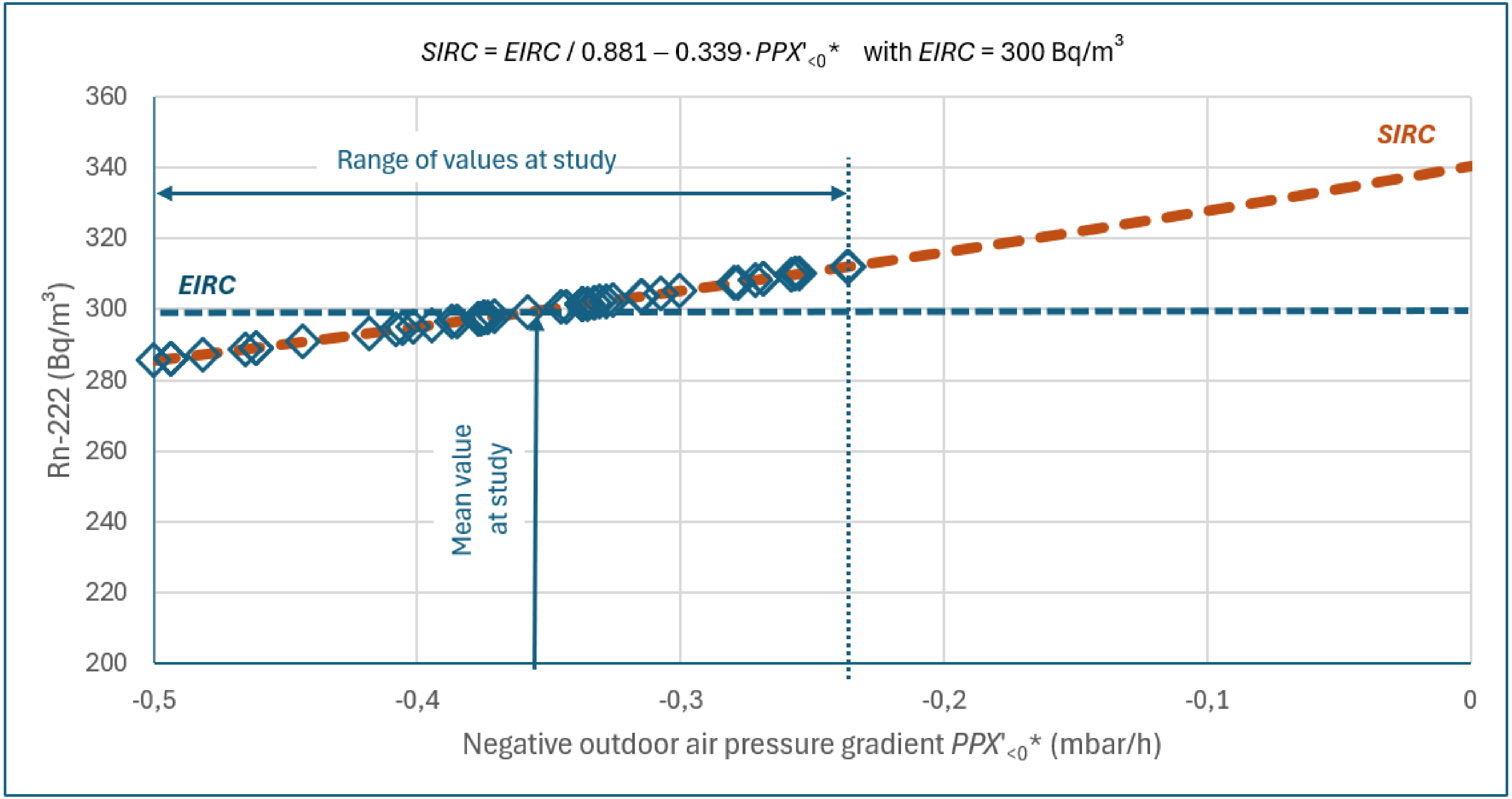
Influence example: Day of the year (season)



