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Influence of some specific meteorological events on indoor radon dynamic in western Switzerland

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Abstract. Radon is a natural radioactive gas that may cumulate in indoor environments. The impacts of weather events on indoor radon concentration had been explored in different places around the world but only marginally in Switzerland. Using basic statistical analysis, this study investigates different meteorological parameters' influence on indoor radon concentrations and shows that outdoor air temperature is the most influential beyond others. Finally, this paper highlights the importance of radon dynamic in buildings, a topic often overlooked by construction professionals and the broader public in Switzerland.

Keywords: Indoor radon, meteorological influence, public health, architecture, Switzerland.

1. Introduction

Radon 222 is an odourless, colourless and tasteless radioactive natural noble gas with a half-life of 3.82 days [1]. It diffuses from underground to the surface through pores and cracks. Ultimately, radon may diffuse into indoor environment mainly by tightness defaults in built-up surface with ground contact [2]. In indoor environments, radon can accumulate and reach harmful concentration because of its continuous source and its decay products. Due to its negative impacts on human respiratory system, indoor radon is of major concern in terms of public health: from 200 to 300 lung cancer deaths are imputable to indoor radon exposure each year in Switzerland [3]. Moreover, radon issues and health impacts are relatively unfamiliar to the Swiss population. In 1995, 31.5% of the Swiss population had heard once about radon gas, while this part reached up to 40% in 2008 [4] and 55% in 2019 [5]. Moreover, radon issues are still too often overlooked by the construction trades and professionals, as underlined by the objectives of the FOPH Radon action plan 2021-2030 [5]. The lack of knowledge from both population and building professionals on radon related topics may increase the exposure and risk, therefore on lung-cancer prevalence. This paper aims to restate the importance of tackling radon related issues.

Swiss federal authorities regulate radon problematics with a new legal basis composed by the Radiological Protection Act (RPA of the Swiss federal constitution) adopted in 1991 and the Radiological Protection Ordinance (RPO of the Federal Council) adopted in 1994, updated in 2017, and enforced January 1, 2018. The reference value of 300 Bq/m³ in housing, schools and normal working places comes from epidemiological studies [6] and international consensus [7, 8]. The Swiss Federal



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Organisation of Public Health (FOPH) leads federal action plans on radon in order to support the implementation of the legislation [5, 9].

Indoor radon concentrations (IRC) are mainly influenced by four different factors: local geology, building characteristics, inhabitants' behaviour and meteorological conditions, the latter being the main object of this study [10, 11, 12, 13, 14, 15].

Weather conditions have an influence on radon concentrations in the atmospheric boundary layer and consequently inside buildings. Literature exploring the links between meteorological parameters and IRC is numerous and consistent. Table 1 synthesizes some meteorological parameters (temperature, air pressure, precipitation and wind) and their impacts on IRC in different environmental contexts. This very short and non-exhaustive literature review is composed by papers tackling several meteorological parameters in similar environments to those in this study.

Table 1. Synthesis of meteorological parameters influences on IRC highlighted in selected papers. (M.: Measurements).

Author	Year	Country	M. type	M. length	Indoor environment type	Influence on IRC
Xie et al. [11]	2015	USA	Active	14 months	Ground floor Basement	Temperature: anti-correlation Pressure: correlation Wind: anti-correlation
Kropat et al. [12]	2014	Switzerland	Passive	3 months	Multiple spaces	Temperature: anti-correlation Pressure: no influence
Kitto [13]	2005	USA	Active & Passive	15 months	Bedrooms Basement	Precipitation: anti-correlation Wind: no influence
Rowe et al. [14]	2002	UK	Passive	3 days & 1 month	Main room	Temperature: anti-correlation Precipitation: small influence Pressure: small influence Wind: influence
Buchli et al. [15]	1985	Switzerland	Active	1-3 weeks	3 homes	Wind: anti-correlation

As shown above, meteorological impacts on IRC vary largely according to the geographical location but also by the geological context, the building characteristics and the inhabitants' behaviour.

We herein aim to analyse IRC through four case-studies on three different sites in Switzerland. Based on continuous long-term radon and meteorological measurements, results highlight the influence of meteorological parameter on IRC in the Western Switzerland context. These findings should allow to enhance the quality of radon diagnostic interpretation in existing buildings made by FOPH recognized radon professionals. Ultimately, this paper seeks to raise awareness of professionals and broader public to radon related-topics and to promote the respect and observance of best practices during building construction or renovation to limit the population's radon exposure.

