

Evaluation of radon levels in indoor gymnasia of Palermo (Sicily) and Sassari (Sardinia)

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Abstract

Background: In the last decades, there has been increased worldwide interest in the management of health risks from indoor radon.

Methods: From 2006 to 2008, a survey on air radon levels was carried out in a total of 57 indoor gymnasia respectively located in the urban area of Palermo (Sicily) and Sassari (Sardinia).

Results: The indoor radon levels were generally low with different geometric means in the two geographic areas (14.3 Bq/m³ in Palermo and 36 Bq/m³ in Sassari, respectively). Overall, in both groups increasing values of radon were found during the night and the early morning, with radon concentrations significantly lower during working time than at other times. The analysis of structural parameters showed that direct contact with the soil significantly correlated with increased levels of radon in gymnasia located in Palermo's area ($p < 0.05$). Furthermore, higher radon levels in Sicilian structures were also associated, although not significantly, with lack of sumps (19.3 vs 12.9 Bq/m³), location below the ground level (18.8 vs 8.7 Bq/m³), lack of windows (25 vs 13.2 Bq/m³), presence of forced ventilation (15.5 vs 7.3 Bq/m³) and with cracks or moisture tracks (15.7 vs 13.2 Bq/m³).

Conclusions: Radon tends to accumulate in indoor sites and its monitoring, especially in buildings with potentially overcrowded conditions, could be of public health interest. Mitigation measures and minimization of the number of structural and functional risk parameters should be strongly encouraged in order to limit radon accumulation especially in countries with higher radium concentration in the soil.

Key words: indoor radon, gymnasia, risk assessment.

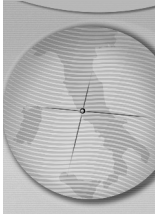
Introduction

Radon is a natural radioactive noble gas that arises naturally from the decay of uranium-238. It is present throughout the earth's crust and has a half life of 3.8 days. Radon decays by producing α particles into a series of radioactive progeny. If inhaled, lived progeny tends to be deposited on the bronchial epithelium, thus exposing cells to α irradiation. Radiobiological evidences suggest that cells exposed to radon became appreciably damaged [1]. In 1988, the International Agency for Research on Cancer (IARC) classified radon as a known pulmonary human carcinogen [2].

Because of its noble character, radon can migrate through the soil and accumulate in enclosed or poorly ventilate buildings. In general, radon has the highest concentration in basements and underground places that are in direct contact with the soil [3]. The highest exposures to radon have

been recorded in closed and underground spaces such as in uranium mines. Studies of exposed miners have strongly supported associations between radon and lung cancer [4]. However, the dose-response relation is likely to be linear [5] and lower residential exposure of much larger general populations could cause a substantial minority of all lung cancers [6]. Case-control studies conducted in nine European countries estimated that the risk of lung cancer increases by 8.4% (95% CI 3 to 15.8%) per 100 Bq/m³ increase in measured radon [6]. Moreover, for any given level of radon, smokers have about 25 times the risk of developing lung cancer as non-smokers [7].

According to national law (241/2000), in Italy all public and private institutions have to control the radon level in rooms that are located directly in contact with the earth or built underground [8]. These last characteristics are usually common to



indoor sites dedicated to intensive activities where radon can accumulate reaching levels of interest for human health. Therefore, intensive physical activities increase respiration rate (number of breaths per minute) ultimately increasing the risk of radon exposure. The aim of the present study was to assess the levels and the daily trend of hourly radon concentrations in indoor gymnasia belonging to different geographical areas and with different conditions of use (working times, contact with the soil, ventilation, customers etc).

Moreover, main structural and functional parameters of all buildings were analyzed in order to evaluate their associations with higher indoor concentrations of radon.

Methods

From October 2006 to May 2008, excluding the summers, a survey on indoor air radon levels was conducted on a total of 57 gymnasia, respectively located 34 in the urban area of Palermo (Sicily) and 23 in Sassari (Sardinia).

All the study sites in Palermo were private, located inside the city and affiliated to the Italian National Olympic Committee (CONI). They were attended mostly during the post-meridien hours (commonly from 13.00 to 24.00) but also in anti-meridien by a variable number of customers (range 30-500 per day).

