Academy of Sciences and Arts of Republic of Srpska
under the patronage of
Ministry of Health and Social Protection of Republic of Srpska
organizes

**International Symposium**

**The Influence of Radon and Toron to the Health of People**
Teslić, Hotel Kardial, Congress Centre, April 13, 2018

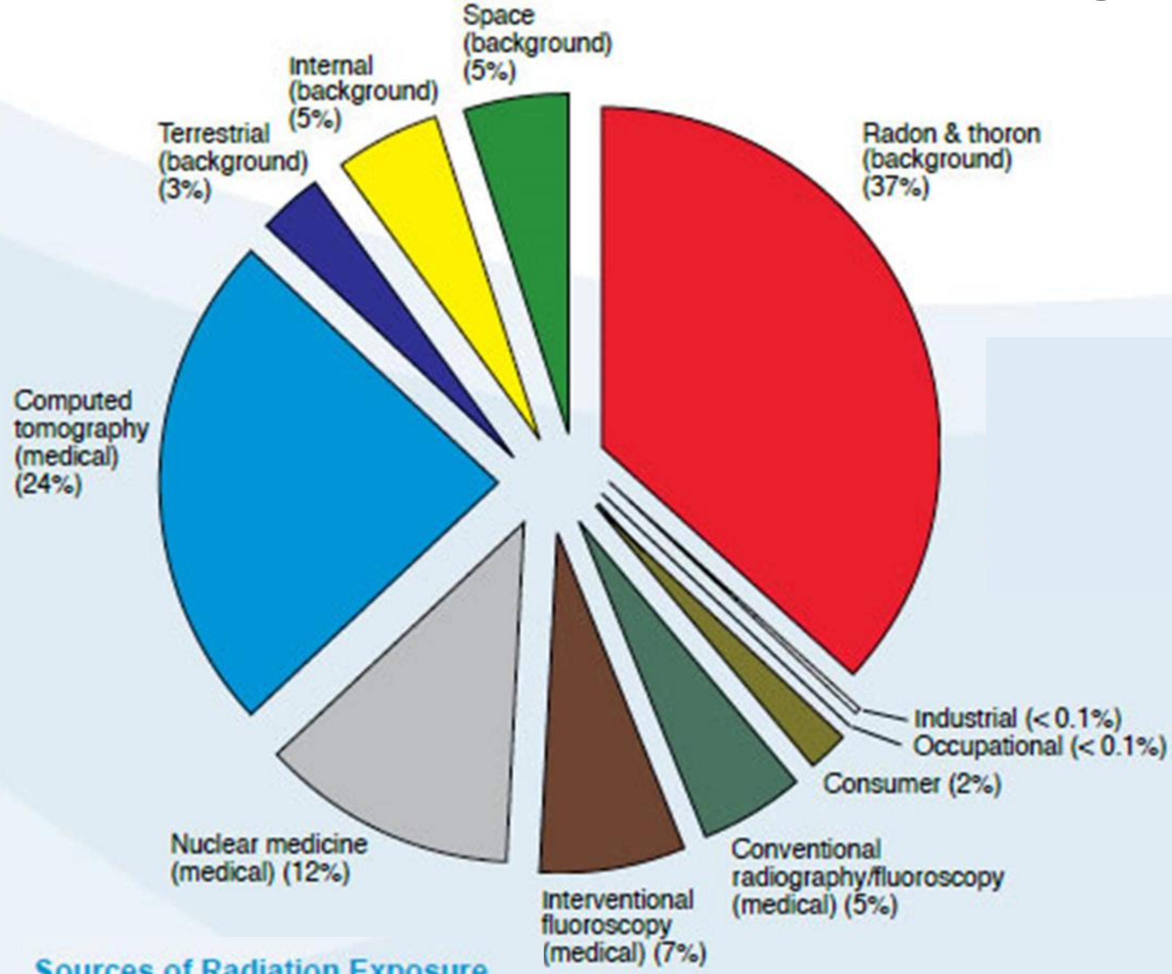
# Experiences and general conclusions from indoor radon surveys performed in the Republic of Macedonia

Zdenka Stojanovska[1]

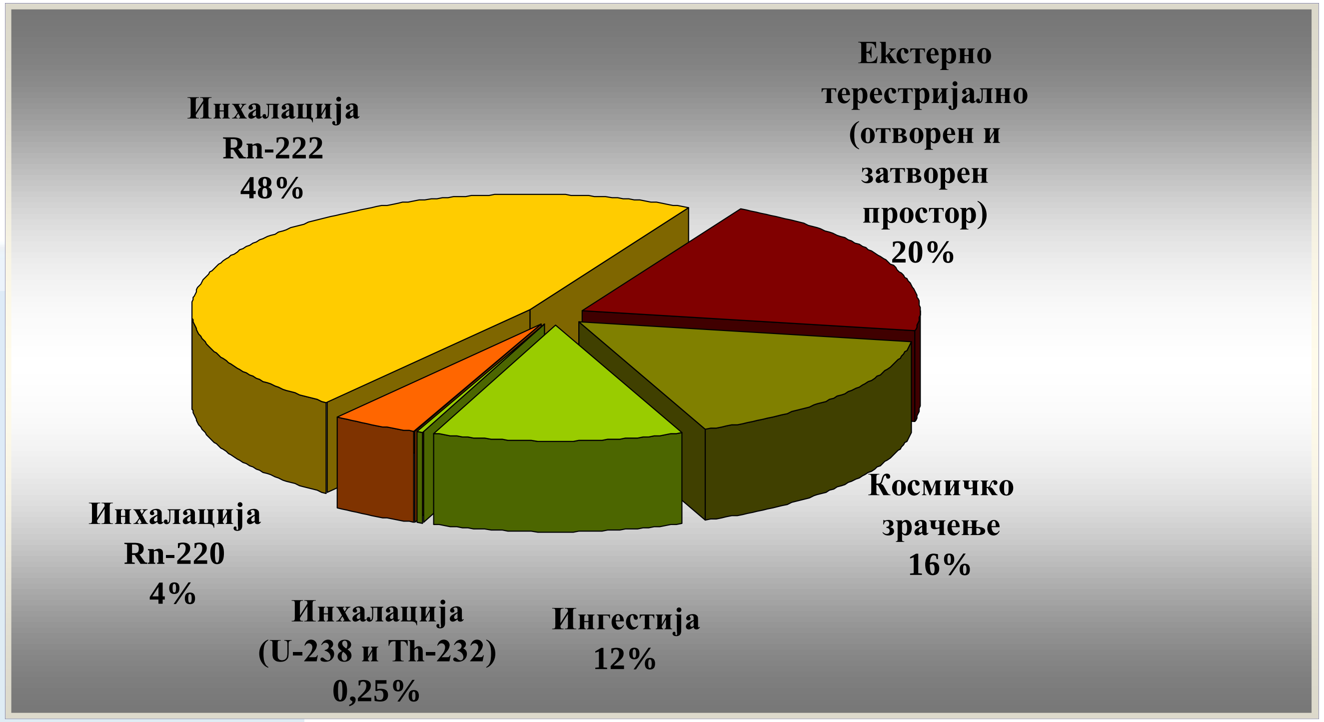
[1]*Faculty of medical sciences, UGD Stip, Republic of Macedonia;*
*zdenka.stojanovska@ugd.edu.mk*

# Introduction

- Large-scale surveys, have been performing in a many countries over the world in order to: estimate average exposures to different radioactive sources




Sources of Radiation Exposure
From: *NCRP Report No. 160*




**Radiation Exposure from the Natural sources**

From: UNSCEAR report, 2000

# Indoor radon

- The main source of indoor radon is $^{226}Ra$ contained in building materials as well soil;
- Transport pathways are the porous environment of the soil and the building materials, as well as cracks, faults, etc.
- The radon transport mechanisms: diffusion and advection cased by the concentration and temperature gradients , respectively.