2. Methods

Table 2. Buildings and measurements characteristics used in this study. Meteorological statistics comes from the 1981-2010 norm [16].

Building-site	Bevaix	La Brévine	Gunzgen
Canton	Neuchâtel	Neuchâtel	Solothurn
Swiss region	Swiss Plateau near lake Neuchâtel	Jura mountains	Heart of Swiss Plateau
Geology unit	Quaternary deposits	Limestone	Limestone and Quaternary deposits
Altitude	475 m. asl.	1075 m. asl.	430 m. asl.
Building type	Family house	Jura farm	Townhall
Year of construction	Approx. 1895	18 th Century	1845
Sensor used in occupied space	RadonMapper	RadonMapper	RadonMapper
Measurement start date	15.10.2017	23.01.2018	17.01.2014
Measurement end date	10.06.2019	10.06.2019	12.12.2017
Distance from nearest meteorological station	3.2 km (Boudry) 13.5 km (Neuchâtel)	1.3 km (Brévine)	0.8 km (Härkingen) 7.5 km (Wynau)
Mean temperature (min.; mean; max.) [16]	6.8; 10.2; 14 °C	-1.6; 4.9; 10.6 °C	4.8; 9; 13.9 °C
Sum of annual rainfalls [16]	978 mm	1597 mm	1129 mm
Mean wind speed [16]	2.6 m/s	/	1.7 m/s

Long-term radon measurements have been performed in living spaces in three different buildings sites in radon-prone areas in Switzerland (cf. Table 2). IRC are measured every minute by RadonMappers made by Tecnavia SA brand (Switzerland). Moreover, CO₂ sensors were installed on RadonMappers in order to characterize the space occupancy. Hourly means are then calculated. Meteorological variables stem from the nearest available station observations (cf. Table 2). Hourly means of screen-level air temperature, sea-level pressure, wind speed and direction, whereas hourly sum of precipitation, are used. These datasets come from IDAWEB, the Federal Office of Meteorology and Climatology MeteoSwiss online platform [17]. Radon and meteorological timeseries have been analyzed through statistics: distributions, time series plots, scatterplots and Pearson's linear correlations.

3. Results and discussion

This section presents only one specific example for each meteorological parameter in either one of our study-site selected on their readability. However, results recurrence between the three study sites, which is giving strength to our findings, will be presented through the main poster.

3.1. Outdoor air temperature

The first case study highlights temperature influences on IRC. Figure 1 shows a time-series and a correlation matrix of outdoor air temperature, IRC and indoor CO₂ at Bevaix in April 2018.

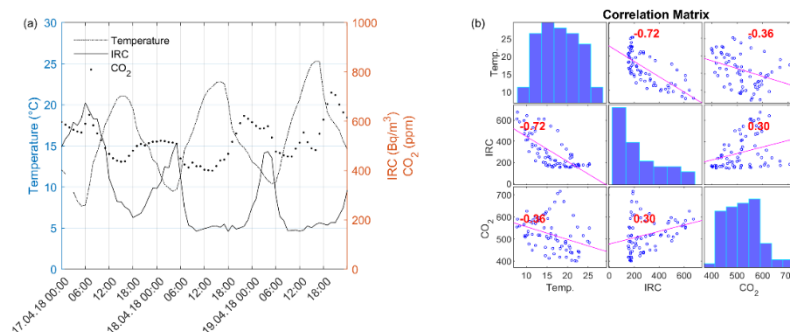


Figure 1. (a) Outdoor air temperature measured at Bevaix, IRC and indoor CO₂ temporal variations between the April 17 and the 20, 2018 at Bevaix. (b) Correlation matrix of outdoor air temperature, IRC and indoor CO₂. P-values are significant at a level of 5%.

A strong and significant anti-correlation is found between IRC and outdoor temperature. When outdoor temperature reaches its minimum early in the morning, IRC level is at its highest (Fig 1a). This may be explained by the difference between indoor and outdoor temperature inducing a pressure difference between indoor and outdoor environments. At this time, pressure difference between indoor and outdoor environment is at its maximum. This effect is referred to as the stack effect [18]. When outdoor temperature is lower than indoor, radon infiltration is enhanced through the building from close-to-building ground. Once inhabitants start to be active, a huge gas dilution happens by window and door opening. This daily cycle is typical and greater during winter since stack effect is enhanced by indoor heating. Outdoor temperature and more particularly indoor-outdoor temperature difference influences IRC, which had already been reported in the literature [11, 12, 13, 14], might be the greatest on IRC amongst all the weather parameters. Ventilation may be one of the main keys to reduce radon risk in general and more specifically during night, while exposition time of inhabitant is longer. Building professionals should always promote at least a good ventilation concept in the building as it is formerly required in the SIA180/1 norm [19], and population should be advised that even natural ventilation help to limit IRC.

