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(54) **DEVICE FOR DETECTING AND REDUCING RADON CONCENTRATION IN AN INDOOR ENVIRONMENT**

(57) The present application discloses a device for detecting and reducing radon concentration in an indoor environment. This device comprises at least one radon gas sensor and, at least one differential pressure sensor for measuring the difference between the indoor and outdoor atmospheric pressures, wherein both sensors are connected to a microcontroller configured to perform the pre-processing and aggregation of the data obtained by

said sensors. To reduce radon levels, it triggers at least one physical actuator to activate a ventilation device for reducing the radon concentration in an indoor environment when indoor radon concentration is above a first predetermined threshold or when indoor radon concentration is above a second predetermined threshold and the differential pressure is negative.

EP 4 375 583 A1

Description

TECHNICAL FIELD

[0001] The current description refers to a device for detecting and reducing radon concentration in an indoor environment.

BACKGROUND

[0002] Radon is a radioactive element of natural origin that is ubiquitous in the environment, mainly in soils and rocks, reaching the earth's surface in its gaseous form, after the occurrence of two phenomena: the first is the "emanation" that corresponds to its release from between the mineral grains, and the other is the "exhalation", a process associated with its transport via porous areas of soil and rocks, propagating through air or water. The concentration of radon that reaches the earth's surface depends on several factors, namely the amount of uranium present in the rock, the soil permeability, the porosity of the minerals, the existence of geological faults in the soil substrate, etc. [1].

[0003] Current outdoor radon gas concentration averages around 10 Bq/m³, since wind and temperature gradients rapidly dissolve radon particles emanating from the ground, resulting in a residual risk to human health, considering the gas mixture contained in the atmosphere [2]. In indoor air, radon can become an issue, since it tends to accumulate in enclosed low ventilated environments, where it can reach high indoor concentrations. According to European Directive 2013/59/EURATOM, of December 5th, 2013 [3], indoor radon concentration levels above 300 Bq/m³ must trigger mitigation actions that are mainly based upon ventilation procedures. During the exhalation process, radon tends to flow indoors due to the atmospheric pressure difference between indoor and outdoor air. Normally, indoors, air pressure is lower than outdoors, which facilitates radon accumulation. About 80% of the indoor radon arises from the ground and rocks, and its entry is made mainly through cracks in floors, walls and/or pipes, and through joints in construction materials. The remaining 20% comes from open air and water supply systems, in the latter case, not by ingestion, but by inhaling its release from taps, or during food preparation [4]. People living in a region with an abundance of predominantly rocky soils, especially granite and schist, are prone to radon risk exposure. According to the National Human Activity Pattern Survey (NHAPS) humans spend about 90% of their time indoors [4], so the likelihood of exposure to high concentrations of radon increases. The contribution to the dose of air inhaled by humans does not come only from radon, but also from its short-lived progeny. Such progeny arises from the uranium decay chain and can last from minutes to seconds. The descendants of radon are solid elements that settle in the pulmonary alveoli, and because of this decay process, emit alpha or beta radiation particles. In

the long term, evidence has shown that such particles can affect the respiratory tract and even cause lung cancer, according to several studies carried out over the last 20 years [5]. The emergence of lung cancer does not depend only on the levels of exposure to radon gas, it is also related to the daily time of exposure to it. Therefore, for permanent damage to occur, prolonged exposure to radon gas in indoor environments is required [5].

[0004] The device for detecting and reducing radon concentration in an indoor environment described in this text is a disruptive evolution from the RnProbe version presented in [6-9], by Pereira, Lopes, and Martins *et al.* RnProbe is an Internet of Things (IoT) device designed for indoor air quality monitoring, focused on the measurement and transmission of data in real-time to a cloud platform. When the indoor radon threshold is exceeded, the building administrator is notified to perform manual or mechanical ventilation to reduce indoor radon concentration. The sequence of procedures for radon detection follows three steps: (i) high radon concentration measurement; (ii) alert triggered to the building administrator; and (iii) manual ventilation implementation. The system architecture is composed of a private online network with three main elements: (i) Terminal devices with LoRaWAN modulation, gateway, and server, (ii) Cloud storage and analysis engine, and (iii) a Backend application with a dashboard with notifications. The remaining components are software-based and include an AES128+SSL security mechanism and the MQTT Secure and HTTPS protocols. The RnProbe is also equipped with two communication technologies (LoRa and Wi-Fi) to guarantee redundancy, long-range, and low power; this seeks to ensure that data is always transmitted. The main software platform called RnMonitor [7-9], of which the RnProbe device is a part, is based on IoT technologies and consists of a Web-based Geographic Information System (Web-GIS), to manage radon gas concentration and expedite in-situ sensor installation. This solution presents a data analytics engine and georeferenced information in a visual form, where the internal hierarchical structure of public buildings is used to georeference the compartments. This platform promotes the mitigation of radon risk exposure, taking the human factor into account for physical interventions (what is called "Human-in-the-Loop").

[0005] The scientific article by P. Barros *et al.* [10] lists the state of the art of IoT technologies with respect to managing radon risk exposure. This article has shown that these technologies are currently crucial for improving indoor air quality and play a significant role in the development of the so-called cognitive or intelligent buildings, where human intervention is becoming less essential and tends to be replaced by autonomous building management systems. The intent is to manage critical factors such as energy efficiency, human exposure to radon gas, and user experience. The main challenges and opportunities of these technologies focus on the management of radon exposure, the way they operate, the type of detection mechanisms they use, the type of system archi-

texture, and the auxiliary communication components and technologies.

[0006] Document KR20210023598A discloses a ventilation system, which automatically purifies the air through an indoor air quality sensor, where a Wi-Fi communication module and an air purification system are integrated.

[0007] Document KR101957985B1 discloses a system for detecting and removing radon from an environment, where it has been detected, by opening and closing a window. The removal system comprises: multiple radon detection sensors installed in indoor environments; a window opening and closing mechanism designed to respond to the radon sensor readings, and a controller responsible for overseeing the entire system's operation, including the natural ventilation of indoor spaces by controlling window openings and closings. Upon radon gas detection, the automatic window opening and closing mechanisms are engaged. Therefore, the radon gas contained in indoor air gets diluted with outdoor air, effectively reducing human exposure within the indoor environment.

[0008] These facts are described to illustrate the technical problem solved by the achievements of the present document.

GENERAL DESCRIPTION

[0009] The present description concerns a device for detecting and reducing radon concentration in an indoor environment.

[0010] The presented device for detecting and reducing radon concentration within indoor environments represent a disruptive solution for actively detecting and reducing radon gas levels indoors. It employs an IoT device, fully conceived and developed with relevant technical attributes and validated in an experimental scenario.

[0011] The device development is part of a vision of designing intelligent and sustainable systems, based on IoT and information and communication technologies, which promote the improvement of indoor air quality and the health of its occupants. Thus, the IoT device should be seen only as an element of the system, with the value proposition lying in the balance of three critical factors: 1) indoor air quality, 2) thermal comfort, and 3) energy efficiency of the indoor environment, whether it is a building or any other construction type. By combining the management of these factors, the aim is to focus on promoting the health and quality of life of the occupants of indoor environments. Achieving this equilibrium is a challenge for state-of-the-art devices because typically, when one of the critical factors is optimized, the others tend to underperform, and it is necessary real-time management to maintain the ideal balance point.

[0012] Throughout this description, an IoT device refers to any computing device embedded in at least one everyday object, which promotes internet-based interconnectivity by enabling them to transmit and receive

data.

[0013] The device of the present disclosure detects and reduces radon concentration in an indoor environment and comprises at least a radon gas sensor and at least one differential pressure sensor for measuring the difference between the indoor (P_{indoor}) and outdoor (P_{outdoor}) atmospheric pressures. Both sensors are connected to a microcontroller configured to perform the pre-processing and aggregation of data obtained by such sensors, and trigger at least one physical actuator to activate at least one ventilation device to reduce radon risk exposure, i.e., concentration in an indoor environment, if the indoor concentration is above a first predetermined threshold; or if the indoor radon concentration is above a second predetermined threshold and the differential pressure is negative.

[0014] Typically, the pressure differential between the outdoor and indoor air in an indoor environment is very small, so to obtain precise and consecutive measurements, it is important to incorporate a centralized differential pressure sensor that helps minimize measurement errors. In other words, given the state of technology, to measure the pressure disparity it is impractical to employ separate pressure sensors - one to measure the outdoor atmospheric pressure and another for the indoor environment. This approach introduces a significantly higher level of error compared to what a single differential pressure sensor can accurately measure.

[0015] The device mitigates radon exposure risk whenever it detects a point that exceeds a predefined threshold for radon presence. In an embodiment, the ventilation device is activated for reducing radon concentration in an indoor environment, this happens if indoor radon concentration is above a first predetermined threshold, or if indoor radon concentration is above a second predetermined threshold and the differential pressure is negative ($P_{\text{indoor}} - P_{\text{outdoor}} < 0$).

[0016] In an embodiment, the device can further comprise at least one sensor selected from a list consisting of a temperature sensor, relative humidity sensor, carbon dioxide sensor, total volatile organic compound sensor, or any combinations thereof.

[0017] In an embodiment, the device comprises at least one visual alert element selected from a list consisting of a light-emitting diode, an electroluminescent light-emitting diode, an organic light-emitting diode, or any combinations thereof.

[0018] In an embodiment, the physical actuator for activating the ventilation device comprises a module with at least one AC voltage regulator.

[0019] In an embodiment, the physical actuator activating the ventilation device of the device comprises at least one pulse-width modulation control motor.

[0020] In an embodiment, the device further comprises a communication module.

[0021] In an embodiment, the device further comprises a communication module capable of connecting via Bluetooth, or Bluetooth Low Energy (BLE), or Low Power

Wide Area Network Protocol (LoRaWAN) or Zigbee, or Wi-Fi communication.

[0022] In an embodiment, the radon sensor of the device comprises an ionization chamber or a photodiode for detecting alpha particles.

[0023] In an embodiment, the device further comprises a battery.

[0024] In an embodiment, the ventilation device for reducing indoor radon gas concentration comprises a forced air system.

[0025] In an embodiment, the device further comprises a port for charging and/or power supply.

[0026] In an embodiment, the device further comprises a motion detection sensor.

[0027] In an embodiment, the device is configured to be activated at a predetermined time.

[0028] The present disclosure can also be applied to a building door or window, of construction, that can be developed to comprise the device for detecting and reducing radon concentration in an indoor environment and also integrate the ventilation device, now disclosed.

[0029] Therefore, the present disclosure also describes a building door, of construction, comprising at least one device for detecting and reducing radon concentration in an indoor environment according to the previously described.

