

An Internet of Things (IoT)  
Ecosystem for Detection and Removal of Radon Gas.  
Versão final após defesa.

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## Resumo

A região que serviu de base para a realização deste trabalho é caracterizada pela abundância de diversos tipos de granitos. Em alguns locais, a predominância de determinados minerais uraníferos, a existência de falhas e minas podem, inclusivamente, ser responsáveis pela existência de níveis de radioatividade natural bastante elevados, especialmente no que se refere ao radão. A principal motivação para se estudar os efeitos da exposição das populações ao radão baseia-se no facto de este gás, radioativo, inodoro, incolor e insípido, ser desde 1988, reconhecido pela Organização Mundial de Saúde como a 2<sup>a</sup> causa de morte por cancro pulmonar para a população geral, depois do tabaco. Cerca de 80% da radiação de fundo a que as populações estão, diariamente, expostas tem origem em fontes naturais nas quais se podem incluir os materiais radioativos de origem natural, NORM, presentes na crosta terrestre, na comida, em algumas bebidas e, inclusivamente, em certos materiais de construção.

Em dezembro de 2018, foi aprovada, em Portugal, uma nova legislação, o DL n<sup>o</sup> 108/2018, transposta da Diretiva Europeia 59/2013/Euratom, que estabelece normas de segurança de base uniformes para a proteção da saúde de pessoas sujeitas a exposição profissional, da população e médica contra os perigos resultantes das radiações ionizantes.

O isótopo radão, <sup>222</sup>Rn, que resulta da desintegração do rádio, <sup>226</sup>Ra, e um dos produtos de decaimento do urânio, <sup>238</sup>U, é o principal radionuclídeo com interesse radiológico em termos de saúde humana. Este gás radioativo liberta-se, espontaneamente de algumas rochas e, sendo ligeiramente mais denso do que o ar, tem tendência a acumular-se em zonas térreas de espaços fechados e é responsável pela maioria da dose de radiação recebida pela população. Algumas soluções tradicionais têm sido aplicadas de modo a resolver o problema, no entanto, depois da deteção do radão estas não usam os dados recolhidos de forma a combater e a prevenir que o gás se acumule nos espaços interiores. Em Portugal é um problema que não tem a devida atenção.

Tendo em conta os possíveis efeitos nocivos do radão na população, a principal motivação deste trabalho consistiu no desenvolvimento de um sistema IoT (Internet das Coisas) com o objetivo de detetar, mitigar e prever os níveis do gás radão no interior das habitações. Partindo deste pressuposto, será possível criar um ambiente mais saudável que permitirá reduzir os riscos para a saúde em ambientes fechados. Para se concretizar este objetivo foi desenvolvido um sistema IoT que consiste em um sensor de radão e um interruptor automatizado, que permite ligar e/ou desligar os ventiladores instalados na residência, bem como prever e tomar decisões perante uma situação potencialmente perigosa com base nos registos fornecidos pelos sensores. Este sistema integra também uma aplicação web que permite ao utilizador consultar os dados estatísticos relativos à concentração média de radão. Por outro lado, através da aplicação web, é possível não só ativar os ventiladores manualmente, como também editar o limite em que os ventiladores são accionados. Este sistema foi testado num contexto real e, por isso, possível comparar dois métodos de mitigação do gás radão e identificar qual seria o mais eficaz. Uma vez determinado o método a ser utilizado e após a estabilização dos dados obtidos pelo sensor, analisaram-se os resultados obtidos pelo sistema que permitiram concluir que o sistema reduziu consideravelmente os níveis de radão na habitação. Foi verificada, em média, uma redução de cerca de 93% na concentração de gás radão. Este resultado demonstra que a implementação do sistema foi um sucesso e permite concluir que poderá ser aplicado numa escala maior.

An Internet of Things (IoT) Ecosystem for Detection and Removal of Radon Gas

## Palavras-chave

Internet of Things, Radão, Mitigação, Serviços Web, Aplicação Web.



## Resumo alargado

### Introdução

O radão e o torão são dois isótopos radioativos, pertencentes às cadeias de decaimento do urânio e do tório, respetivamente [HYH<sup>+</sup>18]. Sendo elementos gasosos têm a capacidade de se escapar naturalmente para a atmosfera a partir das rochas, da água e de alguns materiais de construção. Este gás pode acumular-se em ambientes fechados e, por isso, ser facilmente inalado. Sendo um gás radioativo, reconhecido pela (Organização Mundial da Saúde) OMS como agente cancerígeno, faz dele um potencial risco para a saúde [Che19].

O período de semivida do radão é de 3,8 dias, no entanto, os seus descendentes diretos nomeadamente o polónio, <sup>218</sup>Po e <sup>214</sup>Po, com semividas muito menores podem desintegrar-se no interior do corpo constituindo um verdadeiro risco radiológico. Uma vez que o tempo de semi-vida é curto, é possível que a desintegração ocorra dentro do organismo. Estes isótopos são elementos radioativos sólidos, que não são expelidos do sistema respiratório e, ao ficarem alojados na árvore respiratória, podem irradiar células sensíveis [PAK<sup>+</sup>13]. As partículas alfa, provenientes do decaimento do radão, ao interagirem com a matéria podem provocar danos no ADN e conseqüentemente mutações que podem ser geneticamente transmitidas, potenciar o desenvolvimento de tumores e, inclusivamente, causar a morte das células. Essas células, já danificadas, ao replicarem-se podem levar ao aparecimento de neoplasias [MVLB00].

Em ambientes fechados, o risco de desenvolver cancro do pulmão, devido à presença de radão, aumenta de forma proporcional em relação à exposição ao mesmo. O risco aumenta em 8% por cada 100 Bq/m<sup>3</sup> da concentração média medida com um intervalo de confiança de 95% entre 3 a 16% [ZSO09]. O radão em espaços fechados contribui para cerca de 9% das mortes por cancro do pulmão e é responsável por cerca de 2% do total de mortes por cancro na Europa [DHA<sup>+</sup>05a]. No norte de Portugal, entre 1995 e 2004, ocorreram 8514 óbitos devido a cancro do pulmão e estima-se que entre 1565 e 2406 possam ser associados ao radão, ou seja, entre 18 a 28% do total, devido à constituição litológica da região [VNC12]. Em Portugal estima-se que a concentração média em ambientes interior seja de 62 Bq/m<sup>3</sup> enquanto a nível mundial essa estimativa seja na ordem de 39 Bq/m<sup>3</sup> [ZSO09]. Em regiões onde o solo é rico em rochas contendo urânio, a concentração de radão dentro das habitações pode atingir valores muito elevados [SGVK06].

Para evitar que o radão se acumule no interior das habitações existem soluções tradicionais. A primeira fase consiste em detetar o radão através de sensores. Através dos dados recolhidos pelos mesmos é possível aplicar um método de mitigação. Em geral, os métodos de mitigação permitem impedir a entrada ou a remoção do gás radão.

As tecnologias IoT potenciam um ponte de comunicação entre os sensores e os dispositivos de mitigação, o que faz com que seja possível criar um sistema inteligente que permita agir segundo os dados recolhidos. Esta condição permite-nos concluir que é possível criar novas soluções baseadas em IoT.

Como o objetivo de melhorar a qualidade do ar interior, o sistema proposto irá permitir detetar, mitigar e prevenir as concentrações médias de radão. Espera-se que o sistema permita reduzir os níveis de radão em ambientes fechados e habitados e assim reduzir a exposição ao gás radão às pessoas e os riscos para a saúde.

## Motivação

Alguns dos fatores que condicionam a divulgação dos efeitos do radão são, por exemplo, o facto de se tratar de um gás invisível, inodoro, insípido e que ocorre naturalmente na natureza. Por outro lado, não existem ligações a mortes por exposição ao radão e o período de latência é muito grande. Como não se trata de um tema sensacionalista não é noticiado e, por isso, não existem advertências frequentes que nos levem a pensar no assunto. Por isso, a população não está informada e até desconhece a existência deste gás. Uma vez que o mesmo é inodoro e invisível as pessoas tendem a ignorar os riscos relativos a ele. Em meados de 2016, foram efectuados testes na minha residência devido à existência de minas de uranio na região . À data da realização desta dissertação, o conhecimento sobre estas minas era duvidoso, uma vez que era pensado que as minas existentes eram de volfrâmio. Foi verificada a presença de radão com níveis elevados na habitação, através da instalação de sensores por uma equipa de investigação da área. Assim na habitação, foram investidas quantias avultadas em métodos de mitigação ativos e passivos que não foram eficazes. Os resultados mostraram-se inconclusivos, pois a concentração do gás permanecia elevada. O interesse pelo tema supracitado foi aumentando, uma vez que era algo pessoal. Assim, tornou-se pertinente investigar o tema em causa e, conseqüentemente, procurar uma maneira de resolver o problema. Com o resultado da pesquisa foi possível perceber que existiam formas de detetar e de mitigar o radão. No entanto, existem poucos sistemas autónomos que permitam resolver o problema. A pesquisa permitiu concluir que as tecnologias IoT vêm potenciar o desenvolvimento de soluções e trabalhos de investigação sobre o assunto. Com isto, foi proposto um sistema para a elaboração desta dissertação que permite não só auxiliar a resolução deste problema que se tornou pessoal, mas também auxiliar uma grande parte da população que é afetada pelo gás e o desconhece. Este sistema tem como principal objetivo reduzir a exposição ao gás reduzindo o risco de desenvolvimento de cancro. Este será capaz, através dos dados obtidos, tomar decisões e prever situações onde as concentrações atingem níveis perigosos para saúde.

## Objetivos

O principal objetivo deste projeto tem como base a construção de um sistema que permite detetar, mitigar e prever o gás radão numa habitação. Para isso, após a contextualização e a idealização do sistema, as várias etapas desta dissertação foram as seguintes:

- Estudo do problema, trabalhos efetuados e tecnologias já existentes sobre o tema;
- Desenho conceptual do sistema e da sua arquitetura;
- Implementação do dispositivo IoT que permite detetar o gás radão;
- Implementação do dispositivo IoT que permite ativar o método de mitigação;
- Implementação da aplicação web e da base de dados;;
- Teste em contexto real do sistema;
- Escolha do método de mitigação tendo em conta os resultados obtidos;
- Analise de resultados;
- Implementação do algoritmo de machine learning;

## Organização da tese

### Revisão de literatura

No capítulo 2 foi realizada uma revisão de literatura assente em trabalhos académicos e nas tecnologias existentes a nível comercial envolvendo o IoT. São também abordados os diferentes métodos de mitigação, os vários tipos de sensores existente para a deteção do gás, um enquadramento a problemática do gas radão e o conceito das tecnologias IoT.

### Desenho conceptual e implementação

No capítulo 3 foi realizada uma revisão de literatura assente em trabalhos académico e nas tecnologias existentes a nível comercial. São também abordados os diferentes métodos de mitigação e os vários tipos de sensores existentes para a deteção do gás.

### Protótipo e Demonstração

No capítulo 4 é apresentado o resultado final dos dispositivos baseados em IoT e da aplicação web. É também explicado como estes foram implementados.

### Avaliação do desempenho

No capítulo 5 são apresentados os testes realizados ao software e incluídas algumas anomalias encontradas, resolvidas durante esta fase. É, também, descrita a fase de teste em contexto real que permite perceber como o sistema se comporta e quais os resultados obtidos.

### Conclusões e trabalho futuro

No capítulo 6 são expostas as conclusões finais da tese e os resultados gerais do trabalho. Tendo em conta as dificuldades encontradas ao longo da realização deste trabalho de investigação, é apresentada uma análise sobre os objetivos iniciais e aqueles que foram atingidos. Por fim são dadas diretrizes para melhorar o sistema num trabalho futuro.



## Abstract

The region that served as the basis for this work is characterized by the abundance of different types of granite. In some places, the predominance of certain uraniferous minerals, the existence of faults and mines may even be responsible for the existence of very high levels of natural radioactivity, especially with regard to radon. The main motivation for studying the effects of population exposure to radon is based on the fact that this gas, radioactive, odorless, colorless and tasteless, has been recognized since 1988 by the World Health Organization as the 2nd leading cause of death from lung cancer for the general population, after tobacco. Approximately 80 % of the background radiation to which populations are exposed daily comes from natural sources, which can include radioactive materials of natural origin, NORM, present in the earth's crust, in food, in some drinks and, including certain building materials.

In December 2018, a new legislation was approved in Portugal, DL n° 108/2018, transposed from European Directive 59/2013 / Euratom, which establishes uniform basic safety standards for the protection of the health of people subject to exposure professional, public and medical professionals against the dangers arising from ionizing radiation. The radon isotope,  $^{222}\text{Rn}$ , which results from radio disintegration,  $^{226}\text{Ra}$ , and one of the uranium decay products,  $^{238}\text{U}$ , is the main radionuclide of radiological interest in terms human health. This radioactive gas is spontaneously released from some rocks and, being slightly denser than air, it tends to accumulate in ground areas of closed spaces and is responsible for the majority of the radiation dose received by the population. Some traditional solutions have been applied in order to solve the problem, however, after the detection of the radon they do not use the data collected in order to combat and prevent the gas from accumulating in the interior spaces. In Portugal it is a problem that has not been given due attention. Taking into account the possible harmful effects of radon on the population, the main motivation of this work was the development of an IoT (Internet of Things) system with the objective of detecting, mitigating and predicting the levels of radon gas inside homes. Based on this assumption, it will be possible to create a healthier environment that will reduce health risks in closed environments. To achieve this goal, an IoT system was developed, consisting of a radon sensor and an automated switch, which allows the fans installed and / or switched off to be installed in the residence, as well as predicting and making decisions in the face of a potentially dangerous situation based on the records provided by the sensors. This system also includes a web application that allows the user to consult the statistical data related to the average radon concentration. On the other hand, through the web application, it is possible to not only activate the fans manually, but also to edit the limit at which the fans are activated. This system was tested in a real context and, therefore, it is possible to compare two radon gas mitigation methods and identify which would be the most effective. Once the method to be used was determined and after stabilizing the data obtained by the sensor, the results obtained by the system were analyzed, which allowed us to conclude that the system reduced considerably the levels of radon in the house. On average, there was a 93% reduction in the concentration of radon gas. This result demonstrates that the implementation of the system was successful and allows us to conclude that it can be applied on a larger scale.

## Keywords

Internet of Things, Radon, Mitigation, Web Services, Web Application.



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## Lista de Acrónimos

UBI	Universidade da Beira Interior
IoT	Internet of Things
DNA	Deoxyribonucleic Acid
WHO	World Health Organization
SOAP	Simple Object Access Protocol
REST	Representational State Transfer
HTTP	Hypertext Transfer Protocol
IP	Internet Protocol
TCP	Transport Control Protocol
OSI	Open System Interconnection
WWW	World Wide Web
GIS	Geographic information system
IAQ	Indoor Air Quality
COTS	Commercial Off-TheShelf
USEPA	United States Environmental Protection Agency
CPU	Central Processing Unit
SQL	Structured Query Language
PVC	Polyvinyl chloride
API	Application Programming Interface
EDP	Energias de Portugal
UART	Universal Asynchronous Receiver-Transmitter
HTTPS	Hypertext Transfer Protocol Secure



# Chapter 1

## Introduction

### 1.1 Scope of the Dissertation

Radon and thorium are two radioactive isotopes, belonging to the decay chains of uranium and thorium, respectively [HYH<sup>+</sup>18]. Being gaseous elements have the ability to escape naturally to the atmosphere from rocks, water and some building materials. This gas can accumulate indoors and therefore be easily inhaled. Being a radioactive gas, recognized by the (World Health Organization) WHO as a carcinogen, it makes it a potential health risk [Che19].

The radon half-life is 3.8 days, however, its direct descendants, namely polonium, <sup>218</sup>Po and <sup>214</sup>Po, with much shorter half-lives can disintegrate inside the body, constituting a true radiological risk. Since the half-life is short, it is possible for disintegration to occur within the body. These isotopes are solid radioactive elements, which are not expelled from the respiratory system and, when they are housed in the respiratory tree, they can radiate sensitive cells [PAK<sup>+</sup>13]. Alpha particles, derived from the decay of radon, when interacting with matter can cause DNA damage and consequently mutations that can be genetically transmitted, potentiate the development of tumors and even cause the death of cells. These cells, already damaged, when replicating can lead to the appearance of neoplasms [MVLB00].

