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Autodigit-RAD: Towards an automation of the radon's concentration dataflow in a new and innovative building

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Abstract. Radon is a noble, natural, and radioactive gas coming mainly from the ground which might accumulate indoors and lead each year to 200-300 deaths from lung cancer in Switzerland. A brand new and innovative living lab will be built as of 2023 in Fribourg (Switzerland) which will allow to tackle the built environment and the relationship with its occupants. Among a large panel of environmental parameters, radon gas will be continuously monitored under and around the building as well as in the building envelope. This paper aims to present the overall process of the radon dataflow: 1) design of the sensor probes, 2) implementation of the radon sensor probes in the ground and 3) go-live with the data sharing platform with the building users. Such an infrastructure will bring the opportunity to researchers to lead new and innovative radon-related research.

1. Introduction

Radon is a noble and radioactive natural gas, which can accumulate into buildings and consequently harm human health. In Switzerland, between 200 and 300 deaths are due to lung cancer only caused by indoor radon exposition each year [1]. Radon exposition is a constructive problematic and more broadly became a public health issue since the mid-80's in Switzerland [2]. Nowadays, in a context implying an optimization in terms of building energy consumption, indoor comfort and indoor air quality, a new and innovative building will be built as of 2023 in the blueFactory district in Fribourg, Switzerland. This building will be both the researchers' workplace and their main research infrastructure. In it, experiments

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will be carried out in real-world conditions to improve the built environment and the relationship with its occupants. To that purpose, numerous environmental parameters (physical, chemical, comfort, occupancy and human interaction) will be monitored continuously and on a long-term basis inside, outside. The building will also include an innovative research facility, unique in Europe, for monitoring radon concentrations. Radon measurement devices will be installed at different levels in the soil under the building as well as in its envelope close to the ground and in the natural field out of the building emprise.

From an architectural perspective, this building will cover a total floor aera of 4’904 m^2, and a volume of 19'974 m^3, spread on 6 different levels. From a constructive standpoint, this building has been designed to meet the requirements of the Swiss Minergie-A-ECO and SNBS Gold labeling. The maximum annual average of radon concentration must therefore not exceed 100 Bq/m3. To answer that objective, two specific preventive constructive methods will be installed in the building. The building will be installed over a geothermal probes field. A radon-tight membrane will be casted on the western part of the building that will be built on solid ground. On the eastern part, a specific radon drainage will be installed under the basement floor.

Among other objectives, researchers will use their building as a lab to tackle research questions in the field of radon as well as in the monitoring of long-term protection of the building. There are still unanswered questions regarding the behavior of radon gas at the soil/building interface in relation to atmospheric and building conditions. Especially in this case study, the presence of a geothermal probe field underlying the building is indeed interesting to study. So far, there is currently no pervious knowledge on the influence of such an installation on the gas dynamics near the building foundations, which consists in a research gap. Moreover, and in the context of the energy transition, this type of installation might be extended in the years to come in urban centers.

Therefore, it is of great interest to monitor radon in several points under the building as well as in some technical installations such as radon drainage or near geothermal probes likewise in the envelope in contact with the ground. Such an installation is absolutely innovative for radon research field. At first, it required the development of radon probes allowing to measure radon gas at these different points. Secondly and considering the amount of data that will be collected, it will be necessary to develop an IT platform that will allow to monitor, store, analyze and visualize the radon behavior. This paper aims to present the overall process: 1) design, 2) implementation of the radon sensor probes in the ground and 3) go-live with the data sharing platform with the building users.

2. Installation of radon probes

Radon is a decay product of uranium (^{238}U) that mainly comes from the ground. Consequently, a unique and large field of about 100 radon sensor probes will be installed in the soil at different depths and positions under and around the building as well as in the building envelope in contact with the ground. Two different type of radon probes were developed, prototyped, and preliminary tested in the field where the building will be built (cf. Figure 1). These probes were both designed as a porous chamber using sinterized metal, which allow radon to be sampled at different depth, without being blocked by rock and earth fragments. Type 1 are cylindrical and designed to fit in the ground and type 2 are flat, to fit in some specific places on the building envelope and more precisely in the insulation and radon barrier membrane. The main difference between both probes lies in their shape design. Although the process to catch radon gas is similar with both probes, their design was adapted regarding their location, to perfectly fit their environment (*i.e.*, in the ground or in the building insulation). The air coming from the ground will be pumped towards a Lukas chamber (scintillation chamber) and return to the ground via a closed circuit. Table 1 gives an idea of the diversity of data that will be collected and the repartition of the radon probes.

