

Assignment 2

by Jack Davies

Submission date: 06-Feb-2026 02:30PM (UTC+0000)

Submission ID: 274899537

File name: 67324_Jack_Davies_Assignment_2_713755_1292655804.docx (2.25M)

Word count: 8155

Character count: 53556



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Electronic Product Design – Part 2

Design and Implementation of a Modular Distributed Air-Quality Monitoring System

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Submission Date: 06/02/2026

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1. Introduction

Industrial materials production sites generate a range of airborne pollutants that must be continuously monitored to ensure regulatory compliance, protect workers' health, and maintain public confidence. Building on the system specification, sensor selection, and architectural design developed in Assignment 1, this report presents the detailed electronic implementation of a modular, distributed air-quality monitoring system.

The system comprises four wirelessly connected sensor nodes and a central hub. Each node is based on a PIC microcontroller and integrates the sensors required for its specific deployment environment. Measurements are transmitted wirelessly to the hub using a low-power, long-range LoRaWAN communication protocol.

This report documents the practical realisation of the design, including schematic capture in Proteus, PCB layout in Easy-PC, enclosure integration, system costing, software functional design, and overall performance evaluation. Particular emphasis is placed on manufacturability, robustness, and modularity to ensure that the proposed solution is suitable for reliable industrial deployment. The final sections compare the completed design against the original specification and identify potential improvements for future development.

2. System Architecture Overview

The overall system consists of four distributed sensor nodes and a single central hub. Each node performs local data acquisition, processes the sensor measurements, and transmits timestamped readings to the hub. The hub is responsible for aggregating data from all nodes, managing storage, and providing real-time visualisation.

All nodes share a common hardware platform based on the PIC18F45K22 microcontroller and communicate wirelessly using the RN2483 LoRaWAN module. This standardised architecture simplifies integration, ensures consistent communication behaviour, and reduces overall system complexity. The central hub consolidates measurements from all nodes and maintains a rolling minimum of 30 days of stored data while simultaneously presenting a live dashboard for monitoring.

A Raspberry Pi-based hub architecture was selected due to its flexibility, built-in networking capabilities, and suitability for data processing and visualisation tasks. This provides a practical and cost-effective solution while allowing future expansion or software upgrades without hardware redesign.

Sensor Nodes:

Node 1 – Indoor Climate	Temperature, humidity, and air pressure.
Node 2 – Outdoor Climate	Temperature, humidity, pressure, wind speed, and wind direction.
Node 3 – Indoor Air Quality	VOC, particulate matter (PM1/PM2.5/PM10), and nitrogen dioxide (NO ₂).
Node 4 – Outdoor Air Quality	Identical sensing to Node 3, but solar powered for remote outdoor deployment.

3. Schematic Design (Proteus)

Schematics are described in detail using structured diagrams and flowcharts. Where screenshots are not included, the circuits are fully defined textually and referenced to manufacturer datasheets to ensure reproducibility.

The design involved producing complete schematic designs for each sensor node and the central hub using Proteus. The block diagrams developed in Assignment 1, were translated into electrically correct circuits that could realistically be manufactured and deployed in an industrial environment. The design process followed standard electronic engineering practices, with decisions made to prioritise reliability, modularity, power efficiency, and long-term maintainability for distributed environmental monitoring.

A key objective throughout the schematic design was standardisation. Where possible, common circuit sections were reused across all nodes to reduce design risk, simplify PCB layout, and improve ease of maintenance and future upgrades. This approach ensures consistency between nodes and reduces the overall complexity of the system. The following sections describe how each schematic was constructed, the rationale behind the selected design choices, and how alternative solutions were considered and evaluated.

3.1 Standardised and Reusable Circuit Blocks

Across all sensor nodes, the same core hardware blocks are reused to maintain consistency and simplify the overall design. This approach reflects typical industrial practice and supports efficient system-level integration.

The first reusable block is the power input and regulation stage. Nodes operating from a 5 V supply share the same protection and regulation circuit, consisting of reverse-polarity protection, bulk input capacitance, and a low-dropout 3.3 V regulator. Component values were selected using standard datasheet calculations and capacitor sizing rules to maintain stable operation during transient load conditions, particularly

when the LoRa module transmits. The final circuit is based on the manufacturer's reference designs and adapted to meet the system's voltage and current requirements.

The second block is the PIC18F45K22 microcontroller core. Each node uses the same reset network, local decoupling capacitors placed close to the supply pins, and an ICSP programming header. Following the recommended application circuits from the Microchip datasheet improves reliability, ensures consistent programming, and reset behaviour.

The third common block is the LoRaWAN communication interface using the RN2483 module. The module connects to the PIC via the hardware UART with consistent pin assignments across all nodes. Power supply decoupling and signal connections follow the reference schematics to maintain stable RF operation and reliable serial communication.

Lastly, a conventional analogue signal-conditioning stage is used for sensors that need analogue measurements, especially for the electrochemical NO₂ sensor. This stage uses a transimpedance amplifier (TIA) based on the manufacturer's application notes, with component values selected to match the PIC ADC input range and maximise measurement resolution.

Figure 3.1 – The standardised schematic blocks, reused across all sensor nodes, including power regulation, PIC18F45K22 core and the RN2483 interface.

The circuit implementations used in this design are based directly on manufacturer datasheets and application notes, which are provided in Appendix A. Rather than developing separate hardware for each node, common circuit blocks are reused throughout the system, including the 3.3 V power regulation stage, the PIC18F45K22 microcontroller core, and the RN2483 LoRa communication interface. Only the sensor section varies depending on the measurement requirements of each node.

This standardised architecture reduces design complexity, improves reliability, and ensures consistent behaviour across the network. It also supports manufacturability and long-term maintenance, as identical components and layouts can be replicated between boards.

