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S.Ind.Ai.R.—School Network for Indoor Air Quality and Radon: An Innovative Platform for the Flexible Development of Indoor Environment Research Projects in Greek Schools †

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Abstract: Indoor air quality (radon, pollution, thermal fatigue, ventilation) is crucial for health and performance, especially for children. It is necessary to increase public awareness about the significance of air quality, particularly radon. Environmental school networks can enhance public awareness and provide research opportunities for scientists. SINDAIR, a school network based on SIMA-AEP, provides a flexible platform for larger scale educational and research projects. SINDAIR is in its pilot phase, involving various schools around Greece. With the assistance of UniWA, SINDAIR has started a pilot radon measuring campaign. Preliminary results show increased radon concentrations in certain school rooms, higher than expected, justifying further radon risk and air quality assessment, management, and perception programs.

Keywords: radon; air quality; thermal comfort; indoor environment; school networks

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1. Introduction

Schools are also workplaces, with the same health and safety challenges as any workplace, especially since children are more vulnerable [1]. Air quality is key for health, general well-being and performance [1–3]. Thermal comfort and ventilation are associated with performance [4,5], while radon and air pollution induce health risks [1–3,6,7]. Radon, a radioactive gas largely unknown to the public, is the most significant cause of lung cancer [8–11] among non-smokers. It is investigated for synergies with other risk factors (for example COVID-19 or air pollution) [12–16] to induce further health risks. Various harmful pollutants also exist in the indoor school environment [17]. The long-term average indoor radon concentration is the main indicator of radon risk [8–10], so passive measurements [18] are used to create regional radon maps [19]. Extensive measurements of radon have been conducted at schools in 8 out of the 13 Greek regional administrative directorates [20], with the average concentration of radon in 17% of the schools exceeding 200 Bq/m^3 (the reference level is 300 Bq/m^3 [21]). The damage from ionizing radiation is cumulative [8,9,11], so there is no "safety" limit and protective measures should be taken for vulnerable people (children, patients, the elderly, etc.). Hence, schools are places of high interest for the study of radon [6,7,20,22,23]. Even at low yearly average radon concentrations, the actual concentration at certain times or in certain locations may rise significantly [13,24–26], raising health risk concerns. Constant monitoring of the indoor radon concentration is viable with low-cost instruments [27]. The Greek National Plan for Radon was recently ratified and is now in its early stages https://eeae.gr/files/nomothesia/FEK_214_B_03.02.2020.pdf (accessed on 23 August 2023). An innovative school network for radon and air quality was incepted to increase awareness, monitor air quality, aid the educational aspect of the Greek National Plan for Radon: S.Ind.Ai.R.—School network for Indoor Air quality and Radon Awareness (https://sindair.blogspot.com).

2. SINDAIR: An Innovative School Network for Health Awareness and Research

SINDAIR encourages scientists to conduct original environmental research in schools and schools to invite environmental scientists and follow or join their research. SINDAIR is open to all researchers, to freely engage with the network with flexible research programs, while the schools and their educators can conceive projects and activities, invite researchers to assist them, cooperate, or conduct joint research. The scope of SINDAIR is the indoor air quality in schools, focusing on radon monitoring, mitigation, and awareness. Also, it investigates pollutants and aerosols, human thermal comfort–discomfort, and other indoor atmospheric factors that affect health, safety, and performance at school [1–3]. It collaborates with the radon and air quality related research being conducted at the University of Western Attica (UniWA), who provide instruments and scientific counseling. SINDAIR also aims to cooperate with the Ministry of Labor (health and safety in workplaces), the Greek Committee of Atomic Energy (radon assessment and mitigation), and the University of Thessaly (the effect of air quality on human physiology and performance).

SINDAIR emerged and started to grow as a subnetwork of SIMA-AEP (Today's Student—Tomorrow's Active Citizen, https://simaaep.wordpress.com/ accessed on 23 August 2023), a school network for the empowerment and capacity building of students, in relation to civil rights, digital literacy, environmental problems, etc. In 2022–2023, SINDAIR is in a pilot phase with a limited number of schools around the country and scientific assistance from UniWA.