3.2. Outdoor atmospheric pressure

The second case-study focuses on sea-level pressure influence on IRC. Figure 2 shows how atmospheric pressure influences IRC. Figure 2(a) shows a three-day time-series in which atmospheric pressure

decreases with simultaneously increasing IRC at Gunzgen. A strong and significant anti-correlation supports this finding (Fig. 2b). A decrease of atmospheric pressure allows radon to exhale easily from the underground. As for outdoor temperature, when indoor environment is underbalanced relative to outdoor environment, radon probability to enter the building will be enhanced. Huge atmospheric pressure variations, as for instance during frontal passages or thunderstorms, may induce variations of IRC. Atmospheric pressure influence on IRC can be limited by a good building air-tightness. However, it has been shown that building energy renovation tend to increase the radon level by 20% [20, 21, 22]. The main reason is that energy renovation works are carried out on the outside envelope of the building (e.g. windows replacement) and not on the building's ground-contact zone. Radon will therefore keep entering into building and the airtight envelope will prevent radon from escaping indoor environments.

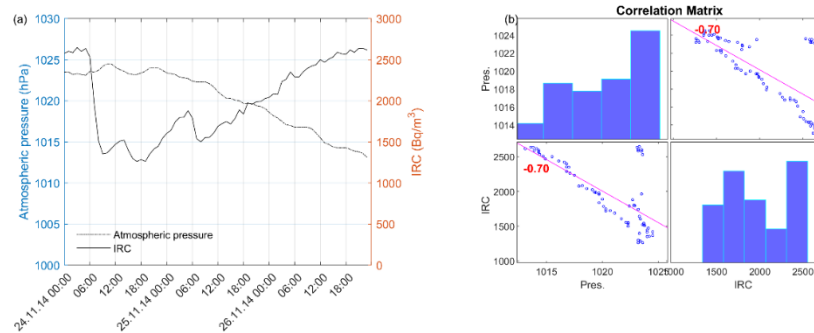


Figure 2. (a) Atmospheric pressure measured at Härkingen and IRC temporal variations between November 24 and 27, 2014 at Gunzgen. (b) Correlation matrix of Atmospheric pressure and IRC. P-values are significant at a level of 5%.

3.3. Precipitation

The third case-study shows how precipitation events influence IRC. This is evidenced in Fig. 3, in which high precipitation occurred during the evening of September 23, 2018, at La Brévine. After this event, IRC rose. This result may be explained by the following: firstly, rainfall seals the ground, except under the building which is the only escape for radon because it stays dry, and secondly, inhabitants' behavior might influence IRC by closing the window before the precipitation event. These could also be an explanation to why IRC rose before rainfall start. Moreover, a short precipitation occurred on the morning of September 23, 2018. Despite of the lack of statistical link between precipitation and IRC, explained by the short duration of precipitation events, this case study highlights the strong influence that precipitation events have on IRC on the short term.

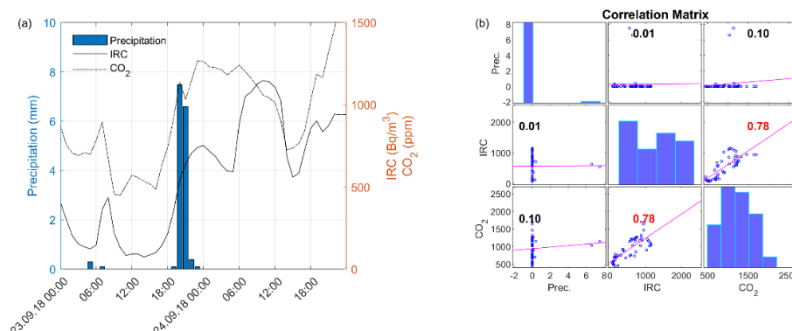


Figure 3. (a) Precipitation measured at La Brévine, IRC and indoor CO₂ temporal variations between September 23 and 25, 2018 at La Brévine. (b) Correlation matrix of precipitation, IRC and indoor CO₂. P-values arising from tests of correlation between IRC and CO₂ is significant at a level of 5%.