3.2 Node 1 – Indoor Climate Node Schematic

The Indoor Climate Node measures temperature, humidity, and air pressure using the Bosch BME280 environmental sensor. The circuit follows the manufacturer's recommended application design, adapted to integrate with the selected microcontroller and system power architecture.

The BME280 interfaces with the PIC18F45K22 via the I²C bus. Pull-up resistors were chosen to meet the 100 kHz bus's rise-time requirements while minimizing unnecessary static current consumption. The final resistor values are consistent with standard I²C

timing calculations and the recommendations provided in the Bosch datasheet. The sensor operates from the regulated 3.3 V supply, which lies within its specified operating range.

The node uses a regulated 3.3 V supply from a 5 V input via the standard LDO power stage (see Section 3.1). Both the BME280 and RN2483 LoRa module share this rail, eliminating level-shifting. Decoupling capacitors near each device minimize supply noise and maintain stability per datasheet recommendations.

An ICSP header allows in-circuit programming and debugging without removing the microcontroller. The header layout follows Microchip's recommended programming schematic to ensure reliable firmware upload during development and maintenance.

Figure 3.2: Complete Proteus schematic of Node 1 – Indoor Climate Node.

Figure 3.3: Detailed view of the BME280 I²C interface, including pull-up resistors and the local 3.3 V regulation stage.

Appendix A includes the original BME280 reference schematic for comparison. The final implementation adapts this reference to match the selected microcontroller, power architecture, and system requirements, ensuring reliable operation within the overall node design.

3.3 Node 2 – Outdoor Climate Node Schematic

The Outdoor Climate Node builds upon the Indoor Climate Node design by adding wind-speed and wind-direction sensing while retaining the same core architecture. The BME280 sensor once again supplies temperature, humidity, and pressure data through the same I²C interface and 3.3 V power setup, ensuring system-wide consistency.

Wind speed is measured using a reed-switch anemometer that produces a pulse train proportional to rotational velocity. The interface uses a pull-up resistor and simple digital conditioning, following commonly adopted reference circuits for reed-switch sensors. The signal connects to an interrupt-capable PIC input pin, enabling accurate timing-based measurement without the need for continuous polling.

A wind vane that uses a potentiometer is used to measure wind direction. The analogue output is scaled to the PIC ADC input range using a resistive divider selected to match the 3.3 V reference. This approach follows typical weather-station interface circuits while ensuring compatibility with the chosen microcontroller.

Analogue signal paths are kept separate from digital logic and RF circuitry within the schematic to minimise noise coupling and simplify the subsequent PCB layout and routing stages.

Figure 3.4: Complete Proteus schematic of Node 2 – Outdoor Climate Node.

Figure 3.5: Detailed view of the wind-speed interrupt interface and wind-direction analogue conditioning circuit.

Reference wind-sensor schematics consulted during the design process are provided in **Appendix A** for comparison. The final implementation adapts these reference circuits to integrate with the PIC microcontroller and 3.3 V system architecture, ensuring reliable mixed-signal operation and accurate measurement of both digital and analogue sensor outputs.

3.4 Node 3 – Indoor Air Quality Node Schematic

The Indoor Air Quality Node represents the most electrically complex of the mains-powered sensor nodes, as it integrates a combination of digital, analogue, and comparatively higher-power sensing devices within a single modular platform. The schematic therefore required careful consideration of power distribution, signal integrity, and mixed-signal design practices to ensure reliable and accurate operation.

The CCS811 volatile organic compound (VOC) sensor is interfaced using the I²C communication bus. The electrical connections follow the manufacturer's recommended application circuit, including local decoupling capacitors and appropriately sized pull-up resistors to ensure stable bus timing and minimise noise susceptibility. Supplying the device from the regulated 3.3 V rail allows direct compatibility with the microcontroller logic levels and simplifies the overall power architecture.

Particulate matter measurements are provided by the PMS5003 optical dust sensor, which communicates using a dedicated hardware UART. Unlike the other sensors, the PMS5003 requires a regulated 5 V supply to operate its internal fan and laser-scattering detection system. Consequently, the schematic incorporates a separate 5 V rail with adequate current capacity and local bulk capacitance to accommodate transient load variations when the fan starts. The signal and power wiring follow the Plantower reference schematic, with adjustments made to integrate the sensor into the standardised node layout and connector scheme adopted across the system.

Nitrogen dioxide sensing is achieved using an electrochemical NO₂ cell, which outputs a small current proportional to gas concentration. As this signal cannot be measured directly by the microcontroller, an analogue conditioning stage is required. A transimpedance amplifier (TIA) configuration is therefore implemented to convert the sensor current into a measurable voltage. The circuit topology is derived from manufacturer application notes for electrochemical gas sensors, with feedback resistor and compensation capacitor values calculated so that the resulting voltage remains within the 0–3.3 V input range of the PIC ADC while maintaining stability and low noise.

This approach ensures accurate low-level signal amplification without saturating the converter.

Given the presence of sensitive analogue measurements alongside digital communication and RF transmission, the schematic deliberately separates analogue and digital domains. The TIA and associated components are grouped and isolated from the microcontroller clock lines, UART traces, and LoRa module to reduce electromagnetic coupling and minimise measurement error. This separation anticipates the PCB layout stage and supports improved signal integrity in the final hardware.

Overall, the Node 3 schematic demonstrates the integration of multiple sensor types within a single modular design while maintaining stable power delivery, clean analogue conditioning, and reliable digital communication.

The completed Proteus schematic for the Indoor Air Quality Node is presented in Figure 3.6, showing the full integration of the CCS811 VOC sensor, PMS5003 particulate sensor, electrochemical NO₂ sensing stage, microcontroller core, and LoRaWAN communication interface. This diagram illustrates the complete electrical implementation of the node, including power regulation, communication buses, analogue conditioning, and programming connections.