# Indoor radon

- The factors affecting the indoor radon concentration variations can be assigned into three groups:

1. *Radon potential* –characterize the building sub-surface (in terms of radon generation in soil and condition for transport until its exaltation of the surface
2. *Building characteristics*
3. *Building user life stile and habits*

- Additionally, all three factors are affected by the meteorological conditions, resulting with high temporal variability
- Indoor radon concentration in an building is presented by the ***annual radon concentration***

# Indoor Rn surveys in Republic of Macedonia

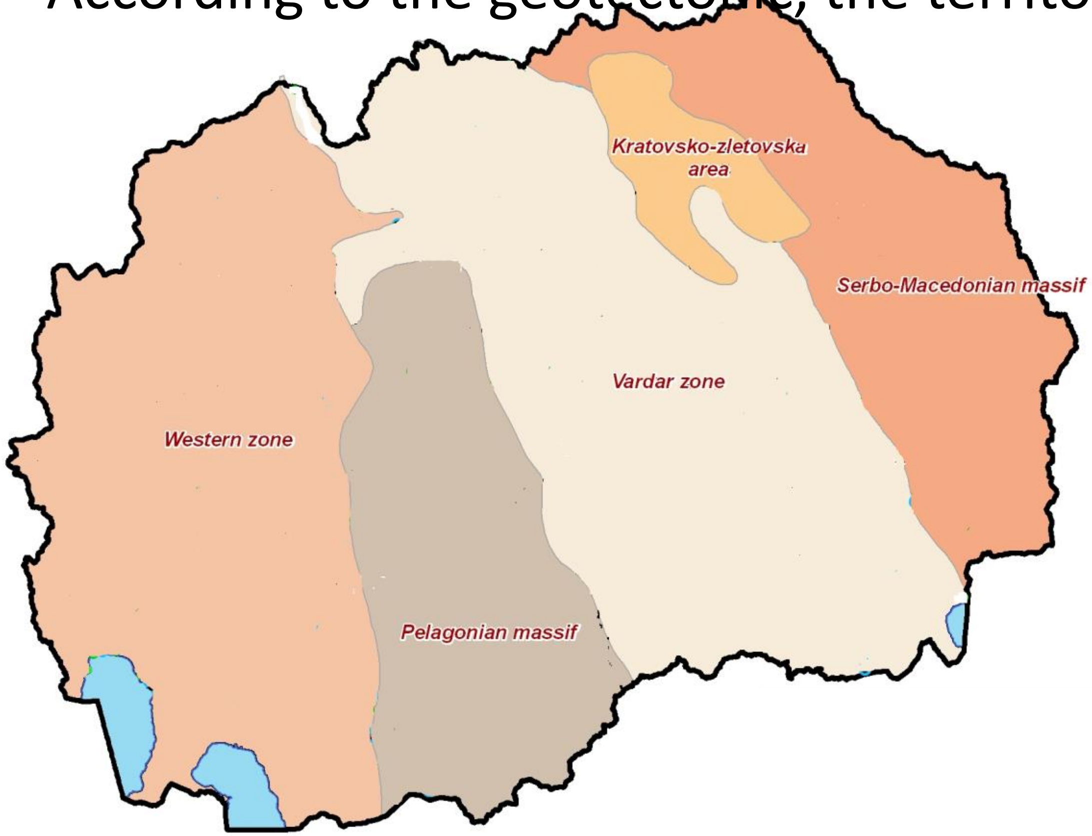
- During the last decade, considerable attention has been payed to the indoor radon surveys in the Republic of Macedonia

| Radon survey performed (year): | No of observation | Period of exposure (months) | Annual radon concentration |
|---|---|---|---|
| 2008/2009 | 437 | 3 x 4 seasons | Arithmetic mean of all seasons |
| 2012 | 73 | 3 x winter season | Seasonally corrected |
| 2013/2014 | 76 | 12 | measured |
| 2013 | 43 | 3 x winter season | seasonally corrected |

- All measurements were done using the nuclear track detectors.
- The detectors were set in the rooms with the highest occupancy time at a distance greater than 0.5 m from each wall and at a minimum of 20 cm from any other object.

# Geotectonical Zones in Republic of Macedonia

- Republic of Macedonia covered 25 713 km$^2$; Population: 2 022 547
- Great diversity though mountains occupy nearly 80% and basins 20% of the country;
- According to the geotectonic, the territory is divided in four zones and an area:




Descriptive statistic of 40K, 226Ra and 232Th specific activities, measured in 213 soil samples by gamma spectrometry

| A(Bq/kg) | No. | Min. | Max. | Med | AM | SD | CV(%) | GM | GSD |
|---|---|---|---|---|---|---|---|---|---|
| 40K \| KZA | 8 | 378 | 783 | 665 | 652 | 122 | 18% | 639 | 1.25 |
| 40K \| PE | 36 | 193 | 959 | 645 | 644 | 159 | 24% | 622 | 1.34 |
| 40K \| SMM | 25 | 348 | 1390 | 684 | 664 | 239 | 35% | 627 | 1.41 |
| 40K \| VZ | 90 | 80 | 1089 | 485 | 496 | 170 | 34% | 463 | 1.51 |
| 40K \| WMM | 54 | 186 | 974 | 644 | 648 | 174 | 27% | 621 | 1.37 |
| 226Ra \| KZA | 8 | 36 | 101 | 60 | 61 | 19 | 30% | **58** | **1.36** |
| 226Ra \| PE | 36 | 36 | 123 | 52 | 57 | 20 | 34% | **55** | **1.35** |
| 226Ra \| SMM | 25 | 23 | 99 | 41 | 42 | 17 | 40% | 40 | 1.43 |
| 226Ra \| VZ | 90 | 9 | 87 | 30 | 31 | 12 | 39% | 29 | 1.47 |
| 226Ra \| WMM | 54 | 18 | 86 | 39 | 41 | 13 | 32% | 39 | 1.38 |
| 232Th \| KZA | 8 | 40 | 67 | 54 | 53 | 9 | 16% | **52** | **1.18** |
| 232Th \| PE | 36 | 35 | 145 | 50 | 59 | 24 | 39% | **56** | **1.40** |
| 232Th \| SMM | 25 | 23 | 83 | 40 | 43 | 18 | 41% | 40 | 1.47 |
| 232Th \| VZ | 90 | 7 | 79 | 31 | 32 | 12 | 37% | 30 | 1.52 |
| 232Th \| WMM | 54 | 17 | 69 | 41 | 42 | 12 | 29% | 40 | 1.36 |

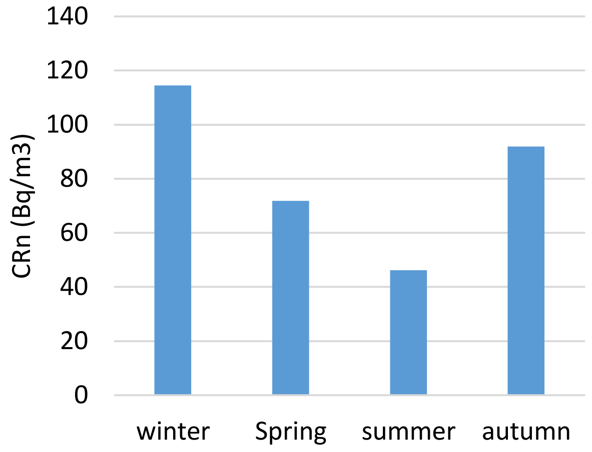
# Variations of indoor radon concentrations in Republic of Macedonia

- Indoor radon seasonal variations
- Annual indoor radon data characterization
- Factor affecting spatial variations
- Spatial variability of building  factors (6 building factors considered in analysis)

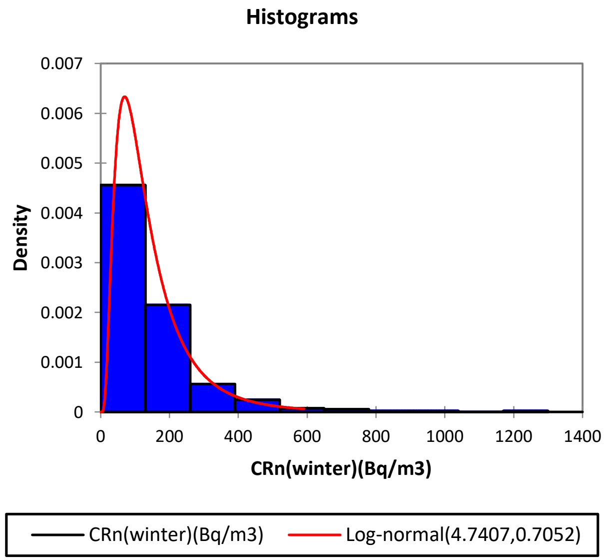
# Rn seasonal variation

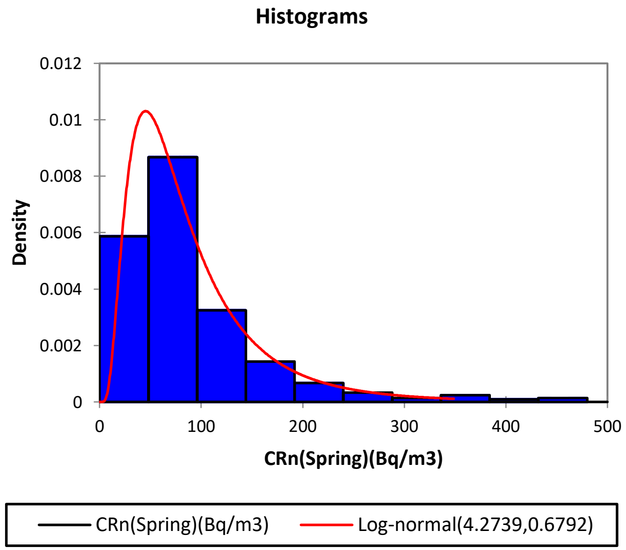
Descriptive statistic of indoor radon measurements in different season (2008/2009)