3.4. Wind

The fourth case-study explores the effects of winds on IRC. Figure 4 shows a north-eastern wind event at La Brévine in April 2018. An anti-correlation is highlighted in Fig. 4(a) and supported by a strong and significative correlation coefficient of -0.65 as shown in Fig. 4(b). In this example of at La Brévine, north-eastern winds reduce IRC. Winds generate a pressure field over the building [23, 24], and

depending on building characteristics it may affect IRC. Wind influences on IRC may be limited by a good building airtightness, which is not the case in this case study.

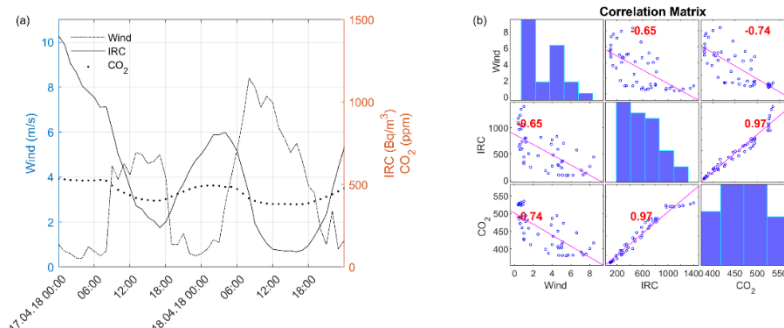


Figure 4. (a) Wind measured at La Brévine, IRC and indoor CO₂ temporal variations between April 17 and 20, 2018 at La Brévine. (b) Correlation matrix of precipitation, IRC and indoor CO₂. P-values arising from tests of correlation are significant at a level of 5%.

3.5. Synthesis

Table 3 synthesizes meteorological parameters' impacts on IRC at the three investigated sites in that paper and within the poster. Globally, outdoor air temperature has the major influence beyond all meteorological parameters. Wind and precipitation influence punctually IRC but not constantly, so as temperature. Atmospheric pressure's influence on IRC might be lower than other parameters but can still be identified in some time-series.

Table 3: Summary of meteorological influences measured at out three study-cases.

Meteorological parameter	Bevaix	La Brévine	Gunzgen
Outdoor air temperature	Temperature influence IRC with an anti-correlation link		
Outdoor atmospheric pressure	Pressure might influence IRC but to a lower extent than other parameters		
Precipitation	Precipitation influence IRC with a positive correlation		
Wind	Wind might strongly influence IRC but tendency depends on wind direction and speed		

4. Conclusion

Outdoor air temperature, atmospheric pressure, precipitation and wind effects on IRC have been explored across four case-studies at three different sites. These examples in the Swiss context support the impact of meteorological parameters on IRC. Outdoor air temperature has the greatest influence on IRC followed by wind and precipitation and to a lesser extent atmospheric pressure. In our outdoor air case-study, anticorrelation between temperature and IRC which coefficient reaches -0.72, which highlight the statistical link between these variables. Simple statistical methods used in that paper allowed us to characterize some meteorological variables impacts on IRC at three different sites. The application of long-term, high frequency radon measurements and meteorological observations allowed to analyze the behavior of IRC over specific weather events on three different sites; this methodology is innovative considering that it allows robustness in our results by replications of indoor radon behaviors relative to meteorological parameters variations.

However, conclusions drawn in these contexts can hardly be widely applicable because each building-site has its own characteristics (geology, building characteristics and inhabitants' behavior) but enhance and take part to build a deeper knowledge available for both radon and building professionals and Swiss population.

In order to reduce radon risk exposure, each building should be carefully investigated, which is difficult to achieve over the whole Swiss housing stock, but could be a goal to achieve in the near future. Consequently, this is why FOPH insist on building recommendations for new constructions. FOPH's main recommendations on constructional measures against radon are to avoid radon entry into the building and to get rid actively or passively of it before it enters into the building [25]. For existing building, the exhaust of radon outside of the building must be considered [25].

These recommendations require adaptation in construction guidelines and techniques according to the building condition (new construction or renovation) [25]. Moreover, these findings are a tool to enhance better knowledges for professionals on indoor radon dynamic. Last but not least, the aim of this paper is to highlight the importance of raising awareness and prevention for both professionals and population on radon related-topics, in order to reduce the radon exposure and the associated lung cancer risk.

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