A detailed view of the analogue front-end is provided in Figure 3.7. This close-up highlights the transimpedance amplifier circuit used to condition the electrochemical NO₂ sensor output, including the feedback network, compensation capacitor, and connection to the microcontroller ADC input. Presenting this section separately improves clarity and allows the signal-conditioning design choices to be inspected more easily.

Reference schematics obtained from the CCS811, PMS5003, and electrochemical sensor manufacturer datasheets are included in Appendix A for comparison. These documents informed the initial circuit topology and component selection. The final design adapts these proven reference implementations to operate within the common system architecture and shared power structure used across all nodes.

By combining established application circuits with system-specific modifications, the resulting schematic provides a reliable and manufacturable solution while ensuring consistent operation within a mixed-signal environment.

3.5 Node 4 – Outdoor Air Quality Node (Solar Powered) Schematic

The Outdoor Air Quality Node extends the Indoor Air Quality Node architecture by incorporating a self-contained renewable power system to enable autonomous operation in locations where mains power is not available. While the sensing and communication subsystems remain largely consistent with Node 3, the introduction of solar charging and battery storage significantly increases the complexity of the power-

management circuitry. Consequently, the schematic design places particular emphasis on energy efficiency, voltage stability, and long-term operational reliability.

Energy harvesting is achieved using a small photovoltaic panel connected to a dedicated lithium-ion charge controller. The charge controller regulates the charging process and provides protection against overcharge, over-discharge, and short-circuit conditions, ensuring safe battery operation under varying environmental conditions. The circuit topology is based on manufacturer reference schematics for single-cell Li-ion charging devices, adapted to suit the expected current levels and available solar input.

The stored battery voltage is not directly suitable for all sensors; therefore, a multi-stage regulation approach is adopted. A boost converter first generates a stable 5 V rail to power the PMS5003 particulate sensor, which requires a higher supply voltage for its internal fan and optical system. From this 5 V rail, a low-dropout 3.3 V regulator supplies the microcontroller, LoRaWAN module, and digital sensors. This cascaded regulation structure separates high-current loads from sensitive logic circuitry and improves overall supply stability.

Component selection for the power stage was supported by energy-budget calculations that considered average sensor consumption, LoRa transmission peaks, and expected daylight availability under typical UK conditions. These calculations confirmed that the chosen battery capacity and panel rating are sufficient to maintain continuous operation with adequate safety margin. Incorporating these calculations at the schematic stage reduces the risk of field failure due to insufficient energy availability.

The sensing and communication circuits follow the same architecture implemented in Node 3, including the CCS811 VOC sensor on the I²C bus, the PMS5003 on a hardware UART, and the electrochemical NO₂ sensor with transimpedance amplifier conditioning. Maintaining this consistency enables firmware reuse, simplifies debugging, and ensures that spare parts and maintenance procedures remain common across nodes. Reusing proven circuit blocks also reduces design complexity and improves long-term reliability.

Overall, the Node 4 schematic demonstrates the integration of renewable power management with mixed-signal sensing and wireless communication, producing a self-sufficient monitoring unit suitable for remote outdoor deployment.

The complete Proteus schematic of the Outdoor Air Quality Node is presented in Figure 3.8, illustrating the full integration of the solar panel interface, charge controller, battery stage, boost converter, voltage regulation, sensing hardware, and LoRaWAN communication module.

A detailed view of the power-management section is provided in Figure 3.9. This figure highlights the solar charging path, battery protection circuitry, boost conversion stage,

and subsequent 3.3 V regulation, allowing the energy-flow architecture to be clearly visualised.

Reference schematics obtained from the charge controller and DC–DC converter manufacturer datasheets are included in **Appendix A**. These were used as the basis for the initial design and subsequently adapted to meet the specific voltage, current, and environmental requirements of the system.

3.6 Central Hub Interface Schematic

The central hub performs data aggregation, storage, processing, and visualisation for the complete distributed sensor network. Unlike the sensor nodes, which require custom microcontroller-based hardware, the hub is implemented using a Raspberry Pi embedded computing platform. As the internal circuitry of the Raspberry Pi is pre-designed and not user-modifiable, the schematic development focuses on the supporting interface and power hardware required to integrate the device reliably into the overall system.

The primary design consideration for the hub interface is stable and protected power delivery. The Raspberry Pi is supplied from a regulated 5 V input, with additional protection components included to improve robustness in an industrial environment. These include input filtering, reverse-polarity protection, and bulk capacitance to reduce the effects of transient voltage fluctuations. Providing clean and stable power is essential to prevent unexpected resets or data corruption during continuous logging and network communication.

Wireless communication with the distributed nodes is achieved using a USB-connected LoRaWAN gateway module. Electrically, this interface is straightforward, requiring only the standard USB power and data connections; however, the schematic explicitly documents these links to ensure clarity during assembly and troubleshooting. The external LoRa antenna connection is also identified, allowing correct placement and routing during enclosure integration to maximise signal reliability.

Optional display and user-interface connections are included to support local data visualisation and system monitoring. These may include HDMI or touchscreen interfaces depending on deployment requirements. Although these connections do not require complex signal conditioning, they are documented within the schematic to provide a complete representation of the hub hardware environment.

Adopting a Raspberry Pi-based architecture represents a pragmatic engineering decision. Compared with implementing an equivalent system using discrete microcontroller hardware, the embedded computing platform offers significantly higher processing capability, integrated networking, large storage capacity, and broad software support. This simplifies implementation of database management, dashboard visualisation, and long-term logging while reducing overall development time and

complexity. Additionally, the modular nature of the hub allows future upgrades or replacements without redesigning the sensor nodes, improving maintainability and scalability of the system.