Alternatively all of the structures in Sassari were public and devoted to scholastic fitness activities. All of them worked prevalently during the morning or in the afternoon (8:00 to 19.00) and 3 were located outside the city (Thiesi).

Measurements were made in all structures under normal operating conditions and were performed using the Sun Nuclear 1027 continuous Radon monitor, approved by the US Environmental Protection Agency. Monitors record the picocuries per liter automatically in 1 hour increments and record the overall average.

Continuous monitoring was conducted for a minimum of 48 hours during working days, according to protocols designed for use in residences, as described in the Environmental Protection Agency's publication [9]. Only in the gymnasia from Palermo, were measurements routinely conducted from Friday morning to Monday morning, including the weekend period in order to collect data related to a prolonged resting time.

Moreover, well trained medical doctors of the Schools of Specialization in Hygiene and Preventive Medicine of the University of Palermo and Sassari installed the detectors and collect all of the data. At the time of measurement, a

standardized technical sheet, including information on presence of sumps, cracks, water infiltrations, moisture tracks, forced ventilation, contact with the soil, windows and location with respect the ground level, was administered to the responsible technical staff of each participating structure.

The statistical analysis was performed by R software package [10]. The significance level chosen for all analyses was 0.05. Radon concentration variations were evaluated assuming log-normal distributions [11,12]. Two-tailed t-test was applied to compare the logarithms of radon concentration. A linear regression analysis was performed between the number of structural and functional risk parameters and logarithms of radon concentration.

Results

Table 1 shows the main structural and functional parameters of the 57 gymnasia stratified by geographic area. Among 34 structures located in Palermo, 21 (67.7%) had sumps, 22 (64.7%) were in direct contact with the soil, 28 (82.4%) were located underground and 14 (41.2%) had cracks or moisture. Moreover, thirty of them (88.2%) had windows and forced ventilation systems. Conversely of the 23 sites located in Sassari, 22 (95.7%) lacked of sumps and 21 (91.3%) lied directly over soil.

Only 3 buildings (13%) were below the ground level, 11 (47.8%) had cracks or moisture tracks, 19 (92.6%) had windows and 4 presented with (17.4%) forced ventilation systems.

Figure 1 depicts the comparison of indoor radon concentrations in the study sites of the two cities. Geometric mean was 14.3 Bq/m³ in Palermo (arithmetic mean= 21.5 Bq/m³; range 1.8 to 123.3 Bq/m³) and 36 Bq/m³ in Sassari (arithmetic mean= 45.5 Bq/m³; range 8.8 to 108.1 Bq/m³). A significant difference in geometric means of indoor radon was found between the buildings of the two different geographic areas (p-value<0.01). Radon concentrations were significantly lower during working time than during resting time both in Palermo (p<0.01) and Sassari (p<0.01).

Moreover, the geometric mean of radon concentrations measured in Palermo during working time was significantly lower than that observed during the same hours of a day off work (data not shown: paired t-test= 3.04; p<0.01).

The daily trends of hourly radon concentrations measured in buildings of Palermo and Sassari are presented in figure 2. In both groups there were high values of radon during the night and early in the morning. Therefore, evident decreases of radon

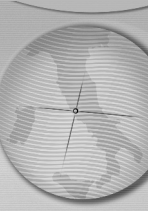


Table 1. Main structural and functional parameters of 57 gymnasia of Palermo and Sassari.

| | | PALERMO | | SASSARI | | TOTAL |
|--------------------------------|-----|---------|--------|---------|--------|-------|
| | | n=34 | (%) | n=23 | (%) | n=57 |
| | | | | | | |
| Presence of sump* | Yes | 21 | (67,7) | 1 | (4,3) | 22 |
| | No | 10 | (32,3) | 22 | (95,7) | 32 |
| Direct contact with the soil | Yes | 22 | (64,7) | 21 | (91,3) | 43 |
| | No | 12 | (35,3) | 2 | (8,7) | 14 |
| Below the ground floor | Yes | 28 | (82,4) | 3 | (13,0) | 31 |
| | No | 6 | (17,6) | 20 | (87,0) | 26 |
| Presence of cracks or moisture | Yes | 14 | (41,2) | 11 | (47,8) | 25 |
| | No | 20 | (58,8) | 12 | (52,2) | 32 |
| Presence of windows | Yes | 30 | (88,2) | 19 | (82,6) | 49 |
| | No | 4 | (11,8) | 4 | (17,4) | 8 |
| Forced ventilation | Yes | 30 | (88,2) | 4 | (17,4) | 34 |
| | No | 4 | (11,8) | 19 | (82,6) | 23 |