In closed environments, the risk of developing lung cancer, due to the presence of radon, increases proportionally in relation to exposure to it. The risk increases by 8 % for every 100 Bq /m<sup>3</sup> of the average concentration measured with a 95 % confidence interval between 3 to 16 % [ZSO09]. Radon in closed spaces contributes to about 9 % of lung cancer deaths and is responsible for about 2 % of the total cancer deaths in Europe [DHA<sup>+</sup>05a]. In the north of Portugal, between 1995 and 2004, 8514 deaths occurred due to lung cancer and it is estimated that between 1565 and 2406 may be associated with radon, that is, between 18 and 28 % of the total, due to the lithological constitution of the region [VNC12]. In Portugal it is estimated that the average concentration in indoor environments is 62 Bq / m<sup>3</sup> while worldwide this estimate is in the order of 39 Bq /m<sup>3</sup> [ZSO09]. In regions where the soil is rich in rocks containing uranium, the concentration of radon inside the houses can reach very high values [SGVK06].

To prevent radon from accumulating inside homes, there are traditional solutions. The first phase consists of detecting the radon using sensors. Through the data collected by them it is possible to apply a mitigation method. In general, mitigation methods prevent the entry or removal of radon gas.

IoT technologies provide a communication bridge between sensors and mitigation devices, which makes it possible to create an intelligent system that allows for action based on the data collected. This condition allows us to conclude that it is possible to create new solutions based on IoT.

As the objective of improving indoor air quality, the proposed system will allow to detect, mitigate and prevent the average concentrations of radon. The system is expected to reduce radon levels in closed and inhabited environments and thus reduce exposure to radon gas to people and health risks.

## 1.2 Motivation

Some of the factors that condition the disclosure of the effects of radon are, for example, the fact that it is an invisible, odorless, tasteless gas that occurs naturally in nature. On the other hand, there are no links to deaths from exposure to radon and the latency period is very long. As it is not a sensational topic, it is not reported and, therefore, there are no frequent warnings that lead us to think about the subject. Therefore, the population is not informed and is even unaware of the existence of this gas. Since it is odorless and invisible, people tend to ignore the risks related to it. In mid-2016, tests were carried out at my residence due to the existence of uranium mines in the region. At the date of this dissertation, knowledge about these mines was doubtful, since it was thought that the existing mines were wolfram. The presence of radon with high levels in the housing was verified, through the installation of sensors by a research team in the area. So in housing, large amounts were invested in active and passive mitigation methods that were not effective. The results were inconclusive, as the gas concentration remained high. Interest in the aforementioned theme was increasing, since it was something personal. Thus, it became pertinent to investigate the topic in question and, consequently, to look for a way to solve the problem. With the result of the research it was possible to realize that there were ways to detect and mitigate radon. However, there are few stand-alone systems to solve the problem. The research allowed us to conclude that IoT technologies enhance the development of solutions and research work on the subject. With this, a system was proposed for the elaboration of this dissertation that allows not only to help solve this problem that has become personal, but also to help a large part of the population that is affected by gas and is unaware of it. This system's main objective is to reduce exposure to gas by reducing the risk of developing cancer. It will be able, through the data obtained, to make decisions and predict situations where concentrations reach dangerous levels for health.

## 1.3 Objectives

The main objective of this project is to build a system that allows the detection, mitigation and prediction of radon gas in a home. For this, after contextualizing and idealizing the system, the various stages of this dissertation were as follows:

- Study of the problem, works and existing technologies on the subject;
- Conceptual design of the system and its architecture;
- Database design and implementation.
- Implementation of the IoT device that allows the detection of radon gas;
- Implementation of the IoT device that allows to activate the mitigation method;
- Implementation of the web application and database;
- Testing in real system context.
- Choice of the mitigation method given the results obtained.
- Results analysis.
- Implementation of the machine learning algorithm.

## 1.4 Thesis Organization

The thesis is organized as follows:

- In chapter 2, a literature review was carried out based on academic works and on existing technologies at commercial level involving the IoT. Also addressed are the different methods of mitigation, the various types of sensors that exist for the detection of gas, a framework for the problem of radon gas and the concept of IoT technologies.
- In chapter 3, an approach is first made to the technologies and materials used. It is also presented the conceptual design of the system that allowed the implementation of the system as well as the implementation process.
- Chapter 4 presents the final result of the devices based on IoT and the web application. It is also explained how these were implemented.
- Chapter 5 - How the software tests were performed, how the system was tested in a real context and an analysis of the results obtained are described.
- Chapter 6 - The thesis conclusions are drawn as well as proposals to improve the system in future work.



## Chapter 2

### Related Work

#### 2.1 Radon

Radon is a radioactive gas that is present in the Earth's crust and can reach high levels in closed spaces. When radon gas escapes from the soil can enter inside the dwellings using cracks in floors or by leaking into walls. Additionally, radionuclides including particularly  $^{226}\text{Ra}$ , can also be present in some building materials used for construction, being sources of indoor airborne radioactivity [SGGS13]. The difference in pressure between the interior of the house, compared to the air pressure in the soil around the foundation, can, if the pressure inside is less, the radon is sucked into the housing through the joints of the wall of the floor, cracks in the foundation and other openings in the building structure [Fie18].

Radon is a natural gas that is created in the process of decomposing uranium and thorium.  $^{222}\text{Rn}$  and  $^{220}\text{Rn}$  are two isotopes that are derived from the decomposition of uranium and thorium respectively. Uranium, radio and thorium occur naturally in the rocks present in the soil and continuously emit radon gas due to the decay process [HYH<sup>+</sup>18].

##### 2.1.1 Radon Health Issues

As we said, radon is chemically inert, so it cannot be detected by our senses and, where the soils and rocks are enriched in uranium, indoor radon concentration can achieve high levels, being a potential health hazard due to long-term exposure. The danger associated to radon is primarily due to the alpha radiation emitted by its descendants, polonium (Po), lead (Pb) and bismuth (Bi), that are called radon progeny. These radionuclides, specially the  $^{214}\text{Po}$  and the  $^{218}\text{Po}$ , can deposit, in the lung tree, highly radioactive and ionizing alpha particles. When these alpha particles interact with the cellular epithelium could deposit all its energy in the interaction point. The huge amount of deposited energy can irradiate more sensitive cells inducing DNA damage or even apoptosis. In indoor, radon exposure is the primary risk factor for lung cancer for non-smokers, and the second for smokers [SGGS13].

In Portugal, a study was carried out in the region of Guarda and houses of the local population to try to understand when this region was affected by radon. As registered, you can select between 75 to 7640 Bq / m<sup>3</sup>, the average allowed value being 1078 Bq / m<sup>3</sup>. Of the houses studied, 66% had a concentration above 400 Bq / m<sup>3</sup>. Regarding the rooms belonging to respiratory cancer patients, 62% have radiation levels in the rooms below 400 Bq / m<sup>3</sup> [LPS<sup>+</sup>12].

The recent changes in Portuguese legislation allow a maximum limit of 300Bq / m<sup>3</sup>. This aims to inspect and raise awareness of the population about the danger of radon and thereby evolve traditional construction methods so that such concentrations are not reached in recent homes to reduce health risks.

Analysis of a set of studies carried out in Europe, North America and China were prepared. The result of the analysis of the data led to the conclusion that the risk of lung cancer increases by approximately 20 % per 100 Bq/m<sup>3</sup> when exposure to radon is very prolonged. A summary of the compilation data for the studies mentioned above and the estimates in table 2.1 [ZSO09].

Table 2.1 Summary of lung cancer risk from indoor radon based on international pooling studies

	Nbr. of studies included	Nbr. of lung cancers	Nbr. of controls	Exposure Windows in years	Percentage increase risk of lung cancer per 100 Bq/m <sup>3</sup> increase in radon concentration	
					Based on measured radon	Based on long term average radon
European [DHA <sup>+</sup> 05b],[DHD <sup>+</sup> 06]	13	7148	14208	5-35	8 (3,16)	16 (5,13)
North American [KLZ <sup>+</sup> 05], [KLZ <sup>+</sup> 06]	7	3662	4966	5-30	11 (0,28)	-
Chinese [LWBJ <sup>+</sup> 04]	2	1050	1995	5-30	13 (1,36)	-
				Average of above results	10	~20

Smokers are at increased risk, as it can considerably increase the chances of lung cancer, by around 25, in table 2.2 are showing the cumulative risk of lung cancer in a 75-year-old person as usual exposure to radon [DHA<sup>+</sup>05a].

Table 2.2 Cumulative risk of lung cancer in a 75-year-old person as usual exposure to radon

Bq/m <sup>3</sup>	Non-smokers	Smokers
0	0.41%	10.1%
100	0.47%	11.6%
400	0.67%	16.0%
800	0.93%	21.6%

In order to reduce the risks associated with radon, the World Health Organization recommends an average concentration below 100 Bq/m<sup>3</sup> and that the maximum limit should not exceed 300 Bq/m<sup>3</sup> [ZSO09]. The portuguese law, that establishes the legal regime for radiological protection, define the reference level for the radon annual average activity concentration in air to a maximum value of 300 Bq/m<sup>3</sup> [Inc].

## 2.2 Types of Radon Sensors

There are multiple devices that allow radon detection. The cheapest type are short-term devices that allow reading between 2 days to 3 months. This type of device uses a method based on charcoal that allows the gas to be absorbed and is then sent to the laboratory for evaluation [Air17].

Long-term devices allow reading from 3 months to 1 year, which allows average levels of radon to be obtained and are also more accurate than short-term devices. These contain containers that have small plastic sheets that allow radiation to be detected. Alpha particles will leave a mark on the plastic sheets, these plastic sheets will then be evaluated [Air17].

Finally, there are digital solutions that allow both short and long term readings. These detectors allow to obtain means and continuous readings. There are different types of digital sensors based on how they detect gas, sensors that use electret ion chambers, scintillation cells, current or pulse ionization chambers or solid-state silicon detectors [Air17].

In Table 2.3 we summarize, the pros and cons of the different types of radon sensors [Air17]:

Table 2.3 Pros and cons of radon detection systems

	Pros	Cons
Short-Term	Low Cost; Easy to Use; Faster than Long Term;	One-time use; No average level; Consistency issues; Accuracy issues; Inconvenience;
Long Term	Relatively low cost; Measures average levels; More accurate than short-term;	One-time use; Long time frame; Inconvenience;
Digital	Flexibility Consistency; Long lifetime; High accuracy; Quick response time;	Trade-off between price and longevity; Flexibility of use;

## 2.3 Available Solutions

The internet of things is the concept of connecting any device to the internet and connected to another device. IoT allows data to be collected and shared in the environment where the device is installed. An IoT ecosystem consists of smart devices that are enabled to connect to the internet using embedded systems, such as sensors, communication hardware, processors. This allows you to collect, send, act on the data and analyze it [Ran20].

Nowadays IoT technologies are increasingly present in our daily lives, since industries are betting heavily on this technology. There are countless possibilities for using Iot as the areas from health, to smart cars to the city. With the introduction of 5G, it is expected that there will be rapid growth in the area of IoT [LXZ18]. With the evolution of IoT technologies, it will be possible to obtain devices with a lower cost, analysts estimate that there may be 25 billion units installed by 2020 and the estimate for 2025 is approximately 2.1 trillion [IM12].

The IoT area brings a lot of health benefits, as it allowed the evolution of how health care and prevention were done. With multiple systems and devices intelligently connected, used by millions of people, it is possible to collect data and use it to make the right decisions [Tec18]. Thus, it is possible to predict the health status of a patient, make decisions, follow patients in real-time and countless other possibilities, that is, to provide better health care to patients.

The existing literature related to IoT and radon gas is not vast. Most of the research is focused on the detection of this gas, however, some studies related to this project.

The Radon Project has as one of the main objectives is to increase public interest in the effects of radon gas on human health. Developing a network of sensors capable of detecting and measuring gas concentrations in buildings in real-time, each device can communicate with a remote system implementing a web-based GIS to show the concentration of radon gas in monitored buildings in real-time. A campaign to raise awareness and create a platform to involve adults stakeholders was also launched. According to the author, the first results, both in technology and in the stakeholders involved in the process, were positive and that the readings allowed to detect the radon in qualitative, quantitative and temporal information [ACD<sup>+</sup>19].

The RnMonitor project that carried out tests on administrative buildings. This system has a continuous and online monitoring radon concentration and other relevant parameters to the Indoor Air Quality (IAQ) like humidity, temperature, pressure and CO<sub>2</sub>. This system will have a trigger that will activate mitigation strategies. Tests were carried out to understand the concentration of radon gas in buildings. It was noticed that the concentrations are high, above the norms, defined by the World Health Organization, and that there is a need to apply migration measures [CSL19].

The article On the design of a Human-in-the-Loop Cyber-Physical System for online monitoring and active mitigation of indoor Radon gas concentration is a about design and specification of the system [LCM<sup>+</sup>18]. The results or conclusions about the RnMonitor project have not yet been published.

An IoT System for Monitoring Indoor Radon Gas Exposure is another study that uses IoT technologies to monitor radon gas in homes so that its users are alerted if gas levels are high. The system is centralized so that the data is saved and processed by a central server, has a remote web interface so that the data is presented to the user of the system and limits can be configured so that the user is notified by remote alerts if the values radon are exceeded. The data is collected from a Commercial Off-TheShelf (COTS) radon sensor. The results obtained from monitoring were compared with a sensor that already exists on the market and verified that the data read from the sensor was correct. The system worked as expected in the real world, as it allowed the monitoring of radon gas levels as well as allowing users to be warned if the levels were exceeded [BNFCFLC18b].

The same authors evolved the system previously presented, adding fans to pressurize the house to mitigate radon gas [BNFCFLC18a].

At the commercial level, there are few monitoring solutions based on internet of things. This allows users to access data from a mobile application or a web application.

The Wave plus sensor from Airthings provides data on indoor air quality, including radon, carbon dioxide, humidity, temperature, atmospheric pressure and volatile organic compounds. It offers a mobile application on various platforms as well as a web application that allows monitoring of air quality [Air].

RadonEye PLUS 2 is a radon detector with Wi-Fi (internet), Bluetooth LE(Android/iOS) and data logger that allows you to monitor radon levels indoors. The RD200 has the dual structured pulsed-ionization chamber system and highly accurate detection circuit designed by FTLab's . This solution allows this sensor to have a higher sensitivity than other sensors on the market. The first reading time is less than an hour or shows other sensors on the market that allow a reading of 24 to 48 hours. This allows access to a dashboard where data is displayed, and alarms can also be identified when the speed cameras are too high. It can also use Amazon Alexa's artificial intelligence services [Rad].

In table 2.4, a comparison is made between the various projects and technologies regarding their functionalities, detection, mitigation and prediction, based on the system proposed in this thesis. A comment is also made about these.

Table 2.4 Comparison table

Name	Measures	Mitigation	Predition	Observations
Radon Project [ACD <sup>+</sup> 19]	YES	NO	NO	This system monitors the levels of gas radon in public buildings and raises awareness among the population. However, it could be further developed, as it does not offer a mitigation system.
RnMonitor [CSL19].	YES	YES	NO	Although this system has already included a mitigation system, it focuses mainly on public buildings. Monitoring in private homes is also important.
IoT System for Monitoring Indoor Radon Gas Exposure [BNFCFLC18b, BNFCFLC18a]	YES	YES	NO	This system is reliable, robust and scalable, which makes it possible to commercialize this solution.
Wave plus [Air]	YES	NO	NO	It contains several atmospheric sensors, it also has an application that allows to consult the obtained values. It only allows for consulting the obtained data.
RadonEye PLUS 2 [Rad]	YES	NO	NO	It is a radon sensor that allows data to be obtained through a web service. It has an alarm if the recommended values are passed. However, it does not propose a mitigation system.

None of the systems presented proposes the forecast and the accumulation of radon gas inside the buildings. This feature is important as it allows us to anticipate and alert the system user to take action. The mitigation system may not be sufficient for specific situations, and so the user can use other supplementary mitigation methods to cope with concentration spikes.