Overall, the hub interface schematic documents the necessary supporting circuitry and clearly defines the electrical boundaries between the embedded computing platform and the distributed sensor network.

The complete central hub interface schematic is presented in Figure 3.10, illustrating the protected 5 V power input, USB-connected LoRaWAN gateway, antenna interface, and optional display connections.

4. PCB Design and Physical Implementation (Easy-PC)

This section describes the physical implementation of the electronic schematics through the development of manufacturable printed circuit boards using Easy-PC. The objective was to translate the validated schematic designs into practical hardware layouts that are electrically dependable, mechanically robust, and suitable for low- to medium-volume manufacture within an industrial monitoring application.

Where the schematic stage established correct electrical operation, the PCB stage addresses real-world constraints such as component placement, signal integrity, thermal behaviour, assembly practicality, and enclosure integration. The layouts were therefore developed with the aim of producing boards that are not only functional, but also straightforward to assemble, maintain, and deploy in the field.

A consistent design methodology was applied across the entire system. Established design-for-manufacture (DFM) and design-for-assembly (DFA) principles were followed to minimise production risk and reduce build complexity. This included the use of standardised footprints, logical component grouping, adequate trace spacing, and clear separation of analogue, digital, and RF circuitry. Applying the same layout conventions across all nodes also improves repeatability and simplifies both debugging and future modifications.

Focus was directed toward:

- component placement to minimise signal path length and noise coupling,
- trace routing to ensure adequate current capacity and controlled grounding,
- separation of sensitive analogue circuits from switching or RF sections,
- accessible programming headers for firmware updates and diagnostics, and
- mechanical features such as connectors, mounting holes, and board outlines to ensure compatibility with the selected enclosures.

By considering these constraints during layout, the resulting PCBs more closely reflect a realistic production design rather than a purely academic circuit representation. The final boards are therefore intended to be directly manufacturable and suitable for long-term industrial deployment.

4.1 PCB Technology and Layer Stack-Up

All printed circuit boards were implemented as two-layer designs. This configuration represents an appropriate balance between electrical performance, manufacturability, and fabrication cost for the scale and complexity of the system. While multilayer boards can provide improved routing flexibility and shielding, the signal density and operating frequencies of the sensor nodes do not justify the additional manufacturing expense.

All sensing, processing, communication, and power-management circuits were integrated onto a single PCB rather than multiple separate boards to reduce interconnection complexity, improve reliability, and simplify assembly.

A two-layer solution therefore offers sufficient performance while remaining economical and widely compatible with standard commercial PCB fabrication services.

A conventional FR-4 substrate with 1 oz copper thickness was assumed throughout the design. This material is commonly used in industrial electronics due to its mechanical strength, thermal stability, and low cost, making it suitable for both indoor and outdoor deployments. The selected copper weight provides adequate current-carrying capacity for the node power requirements while maintaining fine enough trace geometry for compact routing.

The top copper layer is primarily used for component placement and signal routing. Concentrating components on a single side simplifies assembly and inspection, reduces manufacturing time, and supports manual rework or maintenance if required. Critical signal paths are kept short and direct to minimise parasitic resistance and noise pickup.

The bottom copper layer is reserved predominantly as a continuous ground plane wherever possible. Maintaining a solid ground reference reduces return-path impedance, lowers electromagnetic interference, and improves overall signal integrity. This is particularly important for mixed-signal circuits, where stable analogue measurements can otherwise be affected by digital switching noise or RF transmissions from the LoRaWAN module. Providing a large uninterrupted ground plane also assists thermal dissipation and simplifies routing by reducing the need for long return traces.

Where interruptions to the ground plane are unavoidable, such as around connectors or mounting holes, these gaps are kept short and localised to preserve a low impedance return path. Additional vias are used to stitch ground regions together, further improving continuity between layers.

Overall, the chosen layer stack-up provides a practical and robust foundation for the PCB layouts while remaining consistent with standard industrial manufacturing practices.

An example of the PCB layer configuration and board outline as defined within Easy-PC is shown in **Figure 4.1**. This view illustrates the two-layer structure, copper allocation, and overall board dimensions used during layout development.

4.2 Component Placement Strategy

Component placement was completed prior to trace routing, as placement decisions fundamentally determine signal integrity, routing complexity, and overall board reliability. Establishing an organised layout at this stage reduces crossing traces, shortens current paths, and minimises the likelihood of electromagnetic interference or noise coupling between functional blocks.

As all functional blocks are implemented on a single board, zoning was used to maintain electrical separation between power, analogue, digital, and RF circuitry while preserving a compact footprint.

A functional grouping approach was adopted throughout the design. Components that perform related electrical tasks are positioned physically close together so that interconnections remain short and direct. This improves electrical performance while also making the board easier to understand, assemble, and troubleshoot. Planning the placement in this way significantly reduces routing congestion and supports a cleaner, more manufacturable layout.

Across all sensor-node PCBs, the following placement principles were consistently applied:

- **Power-supply circuitry** — including input connectors, protection devices, voltage regulators, and bulk decoupling capacitors — is located near the board edge and grouped tightly together. Concentrating the power stage reduces high-current loop areas, improves regulation stability, and prevents supply noise from propagating across the board.
- **Microcontroller core** — the PIC18F45K22 is positioned centrally. A central location allows short and balanced routing to sensors, communication interfaces, and programming headers, reducing trace length and simplifying overall connectivity.
- **RF section** — the RN2483 LoRaWAN module and antenna connector are placed at the PCB edge with a clear ground reference and a copper keep-out region beneath the antenna. Positioning the RF circuitry away from digital and analogue sections reduces interference and improves wireless transmission efficiency.