[0030] The present disclosure also describes a building window, of construction, comprising at least one device for detecting and reducing radon concentration in an indoor environment according to the previously described.

[0031] The present disclosure also describes the use of the device for detecting and reducing radon concentration in indoor environments to reduce radon risk exposure, namely inside service buildings, offices, homes, and shopping centers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] For an easier understanding, the figures have been attached, which represent preferred embodiments that do not intend to limit the object of the present description.

Figure 1: Schematic representation of the minimum dimensions for indoor healthy living.

Figure 2: Schematic representation of the minimum dimensions for healthy living inside, for example, occupied room vs empty room.

Figure 3: Block diagram of the architecture of a possible embodiment of the device for detecting and reducing radon concentration in an indoor environment.

Figures 4A and 4B: Flowcharts representing mandatory functions executed by one embodiment of the

device for detecting and reducing radon concentration in an indoor environment.

Figures 5A and 5B: Flowcharts representing initialization functions executed by the sensors, radon sensor and differential pressure sensor (5A) and sensors for temperature and/or relative humidity and/or carbon dioxide and/or total volatile organic compounds (5B) of one embodiment of the device for detecting and reducing radon concentration in an indoor environment.

Figures 6A and 6B: Flowcharts representing reading functions executed by the sensors, radon sensor (6A) and sensors for temperature and/or relative humidity and/or carbon dioxide and/or total volatile organic compounds (6B) of one embodiment of the device for detecting and reducing radon concentration in an indoor environment.

Figure 7: Flowchart representing the actuator's control function as executed by one embodiment of the device for detecting and reducing radon concentration in an indoor environment.

Figure 8: Flowchart representing the online communication function executed by one embodiment of the device for detecting and reducing radon concentration in an indoor environment.

Figure 9: Flowchart representing the online monitoring function executed by one embodiment of the device for detecting and reducing radon concentration in an indoor environment.

Figure 10: Graphical representation for radon gas concentration detection by the device for detecting and reducing radon concentration in an indoor environment and a sensor from the prior art in what concerns radon concentration vs time.

Figure 11: Graphical correlation between the radon gas concentration detected by the device and differential pressure sensor data, i.e., the measure of the pressure difference between the exterior and the interior.

Figure 12: Representation of an embodiment of the device for detecting and reducing radon concentration in an indoor environment.

DETAILED DESCRIPTION

[0033] This description concerns a device for detecting and reducing radon concentration in an indoor environment.

[0034] In an embodiment, the device for detecting and reducing radon concentration in an indoor environment

comprises a microcontroller configured to perform the pre-processing and aggregation of data, obtained by at least one radon gas sensor and a differential pressure sensor between outdoor and indoor air of an indoor environment. For actuation, it comprises at least one physical actuator that controls, a ventilation device to reduce radon risk exposure whenever a certain point is found above a predetermined threshold for radon levels.

[0035] Figure 1 presents the conceptual diagram that describes the ideal operating mode of an optimized indoor air quality management system, which consists of a trinomial that encompasses indoor air quality, thermal comfort, and energy efficiency, seeking to guarantee agility, adequate response times, and the lowest possible cost to ensure optimal performance, considering these three performance criteria defined for a healthy life inside an indoor environment. The first dimension is indoor air quality, which includes the chemical composition of the air and the bacteriological component, and is ensured by natural, mechanical, or hybrid ventilation devices, which are intended to supply new air to the occupants of indoor environment or to ensure the extraction of products from polluting sources, which derive from combustion and other sources like Volatile Organic Compounds (VOC's), for instance.

[0036] Along this description, it is considered that hybrid ventilation is any kind of ventilation that combines natural and mechanical ventilations.

[0037] The second dimension, related to thermal comfort, is defined, according to the standard EN ISO 7730:2005 (2005- ergonomics of the thermal environment) [11], as the psychological condition, in which the individual's satisfaction with the surrounding environment (hygrometric conditions) is in good balance, contributing therefore for its health and well-being. This mental condition is a broad concept that varies according to the metabolism of each person through five processes: conduction, convection, radiation, evaporation, and respiration. In addition to these, individual parameters such as clothing and the type of activity are of equal importance, as well as the environmental parameters of the space where people are, such as air temperature, relative humidity, and air velocity. Finally, the third-dimension concerns energy efficiency, referring to the sustainable use of energy by reducing consumption and increasing overall thermal comfort.

[0038] Figure 2 demonstrates the management paradigm of this triad beyond its dimensions. It is essential to combine physical indoor actions with the occupation of spaces in three dimensions: agility, response time, and minimum cost. These factors rely on the combination of different variables, meaning that in occupied building scenarios, achieving the right equilibrium between indoor air quality and thermal comfort is essential. In turn, when the compartments are empty, the requirements concerning indoor air quality, thermal comfort, and energy efficiency should only meet the regulatory standards on the subject since there are no occupants present. It is pos-

sible to optimize these levels when the integrated system is equipped with all the necessary components: terminal devices (such as sensors and actuators), a centralized backend platform, and communication infrastructure, among others, and when the predictive model or algorithm can maximize the quality of the three dimensions and thus guarantee the efficiency of all processes sustainably and at the lowest possible cost. Finally, it should be noted that even more dimensions could be considered, such as noise pollution, since ventilation devices produce airborne sounds that can affect the well-being of occupants. However, to achieve a more capable and responsive system during the occupation period, and considering the challenges in managing the presented trio of factors, the system should aim to optimize the synergy of at least two dimensions, being one of them indoor air quality, which aligns with the primary goal of reducing human exposure to radon gas.

[0039] Figure 3 illustrates the block diagram with a possible architecture of an embodiment for the device for detecting and reducing radon concentration in an indoor environment, which is centralized in a microcontroller, to which at least one radon gas sensor and, at least one differential pressure sensor, are connected. In an embodiment, the device may further comprise at least one sensor for temperature, and/or relative humidity, and/or carbon dioxide, and/or total volatile organic compounds. Conceptually, the radon sensor can use any alpha particle detection technique. Preference is given to detection with an ionization chamber, which reveals greater precision but also greater energy consumption. Another option is photodiode detection, which has the advantage of having smaller dimensions and low energy consumption. In one embodiment, the differential pressure sensor makes it possible to perceive the variability between indoor and outdoor atmospheric pressures, and how they affect the radon content in the indoor environment. After measuring and analyzing the results obtained by the sensors indicated above, the microcontroller performs the pre-processing and aggregation of the detected values, and in case of risk, at least one physical actuator of the ventilation device will be activated to effectively reduce radon risk exposure. Moreover, in one embodiment, the device may further include at least one visual alert element, for example, a light-emitting diode, an electroluminescent light-emitting diode, an organic light-emitting diode, or combinations thereof. In one embodiment, the physical actuator comprises an AC voltage regulator, optionally with pulse-width modulation control, that allows air flow control, through the physical action of a ventilation device that will mitigate radon risk exposure within an indoor environment. As communications technology, the device can include any communications module, for example, Bluetooth, Bluetooth Low Energy (BLE), Low Power Wide Area Network Protocol (LoRaWAN), Zigbee, or Wi-Fi communication, which will help to communicate with Web servers that guarantee the final processing of the data, the online (or local) storage, the visualization of the

received data and the analysis of the impacts of pollutants on the buildings under analysis. This communications module must always guarantee communication redundancy, instantly informing those responsible for the spaces and/or the occupants, about radon levels and indoor air quality in general.

[0040] Figures 4A and 4B shows flowcharts representing mandatory functions executed by one embodiment of the device for detecting and reducing radon concentration in an indoor environment, in particular SETUP, LOOP, and INIT_MESSAGE (Figure 4A), and INTERRUPT Functions (Figure 4B).

[0041] Figures 5A and 5B shows flowcharts representing initialization functions executed by the sensors, radon sensor and differential pressure sensor, Initialization Functions (Rn & DP Sensors, in Figure 5A, and sensors for temperature and/or relative humidity and/or carbon dioxide and/or total volatile organic compounds, Initialization Functions (Air & MOX Sensors) in Figure 5B, of one embodiment of the device for detecting and reducing radon concentration in an indoor environment.

[0042] Figures 6A and 6B shows flowcharts representing reading functions executed by the sensors, radon sensor, Reading Functions (Rn Sensor) in Figure 6A, and sensors for temperature and/or relative humidity and/or carbon dioxide and/or total volatile organic compounds, Reading Functions (DP, Air & MOX Sensors) in Figure 6B, of one embodiment of the device for detecting and reducing radon concentration in an indoor environment.

[0043] In an embodiment, the power supply of the device is an extended capacity portable battery, for example, 10000 mAh, or preferably a direct connection to the AC mains with a 5V DC USB voltage adapter.

[0044] In an embodiment, the Sparkfun ESP32 LoRa 1-CH Gateway development kit can be used as the basis of the device, which uses an ESP32 microcontroller. Regarding the device sensors, examples of potential different sensors are the FTLab RD200M radon gas sensor, which makes use of the ionization chamber detection technique, and the Sensirion SDP810 differential pressure sensor. In another embodiment and in addition to those, a sensor like the Sensirion SCD30 is added to the device to measure carbon dioxide, relative humidity, and temperature. In an embodiment, to measure the Total Volatile Organic Compounds, the Adafruit SGP30 sensor is used, whose new version comes equipped with an I²C interface with Qwiic connectors compatible with the Sparkfun development kit. In an embodiment, a 5 mm RGB LED module can be used as an actuator, for visual indication of radon levels, while an industrial 220V ventilation device can be used for radon gas reduction.

[0045] In an embodiment, the assembled version of the device for detecting and reducing radon concentration in an indoor environment was used, with all the components mounted on a breadboard with the corresponding power circuit and control of sensors and actuators. All sensors were powered directly from the mains with a

5V DC USB voltage adapter, which allows the output of at least 2A of current, with the radon sensor having a step-up of 5-12V. The system can also be powered with an extended-capacity portable battery, preferably with solar charging to avoid power failures. To guarantee successive periods of 7 days of measurement, 50000 mAh is recommended. The fan is powered by 220V and is controlled through an AC voltage regulator that can be also used as a relay, to turn the fan on and off.

[0046] Initially, the physical quantities to be measured were analyzed, to assess the measurement periodicity and to avoid the results presenting large variations in short periods of time. Thus, in the experimental tests, an embodiment of the device for detecting and reducing radon concentration in an indoor environment was configured to collect and transmit values in 10-minute periods, for radon, and in 1-minute periods for the remaining parameters. These time periods fall within the margins of error presented by the sensor manufacturers and allow the verification of any errors during measurements. Whenever large fluctuations occur between readings, the radon measurement is repeated, and the new value is again compared to the previous readings. When the value is consistent with the previous ones, that is, it presents a variation below 20%, it is considered an accurate measurement, and the information is then transmitted via Wi-Fi. When the value is not consistent, it is considered a wrong measurement and discarded.