There are, however, several forms of gas mitigation that will be presented below recommended by the United States Environmental Protection Agency (U.S. EPA) [Age16] :

- Use of Natural ventilation- Open the windows and doors to create an air flow, which reduces the concentration of radon. However, this solution is temporary, because depending on the area where the house is located, there may be cons such as cold temperatures in winter as well as security problems.
- Active soil suction - This is considered the most common and reliable solution for reducing the levels of radon gas. It consists of draining the air under the house through tubes and air extractors.
- Perforated pipe, drain tile or sump-hole suction - This method directs water away from the building's foundations through pipe, tiles or water pumps.
- Sealing cracks and openings in the foundations - Prevents radon from entering the house but has to be applied together with another method to be effective.
- Home pressurization: This technique consists of installing fans that send fresh air to the house, this allows it to create positive pressure in the house and prevent radon from entering the house.

## 2.4 Conclusion

After elaborating the literature review, we can draw the following conclusions:

- Ongoing research works show promising results in advancing solutions, but there is still a lot to develop, as most sensors do not use the IoT concept. However, some projects and companies are already starting to integrate solutions that use IoT-based technologies.
- There are multiple radon gas mitigation systems but they are passive measures, or they are not connected to radon sensors, which would allow these measures to be activated depending on the values obtained by the sensor.
- There are no solutions that use machine learning to predict the radon values in order to warn the user to take measures to avoid peak concentrations.



#### 3.1.4 Nebeans

NetBeans is an integrated development environment for creating applications in different programming languages such as Java, PHP, HTML, JavaScript, CSS, Groovy and C++.

#### 3.1.5 GlassFish

Glassfish is an open-source application server for the Java EE platform. Glassfish allows the creation of applications that are scalable and easy to integrate. Supports all API specifications on the JavaEE platform and defines how to coordinate them.

#### 3.1.6 Soapui

SoapUI is an open-source application that allows you to test web services for SOAP or REST architectures. It is a multiplatform application developed in Java. It is based on XML and HTTP. It allows the process of development of web services to be facilitated by giving support to developers, being able to simulate a web service to check the behaviour of the application against a predefined response or directly call the API to check the behaviour given data entry.

#### 3.1.7 Json

JSON is an acronym for JavaScript Object Notation, it is a compact, independent open standard format that allows simple and fast data exchange between systems of different languages. It uses human-readable text, where there are an attribute and a value that is assigned to it. It is a model of transmitting information in text format, which today is widely used in Rest type web services and AJAX applications, which replaces XML. Many languages have included libraries to generate, analyze and convert to JSON format.

#### 3.1.8 HTML

HTML is a markup language used in the construction of web pages. Together with Cascading Style Sheets and JavaScript formed the three main technologies of the WWW. Browsers running on the client-side receive HTML documents from the Web server and interpret, through a compiler implemented in the browser, these documents.

#### 3.1.9 PHP

PHP is an open-source scripting language that is widely used in the development of web applications since it is especially suitable for this purpose. This language executes the code on the server that prepares the HTML document which is then sent to the client.

#### 3.1.10 CSS

Cascading Style Sheets (CSS) are style sheets used to define the appearance of documents of the type HTML, XHTML, among others. The CSS defines how the elements contained in the document code are displayed.

### 3.1.11 Bootstrap

Bootstrap is a library with style sheets and JavaScript scripts that allows the development of the front-end so that it can be adjusted in the support in which it is to be viewed. It also facilitates the construction of the application design.

## 3.2 Materials

This sub-chapter describes the characteristics of the materials used for the development of the project and the quantity needed, as well as the price and the cost of operation.

### 3.2.1 Vortice lineo 100 V0

It is a fan that is made with self-extinguishing plastic resin material, with a diameter of 100mm. It has two speeds which allow the airflow between 180 m<sup>3</sup> / h to 255 m<sup>3</sup> / h. It is possible after installation to invert the airflow in a simple way, which was very useful for carrying out the tests [vor]. 100 mm PVC tubes are required as well as grids to be placed on the walls .



Figure 3.2: Vortice lineo 100 V0

### 3.2.2 FTLAB Radon Gas Sensor RD200M Detector

The RD200M is a radon sensor that uses a structured pulsed ionization chamber with a double probe to detect radon. It detects the secondary charges that were generated from air collisions and the alpha particle that is released in the decomposition of the radon. The accuracy of this sensor is approximately 10% at 10pCi /L which has been tested by the international standard Radon Testing Laboratory in KTL [RD220].



Figure 3.3: Radon Gas Sensor RD200M

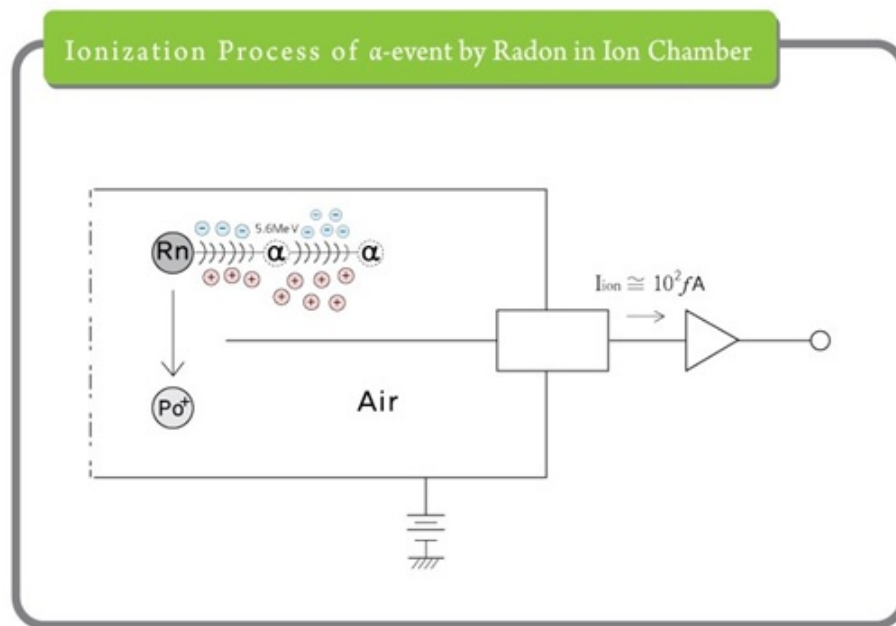


Figure 3.4: Detection process of particles alpha in the air by the sensor. Source: [RD220]

### 3.2.3 Geekcreit UNO R3 ATmega328P Development

It is similar to Arduino Uno, it is a cheaper version and has the same features as the official Arduino version. Uses the Atmega328 microprocessor. It has an input from 5V to 9V and an output of 5V and 3.3V. 3 Arduinos are needed for the development of the project two for the development of the sensor and one for the fans [Banc].



Figure 3.5: Geekcreit® UNO R3 ATmega328P Development

### 3.2.4 SparkFun WiFi Shield - ESP8266

The SparkFun Wifi shield ESP8266 is a shield compatible with Arduino. This gives Arduino internet access and allows Arduino to be used as a client or as a server. It took 2 shields one to send the sensor reading and the other to get the status of the fans [Ele].

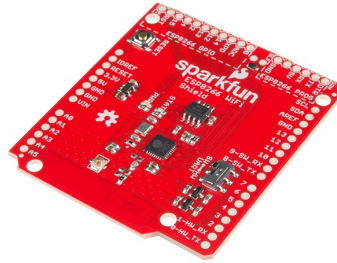


Figure 3.6: SparkFun WiFi Shield - ESP8266

### 3.2.5 BME280 Atmospheric Pressure Sensor

This sensor makes it possible to obtain atmospheric values such as temperature, atmospheric pressure and air humidity. It is used to obtain atmospheric values when a radon reading is taken. With more data it allows the prediction algorithm to be more accurate [Banb].

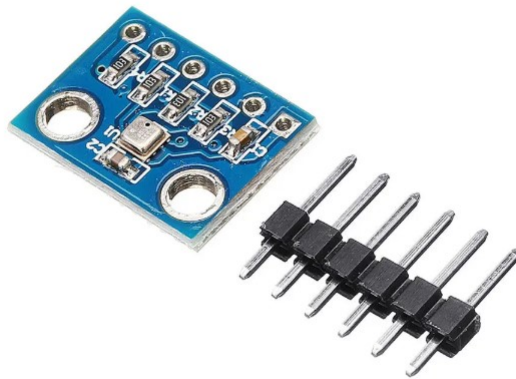


Figure 3.7: BME280 Atmospheric Pressure Sensor

### 3.2.6 Trigger low-level 5V One 1 channel

This trigger is used as an automated switch. This allows you to automatically turn the fans on or off depending on the answer to the API call made by Arduino [Bana].

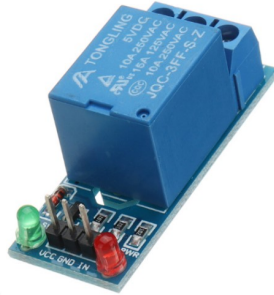


Figure 3.8: Trigger low-level 5V One 1 channel

## 3.3 Material expenses

To be aware of the financial viability of this system, table 3.1 shows a possible budget for the materials used. This budget is for a prototype, and material prices can be reduced depending on the quantity ordered. For example, the cost of the radon sensor can be reduced four times if 1000 units were purchased.

Table 3.1 Material expenses

Name	Quantity	Price	Total
Vortice lineo 100 V0	2	137,90	275,80
FTLAB Radon Gas Sensor RD200M Detector	1	269,00	269,00
Geekcreit® UNO R3 ATmega328P Development	3	6,99	20,97
SparkFun WiFi Shield - ESP8266	2	15,68	31,36
Arduino Stackable Header Kit - R3	2	1,39	2,78
Power Supply 9V 1A For Arduino	3	6,50	19,50
ME280 Atmospheric Pressure Sensor	1	4,70	4,70
		Total	624,11

Other materials are required for installation in a real environment, building materials, construction tools, PVC pipes, jumpers for Arduino and grids. These materials are not possible to quantify since it depends on the housing in which it will be installed.

The total cost of development is 624.11 €, the most expensive material being the sensor, as it is a recent technology and as the demand for this type of device is low, the price remains high. It is difficult to make a price comparison with other systems, since the installation of mitigation systems are done by specialized companies.

## 3.4 Maintenance cost

The cost of maintaining the system was also studied. Like any household appliance, it has a cost of electricity. In this case, the fans have a considerable cost that must be taken into account. A calculation was made to understand the annual electricity cost of operating the fans, this calculation

was made by consumption in watts and by the KW price of the largest electricity distributor in Portugal, EDP. This calculation was made by formula 3.1:

$$Annual_{cost} = \frac{Consumption * hours * Days}{1000} * KW/H_{Price} * (1 + VAT) \quad (3.1)$$

In this calculation, the bi-hourly tariff was used, which consists of two tariffs for day and night consumption. Table 3.2 shows the results of the electricity cost calculations. Under these con-

Table 3.2 Fan maintenance cost

	Watts	Hours	Days	VAT	Price kW/h	Cost/Year	Cost/Mount
Day	23	14	365	23	0.1875	81.32	6.78
Night	23	10	365	23	0.1024	31.72	2.64
					Total	113.04€	9.42€

ditions, the maximum electricity cost with an implemented fan is around 9.42€ per month, that is, 113.04€ per year. This value can be reduced depending on the concentration of radon in the house, that is, the fans are only used if the imposed limit is exceeded.

### 3.5 System architecture

The system architecture is based on the client-server model. This model has a distributed application structure, that is, it distributes tasks among service providers, servers, and for the processes that request services, customers. Figure 3.9 shows the architecture of the implemented system. The system’s customers are Arduinos and remote users who use browsers on devices such as cell

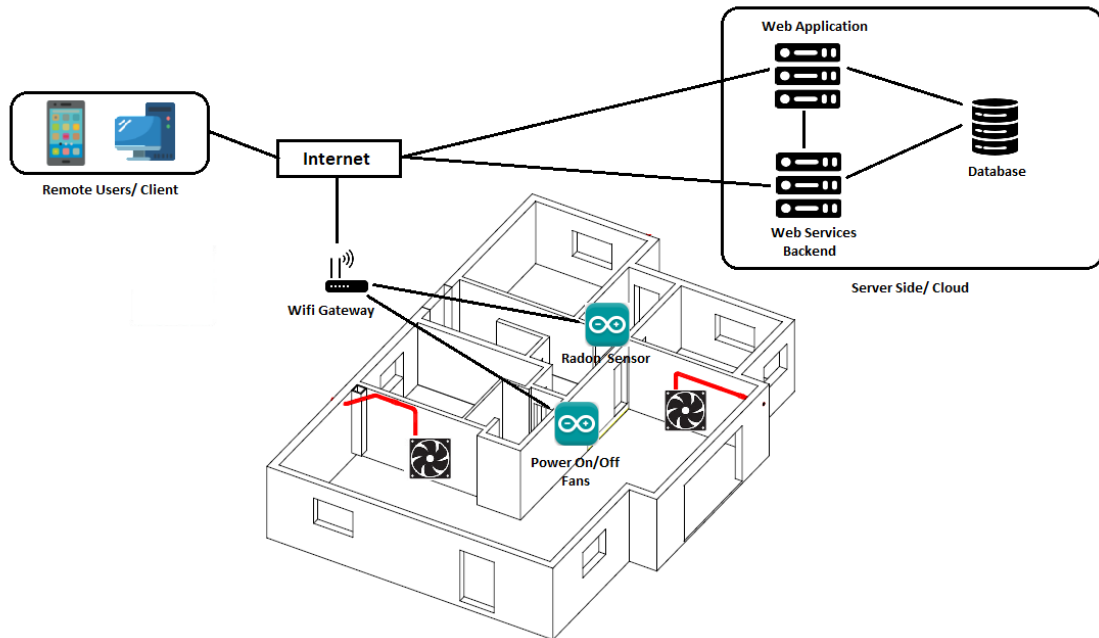


Figure 3.9: Design of the System architecture

phones or computers. The implemented Arduinos, one as a radon sensor and the other as a fan switch, both make REST requests to APIs through the HTTP protocol. Remote users can access the web application through HTTP requests a page is built for them and then returned and interpreted by the browser. On the server-side, there are three virtual machines, in which the

web application that is an Apache server, the web service in glassfish and the database in SQL Server are implemented. The web server makes calls to the various web services to retrieve data or perform operations on the database.

### 3.6 Use case diagram

This section presents the use case diagram that refers to the system that was implemented. Figure 3.10 shows the interaction of the various actors in the system, being the users, the radon sensor, the fan system as the main actors and the web service as the secondary actor.