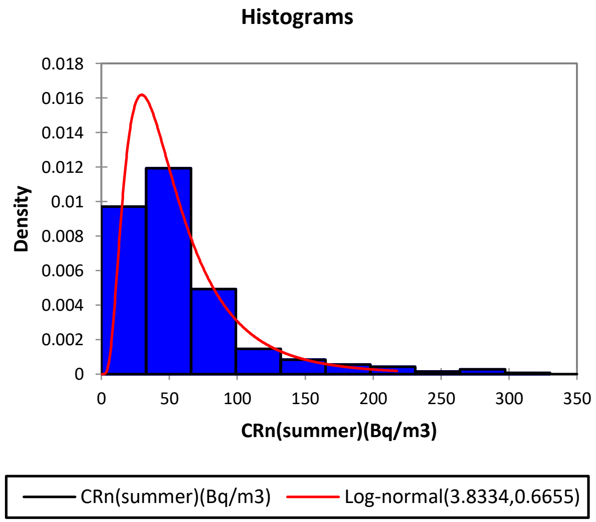
| Sample | N | Minimum | Maximum | Median | AM | SD | CV(%) | GM | GSD |
|---|---|---|---|---|---|---|---|---|---|
| CRn(winter)(Bq/m3) | 437 | 17 | 1276 | 106 | 150 | 136 | 91% | 115 | 2.02 |
| CRn(Spring)(Bq/m3) | 437 | 9 | 478 | 70 | 91 | 73 | 80% | 72 | 1.97 |
| CRn(summer)(Bq/m3) | 437 | 9 | 323 | 44 | 59 | 48 | 82% | 46 | 1.95 |
| CRn(autumn)(Bq/m3) | 437 | 7 | 935 | 93 | 119 | 104 | 87% | 92 | 2.02 |

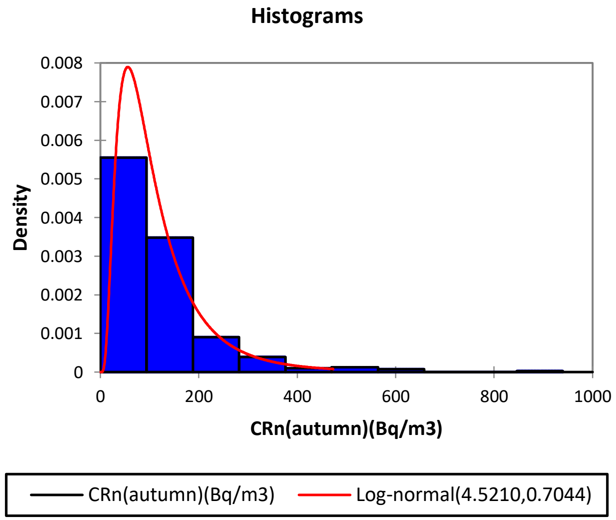



GM of indoor radon concentrations in different seasons



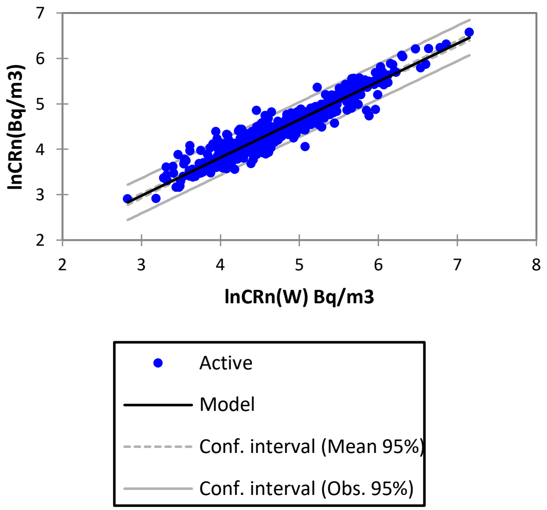



# Seasonal indoor Rn variations models

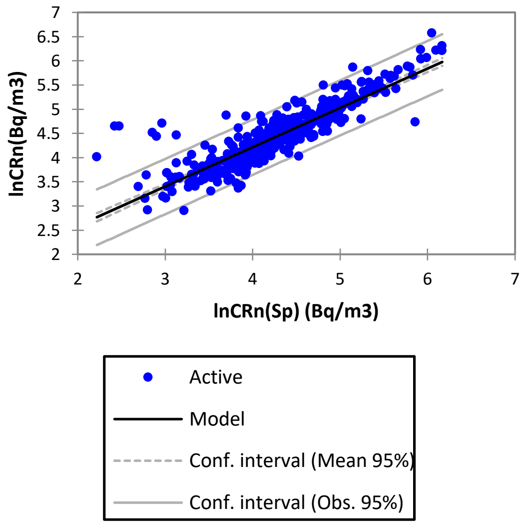
Linear regression model (y=Ax+B) parameters:

| y | X | A | B |
|---|---|---|---|
| ln CRn (annual) | lnCRn, winter | 0.84±0.01 | 0.46±0.06 |
| ln CRn (annual) | lnCRn, spring | 0.81±0.02 | 0.96±0.09 |
| ln CRn (annual) | llnCRn, summer | 0.71±0.03 | 1.71±0.11 |
| ln CRn (annual) | lnCRn, autumn | 0.80±0.02 | 0.83±0.08 |

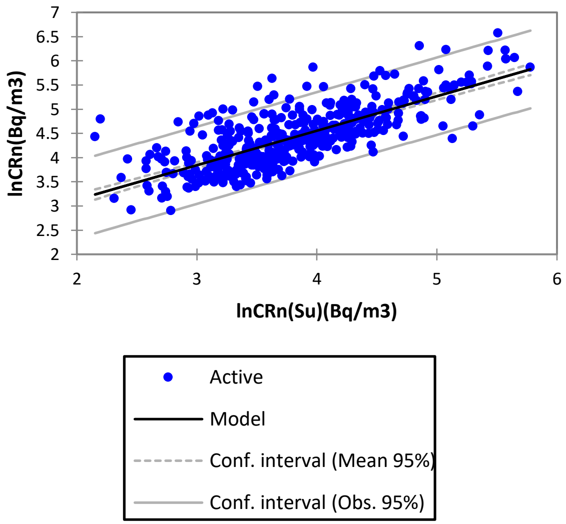
Regression of lnCRn(Bq/m3) by lnCRn(W) Bq/m3 (R2=0.9021)



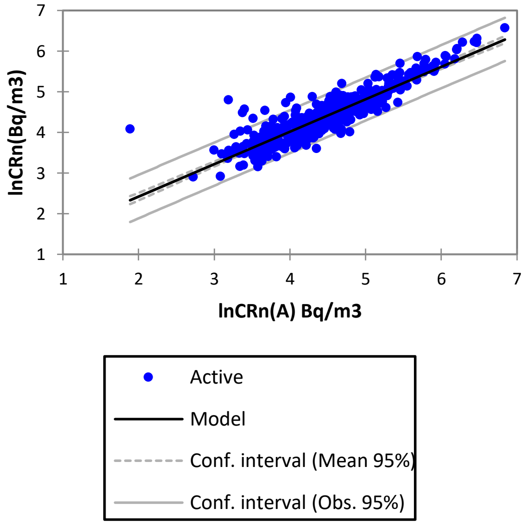

Regression of lnCRn(Bq/m3) by lnCRn(Sp) (Bq/m3) (R2=0.7850)




Regression of lnCRn(Bq/m3) by lnCRn(Su)(Bq/m3) (R2=0.5789)

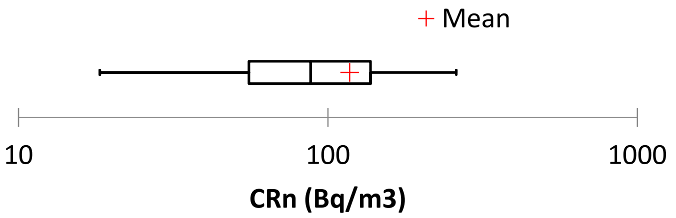



Regression of lnCRn(Bq/m3) by lnCRn(A) Bq/m3 (R2=0.8150)