[0047] The experimental validation process was carried out to approve an embodiment of the device for detecting and reducing radon concentration in an indoor environment and its integration with an online monitoring platform [12]. This process was divided into four parts: (i) Idealization and creation of the experimental scenario; (ii) Integration with the platform; (iii) Validation of the device for detecting and reducing radon concentration in an indoor environment and (iv) Active radon gas reduction.

[0048] To validate the proof of concept, an experimental scenario, with an embodiment, was set up in the outer span of a bedroom, located on the ground floor of a single-family house. The compartment's dimensions are 4.80×3.40×2.50 meters (LxWxH), resulting in an area of 16.32 square meters and a volume of 40.80 cubic meters.

[0049] Within this space, a measuring tube was installed and connected to the differential pressure sensor, which extended outdoors to measure the differential pressure reading at the respective sensor located within the building. Additionally, an industrial mini fan was positioned in a window, strategically placed to facilitate the inflow of outdoor air. Once these components were in place, the remaining window opening was sealed using a stainless steel-coated wooden panel, and any gaps were meticulously sealed with insulating tape and a spongy material plate fastened with a wooden lock.

[0050] Thus, the experimental validation process was carried out over a period of 7 consecutive days, which

took place between June 8 and 16, 2022, and corresponds to a short-term evaluation. The on-site data acquisition took place under normal conditions of space use, that is, the room was unoccupied during the day and occupied during the night. Therefore, opening the interior door during the day or entering and leaving the compartment at any time was interpreted as normal use, and this factor was disregarded in the evaluation. To avoid readings with false positives, some precautions were taken, namely: the external opening remained completely sealed, except for the fan installation hole; the IoT device was protected from sunlight or electromagnetic radiation; an embodiment of the device for detecting and reducing radon concentration in an indoor environment was placed on a drawer module, situated 2.00 meters away from the fan and outside its airflow path; a gap of 25 centimeters was maintained between the device and the wall as well as other objects, and with a ceiling height of 2.50 meters, the device was positioned at a height of 0.80 meters from the floor and 1.70 meters from the ceiling. During the measurement period, the embodiment of the device for detecting and reducing radon concentration remained completely intact, having not been moved or tampered with.

[0051] To send the experimental measurements to the cloud, in an embodiment of the device the ESP32 Wi-Fi module was chosen as the main communication technology, between the development kit and the online monitoring platform, since it speeds up the tests regardless of the user's location. Still, other communication protocol options are possible, e.g., Zigbee, LoRaWAN, Bluetooth, BLE, among other suitable options.

[0052] For accurate and reliable validation of an embodiment of the device for detecting and reducing radon concentration in an indoor environment, a professional-grade active detector called Canary Pro by Airthings was used as a reference and placed within the indoor space during the setup of the experimental scenario. This probe is duly certified, collects instantaneous measurements at 1-minute intervals and saves hourly averages in a total of 24 records per day. In an embodiment, the device for detecting and reducing radon concentration in an indoor environment was configured to collect and transmit values in 10-minute periods for radon, in a total of 6 records per hour, and in 1-minute periods for the remaining parameters, in a total of 60 records per hour. Thus, it was possible to validate by comparison the measurement of the radon concentration whose average concentration for the 7 days was 82 Bq/m^3 with a standard deviation of 39 Bq/m^3 , for the device for detecting and reducing radon concentration in an indoor environment, being within the confidence interval of the reference probe, which showed a standard deviation of 91 Bq/m^3 . Figure 10 clearly shows that the development of radon in both devices is followed over time.

[0053] In an embodiment, the activation of the ventilation device for the reduction of radon gas was set at the limit value of 100 Bq/m^3 , a value recommended by the

WHO [2]. Thus, the following scale of action can be defined to control the actuators: Normal-Radon content less than or equal to 100 Bq/m^3 , which implies the LED lighting in green and keeping the ventilation device off; Alert - Radon content greater than 100 and less than or equal to 300 Bq/m^3 , implies blue LED lighting and ventilation device on; Dangerous-Radon content greater than 300 Bq/m^3 , implies red LED lighting and ventilation device on. During the experimental test, both the visual alert indication of the existing radon levels, facilitated by the RGB LED, and the activation and deactivation of the ventilation device worked perfectly. Therefore, at this point, it can be stated that the achieved outcome was favorable, and the system was effectively managed in a highly satisfactory manner.

[0054] In an embodiment, the differential pressure sensor between the exterior and interior of an indoor environment has two inputs to connect the measuring tubes. The "HIGH" input will produce a positive measurement of the pressure differential between outside and inside, i.e. a value greater than 0 Pa. Conversely, the "LOW" input will produce a negative measurement of the pressure differential between outside and inside, indicating a value less than 0 Pa. In the experimental test, the normal recommendation was followed, which is to measure positive pressures inside the compartment, in this way the "LOW" inlet was connected to the external air pressure, while the "HIGH" inlet remained open to the positive pressure to be measured inside the compartment. If, on the other hand, the intention was to measure the negative or suction pressure, it was sufficient to invert the connections, that is, connect the "HIGH" inlet to the exterior air and the "LOW" inlet to the vacuum compartment. As the vacuum level rises, the pressure difference between the bottom and top sides also increases. Figure 11 presents the results obtained for radon gas concentration and the differential pressure between the exterior and interior over a continuous 7-day time period. At this point, the negative differential pressure between the exterior and interior indicates that the outside air pressure is greater than the inside, so the interior environment is underpressurized. From the data analysis, it appears that if the external and internal pressure differential is negative, we are in under-pressurized internal environment conditions, promoting the suction effect and in the short-medium term the radon content will tend to rise as can be seen on June 15th, at 17:00 in figure 11. On the other hand, if the exterior and interior pressure differential is positive, we are in an over pressurized interior environment, stopping the suction effect and promoting indoor-outdoor airflow, so the radon gas concentration will tend to go down. The graph demonstrates that whenever the external and internal pressure differential becomes negative, the radon concentration follows this trend. Therefore, it will be possible to predict with high precision that the radon concentration will increase in the following hours. In view of this analysis, these results are considered optimal and indicate the existence of a correlation

between the radon content and the pressure differential.

[0055] Figure 12 shows a representation of an embodiment of the device for detecting and reducing radon concentration in an indoor environment.

[0056] In one embodiment and considering the dimension of energy efficiency, the device for detecting and reducing radon concentration in an indoor concentration could also comprise a motion detection sensor that would be configured to activate its operation. In this way, the device can save energy when the analyzed compartment is empty, i.e., without people or animals.

[0057] In one embodiment, the device for detecting and reducing radon concentration in an indoor environment may further be pre-programmed to be activated at a time predetermined by the user.

[0058] In one embodiment, the now disclosed device for detecting and reducing radon concentration in an indoor environment can be used, for example, inside service buildings, offices, homes, and shopping malls.

[0059] In one embodiment, a door and/or window can also be developed to comprise the device for detecting and reducing radon concentration in an indoor environment and its combination with an integrated ventilation device, now disclosed.

[0060] The term "comprises" or "comprising" when used in this document is intended to indicate the presence of the features, elements, integers, steps, and components mentioned, but does not preclude the presence or addition of one or more other features, elements, integers, steps, and components, or groups thereof.

[0061] The present invention is, of course, in no way restricted to the embodiments described in this document and a person with average knowledge of the area will be able to foresee many possibilities for modifying it and replacing technical characteristics with equivalent ones, depending on the requirements of each situation, as defined in the appended claims.

[0062] The following claims define further embodiments of the present description.

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Claims

1. Device for detecting and reducing radon concentration in an indoor environment comprising at least one radon gas sensor, at least one differential pressure sensor for measuring the difference between the indoor and outdoor atmospheric pressures, wherein both sensors are connected to a microcontroller configured to perform the pre-processing and aggregation of the data obtained by said sensors, and trigger at least one physical actuator to activate at least one ventilation device for reducing the radon concentration in an indoor environment,

if the indoor concentration is above a first predetermined threshold;
or if the indoor radon concentration is above a second predetermined threshold and the differential pressure is negative.

2. The device according to the previous claim, further comprising at least one sensor selected from a list consisting of temperature sensor, relative humidity sensor, carbon dioxide sensor, total volatile organic compound sensor, and combinations thereof.
3. The device according to any one of the previous claims, comprising at least one visual alert element selected from a list consisting of a light-emitting diode, an electroluminescent light-emitting diode, an organic light-emitting diode, or combinations thereof.
4. The device according to any one of the previous claims, wherein the physical actuator for activating the ventilation device comprises a module with at least one AC voltage regulator.
5. The device according to any one of claims 1 to 3, wherein the physical actuator activating the ventilation device comprises at least one pulse-width modulation control motor.
6. The device according to any one of the previous claims, further comprising a communication module.
7. The device according to any one of the previous claims, wherein the communication module uses Bluetooth, Bluetooth Low Energy, Low Power Wide Area Network Protocol, Zigbee, Wi-Fi communica-

tion, or combinations thereof, for connection.

8. The device according to any one of the previous claims, wherein the radon sensor comprises an ionization chamber or a photodiode for detecting alpha particles.
9. The device according to any one of the previous claims, wherein the ventilation device for reducing radon gas risk exposure comprises a forced air system.
10. The device according to any one of the previous claims, further comprising a motion detection sensor.
11. The device according to any one of the previous claims, further comprising a battery and/or a port for charging and/or power supply.
12. The device according to any one of the previous claims, wherein such device is configured to be activated at a predetermined time.
13. A building door comprising at least one device described in any of the previous claims.
14. A building window comprising at least one device described in any of claims 1 to 13.
15. Use of the device for detecting and reducing radon concentration in an indoor environment as described in any of claims 1 to 13, for reducing radon risk exposure, namely inside service buildings, offices, homes, and shopping centers.