* Data not available for 3 gymnasia of Palermo

concentrations were observed during the afternoon (with minimum mean value at 15.00 pm) in Sassari and during the evening/night (with minimum mean value at 21.00 pm) in Palermo.

Table 2 summarizes the geometric means of radon concentrations stratified by the presence or absence of different structural and functional parameters. Only direct contact with the soil was significantly associated with increased levels of radon concentrations in sports building of Palermo ($p<0.05$).

Geometric means detected in Palermo were higher, but not significantly, in gymnasia without sumps (19.3 vs 12.9 Bq/m³), located underground (18.8 vs 8.7 Bq/m³), without presence of windows (25 vs 13.2 Bq/m³), with forced ventilation (15.5 vs 7.3 Bq/m³) and with cracks or moisture tracks (15.7 vs 13.2 Bq/m³). The radon measurements observed in gymnasia of Sassari are also presented in table 2.

Finally, figure 3 shows geometric means calculated in the gymnasia of Palermo with respect to the presence of structural risk parameters for radon accumulation. Data demonstrates that structures with none ($n=3$) or at least just one ($n=3$) structural risk parameters had lower radon levels; whereas the accumulation of multiple structure risk parameters were correlated with increased indoor values of radon ($p=0.03$).

Discussion

In the last decades, there has been increased worldwide interest in the management of health risks from indoor radon. In Italy, from 1989 to 1998, a survey was conducted in a sample of 5631 dwellings in order to evaluate the radon levels [13]. The national average of the annual radon concentration resulted 70 Bq/m³ (geometric mean 52 Bq/m³) with higher values in Lazio (119 ± 6 Bq/m³) and Lombardia (111 ± 3 Bq/m³)

Figure 1. Means and 95% confidence intervals of indoor radon concentrations revealed in gymnasia located in Palermo and Sassari during a 24 h period and during working time vs resting time.