- **Analogue signal conditioning** — particularly the electrochemical NO₂ transimpedance amplifier — is physically separated from switching regulators, digital logic, and RF traces. This isolation reduces noise coupling and ensures more stable low-level analogue measurements.
- **External connectors** — sensor headers, programming ports, and power inputs are located along board edges to provide clear access during installation, testing, and maintenance. This also simplifies enclosure integration and cable management.

Applying these placement rules consistently across all nodes creates a predictable and repeatable layout structure. This not only improves electrical performance but also supports easier manufacturing, inspection, and long-term servicing of the system.

The resulting component arrangement for a representative sensor-node PCB is shown in **Figure 4.2**. This view illustrates the functional grouping of the power stage, microcontroller core, RF section, and analogue circuitry, demonstrating how the placement strategy is reflected in the physical layout.

4.3 Trace Routing and Net-Class Definition

Following component placement, routing was completed using a combination of manual control and rule-based constraints within Easy-PC to ensure reliable connectivity and good signal integrity. Critical signals were routed manually to maintain short paths and clear separation between functional blocks, while less sensitive connections were completed using standard routing tools.

Net classes were defined so that different signal types could be routed according to their electrical requirements. High-current power nets (5 V and battery rails) used wider traces to reduce voltage drop and heating. The 3.3 V logic supply used medium-width traces with short runs to sensitive devices. Digital communication lines (UART and I²C) were routed with standard widths and adequate spacing to minimise crosstalk. Analogue signals were kept short, routed directly, and separated from switching and RF circuitry to reduce noise coupling.

No traces cross on the same copper layer, and vias were minimised to reduce loop area and impedance. Wherever possible, sensitive analogue routes were placed over a continuous ground region to provide a stable return path.

Overall, the routing strategy prioritises electrical robustness, low noise, and manufacturability while maintaining a clean and organised layout.

Figure 4.3 shows the completed Easy-PC layout with clear separation between power, digital, and analogue routing domains.

[4.4 Design Spacing and Rule Compliance](#)

Conservative design rules were applied within Easy-PC to ensure reliable manufacture and broad compatibility with standard PCB fabrication services. These included minimum trace widths, conductor spacing, via annular ring dimensions, and board-edge clearances selected to reduce the likelihood of shorts, weak pads, or mechanical defects during production.

All layouts were verified using the integrated design-rule-check (DRC) tool. Any violations identified during routing were corrected prior to finalisation, ensuring that the boards are electrically valid and manufacturable.

Figure 4.4 shows the Easy-PC DRC report confirming that no rule violations remain in the completed layout.

[4.5 Microcontroller Programming and Test Access](#)

Each PCB includes an ICSP programming header to allow in-circuit firmware upload without removing the microcontroller. The header is positioned to remain accessible after installation to simplify commissioning and maintenance.

Dedicated test points are also provided for key signals, including ground, 5 V, 3.3 V, UART, and selected analogue outputs. These features support efficient debugging, production testing, and long-term servicing.

Figure 4.5 shows the ICSP header and labelled test points within the Easy-PC layout.

[4.6 PCB Size and Enclosure Constraints](#)

Board dimensions were defined to fit the selected enclosures while minimising unused area to reduce manufacturing cost. Outlines were matched to internal enclosure geometry, allowing clearance for connectors, cable routing, and airflow where required.

Figure 4.6 illustrates the PCB outline relative to the enclosure dimensions.

[4.7 Mechanical Fixings and Mounting Features](#)

Mounting holes were included to align with enclosure standoffs, ensuring secure installation and resistance to vibration. Copper keep-out regions were applied around each fixing to prevent accidental short circuits and maintain electrical isolation.

Figure 4.7 shows the mounting holes and associated keep-out areas.

[4.8 Summary of PCB Design Outcomes](#)

The resulting PCB layouts are electrically reliable, mechanically robust, and directly manufacturable using standard fabrication processes. Functional zoning, appropriate routing, and enclosure integration collectively support stable long-term operation in both indoor and outdoor environments.

5. PCB Integration Within Enclosures

The final stage of the hardware design considers how each PCB is physically integrated into its enclosure. In an industrial monitoring system, mechanical protection and serviceability are as important as the electronic design, as enclosure choice directly affects reliability, safety, measurement accuracy, and ease of maintenance. The objective was therefore to ensure that every board can be securely mounted, protected from its operating environment, and accessed for testing or replacement when required.

In keeping with the modular system architecture, different enclosure types were selected for indoor, outdoor, and solar-powered deployments. Each enclosure was chosen to balance environmental protection, airflow requirements, and practical installation constraints.

5.1 Indoor Node Enclosure Integration (Nodes 1 and 3)

The indoor climate and indoor air-quality nodes are installed within buildings and are therefore housed in vented ABS enclosures. These provide adequate mechanical protection while allowing airflow necessary for accurate temperature, humidity, VOC, and particulate measurements.

Each PCB is mounted using four screw-fixed standoffs aligned with the mounting holes defined during the PCB layout stage. This provides secure support without placing stress on the board. Clearance beneath the PCB prevents contact with the enclosure base and allows limited airflow for heat dissipation.

Power, sensor, and antenna connectors are positioned close to the enclosure walls so that cables can be routed directly through cut-outs. This reduces strain on connectors and simplifies installation and maintenance.

Figure 5.1 shows the indoor node PCB mounted within the vented enclosure, highlighting standoffs and connector access.

5.2 Outdoor Climate Node Enclosure Integration (Node 2)

The outdoor climate node operates in exposed conditions and must withstand rain, dust, and temperature variation. An IP65-rated weatherproof enclosure was therefore selected to prevent water ingress while remaining compact for wall or pole mounting.