3. Materials and Methods

During the pilot phase, test measurements will be conducted. Radon concentrations will be measured continuously with the low-cost monitor, RadonEye BLE (https://bit.ly/REBLE accessed on 23 August 2023), shown to be reliable for sounding an alarm when reference levels are exceeded [27]. After screening the schools with RadonEye, further studies may be justified where the radon risk is high, or where results are unexpected. Where possible, the measurements will be conducted on a 24 h basis, to obtain diurnal variability data, or longer, to obtain daily average variability data. Indoor radon measurements will be conducted in at least three rooms: one at the lowest level of the school, one at the highest level, and one at the middle level or one at any level that is kept closed for most of the time. The radon monitor will be placed at a height of about one meter over the floor (average student respiratory entrance height) and far from the walls (over 50 cm), to avoid overestimation of radon [28].

4. Preliminary Radon Results

At the present stage, only screening of radon with the RadonEye is underway. SINDAIR prioritized the sampling of radon at schools outside of Athens. Each school is advised to conduct at least three 24 h radon monitoring sessions, as described earlier. If this is not possible, any measurement will be considered, as the main objective at this stage is not the detailed spatial and temporal profiling of the school buildings, but just to determine where the radon concentrations are close to, or above, the reference level of 300 Bq/m^3. Moreover, each school is encouraged to implement their own scenarios, as an important priority is to engage students in the measurement and assessment of radon.

By the time this article was submitted (May 2023), the pilot measurement campaign had been concluded in seven schools in northwestern Greece and two on an island in the Aegean Sea. In total, sixteen rooms in the nine schools were measured. The preliminary results are depicted below (school names coded for confidentiality).

5. Discussion

Figure 1 depicts the diurnal variability of radon concentrations in the various rooms of the nine schools, during the first day of the measurements. Only one room was measured for more than one day. Most rooms were not ventilated. Radon exhibited mild diurnal variability and never exceeded the reference level of 300 Bq/m^3, except for two rooms, one of which (Room A: 009BLaWs—no windows) was all the time high above the reference level, while the other one (Room B: 003GLaWs) was above the reference level only for about half a day, mostly in the night and early morning, with strong diurnal variability. Both classrooms were in the basements of the respective schools and lacked ventilation. When windows were opened in Room B, the radon concentration dropped significantly.

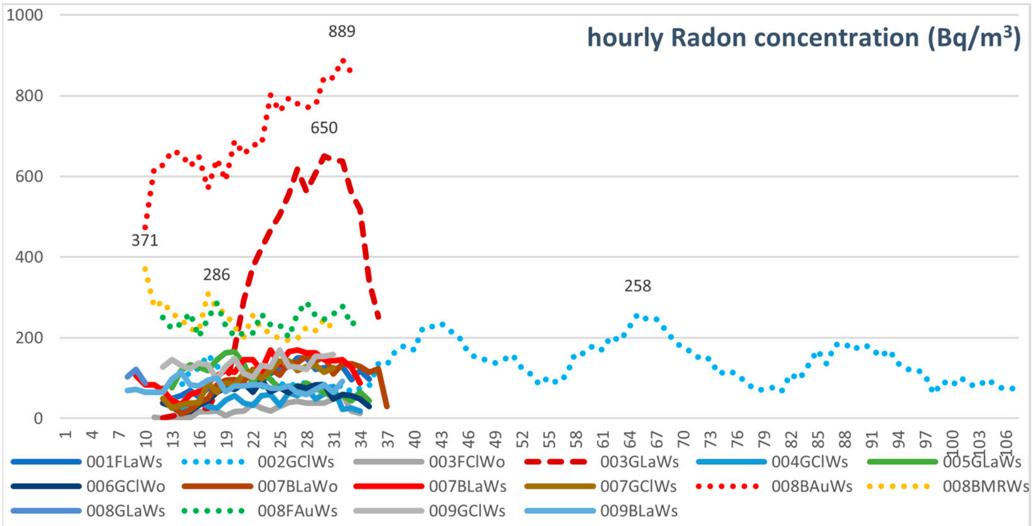

Figure 1. Diurnal variation in radon (Bq/m^3) in 9 schools. The horizontal axis is hour of the day, staring at 00:00 (value: 1) and increments of 1 h (the second day begins at 25, third at 49, etc.).