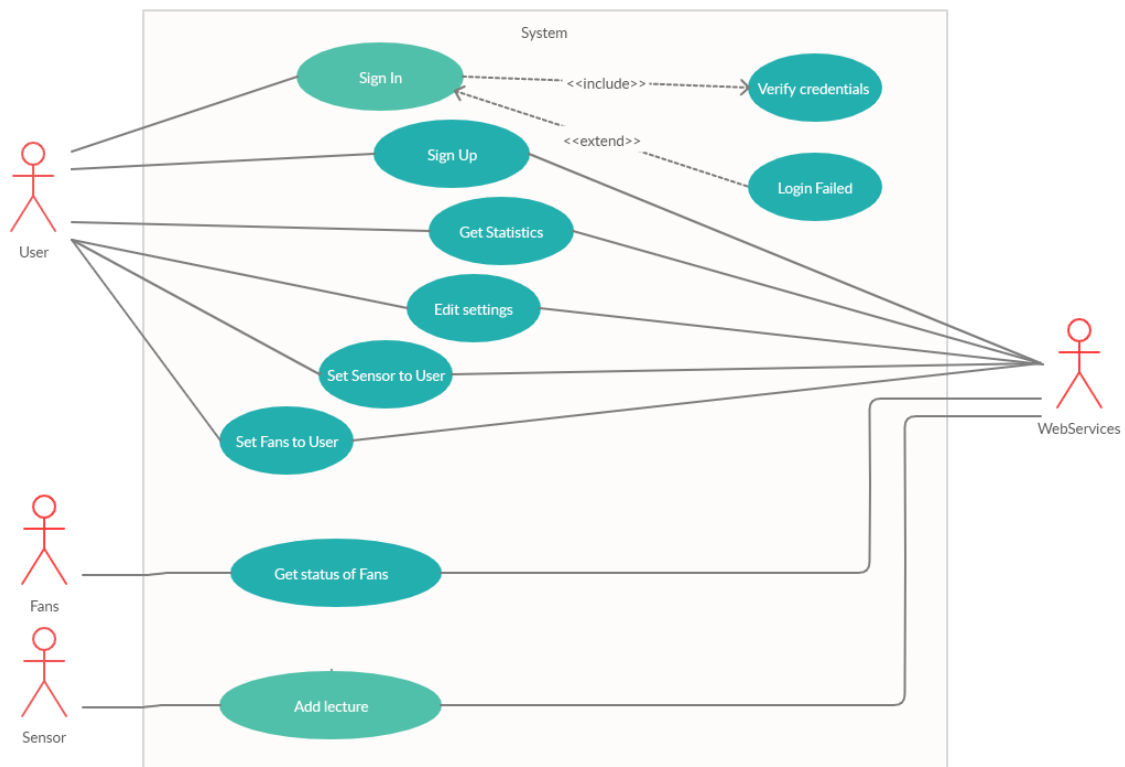


Figure 3.10: Use system case diagram

### 3.7 Database

In this chapter, the database is described, how the data is stored and how the interconnections are made, as well as the stored procedures and triggers.

The database is crucial for the functioning of the project since the construction of the relational model allows us to obtain a better perception of the system and how it will work.

Figure 3.11 shows the relational model of the database used in the system.

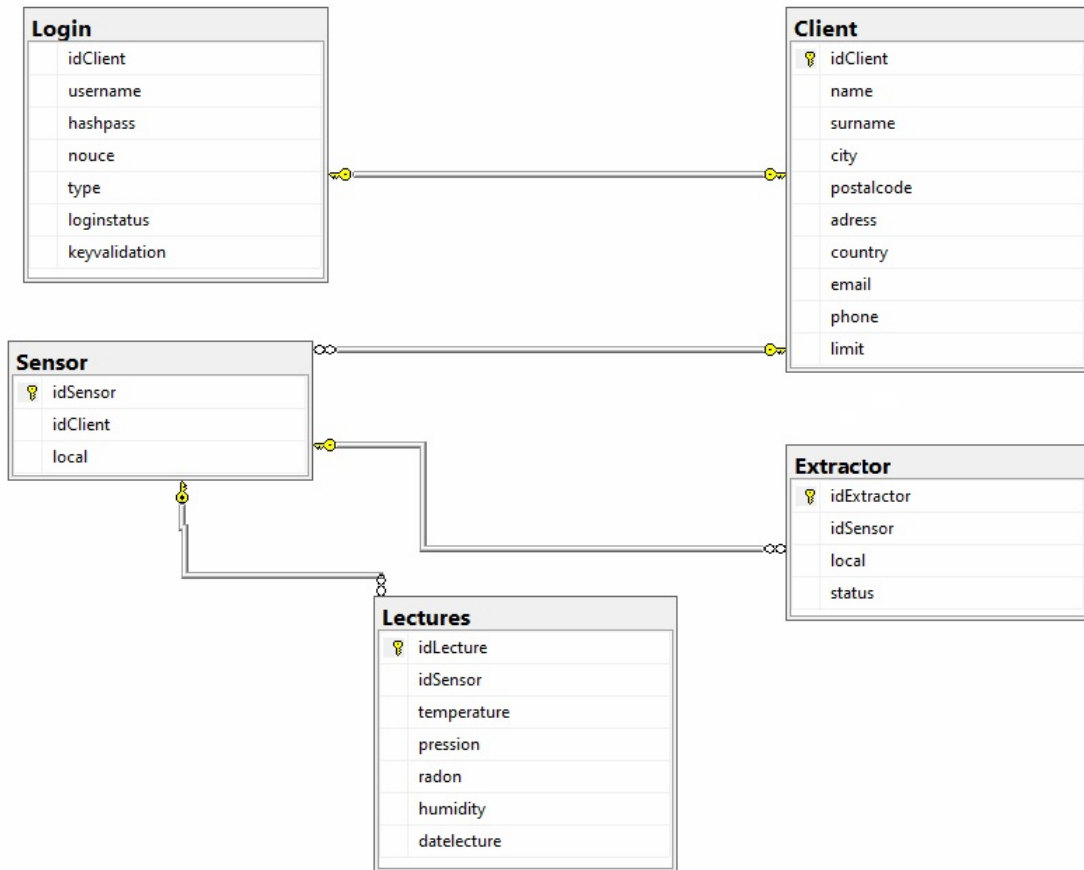


Figure 3.11: Relational database model

The five entities and the relationship between them will be described to obtain better compression of the problem.

- The "Client" table represents the customer. This allows you to store customer data. The attributes of the table are the customer’s identifier, name, address, email, phone number and the radon limit that the customer decides between 0 Bq / m3 and 300 Bq / m3.
- The "Login" table represents the customer’s login to access the web application. It contains the attributes that allow identifying the customer as well as saving the password hash and username.
- The “Sensor” table shows the radon sensor. Its associated with a customer. The table attributes are customer and sensor identifiers and the location where it is installed.
- The “Extractor” table is associated with an automated switch system of one or more ex-tractors connected to the switch. The attributes of the table are the extractor identifier,

the sensor with which it is associated, the location and status that indicates whether the extractors are on or off.

- The “Lectures” table allows you to save the readings made by the sensor. The attributes of the table are the reading identifier, sensor identifier, temperature, pressure, radon level, humidity and the reading date.

Stored procedures have been created that allow you to execute several commands at once. They were designed for repetitive tasks and accept input parameters so that the task can be executed when necessary. These allow to improve the performance of the database, allow to reduce traffic in the network, consist of data, security and facilitate the process of consultations having several applications in different programming languages.

Figure 3.12 shows the various stored procedures implemented in the system. The following will be a brief description of each of the stored procedures implemented.

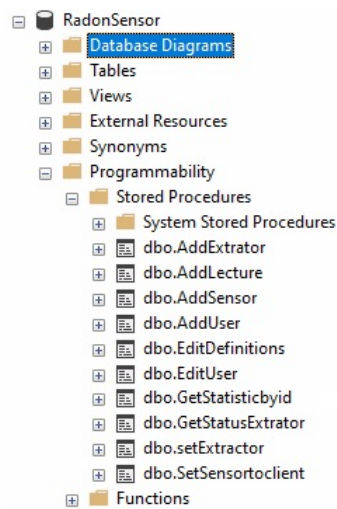


Figure 3.12: Stored procedure implemented in the system

- “AddExtractor” - Allows adding a fan system to the system.
- “AddLecture” - Allows adding reading to the database.
- “AddSensor” - Allows adding a Radon Sensor to the system.
- “AddUser” - Allows adding a user to the system.
- “EditDefinition” - Allows to edit the radon level limit as well as to activate the fans manually.
- “EditUser” - Allows editing user data.
- “GetStatisticsbyid” -Get statistical data for a given radon sensor.
- “GetStatusExtractor” - It allows to obtain the status of the sensor in the database.
- “SetExtractor” - Allows assigning a sensor to the fan system.
- "SetSensortoClient" - Assigns the Sensor to a user.

A trigger was also implemented in the system. In SQL Server, a trigger is an action made automatically when an action is taken on a given table, such as inserting an update or deleting. A trigger was created in the table "Lectures" that acts when a new line is inserted, this allows, after the insert, to consult the last three readings and if the values are higher than the defined limit, the fans are activated and if not higher than the fans are turned off.

### 3.8 Web Services

This Section will describe the operation of each service that has been implemented, the URL of each API and the format of the requests as well as the responses. The different Webservices all work in a similar way having an activity diagram that represents all the Webservices implemented in figure 3.13.

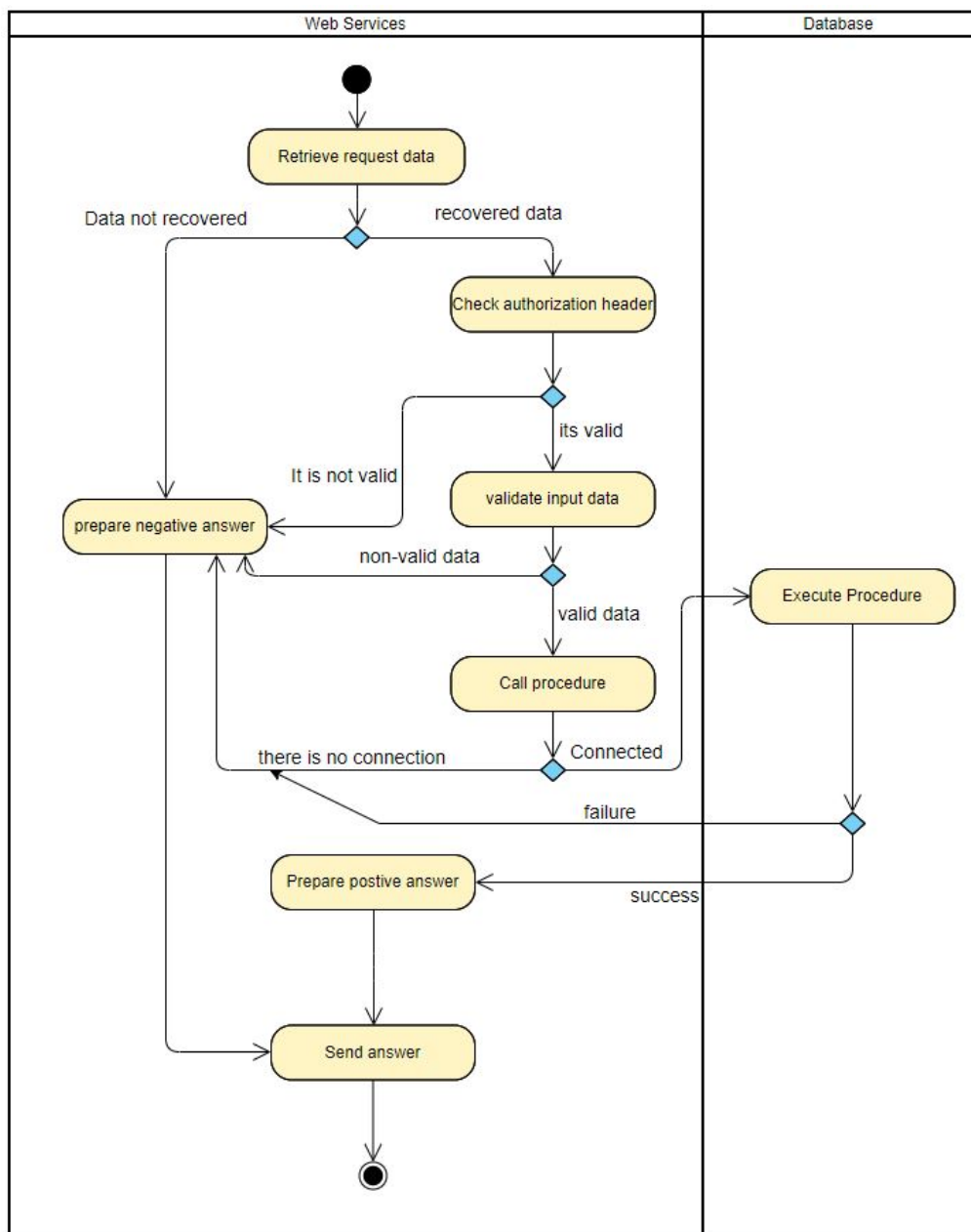


Figure 3.13: Activity Diagram of the Webservices implementation

The difference between the different web services is the various input data and the stored procedure that is called. All web services have a header that allows you to control access to them. The “basic-authentication” header is encrypted in Base64 which is then verified by the web service that is called.

### 3.8.1 AddExtractorWs

The “AddExtractorWS” web service allows you to add and associate a fan system with a specific sensor to act on the data it collects. The method used is POST in the resource “/RadonLectures/webresources/addextractor/ AddExtractorToSystem”.

The input data is received in JSON format the radon sensor identifier and the device identifier that controls the fans. The authentication header is also required. The web service calls the stored procedure “AddExtrator” that adds the extractor to the database.

The answer is given in JSON format that returns the HTTP code, the status and in case of error the error description. Figure 3.14 shows a request made to the “AddExtractorWS” web service that worked correctly.

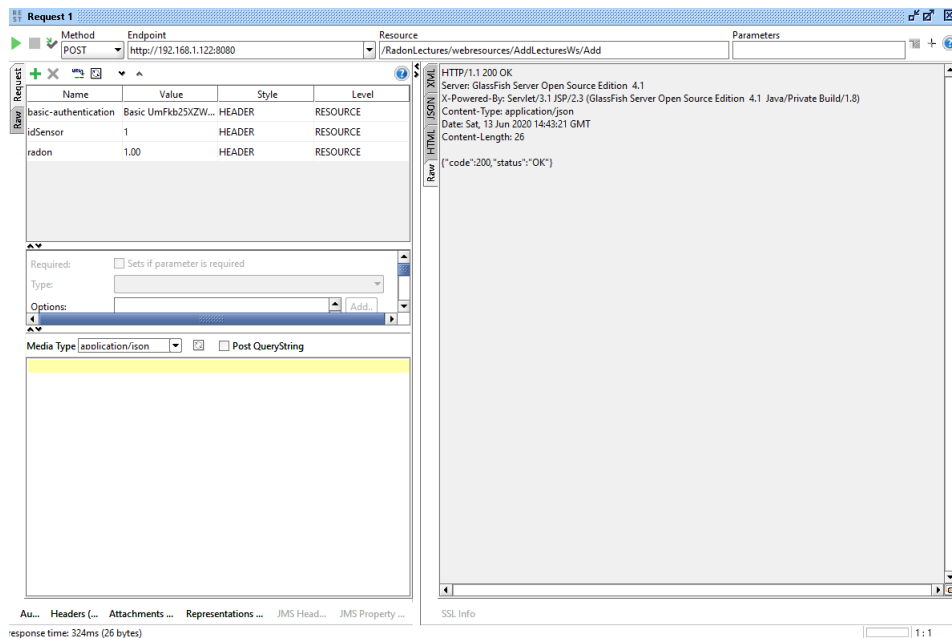


Figure 3.14: Example of request to the web service "AddExtractorWs"

### 3.8.2 AddLecturesWs

The “AddLecturesWs” web service allows you to add a reading made by a given sensor. This uses the POST method in the resource “/RadonLectures/webresources/AddLecturesWs /Add”. The input data are received through the headers, these “basic-authentication” being authorized to access the web service, “idSensor” the radon sensor identifier and finally “radon” which represents the concentration of radon obtained in the reading. The web service makes a call to the stored procedure “AddLecture” that allows adding the obtained reading to the database.

The answer is given in JSON format that returns the HTTP code, the status and in case of error the error description. Figure 3.15 shows a request made to the web services “AddLecturesWs” that worked correctly.