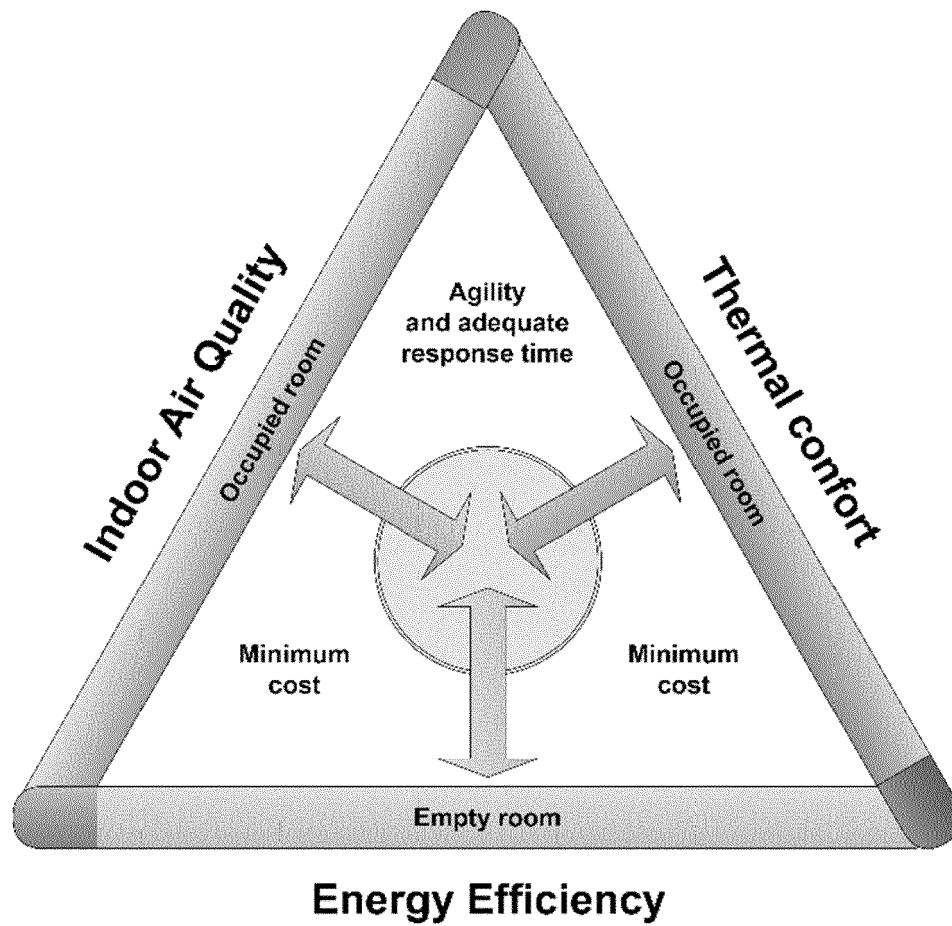


Fig. 1

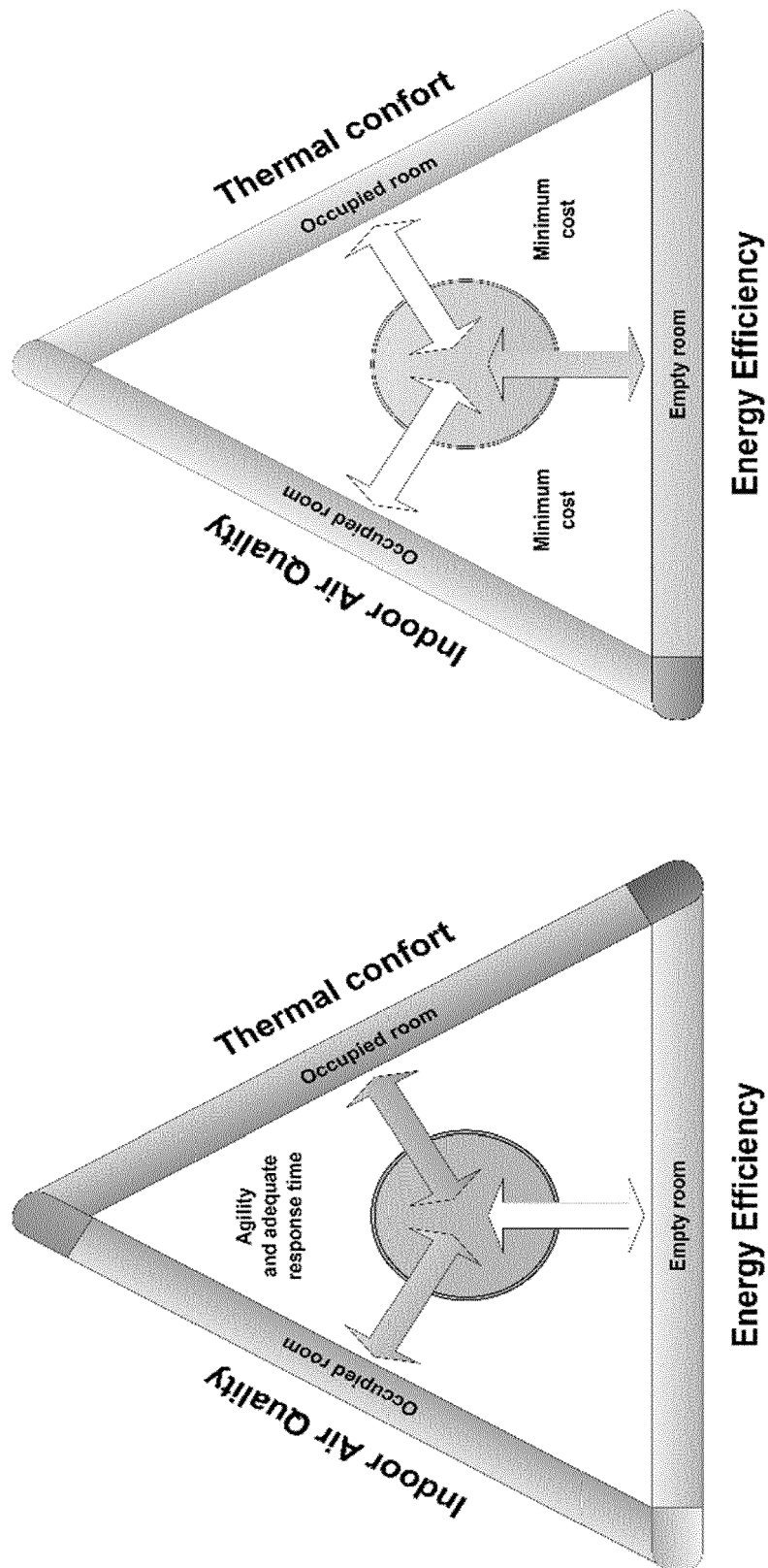


Fig. 2

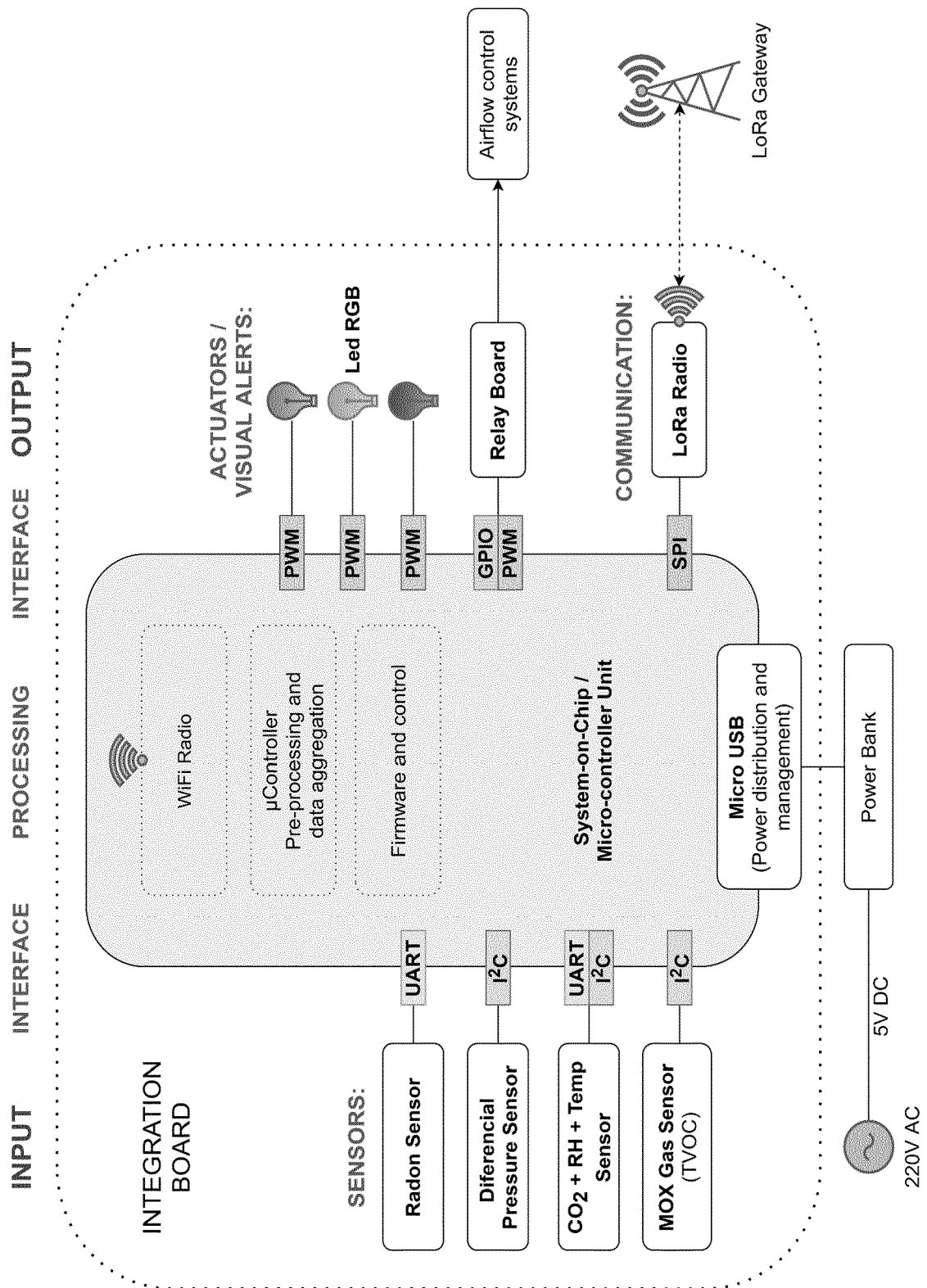


Fig. 3

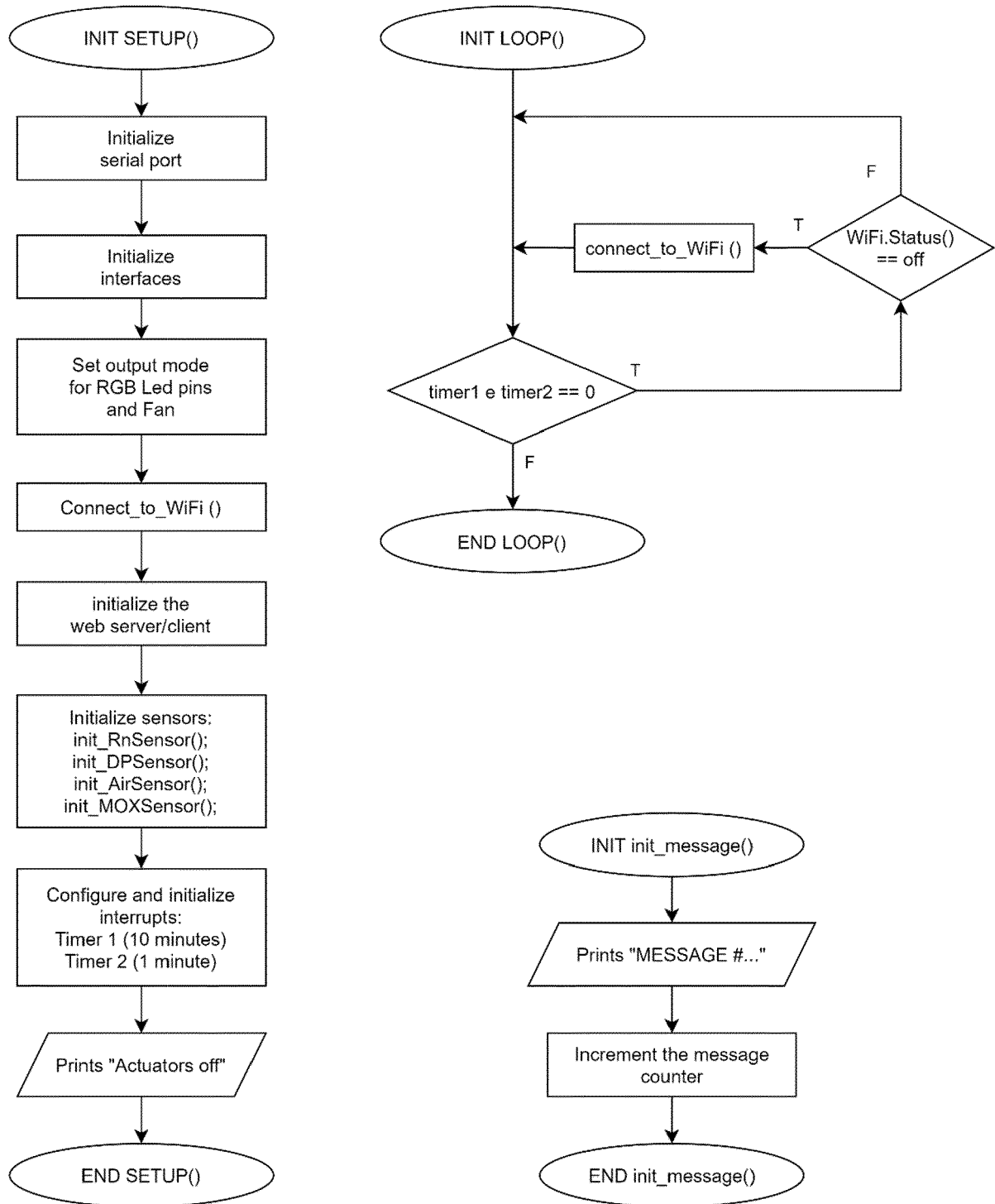


Fig. 4A

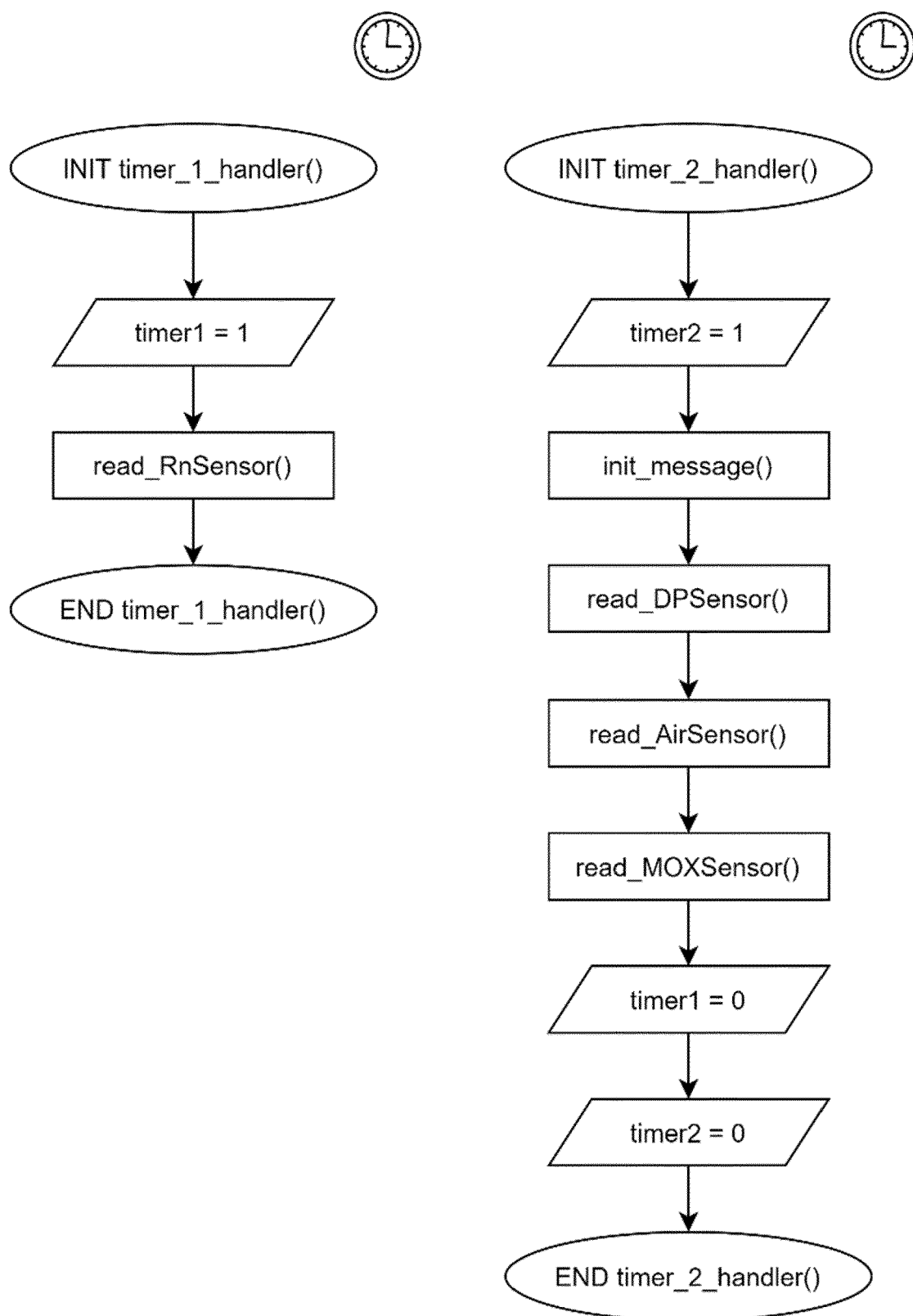


Fig. 4B