Figure 2 depicts the average and peak radon concentration in the same rooms. The diurnal variability is evident; several schools show peak values much higher than the corresponding averages. Room B has an average very close to the reference level, but its peak reaches almost double its average, indicating strong variability. The same figure shows the average and peak between 8 a.m. and 2 p.m., when rooms may be populated. Most averages and peaks are slightly lower during school time, with a few exceptions, but never higher. The annual mean indoor radon concentration value (NMRV) from the National Map of Radon (https://bit.ly/radonmapGR accessed on 23 August 2023) is also shown for comparison. In northern Greece, the measurements are consistent with the NMRV, usually not exceeding it, except for Room B. On the island, the measurements are considerably higher than the NMRV.

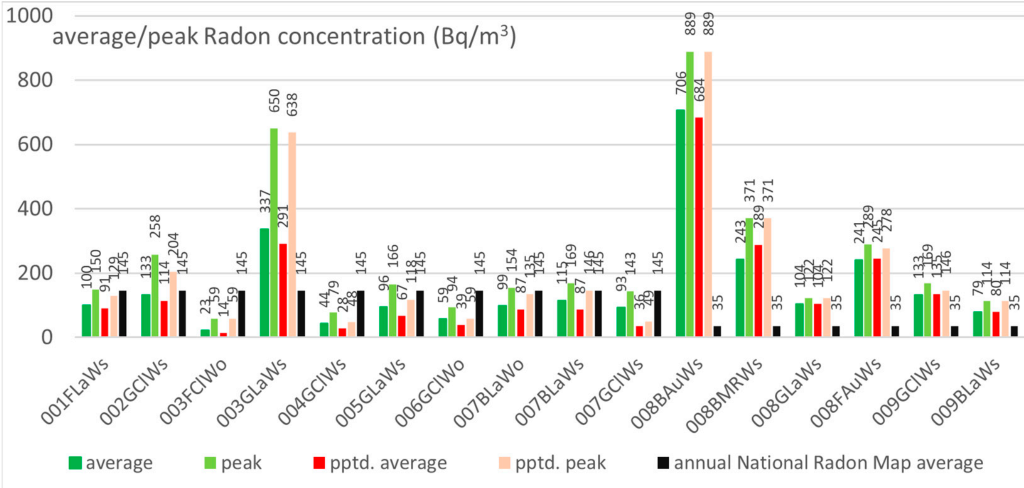

Figure 2. Average and peak radon (Bq/m^3), populated average (pptd. average) and peak (pptd. peak) during populated periods (8 a.m. to 2 p.m.—school hours), and National Radon Map Value.

Figure 3 depicts the frequency at which radon exceeds the EU reference level (300 Bq/m^3) and the USA warning level (148 Bq/m^3). Most rooms show radon exceeding the stricter USA warning level at some point, but only about 35% of the rooms exceed it during school hours. The EU reference level was exceeded in room B for about half a day (and half of the school hours). It was exceeded in room A all the time. It was also exceeded for less than 25% of the school hours and 15% of the day in a classroom next to room A.