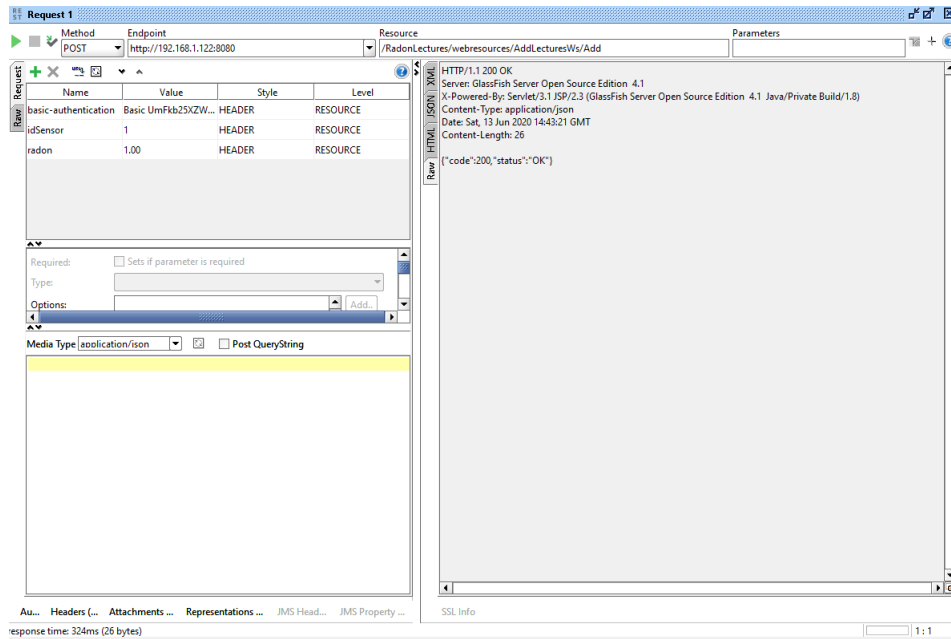


Figure 3.15: Example of request to the web service "AddLecturesWs"

### 3.8.3 AddSensorWs

The “AddSensorWs” web service allows you to add a radon sensor to the system. The method used is POST and the resource “/ RadonLectures / webresources / addsensor / AddSensortoSystem”. The input data received are the “basic-authentication” header and the content in JSON format that provides the sensor identifier that is being added to the system. The web service makes a call to the stored procedure “AddSensor” that allows adding the new radon sensor to the database. The answer is given in JSON format that returns the HTTP code, the status and in case of error the error description. Figure 3.16 shows an example of a request to the web service “AddSensorWs”.

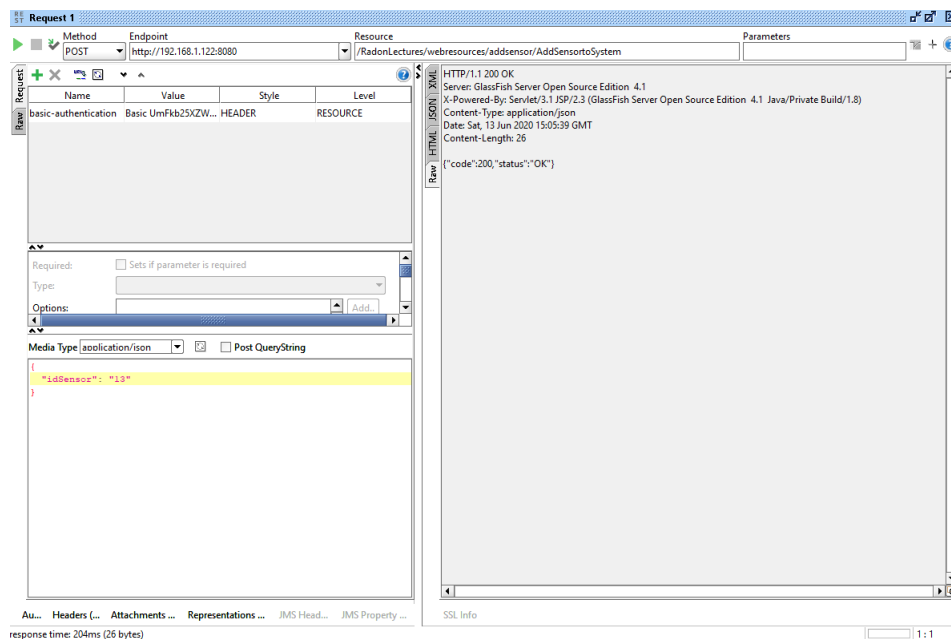


Figure 3.16: Example of request to the web service "AddSensorWs"

### 3.8.4 AddUserWs

The “AddUserWs” web service allows you to add a user to the implemented system. This uses the POST method in the resource “/ RadonLectures / webresources / radonaplication / AddUser”. The input data received are the “basic-authentication” header and the content in JSON format, these being the user data that will be entered into the system. The webservice makes a call to the stored procedure “AddUser” that allows adding the user to the database. The answer is given in JSON format, it returns the HTTP code, the status and the description that in case of a positive response a token is returned and in case of a negative response the cause of the error is returned. Figure 3.17 shows an example of a request to the webservice “AddUserWs”.

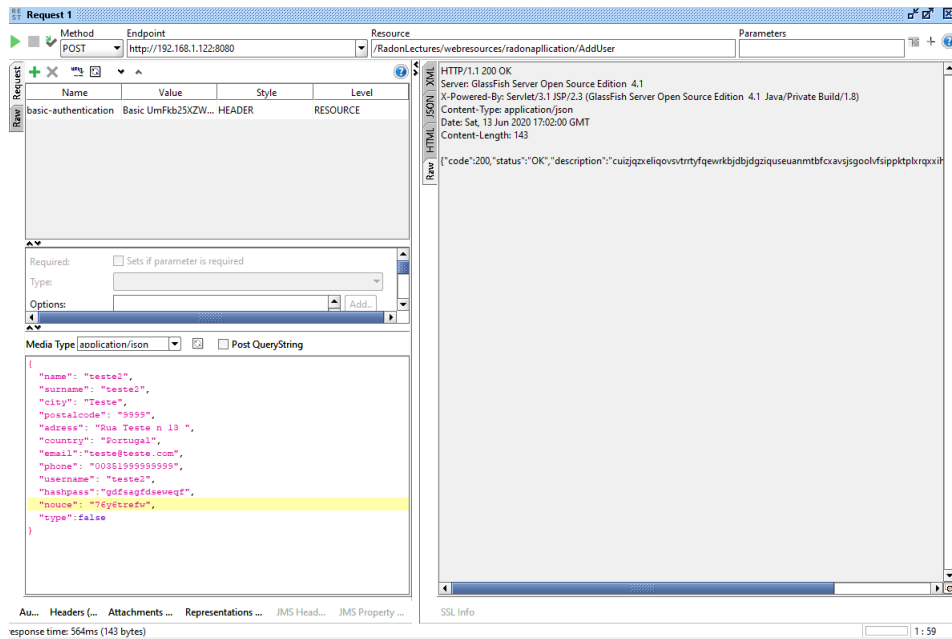


Figure 3.17: Example of request to the web service "AddUserWs"

### 3.8.5 EditUserWs

The "EditUserWs" web service allows you to edit the user data that is present in the system. The method used is POST being the resource "/RadonLectures/webresources/radonaplication/EditUser". The input data is the customer’s identifier and the remaining data as well as the authentication header. To make changes to the database, the stored procedure "EditUser" is called, which allows changes to be made to the database in the user’s information. The answer is given in JSON format that returns the HTTP code, the status and in case of error the error description. Figure 3.18 shows an example of a request to the "EditUserWs" web service.

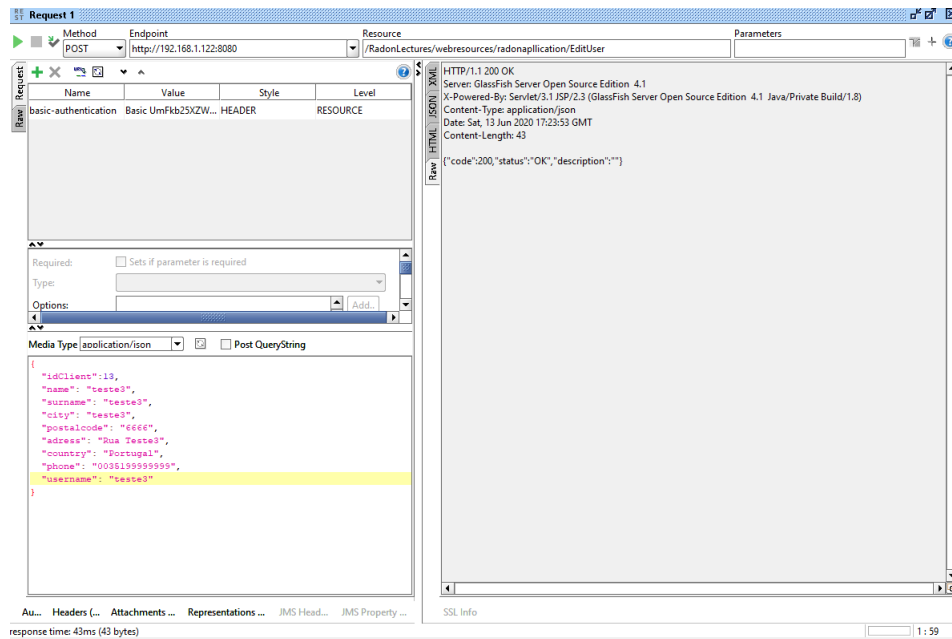


Figure 3.18: Example of request to the web service "EditUserWs"

### 3.8.6 EditdefWs

The “EditdefWs” web service allows you to edit user settings, such as turning on the fans manually and editing the limit at which the fans are activated. The method used is the POST method being the resource “/RadonLectures/webresources/Edit/EditDefinition”. The input data is the user’s identifier, limit and fan status. To make changes to the database, the stored procedure “EditDefinition” is called, which allows changes to be made to the database of user definitions. The answer is given in JSON format that returns the HTTP code, the status and in case of error the error description. Figure 3.19 shows an example of a request to the “EditdefWs” web service.

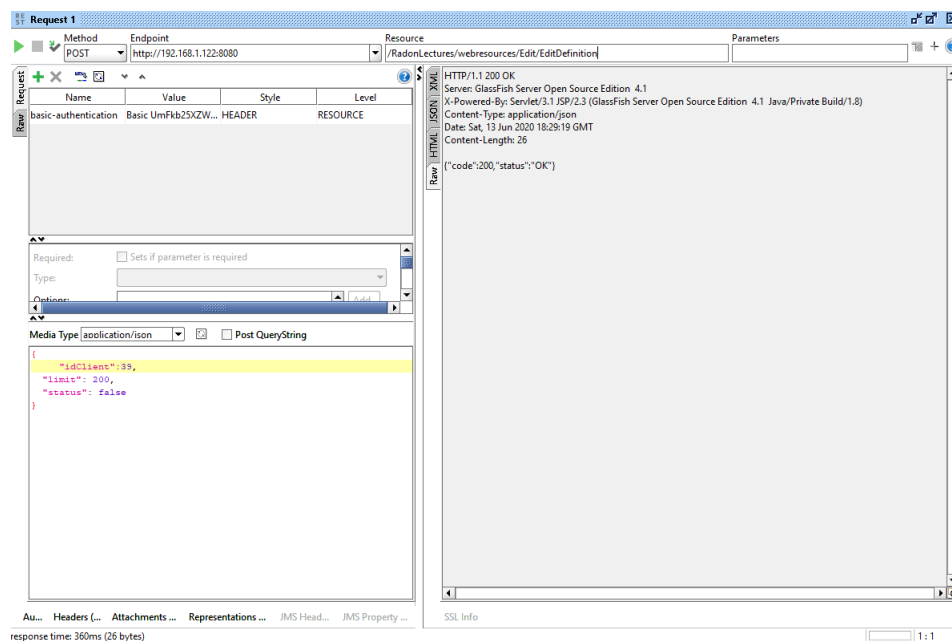


Figure 3.19: Example of request to the web service "EditdefWs"

### 3.8.7 GetStatisticById

The web service “GetStatisticById” allows retrieving statistical data from the database of readings made by the radon sensor. The method used is GET being the resource “/ RadonLectures / webresources / getStatistics / get / idSensor” where “idSensor” is the radon sensor identifier, and a than header allows authentication for the web service to be executed. The web service calls the stored procedure “GetStatisticsbyid” which retrieves the statistical data from the sensor given as an input parameter. The response is sent in JSON format. It contains data such as average daily, weekly, monthly and annual radon levels. The response also includes an array containing daily average values for the last 30 days of readings. Figure 3.20 shows an example of a request to the web service “GetStatisticById”.

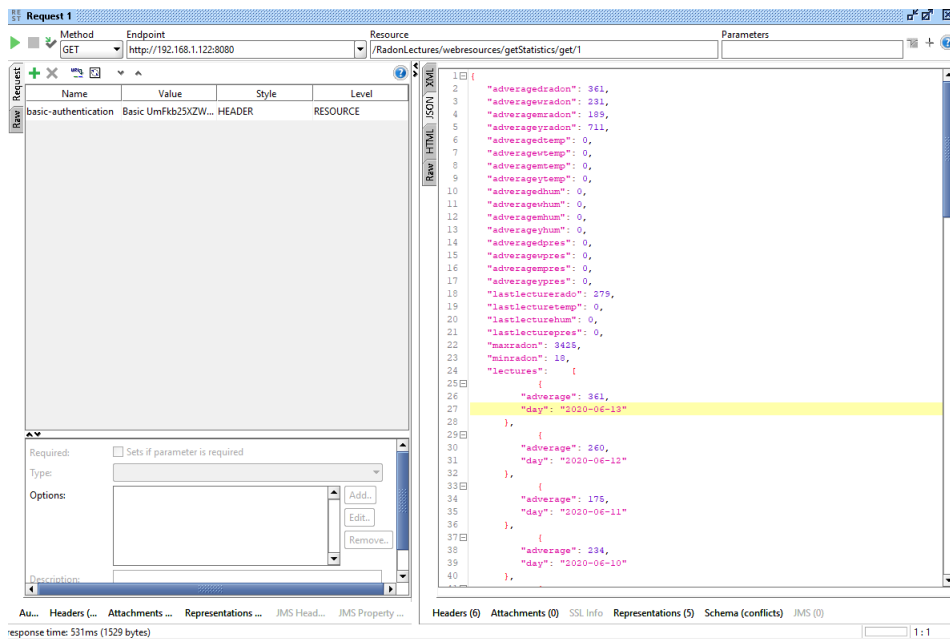


Figure 3.20: Example of request to the web service "GetStatisticById"

### 3.8.8 GetStatusExtractor

The “GetStatusExtractor” web service allows you to recover the status of a specific fan system that, through the trigger, allows you to change the status automatically according to the last readings inserted. The method used is GET and the resource “/ RadonLectures / webresources / getStatusExtractor / get / idExtractor” where “idExtractor” is the identifier of the device that controls the fans, the authentication header is also required to call the API. The query in the database is done through the stored procedure “GetStatusExtractor” that allows recovering the state in which the fans must be. The response is sent through the headers, with the “status” header corresponding to the status of the fans, the answer does not contain content. Figure 3.21 shows an example of a request to the web service “GetStatusExtractor”.

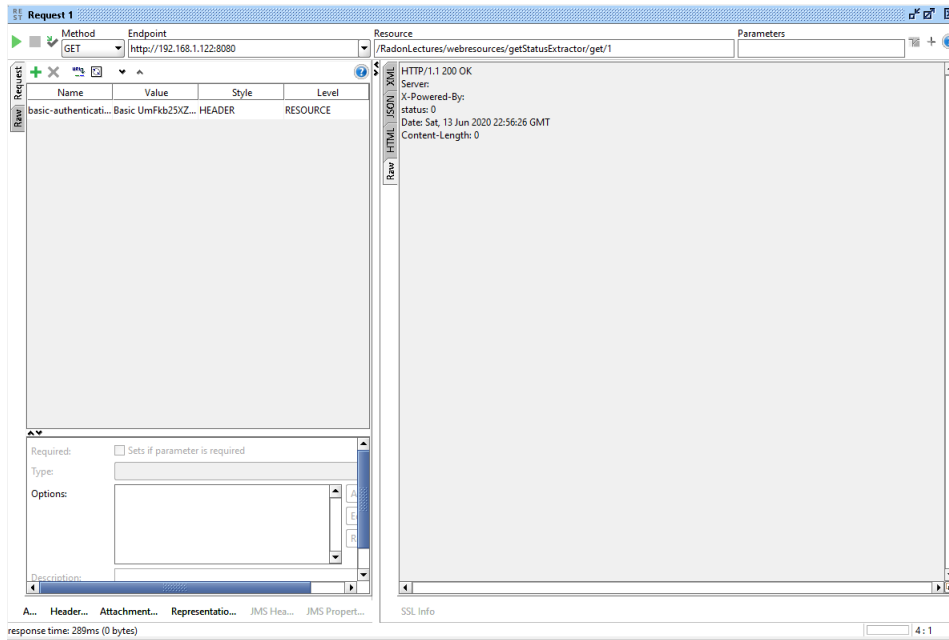


Figure 3.21: Example of request to the web service "GetStatusExtractor"

### 3.8.9 SetSensortoUser

The "SetSensortoUser" web service allows you to associate a radon sensor to a user. The method used is POST being the resource "/ RadonLectures / webresources / setSensor / setSensortoUser". The input data is received in JSON format, the sensor identifier, the user identifier and the location where the sensor will be placed, as well as the authentication header. The query in the database is done through the stored procedure "SetSensortoClient" that allows the user to be linked to the radon sensor. The answer is given in JSON format that returns the HTTP code, the status and in case of error the error description. Figure 3.21 shows an example of a request to the web service "SetSensortoUser".