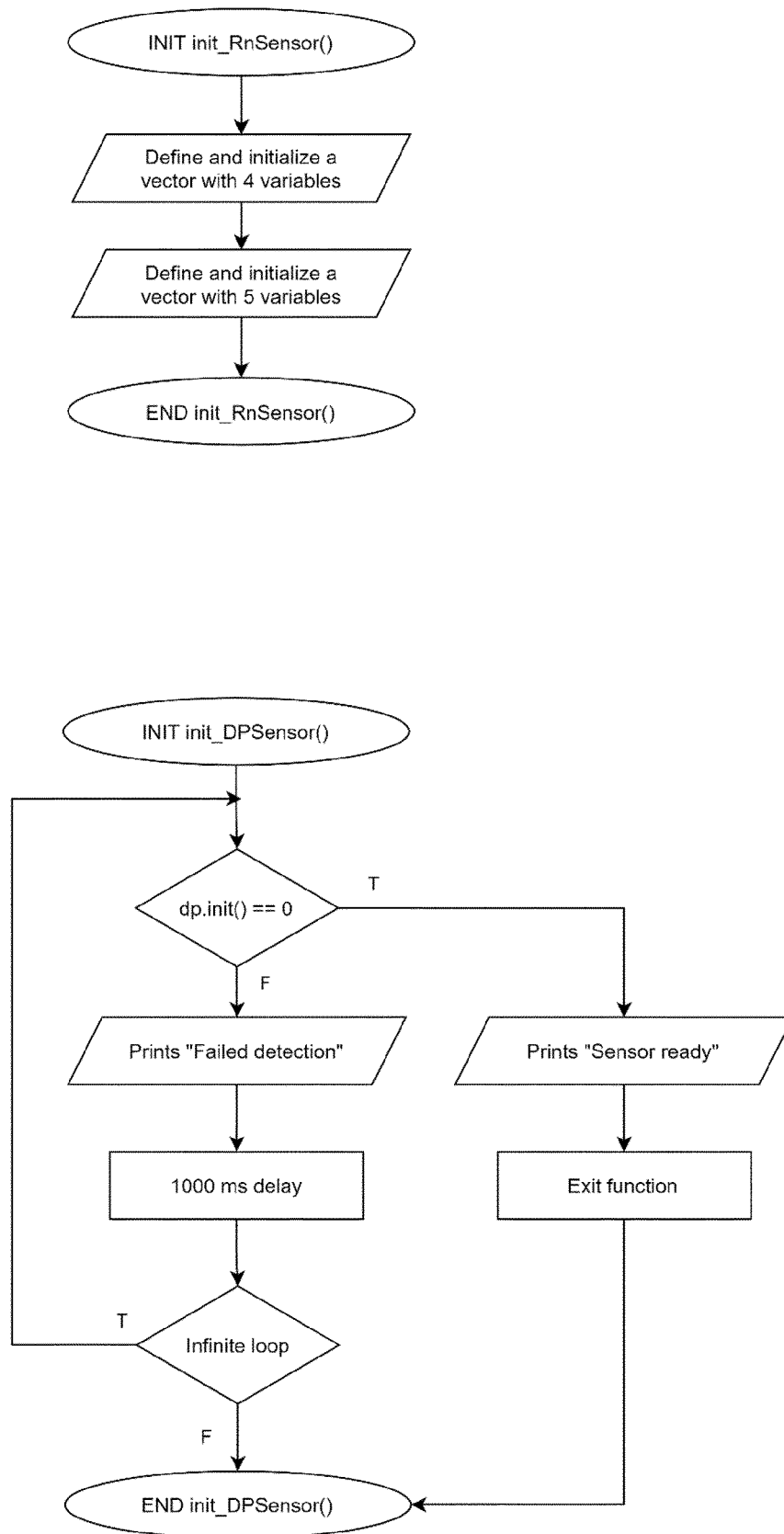


Fig. 5A

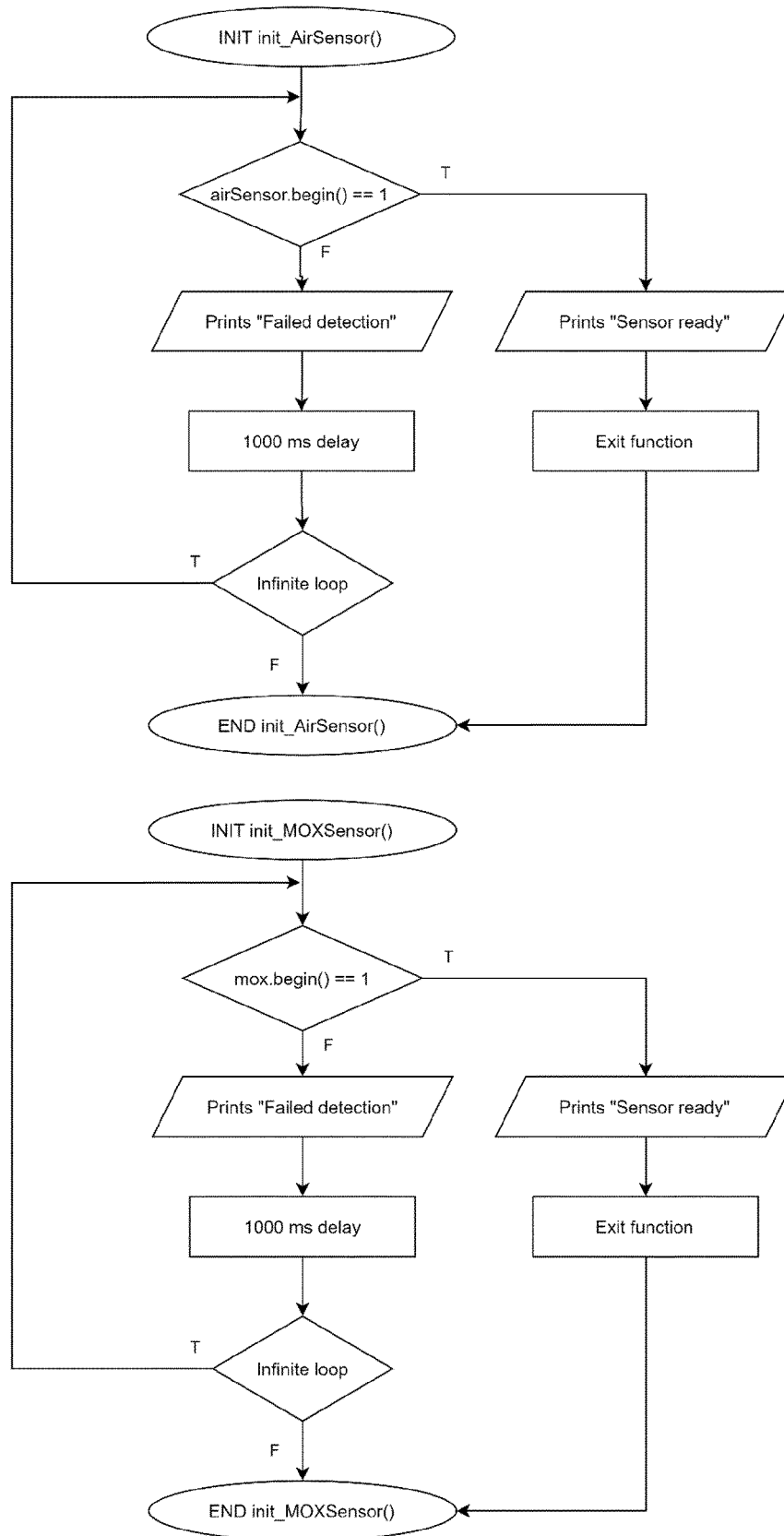


Fig. 5B

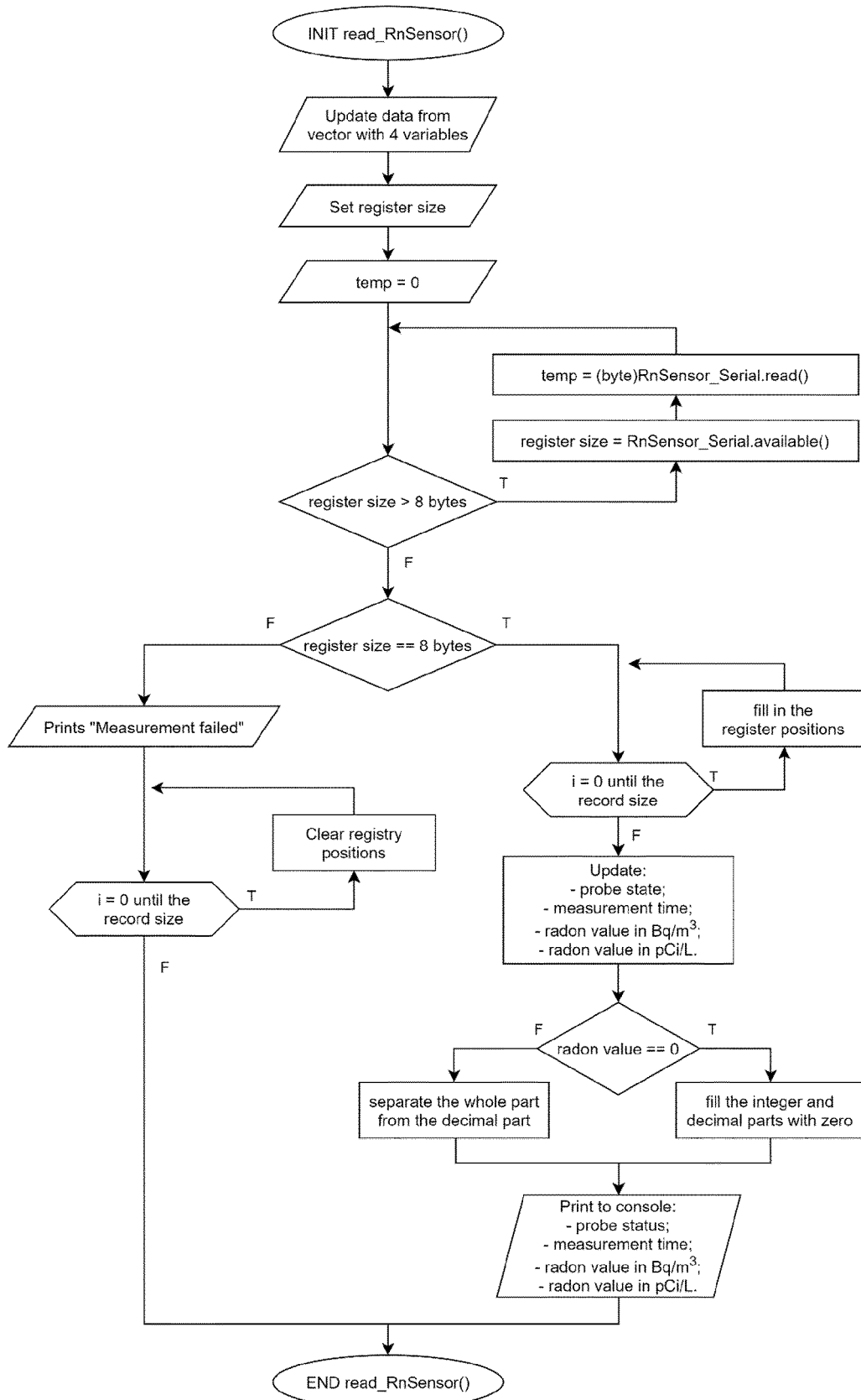


Fig. 6A

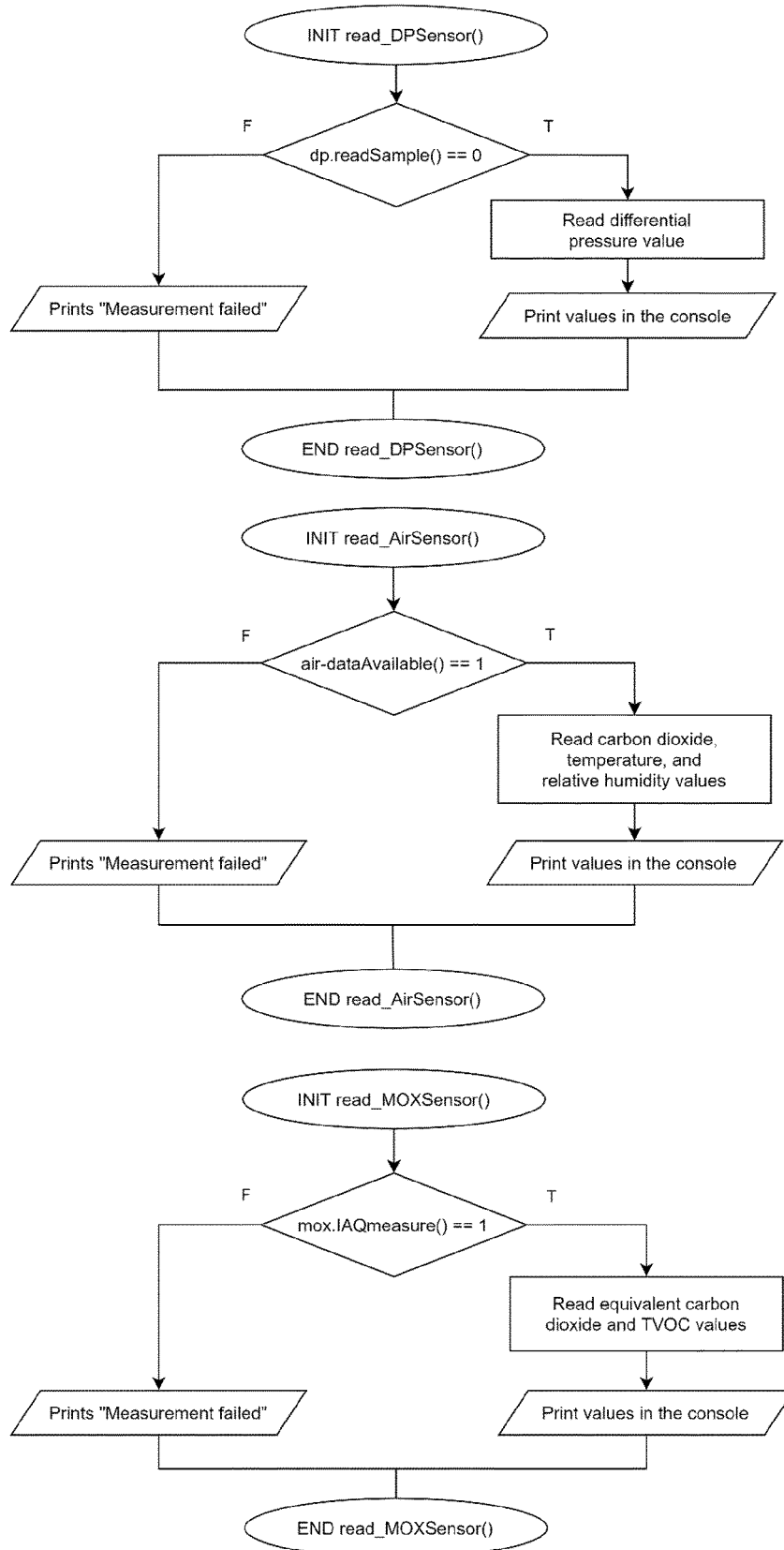


Fig. 6B

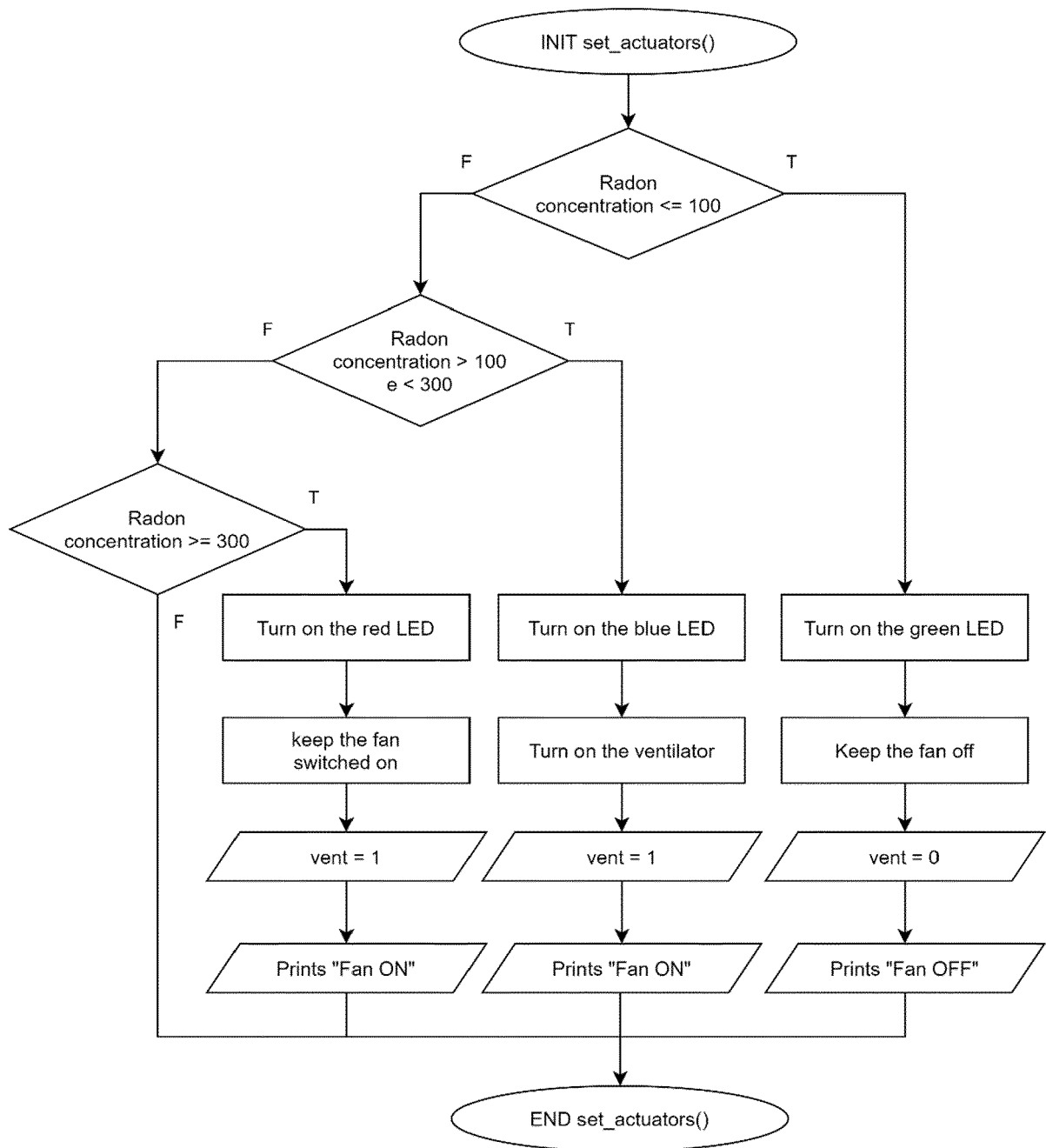


Fig. 7

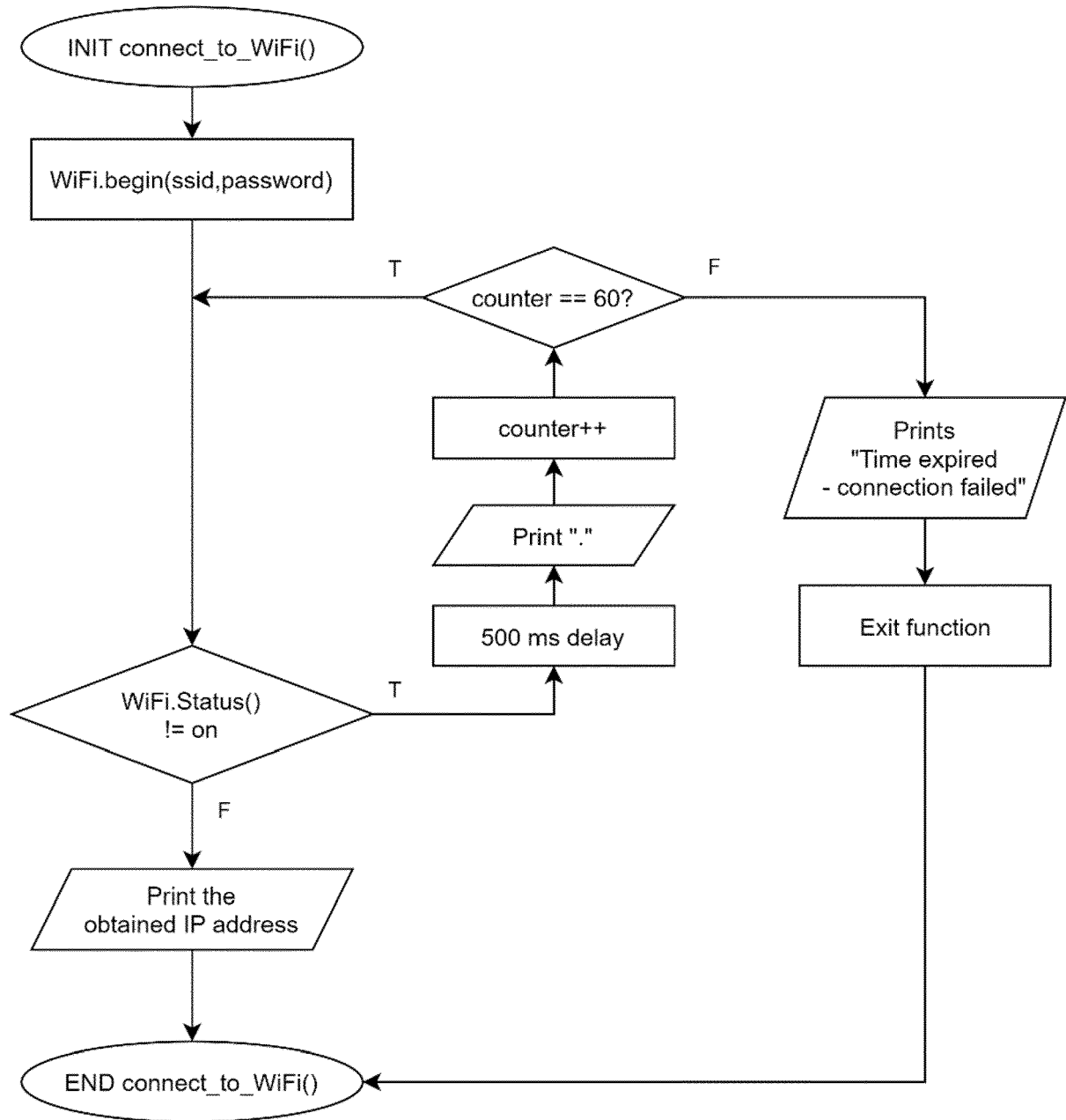