Radon probes will be installed at different depths and locations under and around the building’s ground. Moreover, some measurement points are planned to monitor radon in the radon extraction chimney to quote the drainage efficiency. The use of the radon drainage will be modular: it will be possible to block the radon drainage by closing the base of the chimney and to activate a fan installed vertically above the roof chimney in extraction. This will enable to assess the efficiency of passive and active extraction of radon.

Table 1. Repartition of the cylindrical and flat probes under, around and within the envelope of the building. The reference altitude is 631.3 meters above sea level, i.e., just over the top of the radon barrier.

Location	Probe		Altitude			Project reference level		
	Type	Number	Min.	Max.	Average	Min	Max	Average
Radon drainage – Lime	Cylindrical	14	624.7	628.8	626.7	-6.6	-2.5	-4.6
Radon drainage – Pipe	Cylindrical	14	624.8	628.9	626.8	-6.5	-2.4	-4.5
Geothermal probe head	Cylindrical	12	622.6	622.6	622.6	-8.7	-8.7	-8.7
Backfilled ground	Cylindrical	4	624.65	627.9	625.5	-6.65	-3.4	-5.8
Building insulation	Flat	9	625.25	631	627.4	-6.05	-0.3	-3.9
Radon barrier	Flat	3	631	631	631.0	-0.3	-0.3	-0.3
Natural ground	Cylindrical	13	623.8	629.8	626.0	-7.5	-1.5	-5.3
Earthworks backfill	Cylindrical	13	624.8	630	627.7	-6.5	-1.3	-3.6
Vertical profile	Cylindrical	12	593.3	629.3	611.3	-38	-2	-20.0
Radon extraction chimney	Cylindrical	3	624.8	629.3	627.0	-6.5	-2	-4.3
Total		**97**						

3. From data acquisition to storage

All the probes are developed to sample air from ground, in an air closed loop between the ground and the radon sensors that measures the radon concentrations (Bq/m^3). Two polypropylene tubes will connect each radon probe to radon measuring devices, located in a local in the underground level. The latter will be research-grade radon measuring devices (RADONMAPPERs, Tecnavia SA, Switzerland [3]) and will allow radon to be continuously monitored at different location, depth and context, in line with the objectives of the running study. Radon probes were tested in the near ground (0.9 m depth) on site (cf. Figure 2).

One of the major aims of this work is to develop a pneumatic control panel to optimize the data acquisition. The most important advantage of this method is that it can sample radon from different probes at the same time or consecutively. We then expect a significant increase of the amount of data collected.

In the next step, the focus lies on the data transfer to a central database, called BBData and developed by HEIA-FR iCoSyS institute and maintained by EPFL's Building 2050 IT [4]. BBData is a time series data base offering a single data location across projects and users. Designed for scalability, BBData should match the data storage requirements of the Autodigit-RAD project.

The implementation of the radon analytical system requires to develop an algorithm aiming to attribute each measurement to its correct source (location and depth). Previously a very precise inventory of the radon probes would have been made. The radon mapper records radon concentrations every minute. A data collection protocol will be put in place to monitor regularly and continuously several points under the building but also in a successive way the other probes. This step's objective is to export data from the sensors up to the database, in a homogeneous format.