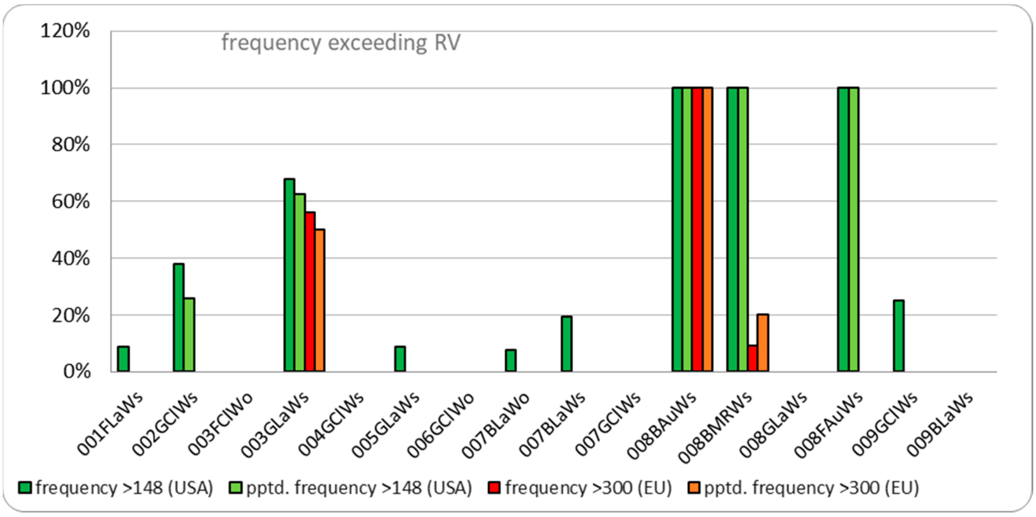

Figure 3. Frequency exceeding RV: percentage of time, when radon concentration exceeds the reference values (RV) of EU (300 Bq/m^3) and USA (148 Bq/m^3). Also, respective frequencies (pptd. frequencies) during periods when the rooms can be populated (8 a.m. to 2 p.m.—school hours).

Figure 4 depicts the maximum annual doses estimated to be delivered from the air of these rooms into the lungs of adults, calculated according to Kendall et al. [29], where doses are considered to practically be the same from small children up to adults. The dose calculation was scaled, assuming that the rooms will be populated only for eight months per year, for about five hours per workday. Figure 4 follows the trends of Figure 2, as the values of Figure 4 are proportional [29] to the corresponding populated averages in Figure 2.

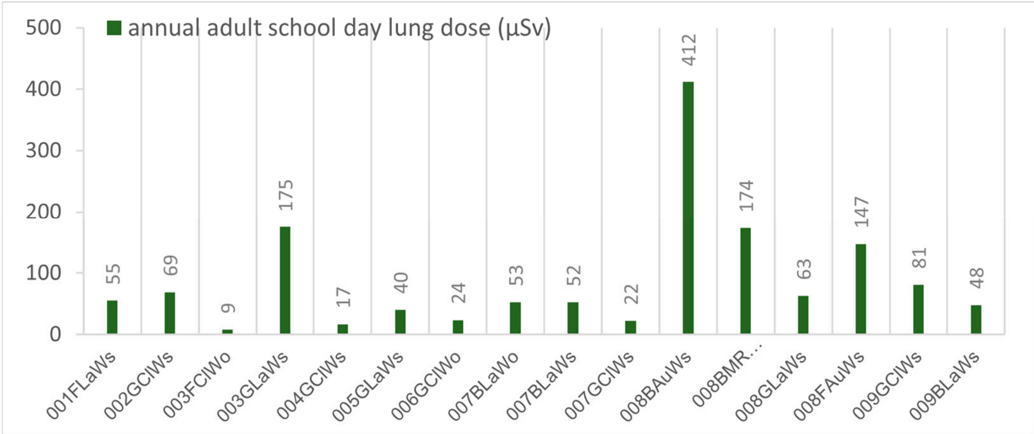

Figure 4. Annual indoor workplace lung dose for adults spending the whole school day in the room (8 a.m. to 2 p.m., about 5 h, excluding breaks), scaled for 8 months a year, 22 days a month, 5 h a day. Dose coefficients and equilibrium factors (F = 0.41) as in [29] for adults (student doses do not differ substantially [29], or may be slightly overestimated, as they spend less than 5 h a day in the same room). The scaling was based on the estimation [29] that 200 Bq/m^3 yield 1.2 mSv per year.

6. Conclusions

All schools seem to fall under the reference level, apart from unventilated classes in basements, where higher concentrations are expected, but they are remedied when ventilation is introduced. The values were measured in May, so the winter values are expected to be higher [8,9], hence the annual dose to the lungs could be higher than the one calculated here. The measured radon concentrations are largely below the EU reference level, but they are not too low (they are higher than the USA warning level), so frequent ventilation is advisable, even during winter. Also, the measurements on the island appear not to be truly consistent with the annual averages of the National Radon Map of Greece.

The measurements are not conclusive. Further studies are needed, possibly with passive dosimeters during the whole winter, to determine the yearly averages and contribute to updating the National Radon Map of Greece. Active measurements may also be justified to further record the diurnal variability, locate possible radon leaks, and propose appropriate remedies. SINDAIR will address these challenges during its next phase.