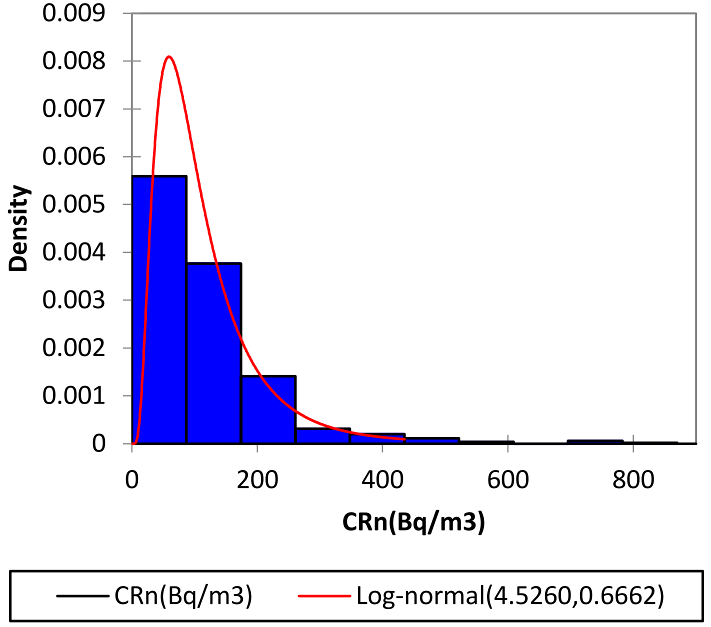


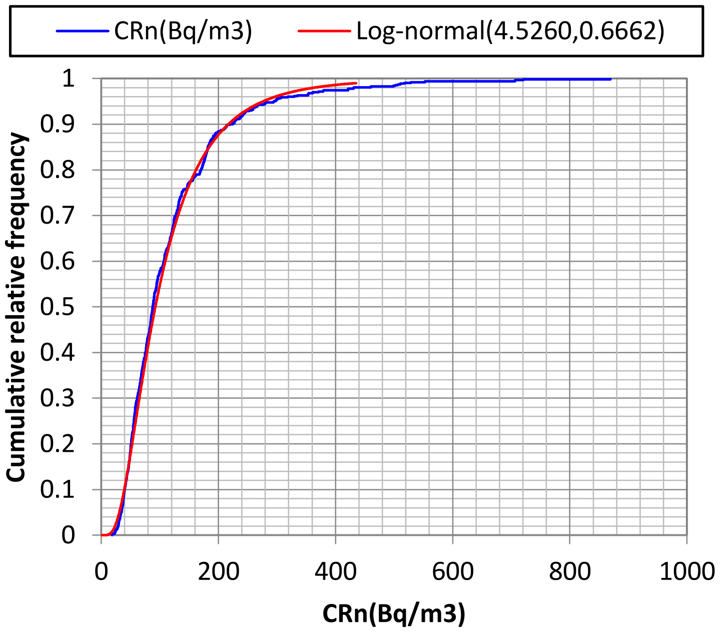
# Indoor radon data characterization

| Statistic | Rn(Bq/m3) |
|---|---|
| No. of observations | 629 |
| Minimum | 18 |
| Maximum | 869 |
| Median | 88 |
| Mean | 118 |
| Standard deviation | 99 |
| Variation coefficient | 84% |
| Geometric mean | **92** |
| Geometric standard deviation | **1.95** |

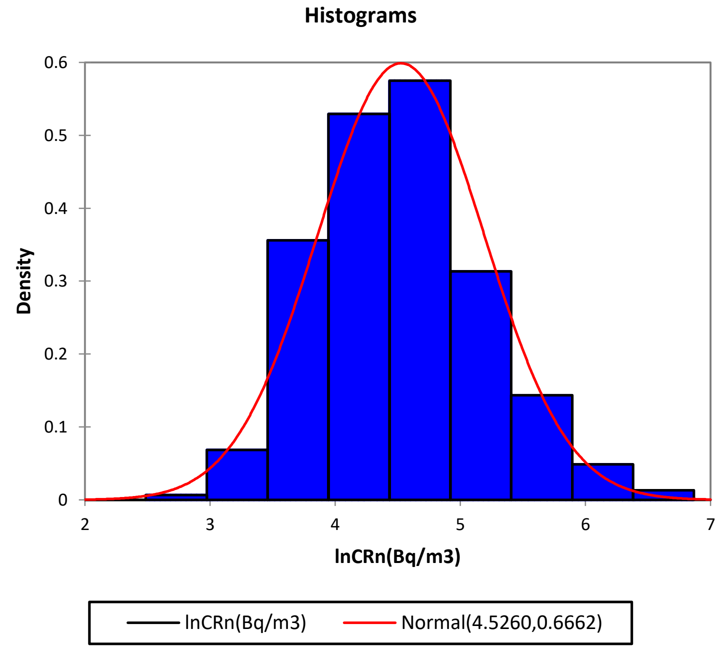


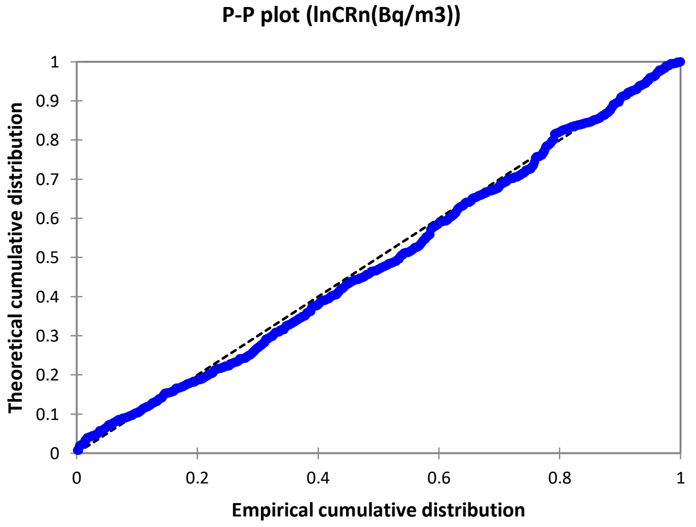

## Rn data



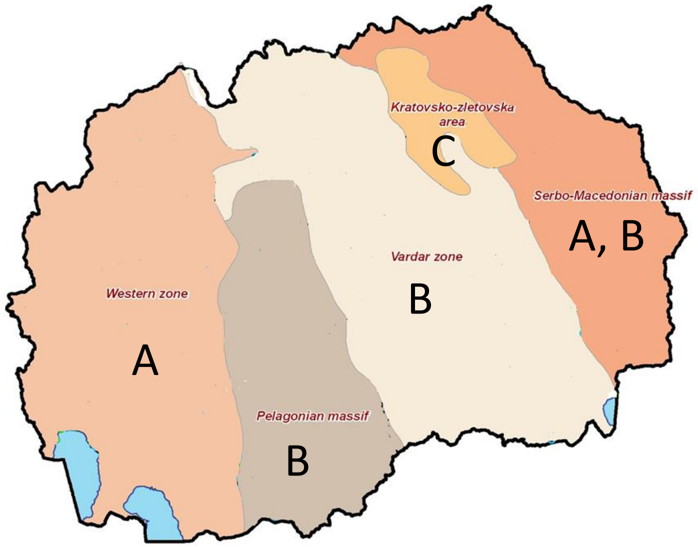




## ln(Rn) data



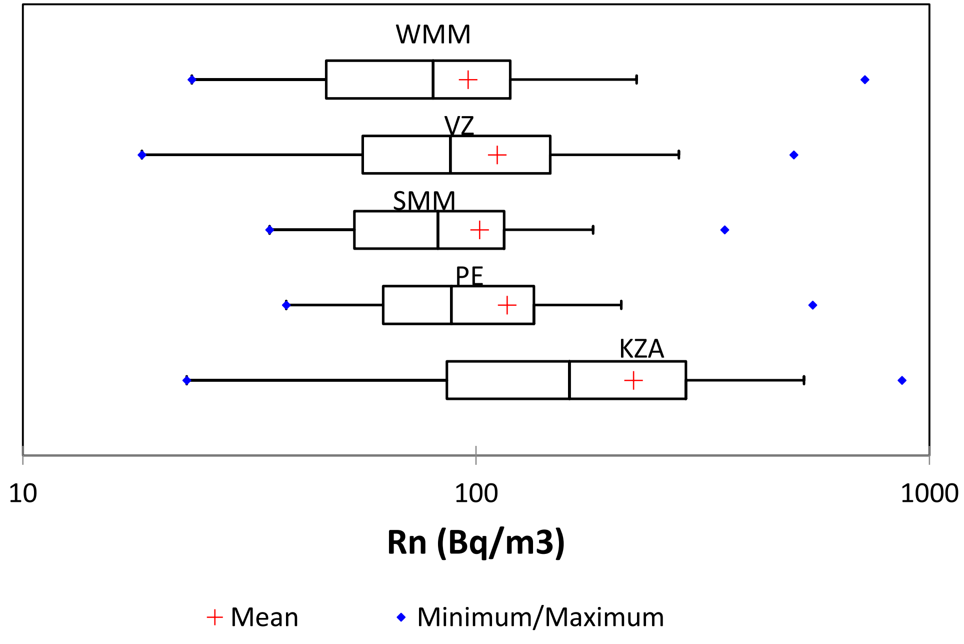



# Rn spatial variation




## 1. Geotectonical Zone

- Non-homogenies (Bartlett test, p=0.012)
- Significant variation between Zones (Kruskal-Wallis test, p< 0.0001)