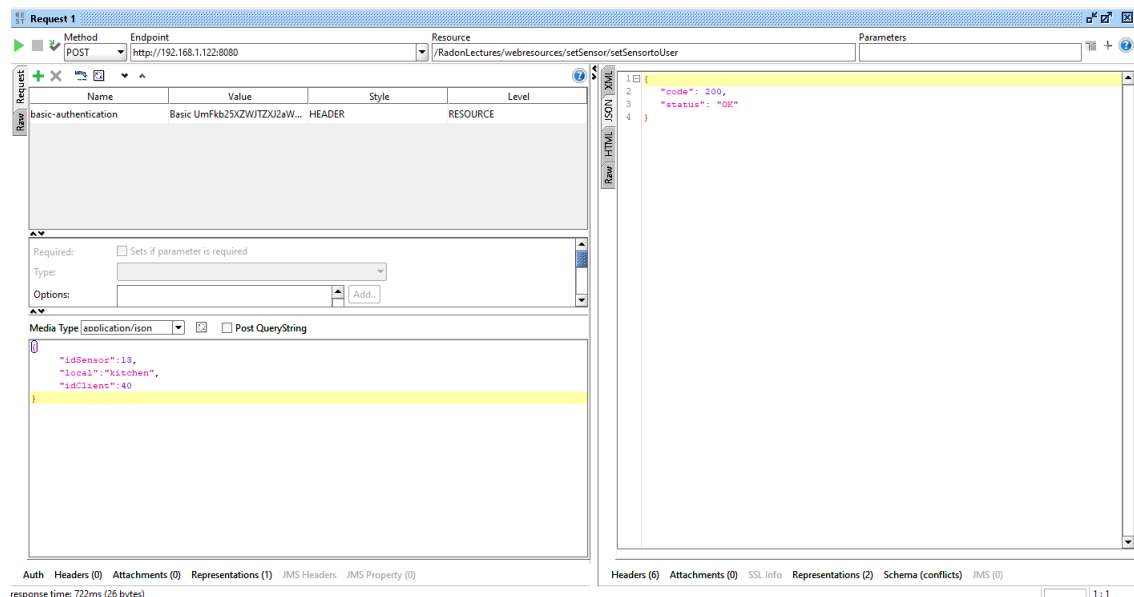


Figure 3.22: Example of request to the web service "SetSensortoUser"



## Chapter 4

### Prototype and Demonstration

#### 4.1 IoT Ecosystem

##### 4.1.1 IoT Sensors

This device allows to obtain radon concentrations in the air where the sensor is installed. For the construction of the device, two Arduino were used, one with a wifi shield and the RD200M radon sensor. Two Arduino were used due to the communication limitations of the Arduino, since, as the Arduino retrieves data from the sensor every second, it does not allow the connection to the network to be made. When the reading is collected every 10 min, the Arduino sends the data to the Arduino who is connected to the network, which sends the data to the server by calling the web service “AddLectureWs”. The reading process starts with the connection to the Arduino, in which two concurrent threads, one that works as a timer and the other that, through the UART and the sensor library, allows to collect the sensor data. When the timer reaches the reading time of 10 minutes, the Arduino sends the reading value by serial to the Arduino that has the shield wifi, this constructs the request and then calls the web service “AddLecture” that processes the data sent and adds it the database. Figure 4.1 shows the image of the IoT system with the corresponding captions.

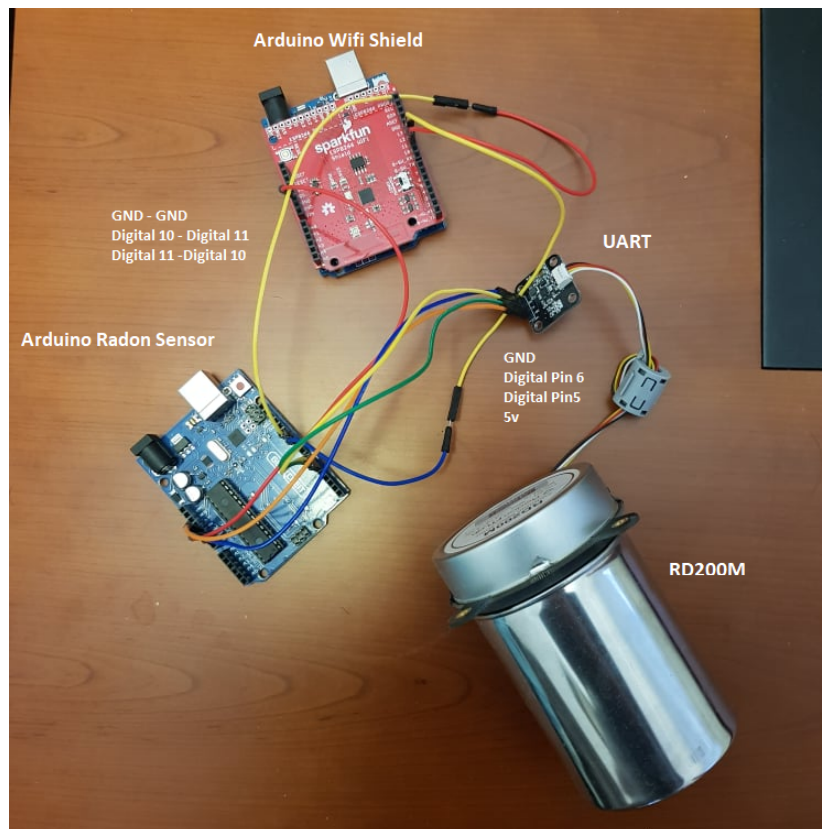


Figure 4.1: IoT System for prevention and detection of Radon Gas

#### 4.1.2 Fan controller

The fan controller allows you to turn the system fans on and off, depending on the radon values. For this, an Arduino with a wifi shield is connected to a trigger that allows it to act as a switch, thus allowing to turn it on and off according to the response it gets from the server. First, the Arduino connects to the local network with internet access, after the connection is made, a call is made to the web service “GetStatusExtractor”, which allows you to recover the state the fan must be in. Depending on the response received, the Arduino sends the signal to the trigger that closes or opens the electrical circuit, thus allowing control over the fans. Figure 4.2 shows the device for controlling the fans.

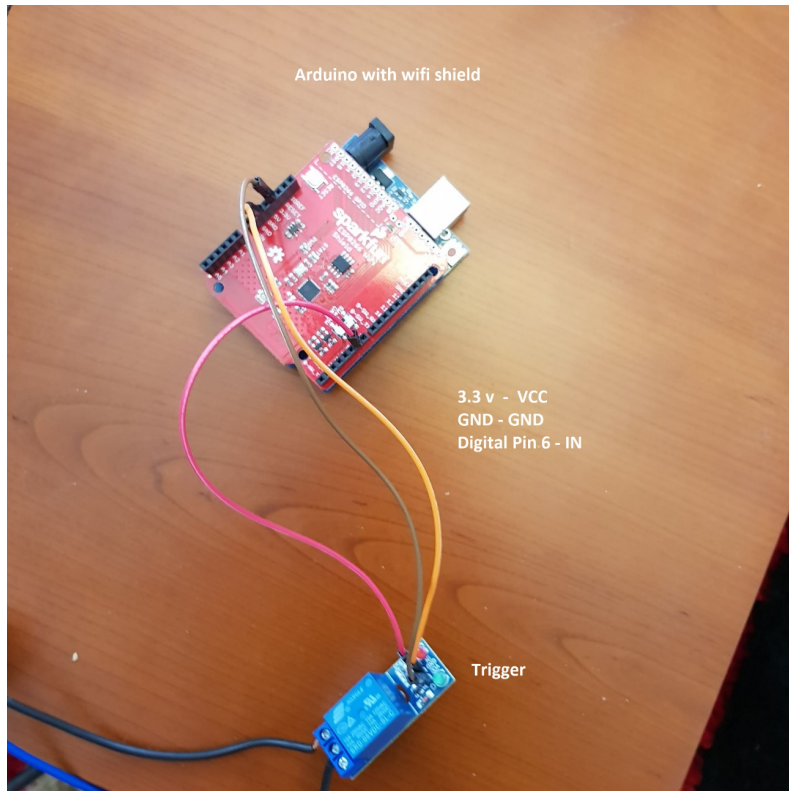


Figure 4.2: Device for controlling the fans.

## 4.2 Web Application

This section will cover the web application developed in the context of the project. The main pages will be presented, how they work and what are the functionalities of each one.

The home page of the web application called “Login”, allows the user to login or access the page to register in the system to be able to access the rest of the web application. When the user tries to access the system, his credentials are verified in the database. If the login is created successfully, a session is created for the user and directed to the “Dashboard” page. Otherwise, you are redirected to the login page. Figure 4.3 shows the login page.

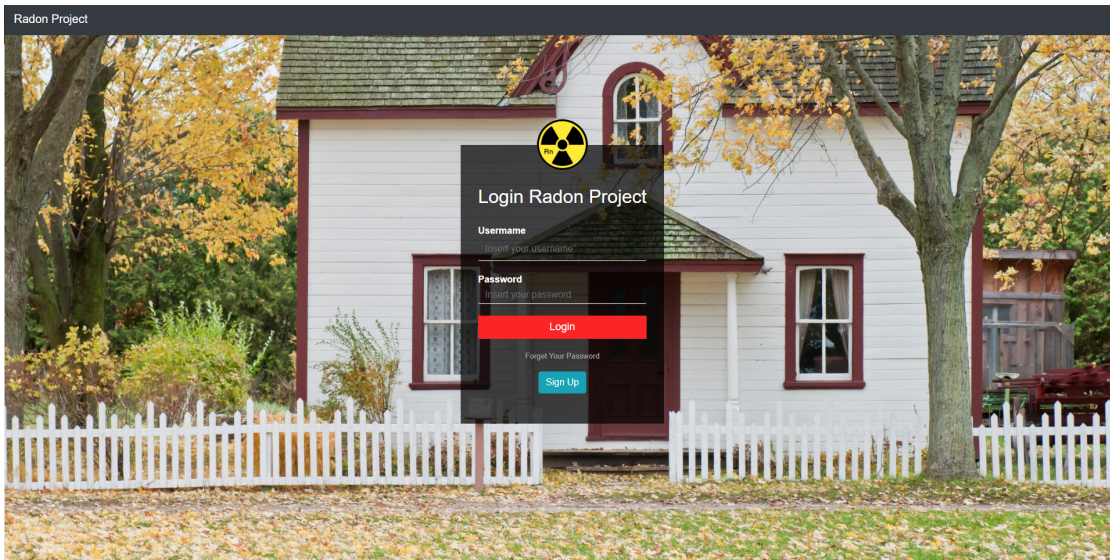


Figure 4.3: Login page.

On the “Sign Up” page, it is possible to enroll a user in the system to be able to access the data of his sensors. The data entered is verified in the web application, which is then sent to the “AddUserWs” service through the request where a new verification of the data is made, which is then inserted into the database through a stored procedure. If the request response to the web service is positive, it means that the user has been inserted and that he will be able to login with that user. Figure 4.4 shows the Sign Up page.

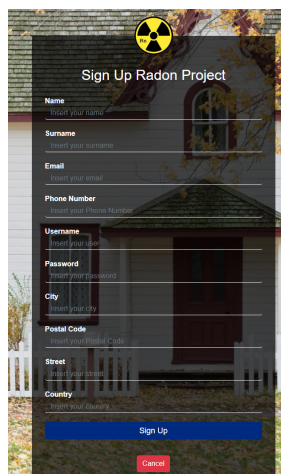


Figure 4.4: Sign Up page.

After the user has successfully logged in, the Dashboard page is displayed. This page is the most

important as it presents the statistical data of the sensor allowing to understand the evolution of radon in the housing. In order to present this page, a call is made to the web service “GetStatisticById” which returns the data in JSON format which after that are retrieved and presented. Figure 4.5 shows the dashboard.

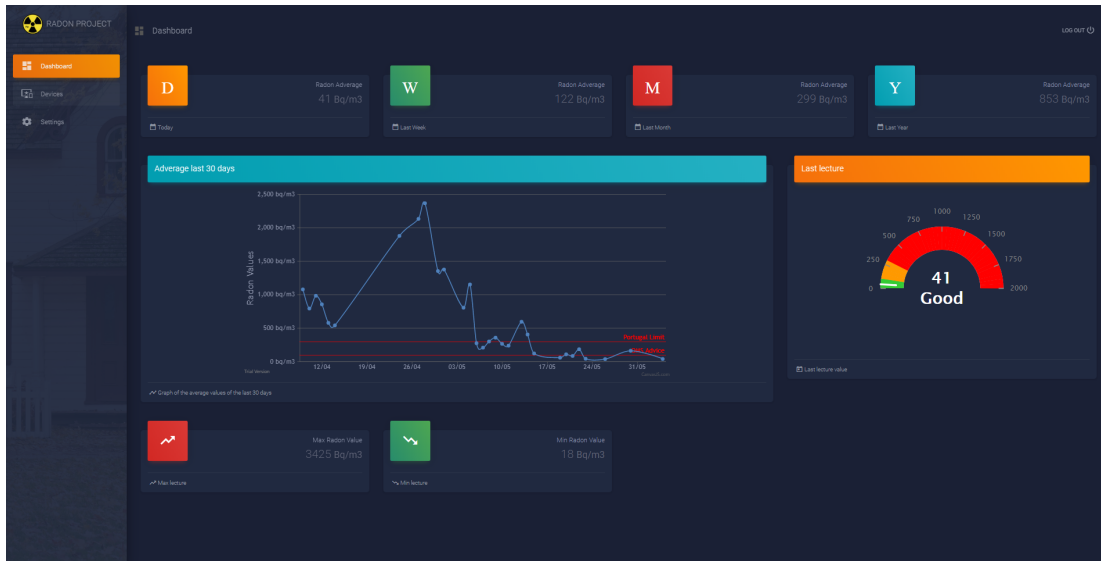


Figure 4.5: Dashboard page.

At the top of the dashboard, labels indicate the average daily, weekly, monthly and annual values. In figure 4.6, the labels at the top of the dashboard are presented in more detail.

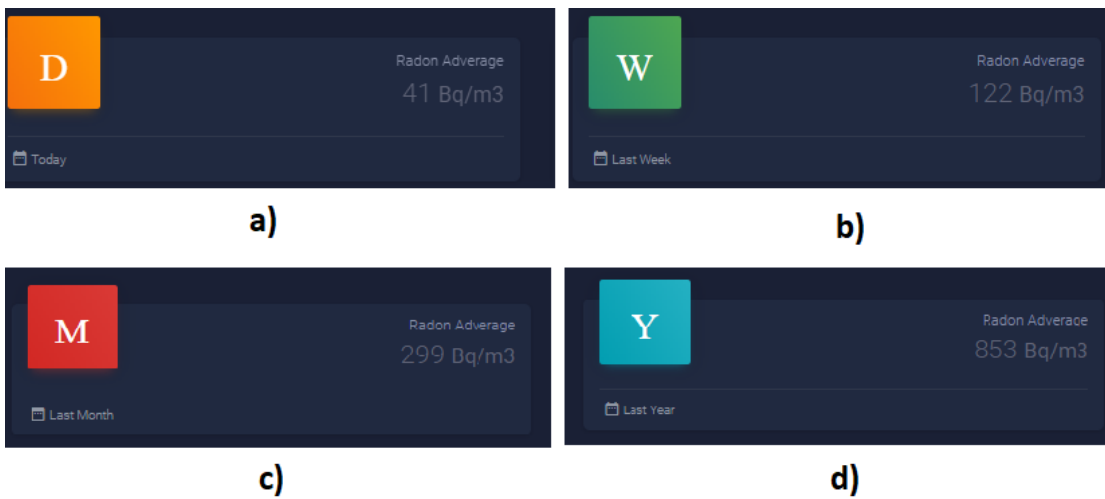


Figure 4.6: a)Daily average b)Weekly average c)Monthly average d)Annual average.