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References

1. Chatzidiakou, L.; Mumovic, D.; Summerfield, A.J. What Do We Know about Indoor Air Quality in School Classrooms? A Critical Review of the Literature. *Intell. Build. Int.* **2012**, *4*, 228–259. [CrossRef]
2. Kelly, F.J.; Fussell, J.C. Improving Indoor Air Quality, Health and Performance within Environments Where People Live, Travel, Learn and Work. *Atmos. Environ.* **2019**, *200*, 90–109. [CrossRef]
3. Kakoulli, C.; Kyriacou, A.; Michaelides, M.P. A Review of Field Measurement Studies on Thermal Comfort, Indoor Air Quality and Virus Risk. *Atmosphere* **2022**, *13*, 191. [CrossRef]
4. Wargocki, P.; Wyon, D.P. The Effects of Moderately Raised Classroom Temperatures and Classroom Ventilation Rate on the Performance of Schoolwork by Children (RP-1257). *HvacR Res.* **2007**, *13*, 193–220. [CrossRef]
5. Coley, D.A.; Greeves, R.; Saxby, B.K. The Effect of Low Ventilation Rates on the Cognitive Function of a Primary School Class. *Int. J. Vent.* **2007**, *6*, 107–112. [CrossRef]
6. Kalimeri, K.K.; Saraga, D.E.; Lazaridis, V.D.; Legkas, N.A.; Missia, D.A.; Tolis, E.I.; Bartzis, J.G. Indoor Air Quality Investigation of the School Environment and Estimated Health Risks: Two-Season Measurements in Primary Schools in Kozani, Greece. *Atmos. Pollut. Res.* **2016**, *7*, 1128–1142. [CrossRef]
7. Synnefa, A.; Polichronaki, E.; Papagiannopoulou, E.; Santamouris, M.; Mihalakakou, G.; Doukas, P.; Siskos, P.A.; Bakeas, E.; Dremetsika, A.; Geranios, A.; et al. International Journal of Ventilation An Experimental Investigation of the Indoor Air Quality in Fifteen School Buildings in Athens, Greece An Experimental Investigation of the Indoor Air Quality in Fifteen School Buildings in Athens, Greece. *Int. J. Vent.* **2003**, *2*, 185–201. [CrossRef]
8. World Health Organization. *WHO Handbook on Indoor Radon: A Public Health Perspective*; World Health Organization: Geneva, Switzerland, 2009; ISBN 978-92-4-154767-3.
9. Appleton, J.D. Radon in Air and Water. In *Essentials of Medical Geology: Revised Edition*; Selinus, O., Ed.; Springer: Dordrecht, The Netherlands, 2013; pp. 239–277, ISBN 978-94-007-4375-5.
10. Riudavets, M.; Garcia de Herreros, M.; Besse, B.; Mezquita, L. Radon and Lung Cancer: Current Trends and Future Perspectives. *Cancers* **2022**, *14*, 3142. [CrossRef]
11. Nunes, L.J.R.; Curado, A.; Da Graça, L.C.C.; Soares, S.; Lopes, S.I. Impacts of Indoor Radon on Health: A Comprehensive Review on Causes, Assessment and Remediation Strategies. *Int. J. Environ. Res. Public Health* **2022**, *19*, 3929. [CrossRef]
12. Zoran, M.A.; Savastru, R.S.; Savastru, D.M.; Tautan, M.N. Impacts of Exposure to Air Pollution, Radon and Climate Drivers on the COVID-19 Pandemic in Bucharest, Romania: A Time Series Study. *Environ. Res.* **2022**, *212*, 113437. [CrossRef]
13. Madas, B.G.; Boei, J.; Fenske, N.; Hofmann, W.; Mezquita, L. Effects of Spatial Variation in Dose Delivery: What Can We Learn from Radon-Related Lung Cancer Studies? *Radiat. Environ. Biophys.* **2022**, *61*, 561–577. [CrossRef] [PubMed]