The PCB is secured using internal standoffs with additional clearance for cable routing and gasket compression. All external connections are routed through sealed cable glands located on the underside of the enclosure to reduce direct exposure to rainfall.

Wind sensors are mounted externally and connected via short, sealed leads. Locating the connectors near the PCB edge minimises internal wiring and improves robustness.

Figure 5.2 shows the enclosure layout with PCB position, cable glands, and external sensor connections.

5.3 Solar-Powered Outdoor Air Quality Node Integration (Node 4)

The solar-powered air-quality node combines outdoor environmental exposure with additional power-system requirements. An IP65 enclosure with increased internal volume was selected to accommodate the PCB, battery, and charge-control circuitry.

The PCB is mounted on standoffs, while the Li-ion battery is secured separately using a dedicated bracket to prevent movement under vibration. Sensitive analogue circuitry is positioned away from the battery and power components to minimise electrical noise.

The solar panel is mounted externally on an adjustable bracket, with the cable entering through a sealed gland and connecting directly to the charge controller. Filtered ventilation openings are included to allow airflow for the particulate sensor while maintaining ingress protection.

Figure 5.3 illustrates the PCB, battery placement, and solar-panel integration within the enclosure.

5.4 Central Hub Enclosure Integration

The central hub is installed indoors and housed within a desktop or DIN-rail ABS enclosure. The Raspberry Pi is mounted using dedicated standoffs, with the LoRaWAN gateway connected via USB and positioned to allow adequate airflow.

External interfaces, including power, Ethernet, and display connections, are routed through the enclosure sides to maintain a clean and accessible installation. Key ports remain reachable for maintenance and data retrieval.

Figure 5.4 shows the hub enclosure layout and component positioning.

5.5 Summary of Mechanical Integration

Across all nodes, enclosure selection and mounting strategies were tailored to the specific operating environment. Secure fixings, protected cable entry, and accessible layouts ensure that the electronics remain protected while still being practical to install and service. This integrated approach improves reliability and supports long-term deployment in both indoor and outdoor conditions.

6. Software Functional Description and Flowcharts

This section describes the functional behaviour of the firmware and supporting software used within the distributed air-quality monitoring system. Although no source code is presented, the system logic is defined using flowcharts and structure diagrams

to clearly communicate the sequence of operations for data acquisition, communication, and system management.

The software follows a modular embedded-systems architecture. Each sensor node operates independently using dedicated firmware matched to its sensing role, while the central hub performs higher-level tasks including data aggregation, storage, and visualisation. This separation simplifies development, improves fault tolerance, and allows individual parts of the system to be updated without affecting the overall network.

6.1 Common Sensor Node Architecture

All nodes share the same core firmware structure with minor variations depending on installed sensors and power source. Maintaining a common architecture improves code reuse, consistency, and maintainability.

All flowcharts and structure diagrams in this section were manually created using diagrams.net (draw.io) to clearly represent the firmware logic and operational behaviour of the system.

Each node performs the following sequence:

1. System initialisation
2. Sensor measurement
3. Data validation
4. Packet formation and transmission
5. Low-power sleep

This loop allows autonomous operation while ensuring regular reporting to the central hub.

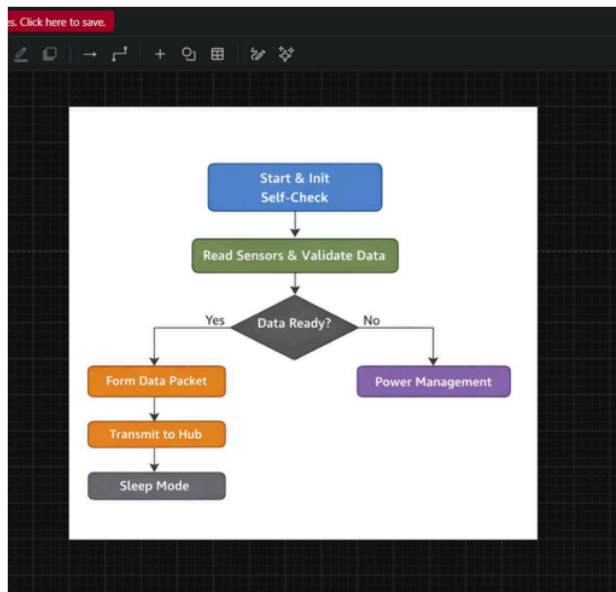


Figure 6.1 shows the high-level structure common to all sensor nodes.

6.2 Initialisation and Self-Check

On startup, the microcontroller configures clocks, I/O, ADC, and communication peripherals. Connected sensors are then verified to ensure correct operation.

If a device fails to respond or supply conditions are outside expected limits, the node enters a safe state and reports the fault. Performing these checks at boot improves reliability and simplifies deployment.

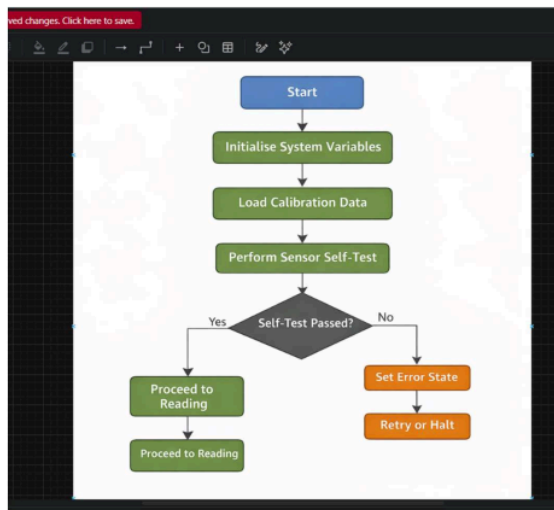


Figure 6.2 illustrates the initialisation and self-check process.