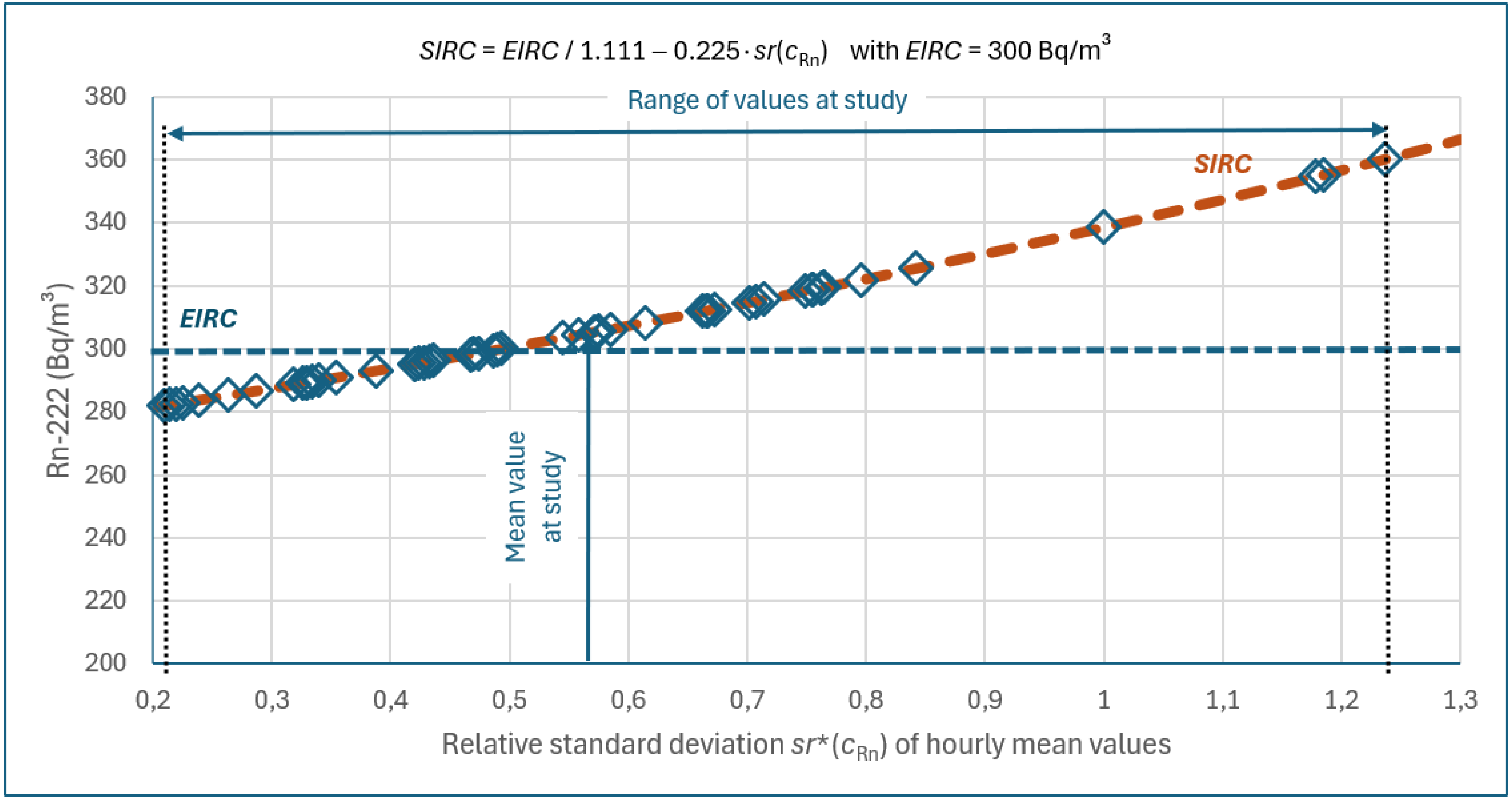
Influence example: Outdoor temperature

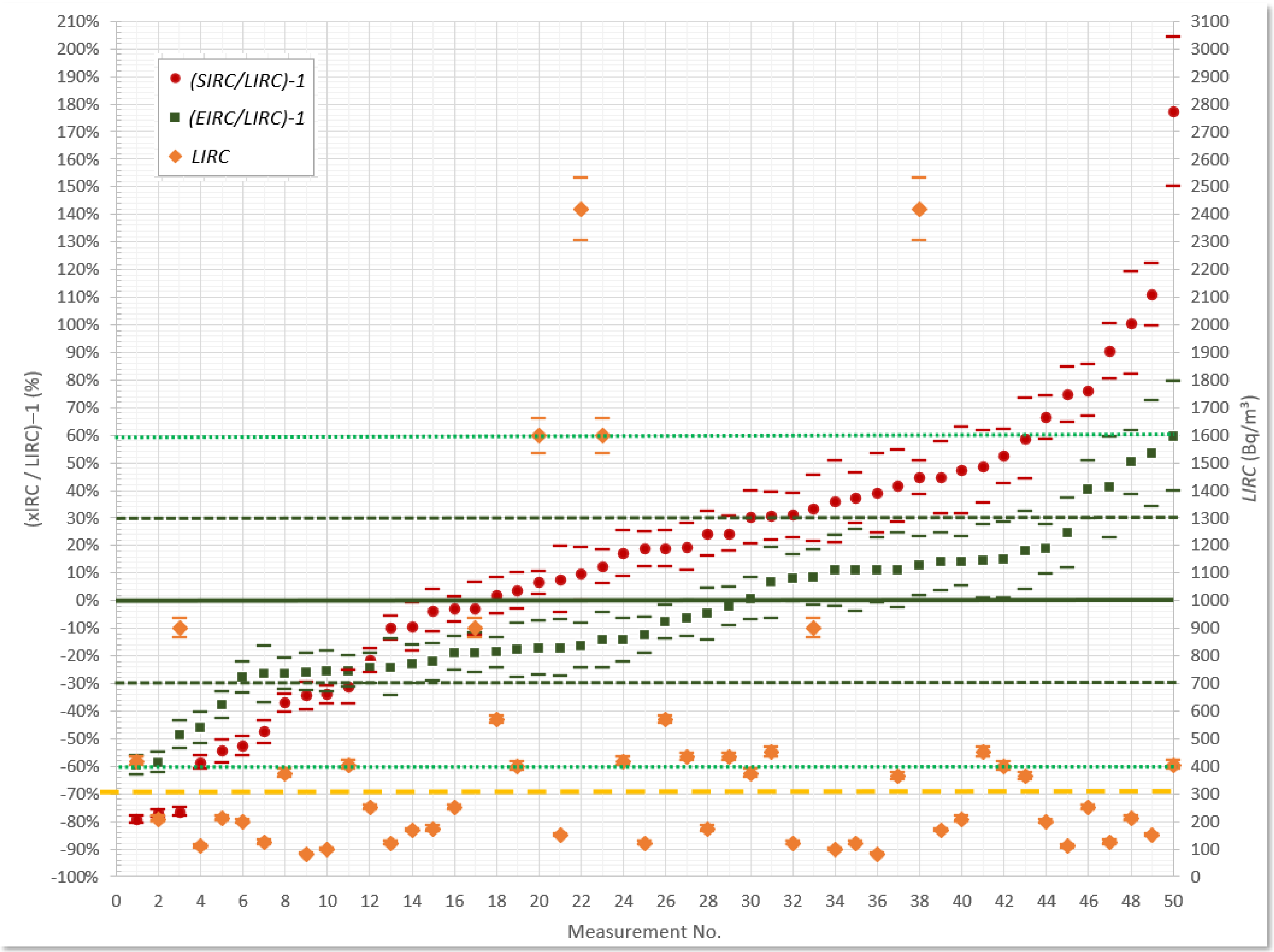


Influence example: negative air pressure gradient



Influence example: Variability of hourly averages





ratios
(with uncertainty bar):