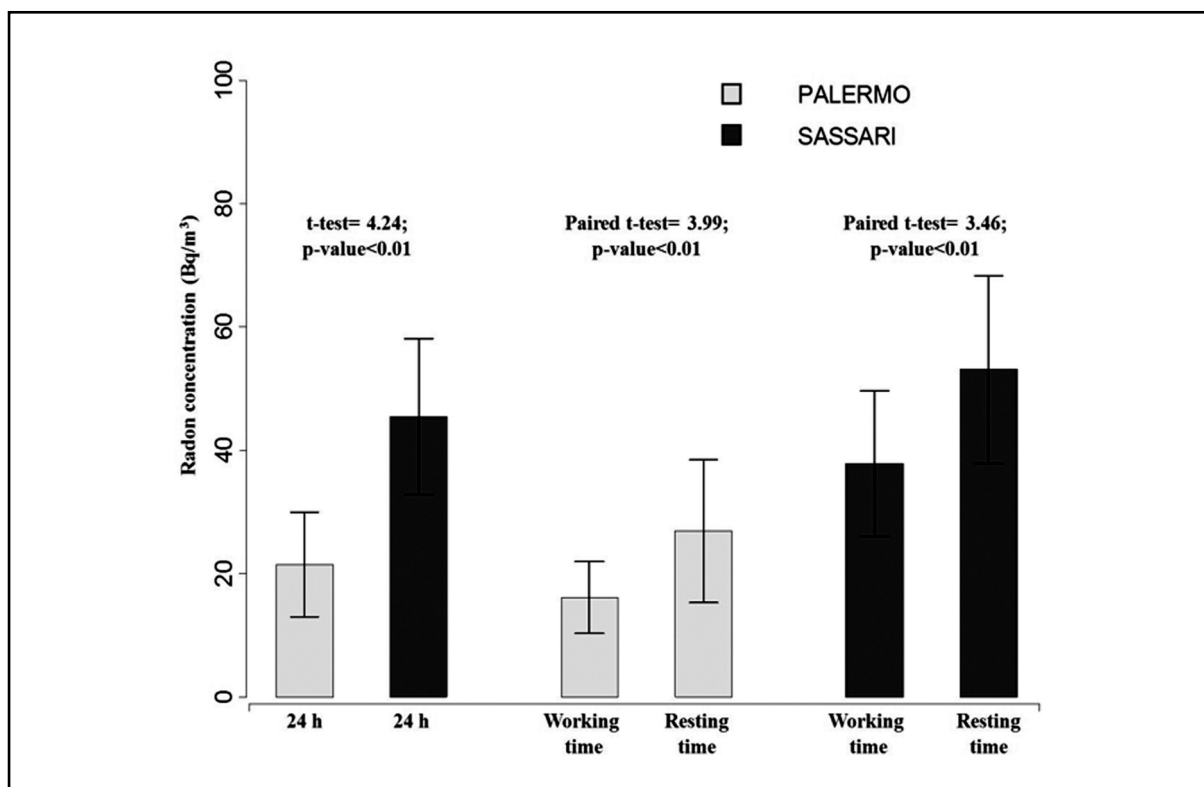
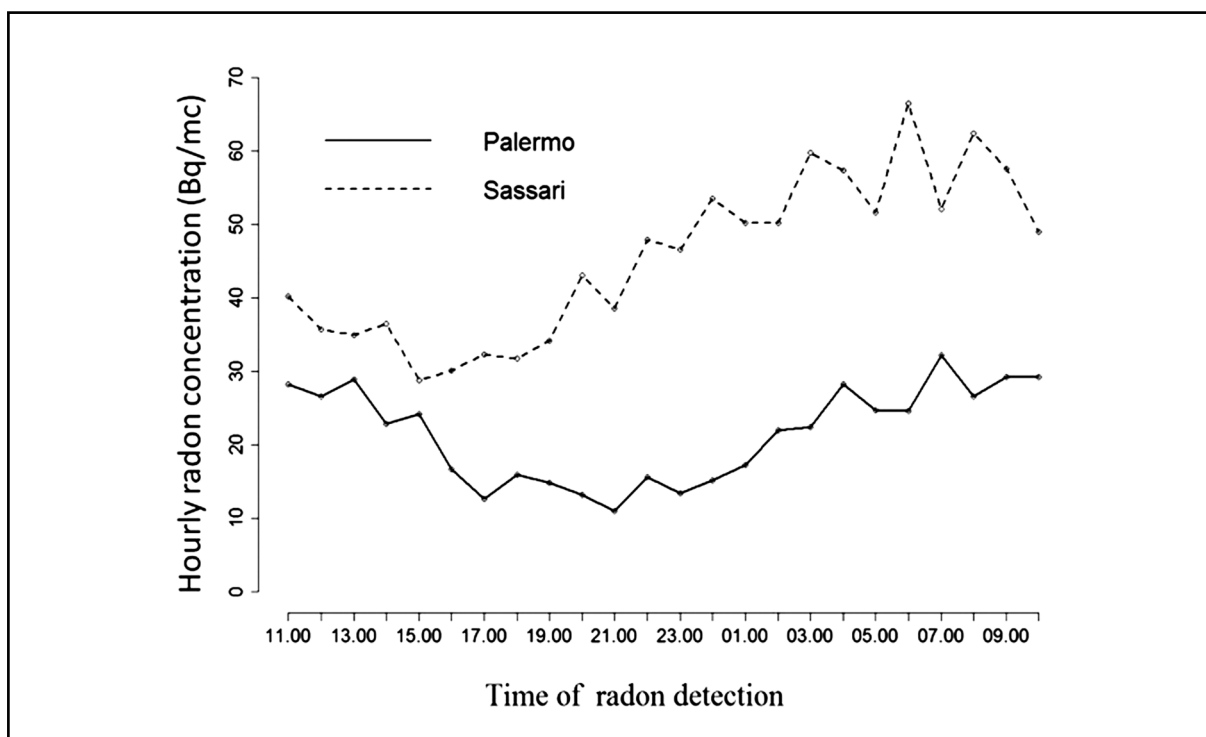


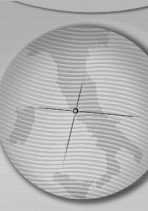
Figure 2. Trends of hourly radon concentrations measured in gymnasia of Palermo and Sassari during 24 h of a working day.