14. Maier, A.; Wiedemann, J.; Rapp, F.; Papenfuß, F.; Rödel, F.; Hehlgans, S.; Gaipl, U.S.; Kraft, G.; Fournier, C.; Frey, B. Radon Exposure—Therapeutic Effect and Cancer Risk. *Int. J. Mol. Sci.* **2020**, *22*, 316. [CrossRef] [PubMed]
15. Palmer, J.D.; Prasad, R.N.; Cioffi, G.; Kruchtko, C.; Zaorsky, N.G.; Trifiletti, D.M.; Gondi, V.; Brown, P.D.; Perlow, H.K.; Mishra, M.V.; et al. Exposure to Radon and Heavy Particulate Pollution and Incidence of Brain Tumors. *Neuro-Oncology* **2023**, *25*, 407–417. [CrossRef]
16. Lu, L.; Zhang, Y.; Chen, C.; Field, R.W.; Kahe, K. Abstract P664: Radon Exposure and Cerebrovascular Disease-A Systematic Review and Meta-Analysis of Observational Studies in Occupational and General Populations. *Stroke* **2021**, *52*, AP664. [CrossRef]
17. Besis, A.; Avgenikou, A.; Pantelaki, I.; Serafeim, E.; Georgiadou, E.; Voutsa, D.; Samara, C. Hazardous Organic Pollutants in Indoor Dust from Elementary Schools and Kindergartens in Greece: Implications for Children's Health. *Chemosphere* **2023**, *310*, 136750. [CrossRef] [PubMed]
18. Bing, S. CR-39 Radon Detector. *Nucl. Tracks Radiat. Meas.* **1993**, *22*, 451–454. [CrossRef]
19. Elío, J.; Petermann, E.; Bossew, P.; Janik, M. Machine Learning in Environmental Radon Science. *Appl. Radiat. Isot.* **2023**, *194*, 110684. [CrossRef]
20. Clouvas, A.; Xanthos, S.; Takoudis, G. Indoor Radon Levels in Greek Schools. *J. Environ. Radioact.* **2011**, *102*, 881–885. [CrossRef]
21. Marsh, J.W.; Tomášek, L.; Laurier, D.; Harrison, J.D. Effective dose coefficients for radon and progeny: A review of icrp and unscear values. *Radiat. Prot. Dosim.* **2021**, *195*, 1–20. [CrossRef]
22. Curguz, Z.; Venoso, G.; Zunic, Z.S.; Mirjanic, D.; Ampollini, M.; Carpentieri, C.; Di Carlo, C.; Caprio, M.; Alavantic, D.; Kolarz, P. Spatial Variability of Indoor Radon Concentration in Schools: Implications on Radon Measurement Protocols. *Radiat. Prot. Dosim.* **2020**, *191*, 133–137. [CrossRef]
23. Loffredo, F.; Opoku-Ntim, I.; Meo, G.; Quarto, M. Indoor Radon Monitoring in Kindergarten and Primary Schools in South Italy. *Atmosphere* **2022**, *13*, 478. [CrossRef]
24. Nikolopoulos, D.; Kottou, S.; Louizi, A.; Petraki, E.; Vogiannis, E.; Yannakopoulos, P. Factors Affecting Indoor Radon Concentrations of Greek Dwellings through Multivariate Statistics-First Approach. *J. Phys. Chem. Biophys.* **2014**, *4*, 2161-0398. [CrossRef]
25. Baltrėnas, P.; Grubliauskas, R.; Danila, V. Seasonal Variation of Indoor Radon Concentration Levels in Different Premises of a University Building. *Sustainability* **2020**, *12*, 6174. [CrossRef]
26. Seftelis, I.; Nicolaou, G.; Trassanidis, S.; Tsagas, F.N. Diurnal Variation of Radon Progeny. *J. Environ. Radioact.* **2007**, *97*, 116–123. [CrossRef] [PubMed]

27. Sá, J.P.; Branco, P.T.; Alvim-Ferraz, M.C.; Martins, F.G.; Sousa, S.I. Radon in Indoor Air: Towards Continuous Monitoring. *Sustainability* **2022**, *14*, 1529. [CrossRef]
28. Tokonami, S. Why Is 220Rn (Thoron) Measurement Important? *Radiat. Prot. Dosimetry* **2010**, *141*, 335–339. [CrossRef]
29. Kendall, G.M.; Smith, T.J. Doses from Radon and Its Decay Products to Children. *J. Radiol. Prot.* **2005**, *25*, 241. [CrossRef]