SIRC/LIRC (red)
and
EIRC/LIRC (green)
sorted in ascending order,

LIRC (Bq/m³) of the
long-term measurement
(orange)

Measurement uncertainties & undercutting of guide values

Measured variables:
Hourly averages c_{RN}* $\rightarrow$ *SIRC*, $f_j \rightarrow$ *EIRC*

Measurement uncertainties:
$u(c_{RN}*) \rightarrow u(SIRC) \rightarrow u_{rel}(EIRC) = u_{rel}(SIRC) + 3\ \%$

Very reliable detection of undercutting:

EIRC **· 2.5 < radon-222 guideline (limit) value => 119 Bq/m³ · 2.5 < 300 Bq/m³**

(*SIRC* · 5.0 < radon-222 guideline (limit) value => 59 Bq/m³ · **5.0** < 300 Bq/m³)

Summary & conclusions

→ Three-week measurements of radon-222 activity concentration (hourly averages) with active radon measuring devices

+ Simultaneous collection and consideration of 10 influencing factors - seasonal, meteorological, metrological

$$\rightarrow EIRC = SRIC \cdot \prod_{i=1}^{10} p_i(f_i)$$

=> **Estimation / delimitation of the 'annual mean value' within a ± 30 % interval (≈ 80 % confidence level)**

=> **Undercutting of guide value detectable with 2.5·*EIRC* < Rn-GV**

Example: 2.5·119 Bq/m³ < 300 Bq/m³

Outlook: Project phase 2

→ Carry out further similar measurements or analyse measurement series (different federal states/regions, different building types, ...)

→ Further develop influencing parameters and functional relationships: e.g. 1-week measurements, adjust 3-hour averages

→ Refined physical-statistical analyses and methods

→ Extrapolate influences on hourly mean values to annual mean values

=> **Estimation / delimitation of the 'annual mean value' within an within an interval smaller than ± 20 % (≈ 95 % confidence level)**

=> **Indicative value undercut detectable with less than 2.*0·EIRC***

Goal

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Radon measuring devices and radon detectors (incl. Tracketch analyses):

- **Seibersdorf Laboratories, Tobias** Moreau
  AlphaGuard radon measuring devices, Rn-tracketch detectors
- **City of Vienna, MA 39, Radiation Protection Laboratory, Hannah Wiedner**
  AlphaGuard Rn measuring devices, AlphaE measuring devices, Rn Tracketch detectors
- **Federal Office of Metrology and Surveying, Robert Brettner-Messler**
  RadonEye measuring device

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- **Marius Blum,** project work and master's thesis
- **Dominik Boya,** project work
- **Xaver Anton Goidinger,** Bachelor thesis
- **Johannes Toth,** project work

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Project deliverables

- **M. Blum, D. Boya, X. Goidinger, F. J. Maringer, T. Moreau, J. Toth, H. Wiedner, Abschätzung des Jahresmittelwertes der Radonkonzentration in Innenräumen mittels aktiver Kurzzeitmessungen**, **Tagungsband**, 10. Gemeinsame Fachtagung des ÖVS und FS, ed. F.J. Maringer, H. Völkle, M. Froning, Österreichischer Verband für Strahlenschutz, Fachverband für Strahlenschutz, Seibersdorf, 2023.
- **M. Blum,** Estimation of the annual mean value of the Rn-222 activity concentration in indoor spaces using active short-term measurements: **Measurements in southern Lower Austria**, **project work**, TU Vienna, 2023.
- **D. Boya,** Estimation of the annual mean value of indoor radon-222 concentrations using active short-term measurements: **Comparison of active with passive measurements in Upper Austria**, **project work**, TU Vienna, 2023.
- **X.A. Goidinger,** Estimation of the annual mean value of indoor radon-222 concentrations by active short-term measurements: **Investigation of meteorological factors influencing radon concentrations in private houses, Bachelor thesis**, TU Vienna, 2023.
- **J. Toth,** Estimation of the annual mean value of radon-222 concentrations in indoor spaces by active short-term measurements: Calibration measurements of active radon measuring devices, **project work**, TU Vienna, 2023.
- **M. Blum,** Neue Kurzzeitmessmethoden für die Ermittlung der Rn-222-Aktivitätskonzentration in Wohnräumen, **diploma thesis**, TU Wien, 2024.
- **F.J. Maringer**, **Leitfaden** - Abschätzung des Radon-222-Jahresmittelwerts in Innenräumen aus Kurzzeitmessungen, Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), 2024
- **BMK**, **Forschungsbericht** - Abschätzung des Radon-222-Jahresmittelwerts in Innenräumen aus Kurzzeitmessungen, Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), (in preparation)
- **F. J. Maringer, M. Blum**, Application of Short-Term Measurements to Estimate the Annual Mean Indoor Air Radon-222 Activity Concentration, Atmosphere, Volume 16, Issue 2, 215, 2025