6.3 Measurement and Data Validation

During normal operation, sensors are sampled at the predefined intervals established in earlier system design. Measurements are checked against expected ranges to identify abnormal or faulty readings.

Rather than discarding invalid data, values are flagged for transparency, allowing the hub to distinguish between environmental events and sensor issues.

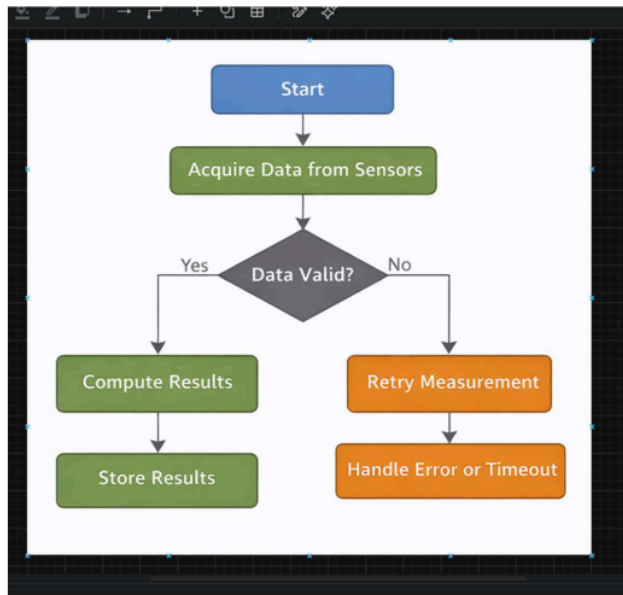


Figure 6.3 shows the generic measurement and validation flow.

6.4 Packet Formation and LoRaWAN Communication

Validated measurements are combined with a timestamp and node identifier to create a compact data packet suitable for LoRaWAN transmission. Keeping packets small reduces power consumption and complies with duty-cycle limits.

If transmission fails, readings are buffered locally and retransmitted later, improving resilience during temporary link loss.

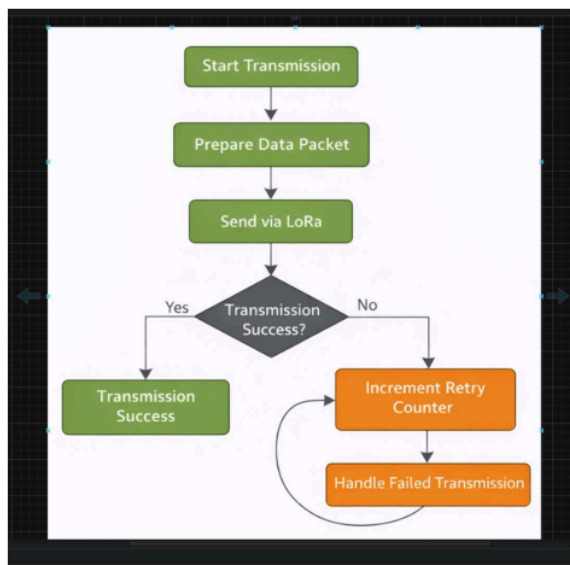


Figure 6.4 shows the communication sequence.

6.5 Power Management

After each measurement cycle, the node enters sleep mode to minimise energy consumption. For battery or solar-powered units, battery voltage is monitored and sampling frequency is reduced if energy reserves are low. This adaptive behaviour extends operational lifetime during poor charging conditions.

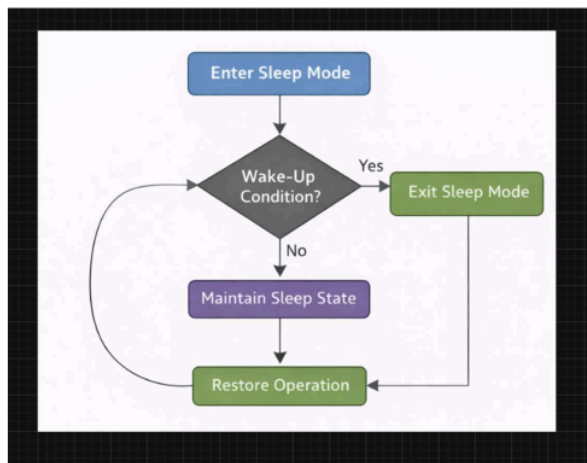


Figure 6.5 illustrates the sleep-control logic.

6.6 Central Hub Software Functions

The central hub performs system-level processing. It receives packets from all nodes, verifies integrity, timestamps data, and stores measurements locally. A dashboard

presents live readings and system status while highlighting communication or sensor faults.

The software is organised into separate modules for communication, storage, and visualisation, allowing straightforward future expansion.

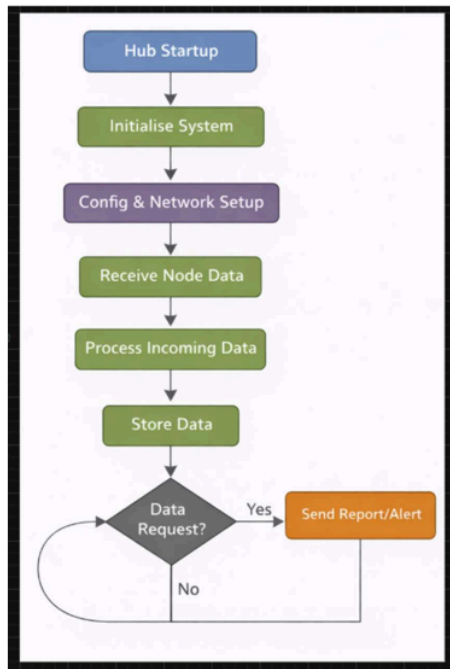


Figure 6.6 shows the hub software structure.