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(a) (b)

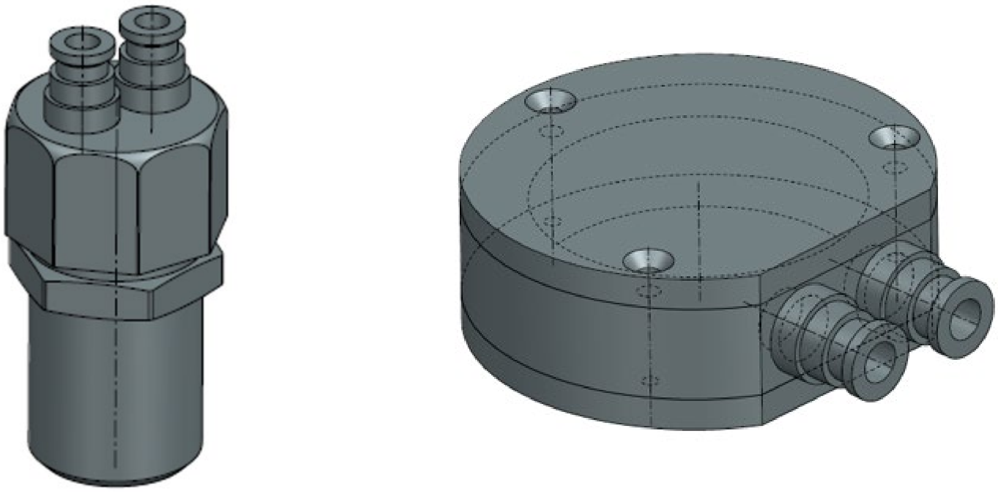

Figure 1. Perspective of a cylindric (a) and a flat (b) radon probes prototypes that will be installed under the new living lab building. Air inlets and outlets' diameter is 4 mm for both probes.

Figure 2. Tests of two cylindric radon probes prototype in a 2x10 cm hole at a depth of 0.9m.

4. Data valorisation

This final step of the overall project consists in the development of a preliminary and specific proof-of-concept project, which aimed to automate the dataflow from the database up to their availability for the purposes of sharing, visualizing, and analyzing. After being retrieved from the database, data have been preprocessed and standardized, to be suitable for statistical analysis, which include in a first step descriptive statistics (e.g., mean, standard deviation, median and percentiles). Some of the building occupancy metrics were also statistically assessed. In a second step, we performed a literature review which aimed to identify the most relevant elements to be presented to obtain the most optimized visualization. It comes out that radon time-based data might be well represented through heatmaps and line charts [5]. Finally, different visualizations were tested taking these identified elements into account.

With the purposes of sharing the available data to the building users, we developed an application using the Streamlit library, encoded in Python [6]. This allows to easily share updated and synchronized data information and their relative analysis to the building users and researchers. We designed it with the purpose of enhancing the user interface in a user-friendly way. The structure of the application, which is described in Figure 3(a), contains different pages, so that the different visualizations lie on their own, allowing users to easily navigate and select meaningful information. Figure 3(b) emphasizes the main page of the application, which display the descriptive statistics. It is followed by a second page, which depicts a heatmap highlighting the temporal radon variability on a selected period, using heatmaps.

This application and the processes to automate the overall dataflow is a foundation for future projects to share radon information, such as the current radon level and basic visualizations, to different people group (e.g. users, occupants, researchers, professionals or stake-holders) This application might be extended to some other available indoor environment parameters (i.e. temperature, relative humidity), indoor air quality (IAQ) data (i-e. CO2, VOCs, PM) and meteorological parameters. The implementation of such of these data might enhance the understanding of indoor radon levels and dynamics, compared with other more common temporal parameters' variations. Finally, these visualizations will be evaluated and compared, to determine the best ways to communicate about radon measurements.