Project *deliverables*

Österreichischer Verband für Strahlenschutz
Mitgliedsgesellschaft der International Radiation Protection Association

Fachverband für Strahlenschutz e.V.
Für Deutschland und die Schweiz
Mitgliedsgesellschaft der IRPA
International Radiation Protection Association

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10. Gemeinsame Fachtagung des ÖVS und FS

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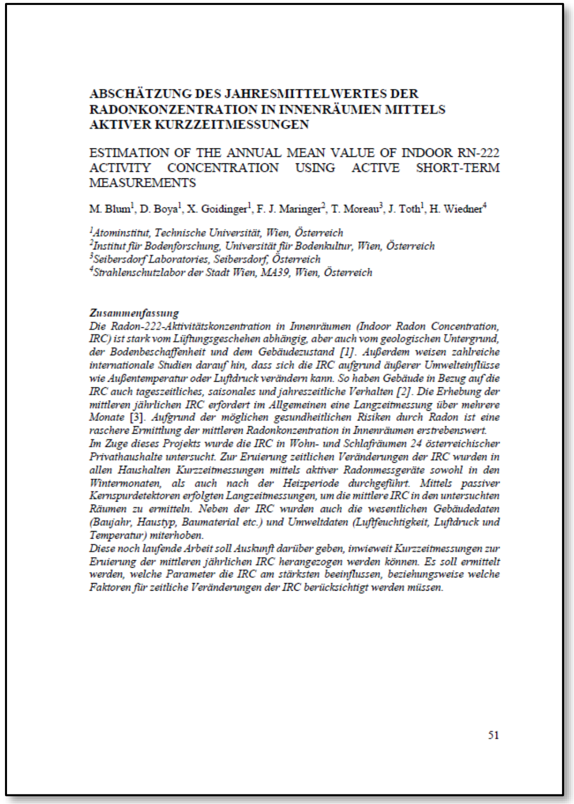
Martina Froning



ABSCHÄTZUNG DES JAHRESMITTELWERTES DER RADONKONZENTRATION IN INNENRÄUMEN MITTELS AKTIVER KURZZEITMESSUNGEN

ESTIMATION OF THE ANNUAL MEAN VALUE OF INDOOR RN-222 ACTIVITY CONCENTRATION USING ACTIVE SHORT-TERM MEASUREMENTS

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[3]Seibersdorf Laboratories, Seibersdorf, Österreich
[4]Strahlenschutzlabor der Stadt Wien, MA39, Wien, Österreich