[13]. Sicily and Sardinia showed lower radon concentrations (35 ± 1 Bq/m³ and 64 ± 4 Bq/m³, respectively) with respect to measurements

observed in other Italian Regions.

Overall, the data presented in this paper are consistent to those above mentioned and confirm

**Table 2.** Geometric means of radon concentrations measured in relation to presence of different structural and functional parameters of gymnasia located in Palermo and Sassari.

| | | Geometric means of radon concentrations measured in Palermo (in Bq/m ³) | P-value | Geometric means of radon concentrations measured in Sassari (in Bq/m ³) | P-value |
|--|------------|---|-----------|---|-----------|
| Presence of sump* | <i>Yes</i> | 12.9 | <i>NS</i> | 58.6 | <i>NC</i> |
| | <i>No</i> | 19.3 | | 35.2 | |
| Direct contact with the soil | <i>Yes</i> | 17.7 | <0.05 | 33.4 | <i>NS</i> |
| | <i>No</i> | 9.5 | | 79.1 | |
| Below the ground floor | <i>Yes</i> | 15.8 | <i>NS</i> | 47.8 | <i>NS</i> |
| | <i>No</i> | 8.7 | | 34.5 | |
| Presence of windows | <i>Yes</i> | 13.2 | <i>NS</i> | 36.5 | <i>NS</i> |
| | <i>No</i> | 25 | | 33.7 | |
| Forced ventilation | <i>Yes</i> | 15.5 | <i>NS</i> | 45.8 | <i>NS</i> |
| | <i>No</i> | 7.3 | | 34.2 | |
| Presence of cracks or moisture tracks | <i>Yes</i> | 15.7 | <i>NS</i> | 33.8 | <i>NS</i> |
| | <i>No</i> | 13.2 | | 38.2 | |