With this application it is also possible to represent, graphically, the daily average values of indoor radon. In the graph, it is perceived the evolution of radon levels, which is an easy way to analyze the radon concentration variation, and where we include, the radon reference level recommended by WHO and by Portuguese legislation, figure 4.7.

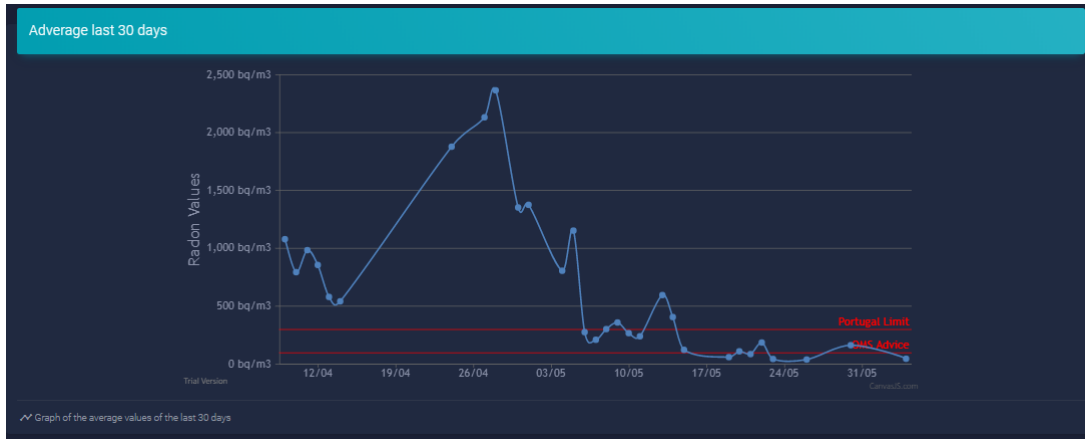


Figure 4.7: Distribution of indoor radon concentration measurements.

The dashboard also shows the interface of the visualization system, which is presented in a similar semi-circle with a pointer, with three ranges: the green for values between 0 Bq/m<sup>3</sup> and 99 Bq/m<sup>3</sup> representing values below the limit recommended by WHO, the orange for values between 100 Bq/m<sup>3</sup> and 300 Bq/m<sup>3</sup> which corresponds to Portuguese reference level of 300 Bq/m<sup>3</sup> and the red for values above 300 Bq/m<sup>3</sup>, figure 4.8.



Figure 4.8: Dashboard of the radon gas monitoring system.

In the visualization system it is also possible see, the maximum and minimum values registered by the radon sensor, figure 4.9.

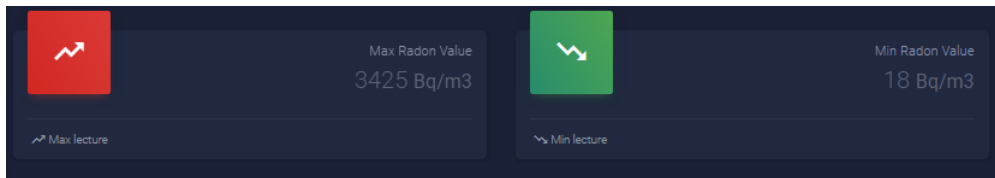


Figure 4.9: Maximum and minimum concentration values recorded

The menu on the left of the dashboard page enables the user allows you to navigate between the remaining pages of the web application. As shown in figure 4.10, the user can choose between the “Dashboard” page, go to the “Devices” page and, the “Settings” page.

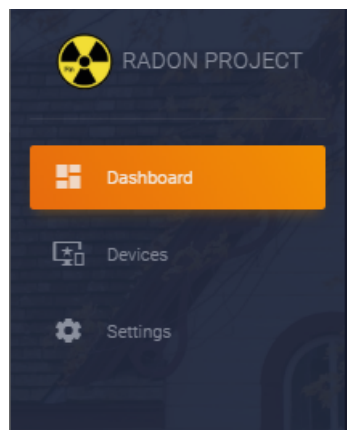


Figure 4.10: Web application menu.

On the Devices page, figure 4.11, it is possible to manage the devices, namely the radon sensors and the device that controls the fans. If no sensor or fan is associated, it is possible to add or edit the location of the existing ones.

Sensor		
Sensor Id	Location	Option
1	Coorna	

Fans				
IdExtractor	IdSensor	Location	Status	Option
1	1		OFF	

Figure 4.11: Devices page content.

On the “Settings” page, it is possible to change the user data as well as edit the limit and activate the fans manually. The layout is shown in figure 4.12. On the left side it is possible to change the user data for this it is called the web service “EditUserWs” while on the right side it is possible to edit the limit value and turn the fans on or off, to perform the operations on the base it is called the “EditDefWs” web service.

# An Internet of Things (IoT) Ecosystem for Detection and Removal of Radon Gas

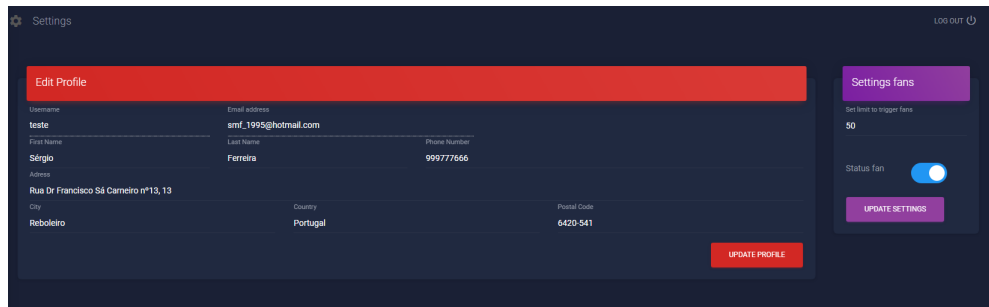


Figure 4.12: Settings page content.



## Chapter 5

### Performance Evaluation

#### 5.1 Software testing

During the implementation of the system, tests were carried out during and after the end of the system development. Unit, regression and integration tests were performed.

##### 5.1.1 Unit tests

Unit tests make it possible to test the software by part, and thus it is possible to correct anomalies with the implementation of each piece of the software.

The various web services implemented were tested with several data sets which allowed to verify their robustness, that is, in case the data is not valid, the program will not stop working due to an exception. The various cases were checked, such as empty or null data, as well as wrong data types. These tests were done through SoapUI, which allows testing of REST-type web services. Anomalies in data manipulation and robustness were detected, and these were corrected.

In the database, the various stored procedures that were implemented were tested, with valid data, that is, nominal data. These tests were not done to verify the robustness, since they are always performed by the web service and that this has already been implemented to avoid errors due to the input data being inconsistent.

The Arduino that is associated with the radon sensor in the development phase, there were numerous anomalies, due to the limitations of the Arduino, the first due to the Arduino's static random access memory that was exceeded by the program variables. After solving the anomaly, a second anomaly was found that did not allow the wifi shield to access the local network due to the Arduino's limitation in having only one active serial connection at the same time.

The threads that are executed calls every 1 second of the interval caused the program to stop working. To solve this anomaly, a second Arduino was added with the wifi shield that receives the data through the serial and sends the data to the webserver.

The tests to the Arduino associated with the trigger that allows controlling the fans were made by simulating the call to the web service through a mock service in SoapUI that allows simulating the response of a web service. The trigger was tested with the help of a lamp to see if the device was working correctly. It was no anomaly when in this testing phase.

In the tests carried out, the web application verified the data validations, the links between pages as well as the functionalities such as the operation of the login, the logout, such as the construction of the dashboard graphics in javascript and the queries made to the database.

##### 5.1.2 Integration tests

Integration tests allow you to see how the various parts of the software interconnect with each other. The tests were done on the Arduino with which the radon sensor is associated allowed to verify that the sending of data to the web services "AddLectureWs" and the execution of the stored procedure worked correctly. An anomaly was detected in the conversion of data from pCi / L to Bq / m<sup>3</sup>. The solution was to save the concentration value in the database in pCi / L. Which is

then retrieved and converted to Bq / m<sup>3</sup> in the stored procedure “GetStatisticbyId”.

In the Arduino that is associated with the trigger that allows controlling the fans, tests were performed that allowed checking the calls to the web service “GetStatusExtractor” through the Arduino and consulting the database made by the stored procedure “GetStatusExtractor”.

During the execution of the tests, an anomaly was detected due to a memory problem to store the response given by the server. As the response was made up of header fields with a lot of characters, when the answer was received, the sensor stopped working. The correction of this anomaly involved reducing the content of the response so that the Arduino does not have any memory problems when receiving the response from the webserver.

Integration tests were also carried out in the web application that allowed to verify the connection between the application and the web services that the data sent in the request and the data collected in the response were correct and that there was no anomaly in this process during the call to the multiple web services which are called by the web application.

### 5.1.3 Regression tests

Regression tests were performed to verify that the correction of anomalies, as well as changes in the database during the development of the system, did not cause errors in the database. During the regression tests, an anomaly was found in the trigger that allows updating the status of the fans given the latest data readings by the radon sensor.

As it had been developed to deal with the data in Bq / m<sup>3</sup> and not in pCi / L, the trigger did not work correctly since the way the data was saved had been changed.

## 5.2 Tests in real environment

After the software tests were carried out, the system was implemented in the real context, which allowed to verify that the system presented results in a real environment.

### 5.2.1 Context of the situation of the case understudy

The chosen test case is a rural dwelling, located in the parish of Reboleiro, that belongs to the municipality of Trancoso of the Guarda district, Portugal. The village has several deactivated uranium mines. Most of the population of Reboleiro is uninformed about the ore that was mined, do not know about the health risks they are subject to and, consequently, also do not know that there are several mitigation processes to avoid indoor radon concentration. The mines called Cimo do Reboleiro, the second largest uranium mines in Portugal, were explored between 1944 and 1959. At that time, it was produced about 9.1 tons of uranium ore per year, the majority exported to the United Kingdom [Cas11].

The mines were explored between 1944 and 1959, that is, about 15 years [Min].

In the geological cartography of Portugal it is possible to visualize the ores and mines present in the subsoil. In figure 5.1 it is shown the geological map of Reboleiro village where the “X” indicate the location of the dwelling used in the test [Dir]. The map dates back to 1972 and, in these forty-eight years, the village grew, and people continued to build their houses on this uranium-rich soils. Using the Google Maps app, with an aerial view it is possible to see that the buildings are concentrated near the mines, figure 5.2. Once this region has high radiation levels, it is very important that people living in this village know about the danger to which they are daily exposed in order to take measures to minimize potential health risk.

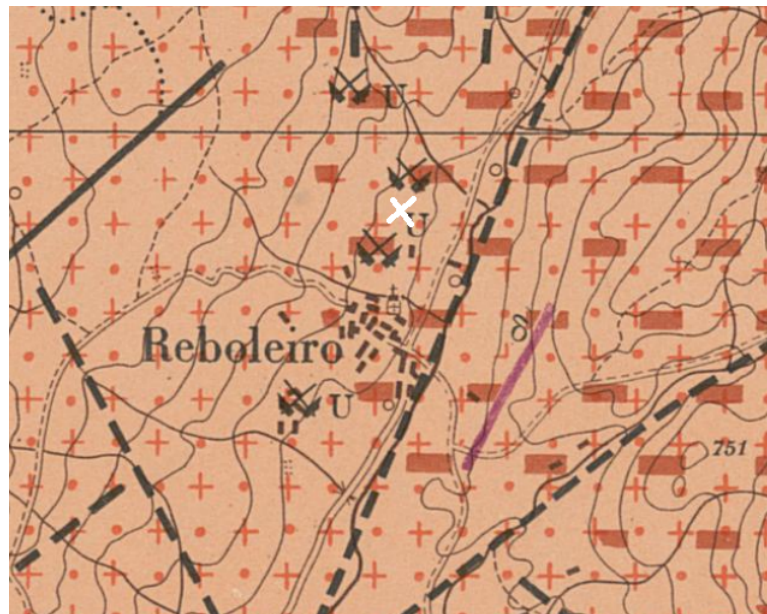


Figure 5.1: Geological cartography of Reboleiro.

The map dates back to 1972, the village grew and continued to be built on uranium-rich soils. As we can notice thanks to Google Maps, the buildings were approaching the mines. In figure 5.2, it is possible to see an aerial view of the village where it is possible to verify that the town continued to be built on top of uranium-rich soil. Without warning to the owners and the dangers to which they are exposed.

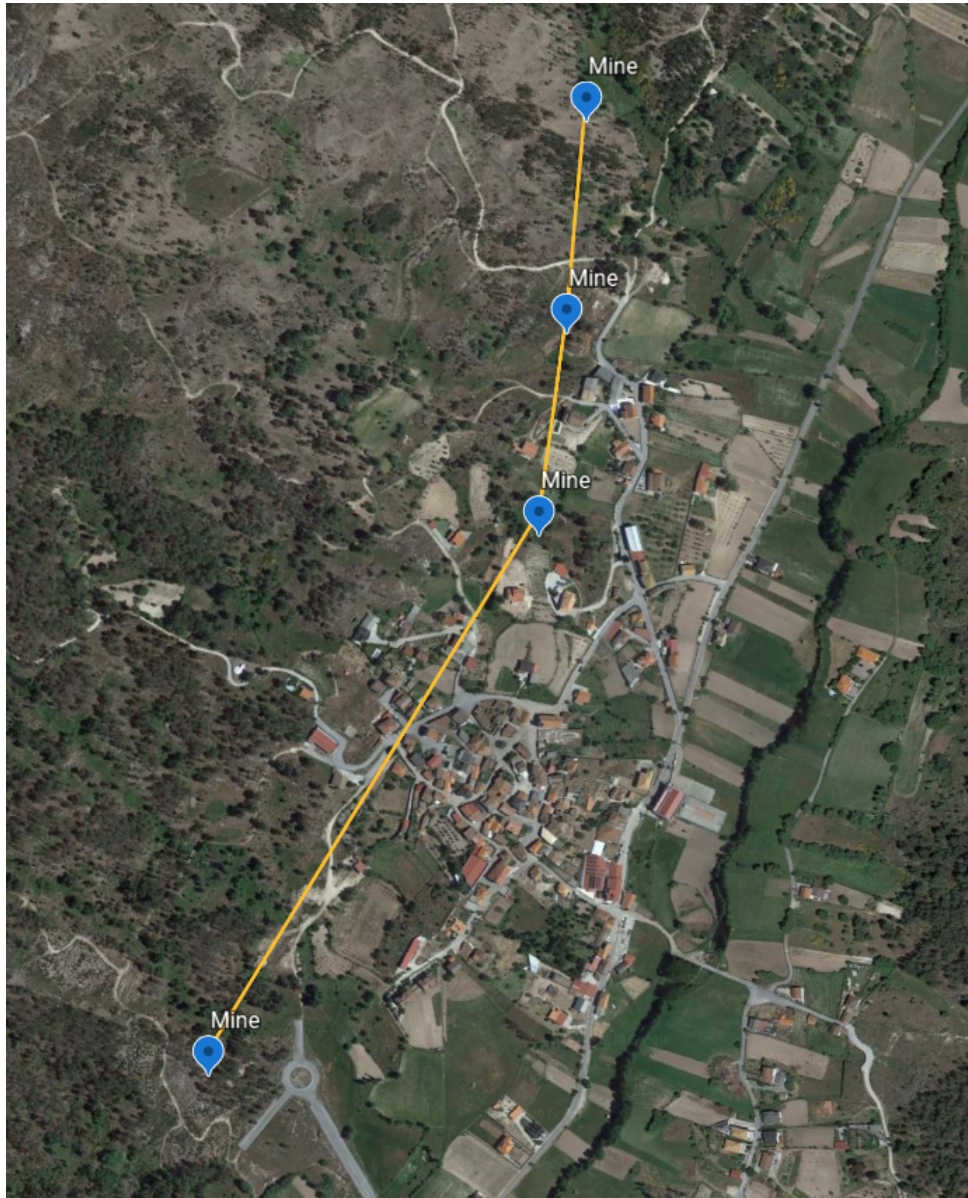


Figure 5.2: Google Earth View of Reboleiro. Source: [Goo]

The house where the system tests were carried out was already tested in mid-2016 by Lisbon Technological and Nuclear Institute in a preventive action given the proximity to multiple deactivated mines.