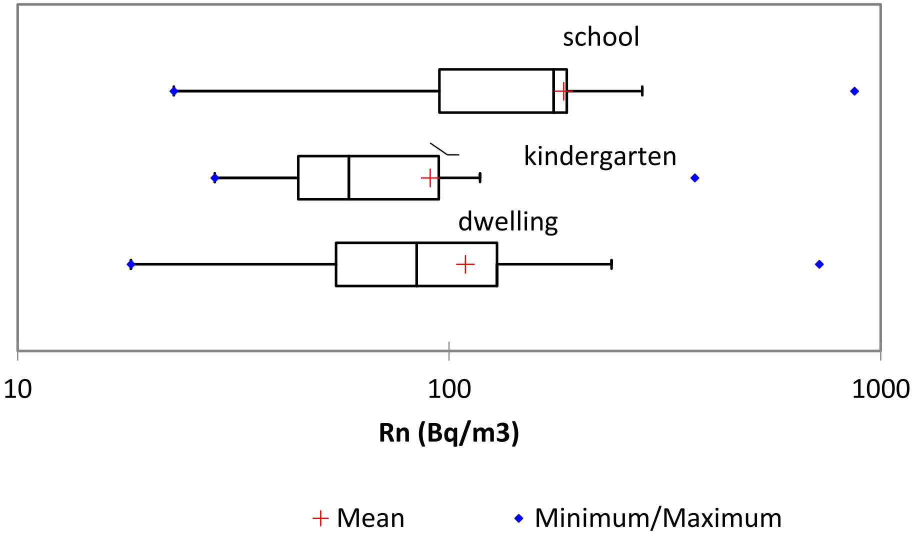



| Zone | N | GM | GSD | Groups Mann-Whitney test (p<0.05) | | |
|---|---|---|---|---|---|---|
| WMM | 114 | 77 | 1.89 | A | | |
| SMM | 59 | 85 | 1.78 | A | B | |
| VZ | 353 | 91 | 1.87 | | B | |
| PE | 49 | 95 | 1.81 | | B | |
| KZA | 54 | 158 | 2.36 | | | C |

# Building factor affecting Rn spatial variation

## 2. Indoor

- Homogenies (Bartlett test, p=0.71)
- Significant variation between different indoor (Kruskal-Wallis test, p< 0.0001)

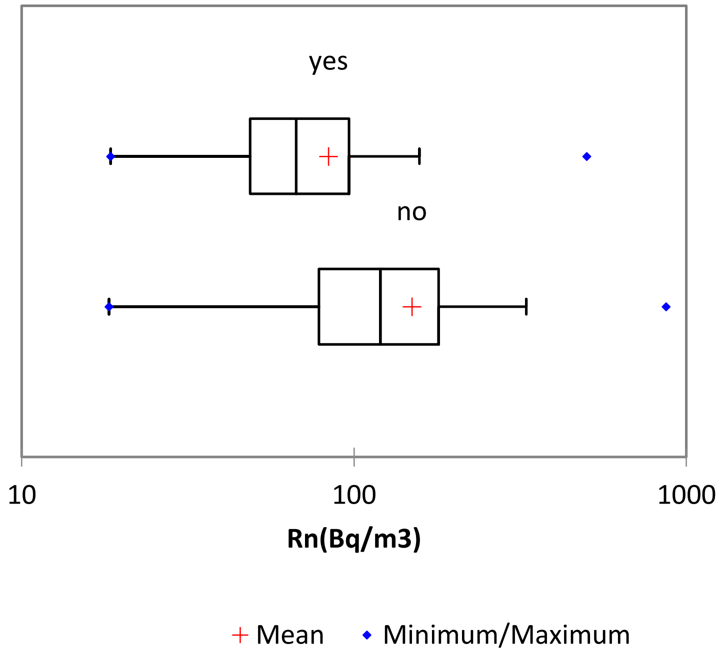



| Indoor | N | GM | GSD | Groups Mann-Whitney test (p<0.05) | |
|---|---|---|---|---|---|
| kindergarten | 14 | 87 | 1.89 | A | |
| dwelling | 540 | 68 | 2.04 | A | |
| school | 75 | 146 | 1.96 | | B |

# Building factor affecting Rn spatial variation

## 4. Presence of basement

- Non-Homogenies (Bartlett test, p=0.09)
- Significant variation (Kruskal-Wallis test, p< 0.0001)

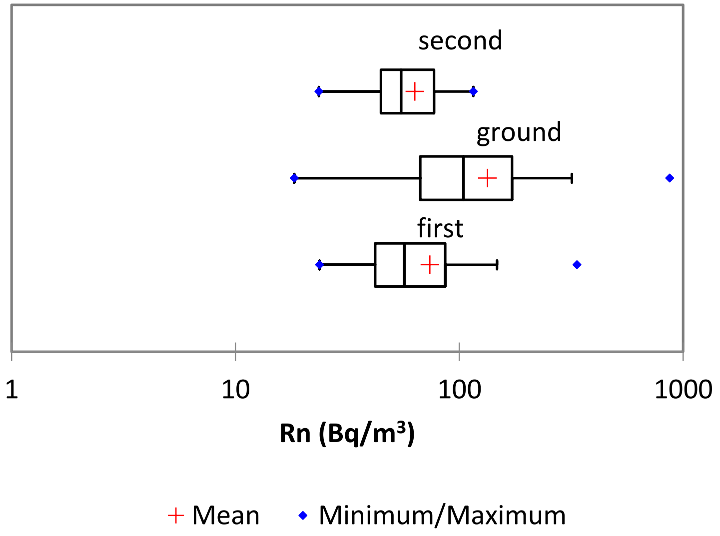



| Presence in basement | N | GM | GSD | Groups Mann-Whitney test (p<0.05) | |
|---|---|---|---|---|---|
| yes | 306 | 70 | 1.75 | A | |
| no | 323 | 119 | 1.92 | | B |

# Building factor affecting Rn spatial variation

## 3. Floor

- Non-homogenies (Bartlett test, p=0.0097)
- Significant Rn variation between different floors (Kruskal-Wallis test, p< 0.0001)

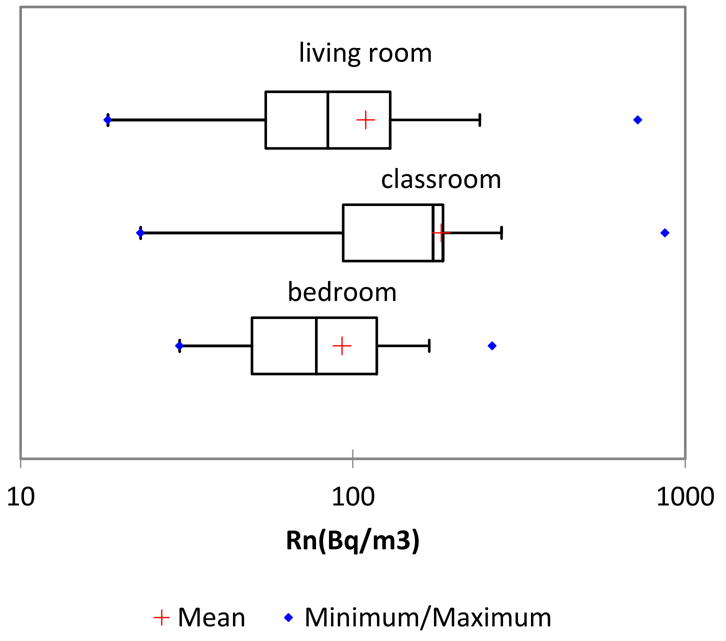



| Floor | Frequency | GM | GSD | Groups Mann-Whitney test (p<0.05) | |
|---|---|---|---|---|---|
| second | 15 | 57 | 1.60 | A | |
| first | 149 | 64 | 1.67 | A | |
| ground | 465 | 106 | 1.94 | | B |

# Building factor affecting Rn spatial variation

## 5. Type of room

- Homogenous data (Bartlett test, p=0.39)
- Significant Rn variation between group (Kruskal-Wallis test, p< 0.0001)

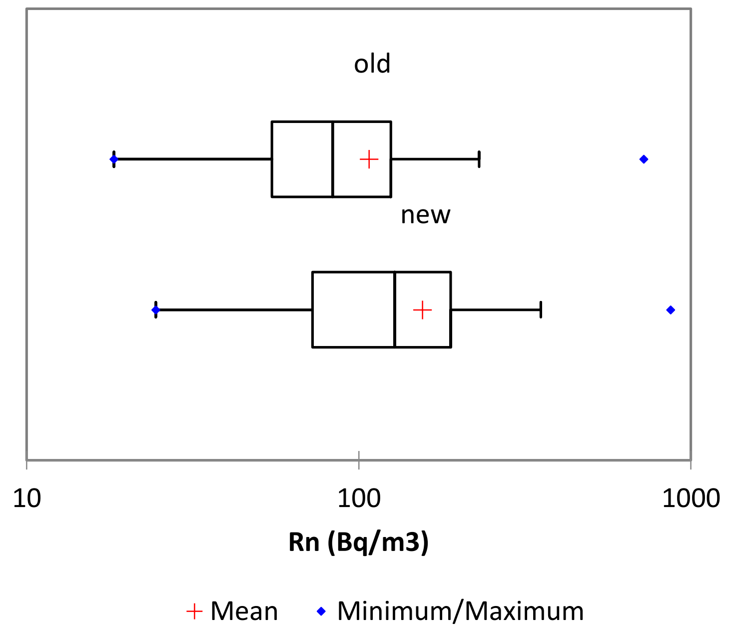



| Floor | Frequency | GM | GSD | Groups Mann-Whitney test (p<0.05) | |
|---|---|---|---|---|---|
| bedroom | 44 | 79 | 1.76 | A | |
| living room | 508 | 87 | 1.91 | A | |
| classroom | 77 | 146 | 1.98 | | B |