* Data not available for 3 gymnasia of Palermo

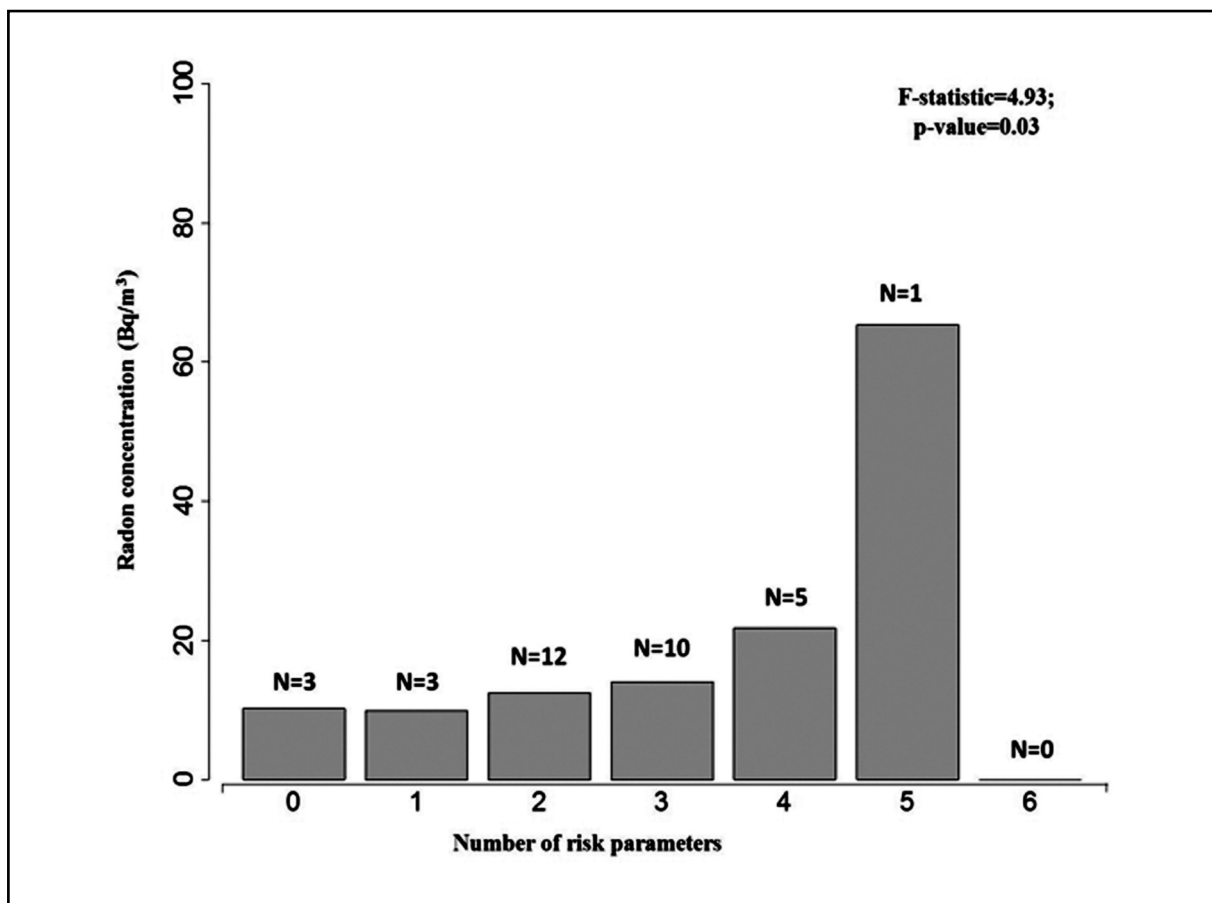
NS: non significant

NC: not calculated (only 1 gymnasium had presence of sump).

that in Sicily, as well as in Sardinia, radon concentrations are probably far from any potential risk for human health. However, a substantial variation of the radon concentrations was described in both Regions with respect to the working and resting times of the studied structures. Radon concentrations were lower during the day and increased steadily during the night. This last finding is consistent with other authors [14] who observed the accumulation of

this gas during the night until the early hours of the morning, followed by a decrease during the postmeridie hours. This finding was expected since we included in our study gymnasia devoted to different fitness activities. Gymnasia sited in Sassari were scholastic structures prevalently attended during the morning or in the afternoon (8:00 to 19:00) whereas buildings of Palermo were private and mostly attended during the postmeridie hours (commonly from 13:00 to 24:00).

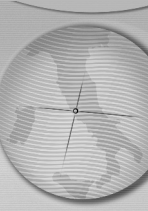
Figure 3. Geometric means of radon concentration measured in 34 gymnasia of Palermo stratified by number of risk parameters considered in the univariate analysis.



In this way, radon concentrations seem to follow a daily trend with respect to working hours.

As suggested, this trend could be attributed mainly to the nocturnal accumulation with temperature inversions [15]. Other factors, as well as the presence of natural and/or forced ventilation, could play a role in decreasing radon concentration during working hours. However, our data seem to suggest a paradoxal inverse correlation between radon concentrations and forced ventilation systems. Although this last finding could be a consequence of the small sample size, it is also probable that the presence of forced ventilation systems was not representative of their efficacy and activity in air mitigation (data not recorded). Moreover different structural and functional data coming from Palermo were linked with indoor radon levels. According to literature [16], lack of sump or windows was associated, but not significantly, with accumulation of the gas such as the presence of cracks or moisture tracks and underground location. As mentioned by others

[17], direct contact with the soil was a strong risk factor that was significantly associated with increased levels of radon. Finally, the contemporary presence of several risk parameters in gymnasia was a good predictor of increased radon concentrations. In conclusion, the present paper enriches the general knowledge of radon exposure and improves the scientific literature lacking of previous assessments of risks from indoor radon in buildings devoted to physical activities. Thankfully, radon concentrations in Sicilian and Sardinian gymnasia were below the European Communities reference/action level [18]. Despite this our experiences may be helpful to public health managers of Regions or countries with radium concentrations in soil higher than Sicily and Sardinia. In these last cases, radon mitigation measures, location above the ground level and reduction of the presence of risk parameters in a same building should be strongly encouraged in order to prevent radon accumulation and minimize public health risk.



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