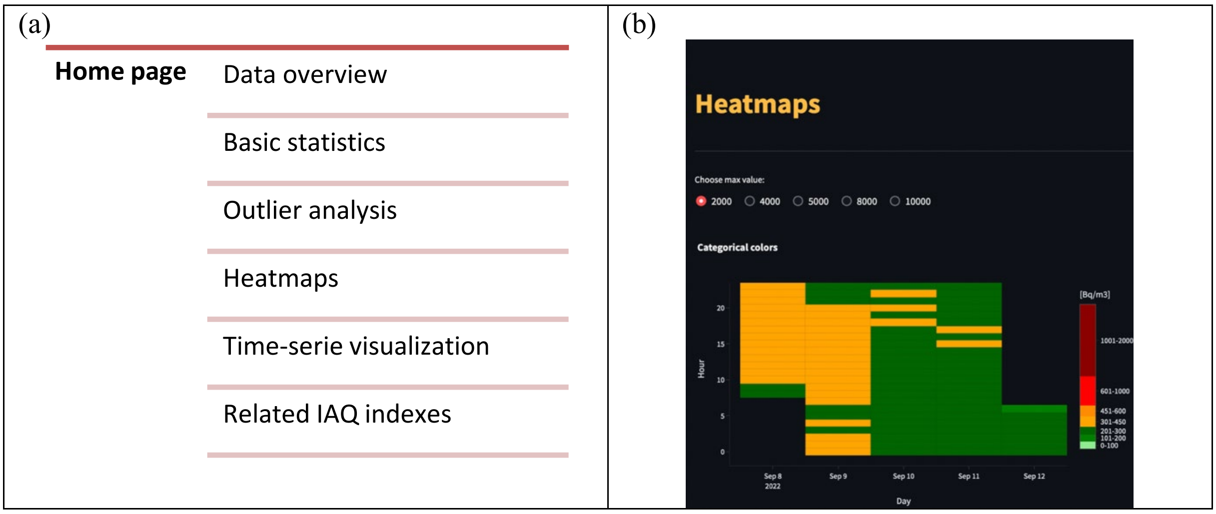

Figure 3. Structure and the different pages included in the developed application (a) and a heat-map visualization (b) based on real radon data.

Future perspectives should consider the potential integration of other parameters more carefully into the application, such as temperature or CO2 for example. The application will be shared among the building community and open to critics leading to updates and improvements. Moreover, empirical data will continuously feed and enlarge the database, which will bring new tools to tackle ambitious research questions. Radon data will be shared and streamed live to the buildings' occupants to make them aware about radon gas dynamics. Moreover, data will be available for research and will be useful among other research, to model radon dynamics in the ground.

5. Discussion and conclusion

The present work demonstrates the success of the two first and main stages of an overall process to monitor, analyze and visualize radon levels measured under buildings. This project aims to integer the overall process from the prototyping of a new experimental radon probe to the data visualization and sharing in the context of further research. It is, above all, a unique facility to monitor and characterize

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the behavior of the radioactive gas in the ground below and in the vicinity of the building. While some previous studies and investigations already focused on radon behavior in soils and undergrounds, none of them were using such a dense under-ground monitoring facility. Compared to other facilities used in other studies, the density of the radon probe field will allow to increase the degree of details.

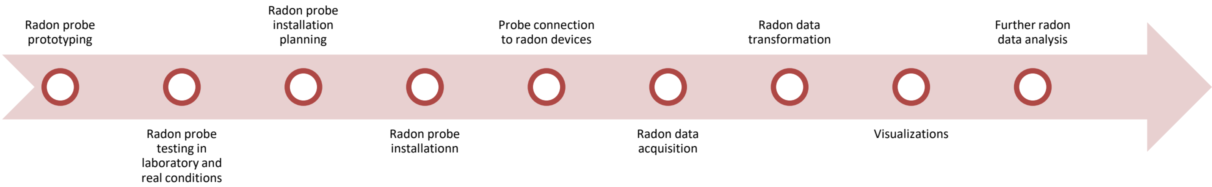

Figure 4. Scheme synthesizing the different steps and their relative progression

Consequently, future studies could fruitfully explore and better characterize the behavior of radon gas under and at the interface ground/building and assess the influences of seasons and meteorological parameters. Moreover, future studies could investigate the influence of a geothermal probes field on radon dynamics under the buildings, and in depth. Radon measurements carried in the drainage zone, and in the drainage itself, in the extraction chimney will allow to assess the efficiency of such installations, often considered as radon prevention method. In a similar way, measurements installed in the building envelope will allow to assess the efficiency of the different envelope' layers and especially the radon-tight membrane. Finally, the monitoring technique might be extended to other type of gas in present in the ground. This project will also contribute to the development of numerous illustrated documents intended for the training of construction professionals as well as for a better knowledge of the sustainability of the preventive actions implemented.

In conclusion, such a project is intended to open new research fields on radon by providing the opportunity and a sustainable infrastructure to researchers, which will be enhanced.

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