# Building factor affecting Rn spatial variation

## 6. Type of windows

- homogenous (Bartlett test, p=0.16)
- Significant variation (Kruskal-Wallis test, p< 0.0001)



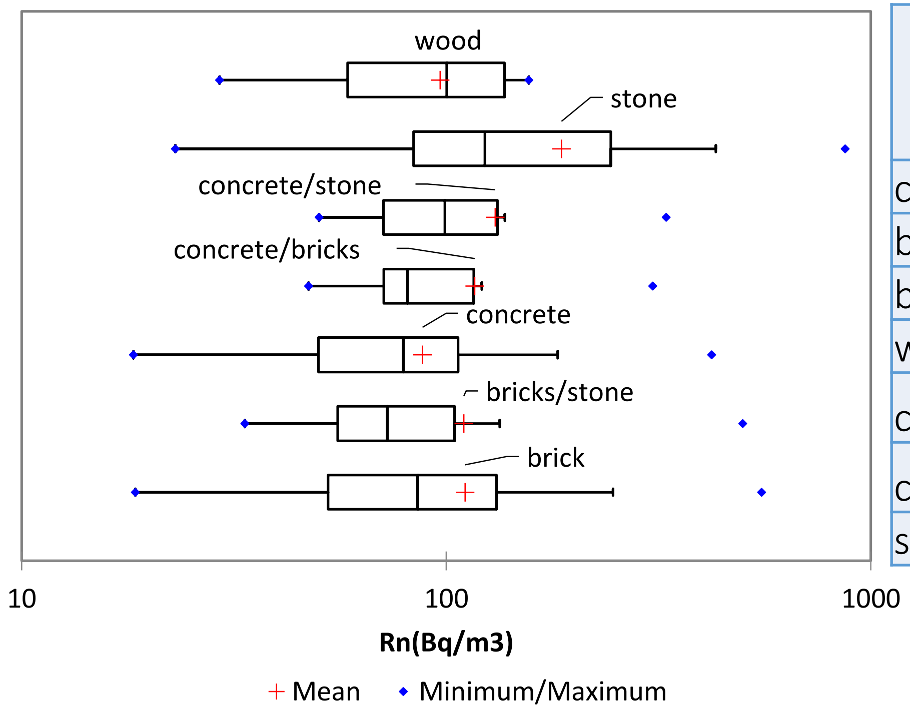

| Type of windows | Frequency | GM | GSD | Groups Mann-Whitney test (p<0.05) | |
|---|---|---|---|---|---|
| Old | 498 | 86 | 1.89 | A | |
| New | 131 | 121 | 2.05 | | B |

# Building factor affecting Rn spatial variation

## 7. Building materials

Homogenous data (Bartlett test, p=0.36)

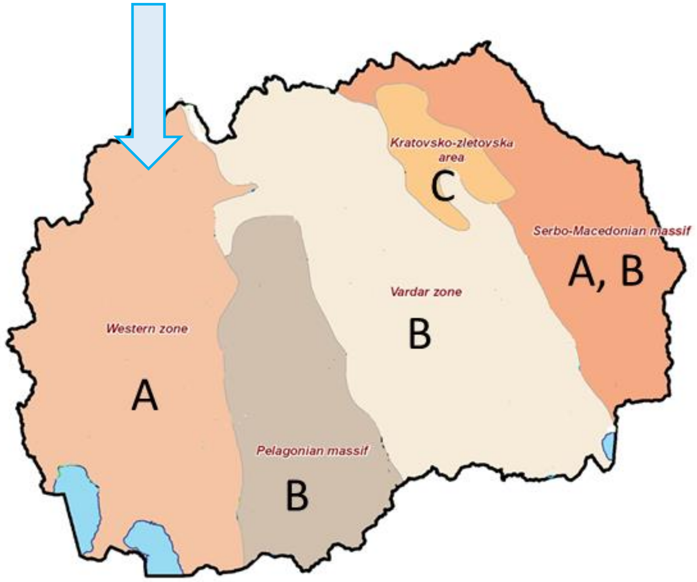
Significant variation between groups (Kruskal-Wallis test, p< 0.0001)




| Building material | Frequency | GM | GSD | Groups Mann-Whitney test (p<0.05) | |
|---|---|---|---|---|---|
| concrete | 104 | 74 | 1.78 | A | |
| bricks/stone | 45 | 86 | 1.92 | A | |
| brick | 326 | 88 | 1.93 | A | |
| wood | 6 | 82 | 1.94 | A | B |
| concrete/bricks | 10 | 98 | 1.80 | A | B |
| concrete/stone | 6 | 107 | 1.94 | A | B |
| stone | 68 | 137 | 2.15 | | B |

# Spatial variability of building factors influence

## Western Zone



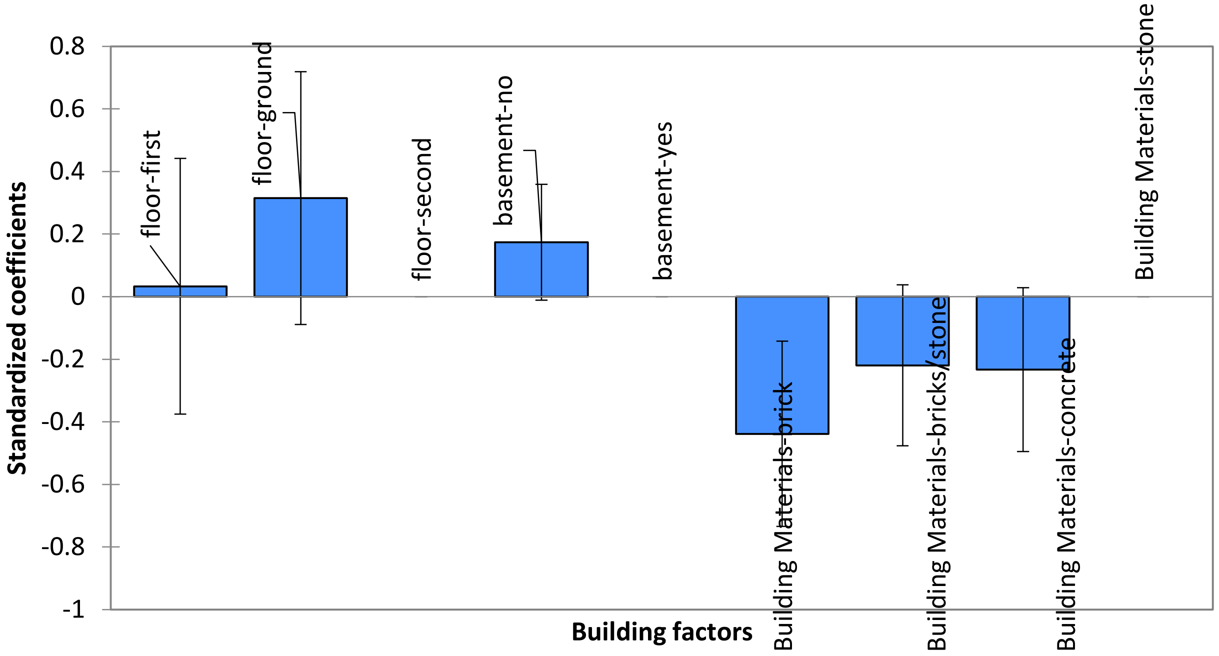

## Univariable linear models results:

| | Western Zone | p | R^2 | RMSE |
|---|---|---|---|---|
| 1 | indoor | | | |
| 2 | floor | 0.0046 | 0.1163 | 0.5652 |
| 3 | basement | 0.0016 | 0.0851 | 0.6115 |
| 4 | room | 0.9856 | | |
| 5 | building material | 0.0490 | 0.0634 | 0.6243 |
| 6 | windous | 0.1133 | | |