Fig. 8

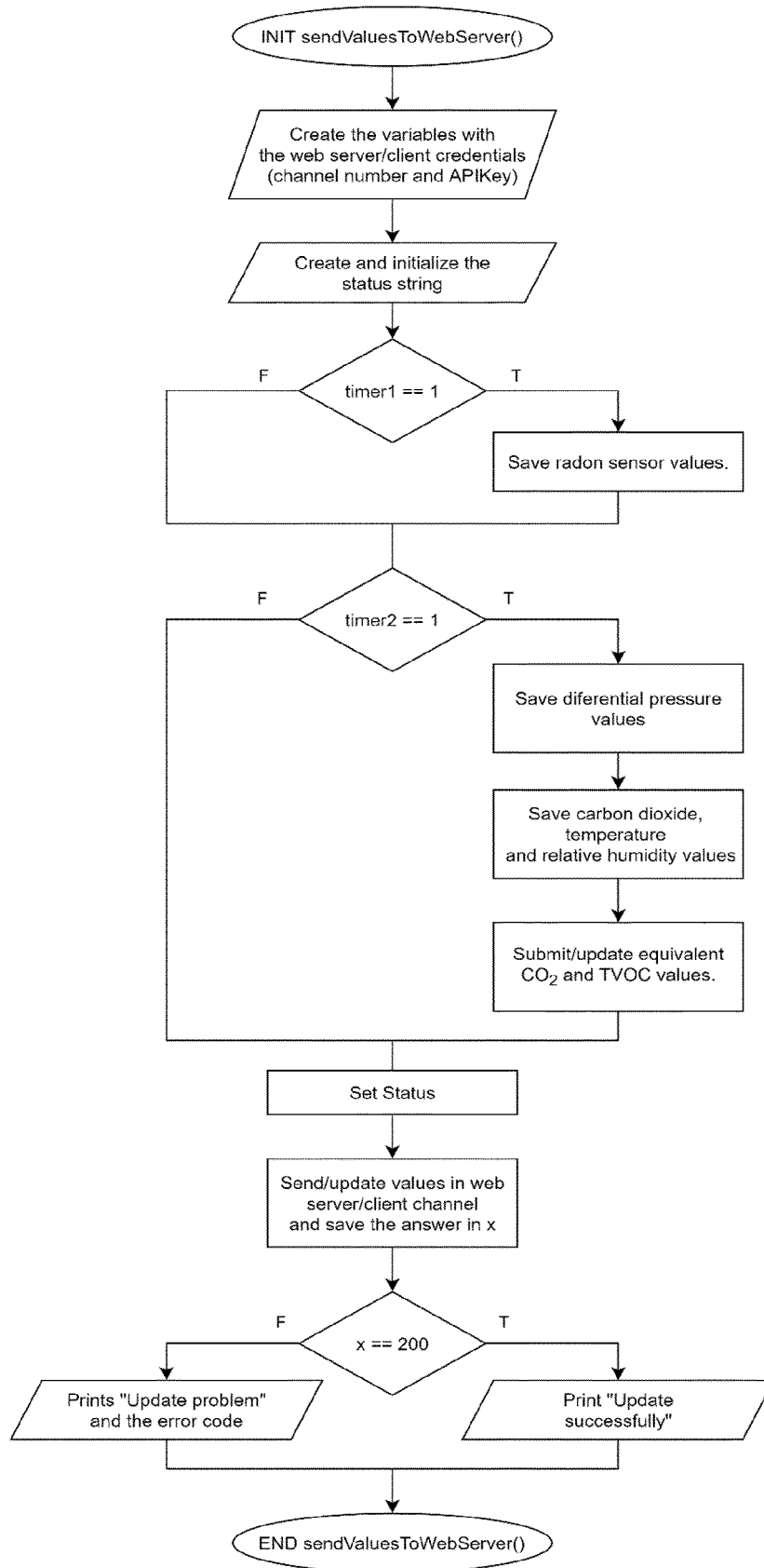


Fig. 9

COMPARISON OF RESULTS: RADON GAS CONCENTRATION

SINGLE HOUSE - Bedroom (ground floor)

— Legal limit - - - - Radon (Airthings Canary Pro) — Radon (IoT Device)

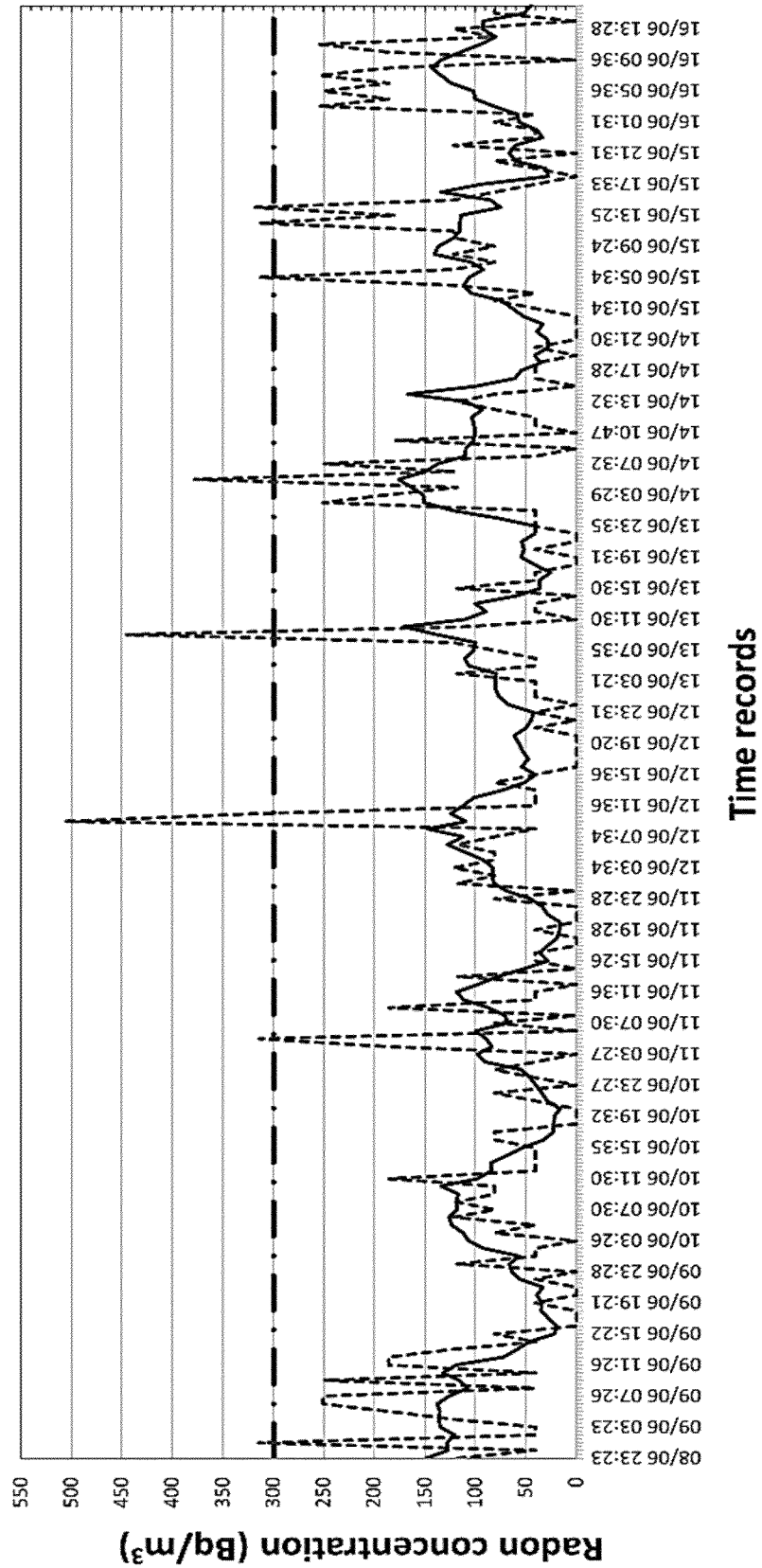