Zusammenfassung
Die Radon-222-Aktivitätskonzentration in Innenräumen (Indoor Radon Concentration, IRC) ist stark vom Lüftungsgeschehen abhängig, aber auch vom geologischen Untergrund, der Bodenbeschaffenheit und dem Gebäudezustand [1]. Außerdem weisen zahlreiche internationale Studien darauf hin, dass sich die IRC aufgrund äußerer Umwelteinflüsse wie Außentemperatur oder Luftdruck verändern kann. So haben Gebäude in Bezug auf die IRC auch tageszeitliches, saisonales und jahreszeitliche Verhalten [2]. Die Erhebung der mittleren jährlichen IRC erfordert im Allgemeinen eine Langzeitmessung über mehrere Monate [3]. Aufgrund der möglichen gesundheitlichen Risiken durch Radon ist eine raschere Ermittlung der mittleren Radonkonzentration in Innenräumen erstrebenswert.
Im Zuge dieses Projekts wurde die IRC in Wohn- und Schlafräumen 24 österreichischer Privathaushalte untersucht. Zur Eruierung zeitlichen Veränderungen der IRC wurden in allen Haushalten Kurzzeitmessungen mittels aktiver Radonmessgeräte sowohl in den Wintermonaten, als auch nach der Heizperiode durchgeführt. Mittels passiver Kernspurdetektoren erfolgten Langzeitmessungen, um die mittlere IRC in den untersuchten Räumen zu ermitteln. Neben der IRC wurden auch die wesentlichen Gebäudedaten (Baujahr, Haustyp, Baumaterial etc.) und Umweltdaten (Luftfeuchtigkeit, Luftdruck und Temperatur) miterhoben.
Diese noch laufende Arbeit soll Auskunft darüber geben, inwieweit Kurzzeitmessungen zur Eruierung der mittleren jährlichen IRC herangezogen werden können. Es soll ermittelt werden, welche Parameter die IRC am stärksten beeinflussen, beziehungsweise welche Faktoren für zeitliche Veränderungen der IRC berücksichtigt werden müssen.

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TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Diplomarbeit

Neue Kurzzeitmessmethoden für die Ermittlung der Rn-222-Aktivitätskonzentration in Wohnräumen

zur Erlangung des akademischen Grades
Diplom-Ingenieur

im Rahmen des Studiums
Physikalische Energie- und Messtechnik

eingereicht von

Marius Blum, B.Sc.
Matrikelnummer 1425615

ausgeführt an der
Technischen Universität Wien
Karlsplatz 13
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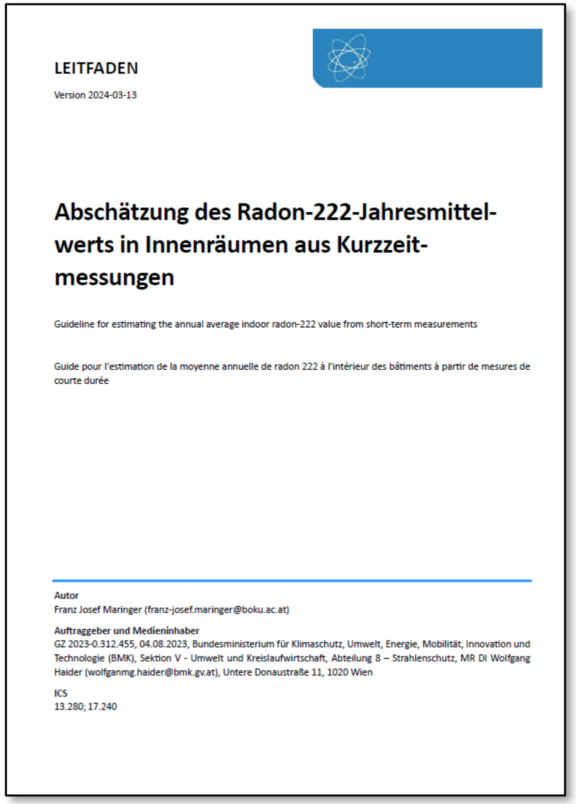
unter der Anleitung von

Univ.-Prof. Dipl.-Ing. Dr. techn. Franz Josef Maringer

Wien, am 14. Mai 2024

Unterschrift des Verfassers | Unterschrift des Betreuers



LEITFADEN

Version 2024-03-13

Abschätzung des Radon-222-Jahresmittel-werts in Innenräumen aus Kurzzeit-messungen

Guideline for estimating the annual average indoor radon-222 value from short-term measurements

Guide pour l'estimation de la moyenne annuelle de radon 222 à l'intérieur des bâtiments à partir de mesures de courte durée

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Auftraggeber und Medieninhaber
GZ 2023-0.312.455, 04.08.2023, Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (BMK), Sektion V - Umwelt und Kreislaufwirtschaft, Abteilung 8 – Strahlenschutz, MR DI Wolfgang Haider (wolfganmg.haider@bmk.gv.at), Untere Donaustraße 11, 1020 Wien

ICS
13.280; 17.240

Thank you for your attention!