## Multivariable linear model ($R^2$=0.21; RMSE=0.58)

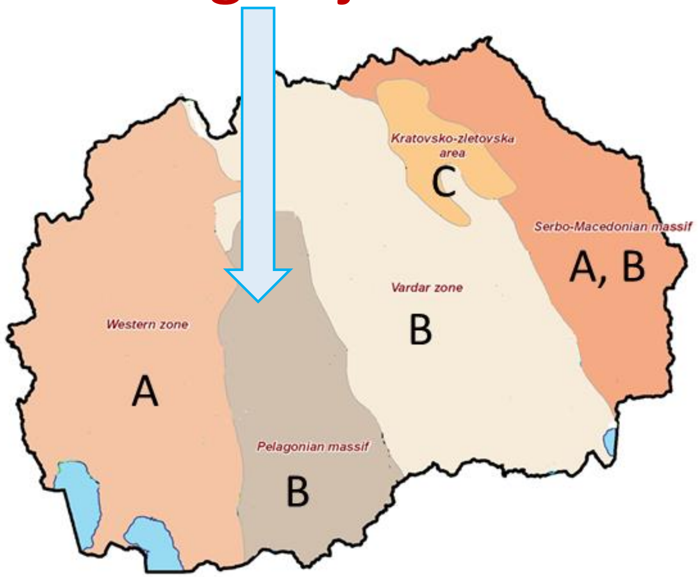
Equation of the multiple regression model:

lnCRn(Bq/m3) = 4.39197+0.04551*floor-first+0.41828*floor-ground+0.22329*basement-no-0.55592*Building Materials-brick-0.35870*Building Materials-bricks/stone-0.37402*Building Materials-concrete



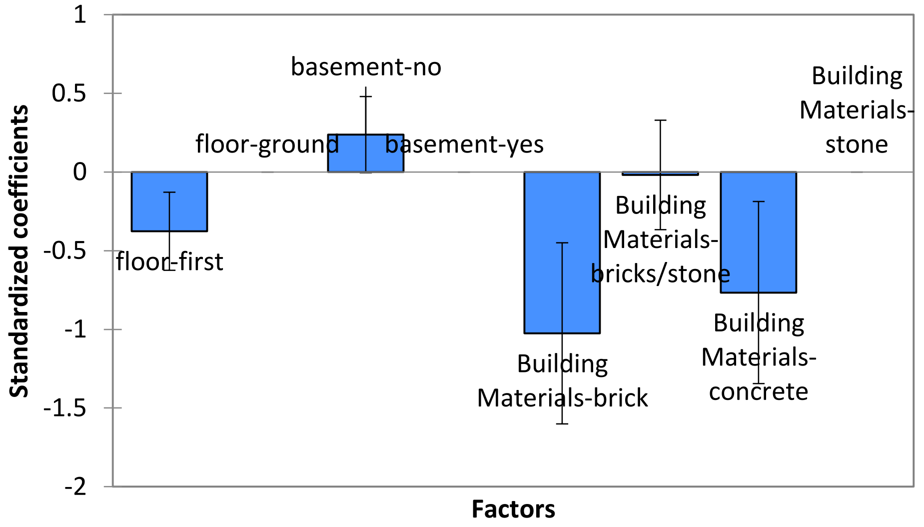
# Spatial variability of building factors influence

## Pelagonija




## Multivariable linear model (R^2=0.49; RMSE=0.45)

Equation of the model:
lnCRn(Bq/m3) = 5.58556-0.44397*floor-first+0.27989*basement-no-1.22853*Building Materials-brick-0.04550*Building Materials-bricks/stone-0.90219*Building Materials-concrete

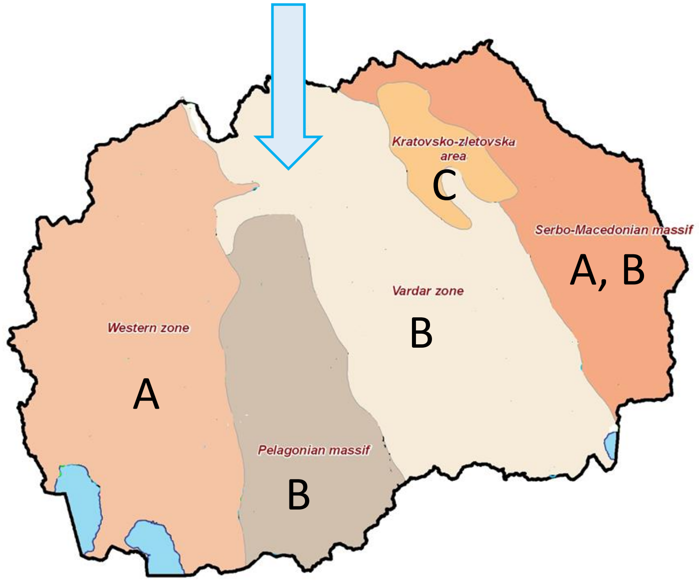



## Univariable linear models results:

| | Pelagonija | p | R^2 | RMSE |
|---|---|---|---|---|
| 1 | indoor | | | |
| 2 | floor | 0.0165 | 0.1163 | 0.5652 |
| 3 | basement | 0.0300 | 0.0952 | 0.5719 |
| 4 | room | | | |
| 5 | building material | 0.0050 | 0.2508 | 0.5318 |
| 6 | windous | 0.4151 | | |

# Spatial variability of building factors influence

## Vardar Zone



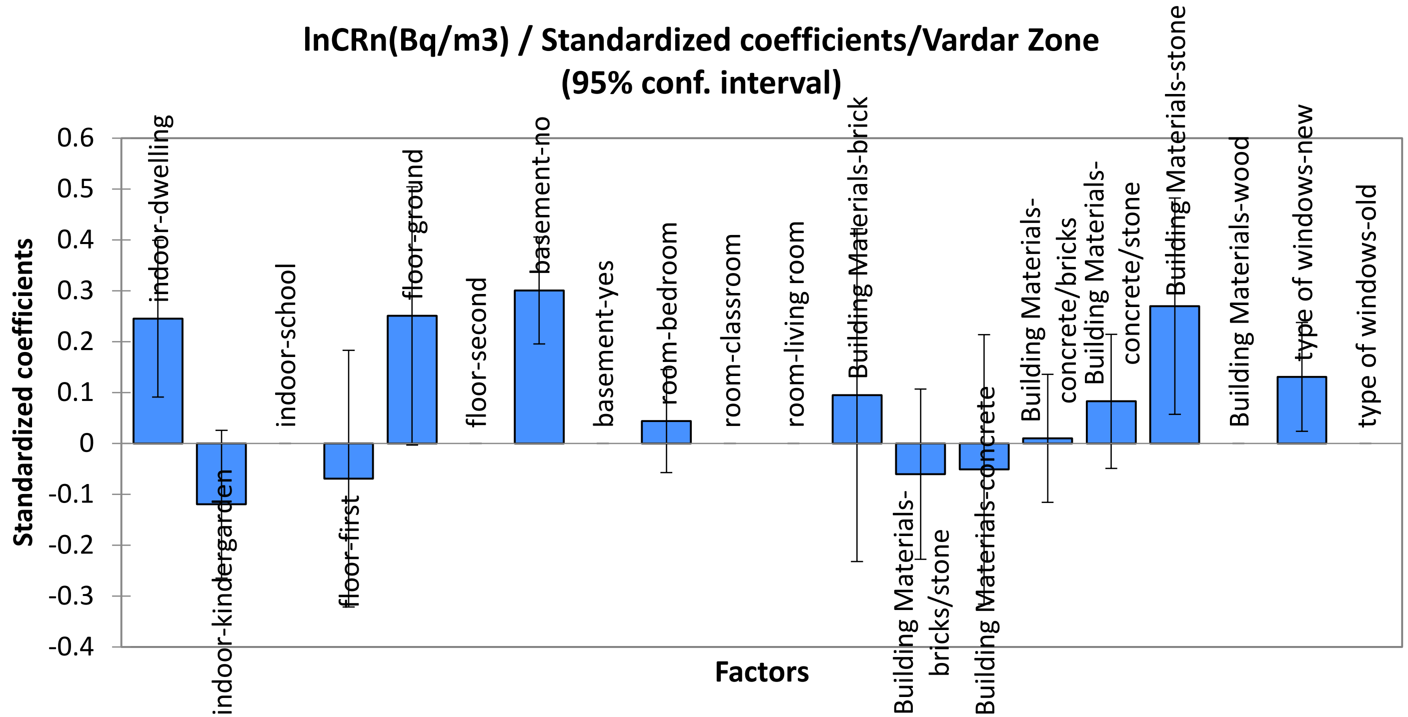

## Univariable linear models results:

| | Vardar zone | p | R^2 | RMSE |
|---|---|---|---|---|
| 1 | indoor | < 0.0001 | 0.11 | 0.59 |
| 2 | floor | < 0.0001 | 0.11 | 0.59 |
| 3 | basement | < 0.0001 | 0.12 | 0.59 |
| 4 | room | < 0.0001 | 0.08 | 0.60 |
| 5 | building material | 0.0009 | 0.08 | 0.62 |
| 6 | windows | 0.0065 | 0.02 | 0.62 |