Wells that provided water for irrigation and consumption in the area were tested, as well as the radon concentration of several houses in the village. The test results were conclusive and pointed to a high concentration of radon inside the housing in which the system will be tested. When the owners were informed, they look for a solution to mitigate the gas that was on the market at the time. An Active Soil suction system was installed, and to control the radon levels they acquired a passive digital sensor Corentium Home. However, the gas level remained very high. A

rubber and aluminum foil were subsequently placed on the ground floor in order to seal the soil to prevent radon gas from entering the house. Unfortunately, Even after the film was installed, radon concentrations remained very high.

### 5.2.2 Implementation in a real context

In order to mitigate the radon gas, the tubes and fans of the Active soil suction system were recovered. Holes were drilled in the walls at two locations on the ground floor at opposite locations, which allows for better air circulation in which these holes were covered by grilles for aesthetic reasons. The holes were drilled at 20 centimeters from the ground since the radon gas is approximately seven and a half times denser than the air [Uni], which means that the gas tends to accumulate close to the ground.

New electrical cables were added between the two fans so that the electrical connection of the Arduino and the trigger becomes simpler and that there is only the need for a device to control the fans. To make ventilation effective, it is necessary to have an air inlet on the upper floor that allows a better circulation of air inside the house. Figures 5.3 presents the installation of the PVC pipes and the fan in the living room on the ground floor.

Figures 5.3 shows the installation of the PVC pipes and the fan in the living room on the ground floor, and figure 5.4 presents the installation of the PVC pipes and the fan in the ground floor room



Figure 5.3: Ventilation system installation in the living room- a) outdoor installation b) Installation of tubes and fan c) indoor installation

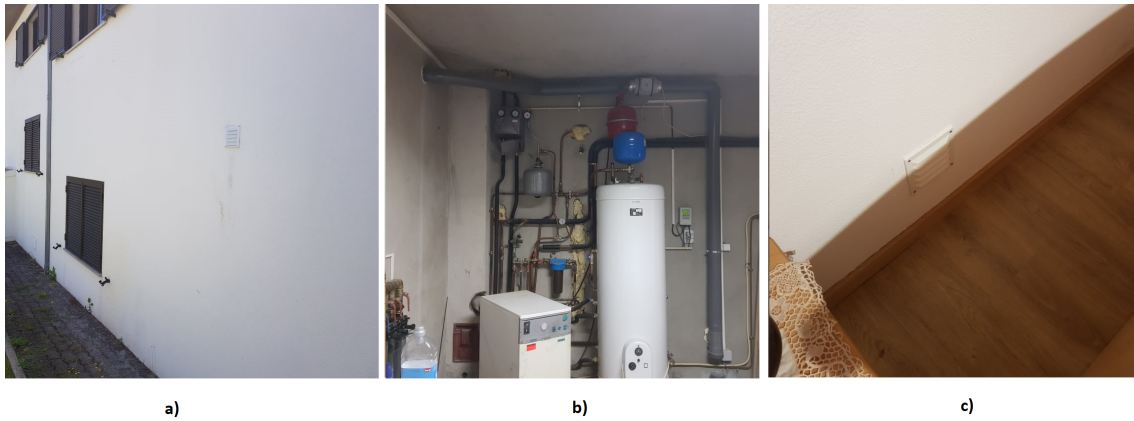


Figure 5.4: Ventilation system installation in the ground floor room - a) outdoor installation b) Installation of tubes and fan c) indoor installation

The location where the Arduino and the trigger are installed "b)", which allows activating the deactivate the fans, is presented in figure 5.5. The trigger is installed as a switch in which it opens or closes the electrical circuit depending on the response obtained by the server. The location of the "a)" radon sensor is also presented in figure 5.5. This is installed at a height of 50 cm, as the gas is denser than air, it tends to accumulate close to the floor.

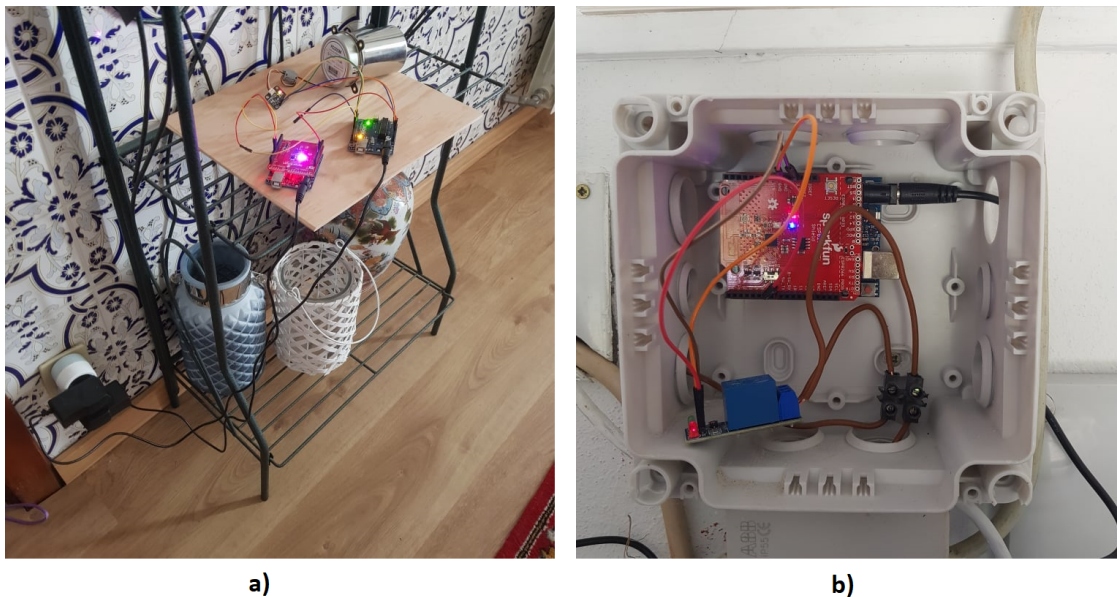


Figure 5.5: Installation of the IoT system a) IoT Sensor b) IoT Fans

### 5.3 Results

Before the implementation of the system, a reading was taken to have a reference base in relation to the concentration of radon gas in the dwelling. The result was obtained through the Air things Correntium radon sensor that had been purchased by the owner. The result obtained through the Air things Correntium radon sensor that had been purchased by the owner. The result obtained by the sensor that indicates the radon concentration before installing the system was  $2943 \text{ Bq/m}^3$ . When the system was turned on, it was possible due to the data collected to verify that the system was working correctly. An analysis was made through the data obtained to try to understand the

oscillations of radon concentration verified during the period in which the system was in operation. Two different mitigation methods were tested to see which one achieved the best results. One of them allows forcing the air inlet through the ventilation system and the other to remove the air from inside the room. Figures 5.6 and 5.7 show the graphs obtained through the average daily reading.

In the graph, in figure 5.6, the red line represents the change in the mitigation system. Until April 28, 2020, the mitigation method used introduced air inside the house, with the aim of increasing the atmospheric pressure of the house. However, the result obtained was not as expected, since this led to a peak concentration of 2364 Bq / m<sup>3</sup>. From that day on, the other mitigation method was used, which allows the air to be removed from inside the dwelling, which allowed to reduce the concentration of radon to levels below the maximum limit of the Portuguese legislation. With the results, it was possible to verify that the best method was to extract the polluted air from inside the house.

The graph in figure 5.7 contains two lines where one represents the limit recommended by WHO in green, and the yellow line represents the limit of the Portuguese legislation. From May 6, 2020, the level of radon concentration began to stabilize. It was possible to calculate the average concentration obtained during that period and thus compare it to the value obtained before the installation of the system in the home. It was found that on average, the concentration of the radon was reduced by 93%.

The peaks of radon concentration recorded from May 15 are due to weather conditions outside, that is, in those periods of time when the peaks rained in the locality.

With the rain the soil outside creates a natural barrier in the soil which traps the gas in the soil and the easiest way to escape is through the foundations of the housing which explains the peaks of radon concentration.

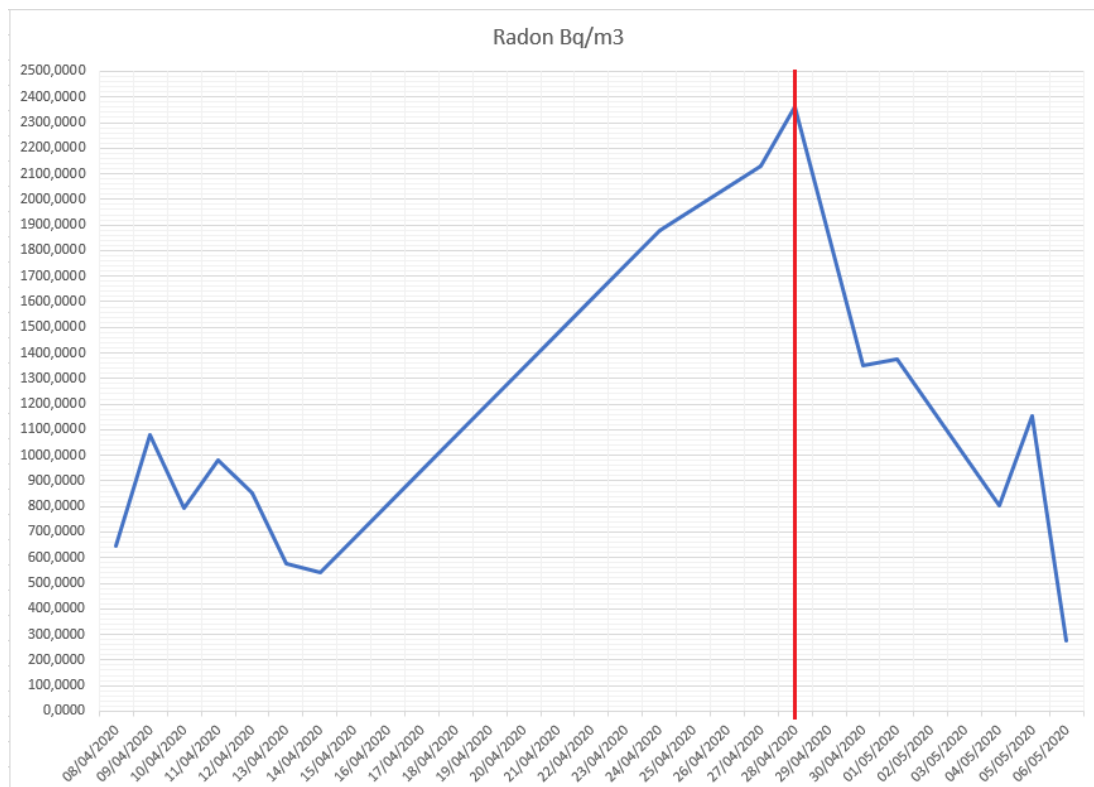


Figure 5.6: Graph of the evolution of the daily average level of radon until the 6th of May.

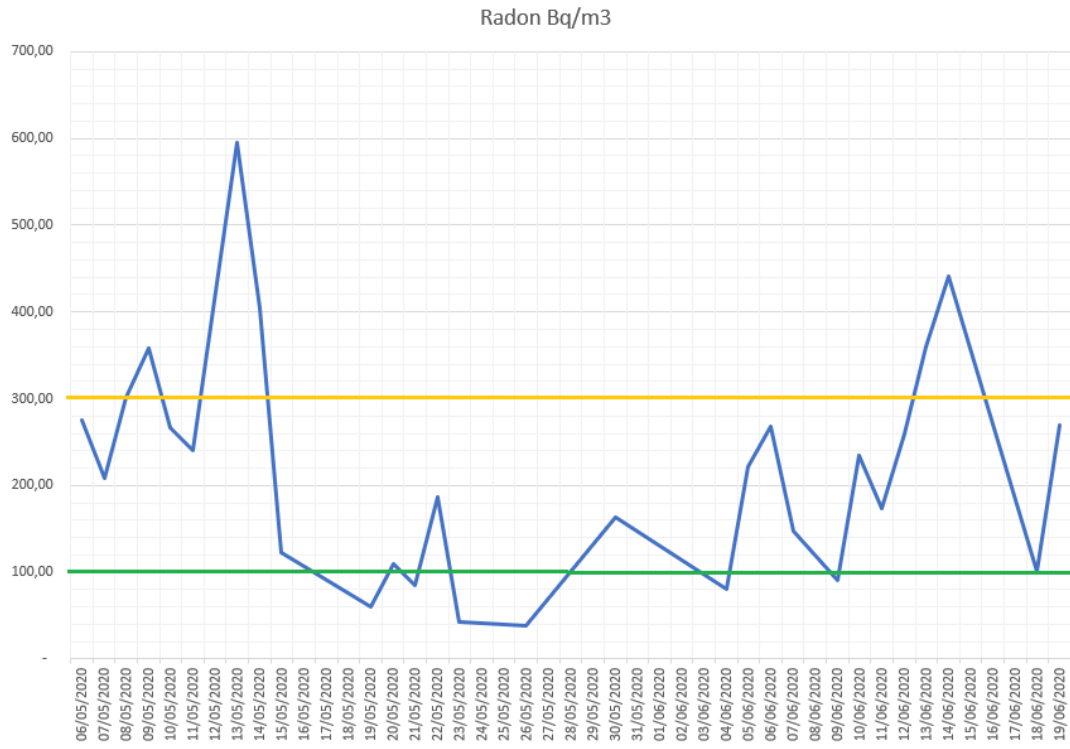


Figure 5.7: Graph of the evolution of the average daily radon level after May 6.

## Chapter 6

### Conclusions and Future Work

#### 6.1 Main Conclusions

With the evolution of Internet-related technologies in recent years, such as 4G fiber and soon, the implementation of the 5G network, allows objects to be increasingly connected to the internet. This evolution allowed the creation of new technologies in objects to solve everyday problems by merely creating a communication bridge between them. The main objective of this thesis was to develop a solution with IoT technologies, to detect, mitigate and predict radon gas in a home. The idea of creating a scalable system that is effective in combating concentrations of radon while reducing the health risks of occupants of the house. The study of existing systems helped to design the system, as well as to choose the technologies to be used as well as the mitigation selected methods for the testing phase.

The system was tested in a dwelling with radon problems, which allowed to verify the proper functioning and effectiveness of the system in a real context. With the data collection, it was possible to verify which mitigation method is the most effective. After analyzing the results obtained, it can be seen that radon levels were reduced considerably, on average by 93%, considering the radon concentration value based on the beginning of the tests. Because of the tests and research done on the housing situation where the system was checked, the Reboleiro parish council proposed an informative action to the population of the village.

During the implementation of the system, unfortunately, the sensor used to collect data on humidity, atmospheric pressure, and temperature suffered malfunctions and it was impossible to use. With the deadline of this work approaching and the world situation given to Covid-19, it was not possible to order a new one in time. Without these data, the implementation of the machine learning algorithm for predicting radon concentrations became unviable. However, although the machine learning allegations have not been implemented, the main objectives of the dissertation have been successfully achieved.

## 6.2 Future Work

To complete this work, some suggestions for future work are presented.

The implementation of a machine learning algorithm for linear regression that allows predicting future concentrations through the data obtained from the radon sensor and the atmospheric sensor. The system can act in advance and warn the user of potentially dangerous situations. The system can also be tested on a large scale in areas affected by radon. Use different Wifi components than those used in the system as they did not allow HTTPS connections. It will also be necessary to invest in a server with more capacity for hosting the system.

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