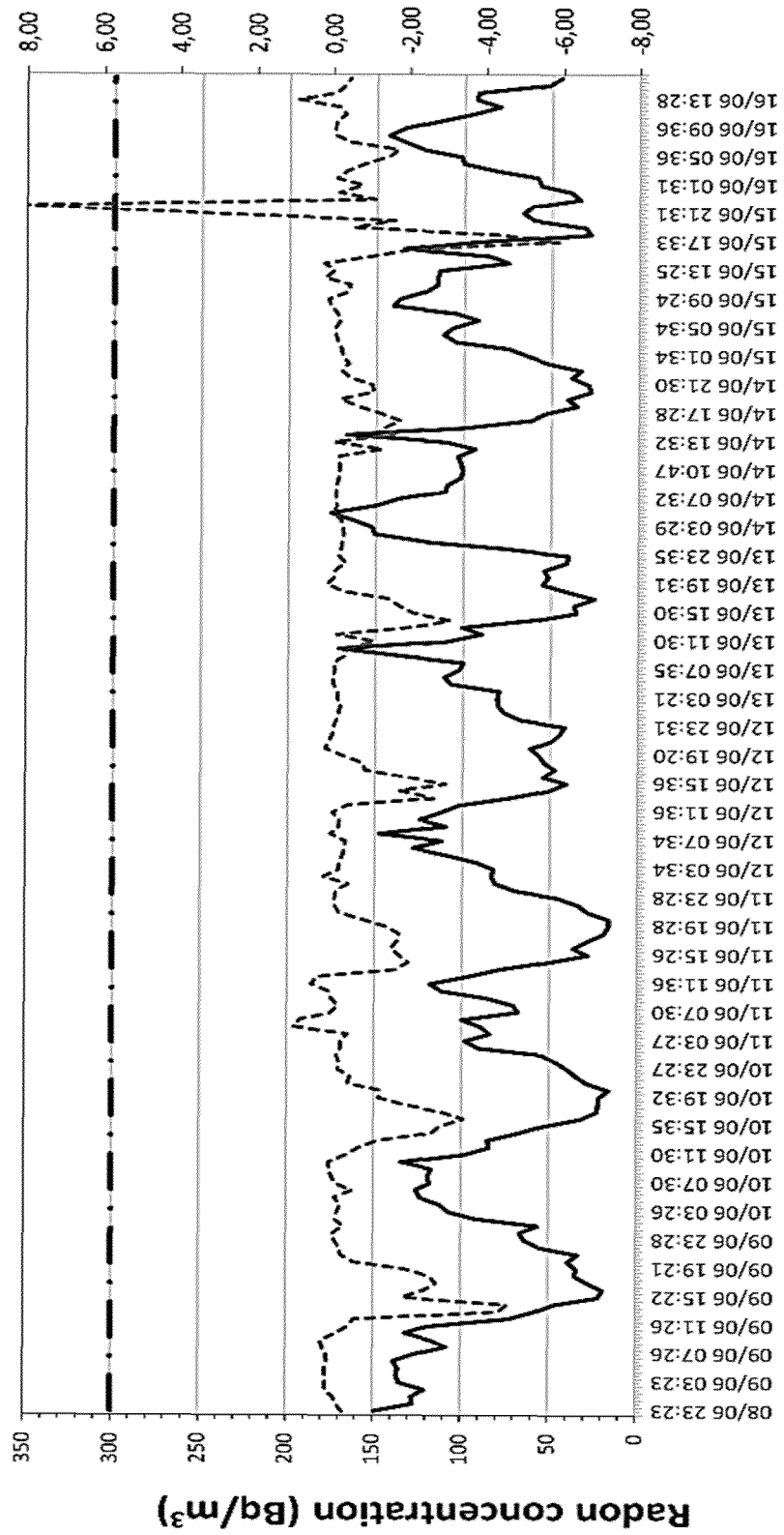


Fig. 10

GRAPHICAL CORRELATION BETWEEN RADON AND DIFFERENTIAL PRESSURE

SINGLE HOUSE - Bedroom (ground floor)

— Legal limit — Radon (IoT Device) - - - - Differential pressure (IoT Device)



Time records

Fig. 11



Fig. 12



EUROPEAN SEARCH REPORT

Application Number

EP 23 20 0621

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Place of search Munich		Date of completion of the search 28 February 2024	Examiner Degen, Marcello
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