## Multivariable linear model ($R^2$=0.32; RMSE=0.54)

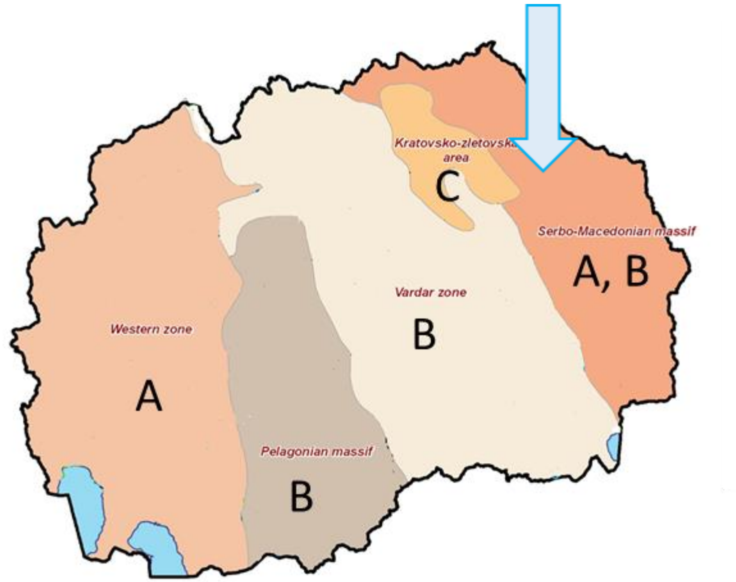
Equation of the multiple regression model:

lnCRn(Bq/m3) = 3.33447+0.58409*indoor-dwelling-0.39647*indoor-kindergarden-0.10662*floor-first+0.36619*floor-ground+0.38119*basement-no+0.10066*room-bedroom+0.12733*Building Materials-brick-0.19183*Building Materials-bricks/stone-0.08971*Building Materials-concrete+0.05245*Building Materials-concrete/bricks+0.40046*Building Materials-concrete/stone+0.62988*Building Materials-stone+0.20736*type of windows-new



# Spatial variability of building factors influence

## Serbo-Macedonian Massif



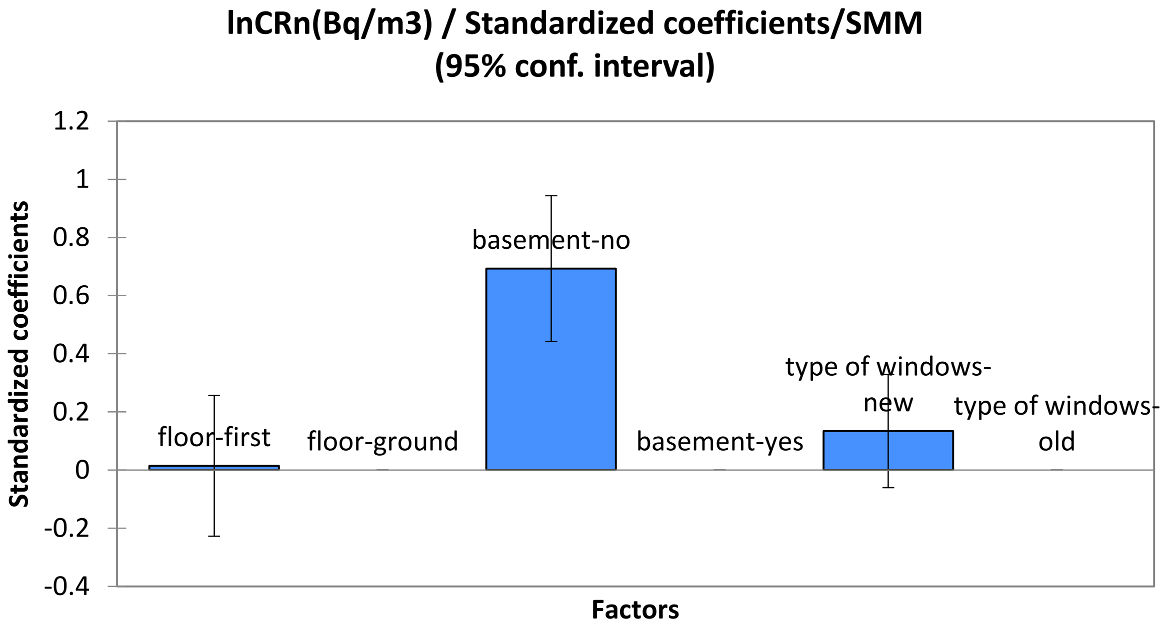

## Univariable linear models results:

| | Serbo Macedonian Massif | p | R^2 | RMSE |
|---|---|---|---|---|
| 1 | indoor | | | |
| 2 | floor | 0.0001 | 0.2344 | 0.5087 |
| 3 | basement | < 0.0001 | 0.5392 | 0.3947 |
| 4 | room | 0.6051 | | |
| 5 | building material | 0.2300 | | |
| 6 | windows | 0.0021 | 0.2344 | 0.5087 |

## Multivariable linear model (R^2=0.56; RMSE=0.40)

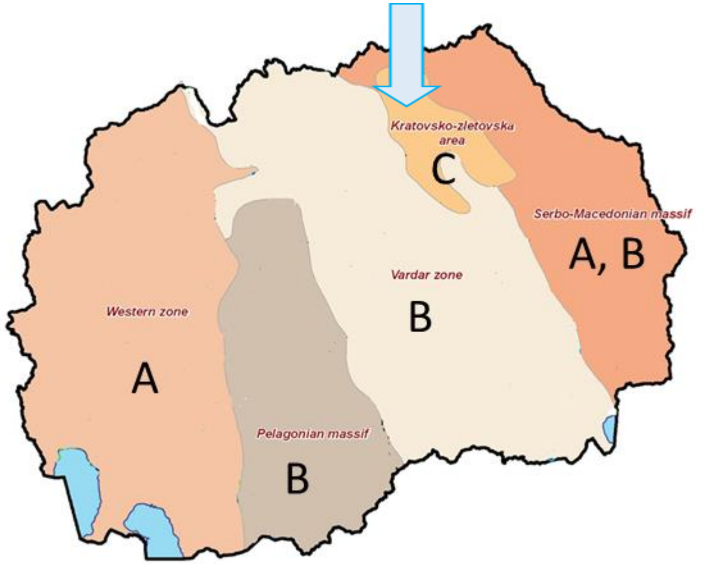
Equation of the model:

lnCRn(Bq/m3) = 4.05379+0.01685*floor-first+0.79762*basement-no+0.25412*type of windows-new



# Spatial variability of building factors influence

## Kratovsko-Zletovska Area



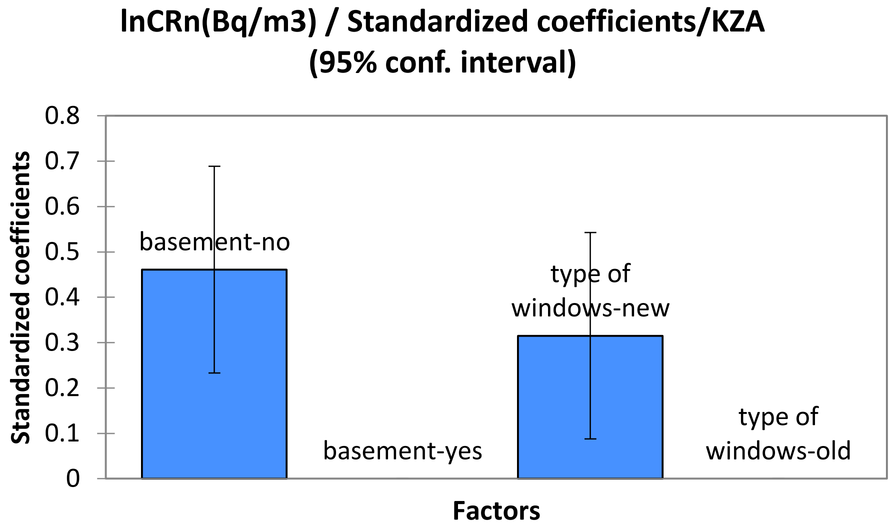

## Univariable linear models results:

| | Kratovsko-Zletovska area | p | R^2 | RMSE |
|---|---|---|---|---|
| 1 | indoor | 0.9400 | | |
| 2 | floor | 0.1800 | | |
| 3 | basement | < 0.0001 | 0.2821 | 0.7335 |
| 4 | room | 0.7295 | | |
| 5 | building material | 0.6530 | | |
| 6 | windows | 0.0017 | 0.1748 | 0.7864 |

## Multivariable linear model (R^2=0.38; RMSE=0.69)

Equation of the model:

lnCRn(Bq/m3) = 4.35603+0.81964*basement-no+0.58634*type of windows-new



# Summary

- Seasonal variability of Rn (highest concentrations in the winter and lowest in summer) is confirmed;
- The models for assessing of annual Rn from 3 months measurement are developed. The model with the best performance refers to the linear relationship between the Rn measurements in winter and annual Rn ($R^2$=90%).
- Differences in the Rn in various geotectonic zones of the country is significant;

# Summary

- In general, building factors: floor, basement, type of windows, the indoor type, type of room, building material significantly affect Rn variation. On the other hand, their impact is associated with geotectonic zones .
- Practically no all factors as well each factor separately has equal contribution to Rn variations in individual geotectonic units. Our results showed that Rn variations which originating by the building characteristics are in the range: from 21% in Western zone to 56% in the Serbo-Macedonian Massif.

Хвала на пажњи!