Bundesministerium
Klimaschutz, Umwelt,
Energie, Mobilität,
Innovation und Technologie

Endbericht

Bezeichnung des Auftrages: Erstellung eines Leitfadens für Kurzzeit-Radonmessungen zur Abschätzung des Radon-222-Jahresmittelwertes

Wien, 2024

Bundesministerium
Klimaschutz, Umwelt,
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Innovation und Technologie

Leitfaden

Abschätzung des Radon-222-Jahresmittelwerts in Innenräumen aus Kurzzeitmessungen

Wien, 2024

atmosphere MDPI

Article

Application of Short-Term Measurements to Estimate the Annual Mean Indoor Air Radon-222 Activity Concentration

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Abstract: A method was developed to estimate the average annual indoor radon activity concentration from three-week short-term measurements using active radon-222 measuring devices, taking into account the relevant influencing parameters (season, temperature difference, temporal air pressure gradient, etc.) during the short-term measurements. A total of 24 long-term measurements (6 months) and 50 short-term measurements (3 weeks) were carried out in 24 indoor spaces in private houses in four Austrian federal states between October 2022 and July 2023. At the same time as the short-term measurements, ambient parameters (outsi[illegible] and in[illegible] temperature, air pressure inside, ou[illegible]de, air hu[illegible]dity i[illegible]ide, [illegible]ed, wind dir[illegible], amount of precipitation) [illegible]re also [illegible]d to [illegible]vestig[illegible] their [illegible]fluence [illegible] the [illegible]easure[illegible] radon [illegible] concentrations. Building a[illegible] usage [illegible]ta of [illegible] indoor spac[illegible] examined were [illegible]so coll[illegible]ed. Ba[illegible] on the evaluation [illegible] the ra[illegible]n-22[illegible] measure[illegible]ents [illegible]rried o[illegible] a fi[illegible] guidel[illegible] was d[illegible]veloped for estimat[illegible] the a[illegible]ual m[illegible] valu[illegible] of the [illegible] activ[illegible] concen[illegible]ation from short-term measurements lasting around three weeks. The result shows th[illegible] by ap[illegible]ing the developed method, the approximation to the long-term average value can be significantly improved, at least by a factor of 2. This criterion is only valid for the 24 indoor spaces examined in this study. Generalisation requires a test and validation study of the method presented. It is planned to test and validate the developed method in other indoor spaces by means of further measurements and in-depth physical-statistical considerations, and to improve the functional relationships and the approximation to the long-term average value.

Keywords: public health; radiation protection; indoor air pollution; radon-222; short-term radon measurements; annual mean radon activity concentration

check for updates

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1. Introduction

The indoor air radon activity concentration (IRC) is influenced by several factors. These include mainly geological factors, such as the rock subsoil and the soil conditions under the building, the condition of the building (type of foundation, insulation, etc.), the usage behaviour of the residents (ventilation habits, room temperature, etc.), as well as meteorological influences (outside temperature, air pressure, etc.) [1]. Due to the influences mentioned, the IRC is subject to fundamental changes over time [2]. Buildings, therefore, also have diurnal, seasonal, and annual behaviour in relation to the IRC [3]. The main factors influencing the temporal variability of the IRC value in an interior are meteorology and user behaviour.

Atmosphere 2025, 16, 215 https://doi.org/10.3390/atmos16020215

Best regards and wishes from all ÖVS colleagues and thank you for the good and unifying co-operation of our radiation protection associations in Central Europe - especially in the context of the k&k 'Monarchy Conferences' in the past 50 years!

Glückauf - ad multos annos!