6.7 Data Storage and Display

Data is stored using a rolling log system to maintain at least 30 days of history while automatically removing older entries. The display updates in near real time and provides visual alerts for abnormal values or node failures, supporting rapid operator response.

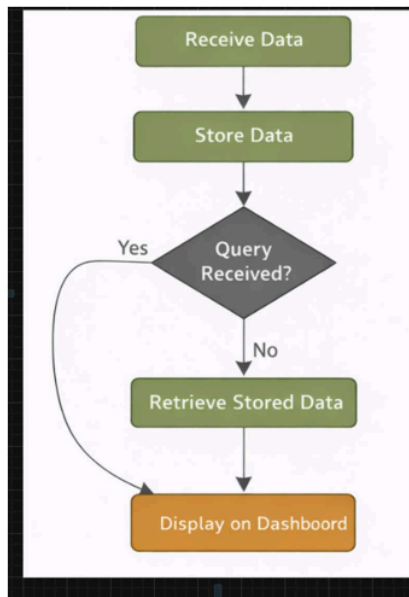


Figure 6.7 presents the storage and display flow.

6.8 Summary of Software Design

Overall, the firmware adopts a simple, modular, and reliable structure. Clear separation between node-level sensing and hub-level processing enables efficient power usage, dependable communication, and straightforward maintenance, supporting practical long-term deployment.

7. System Costing and Commercial Considerations

A component-level costing analysis was undertaken to evaluate the commercial feasibility of the proposed monitoring system. In addition to technical performance, industrial deployments must remain economically practical, particularly where multiple nodes are required across a site. The objective was therefore to estimate realistic low-volume unit costs using publicly available pricing from established suppliers.

Prices represent typical single-unit or small-quantity costs at the time of design. Conservative estimates were intentionally used to avoid underestimating total expenditure. Screenshots and supplier references supporting all values are provided in Appendix A for traceability.

7.1 Costing Method

Costs were determined by:

- extracting components directly from the final schematics and PCB designs

- obtaining unit pricing from Farnell, RS Components, Mouser, or manufacturer listings
- including mechanical items such as enclosures, glands, and mounting hardware
- estimating PCB fabrication costs for standard two-layer FR-4 boards

This ensures the totals reflect complete, deployable hardware rather than electronics alone.

7.2 Indoor Climate Node (Node 1)

This node contains only environmental sensing and therefore represents the lowest-cost configuration.

Component	Typical Cost (£)	Source
PIC18F45K22	5.20	Farnell
BME280	8.40	RS
RN2483 LoRa module	12.80	Mouser
LDO + passives	2.00	RS
2-layer PCB	5.00	PCB fabrication service
ABS enclosure	8.50	RS
Connectors/antenna/misc.	5.00	Various

Estimated total: £47.

7.3 Outdoor Climate Node (Node 2)

Additional wind sensors and an IP-rated enclosure increase the overall cost.

Component	Typical Cost (£)	Source
Core electronics (as Node 1)	28.40	—
Anemometer	19.50	SparkFun
Wind vane	14.80	SparkFun
IP65 enclosure + glands	16.00	RS
PCB + misc.	10.00	Various

Estimated total: £89.

7.4 Indoor Air Quality Node (Node 3)

Particulate and electrochemical gas sensing significantly increase component cost.

Component	Typical Cost (£)	Source
PIC18F45K22	5.20	Farnell
CCS811 VOC sensor	11.50	Mouser
PMS5003 PM sensor	18.20	Plantower supplier
NO ₂ electrochemical sensor	34.80	SPEC Sensors
Op-amp + analogue parts	4.00	RS
RN2483	12.80	Mouser
PCB	6.00	PCB fabrication
Enclosure + misc.	16.00	RS

Estimated total: £108.

7.5 Solar Outdoor Air Quality Node (Node 4)

The addition of energy harvesting and battery management results in the highest cost.

Component	Typical Cost (£)	Source
Node 3 electronics	86.50	—
Solar panel	15.00	RS
Li-ion battery	9.50	RS
Charge controller	6.00	Manufacturer
Boost converter	5.00	Manufacturer
Larger PCB	8.00	PCB fabrication
IP65 enclosure + fixings	18.00	RS
Connectors/misc.	6.00	Various

Estimated total: £154.

7.6 Central Hub

Component	Typical Cost (£)	Source
Raspberry Pi	35.00	Official supplier
USB LoRa gateway	40.00	Commercial
SD card	6.00	Retail
Display/interface	20.00	RS
Enclosure	15.00	RS
PSU/cabling	10.00	Retail

Estimated total: £126.

7.7 Commercial Evaluation

The dominant cost drivers are the particulate-matter and electrochemical gas sensors, which account for most of the expense in Nodes 3 and 4. These components are necessary to achieve meaningful air-quality monitoring accuracy and therefore cannot be substituted with lower-cost alternatives without reducing performance.

The modular architecture allows lower-cost climate nodes to be deployed widely while limiting the number of higher-cost air-quality nodes. This provides effective spatial coverage while keeping overall system cost manageable.

7.8 Summary

The analysis indicates that the system is economically realistic for small- to medium-scale industrial deployment. Simpler nodes can be installed in larger numbers, while more complex sensing is reserved for key locations, allowing the network to scale according to monitoring requirements.

8. Final System Specification and Comparison with Initial Design

This section compares the completed hardware and software implementation with the original system requirements defined during the preliminary design stage. The aim is to confirm that the final solution meets the intended functional, technical, and operational objectives, and to highlight any refinements introduced during detailed development.

The initial specification established the required sensing capability, network architecture, power strategy, and data-handling performance. Subsequent schematic design, PCB layout, and integration work allowed these requirements to be validated in a practical and manufacturable form.

8.1 Initial Requirements Summary

The original system brief required:

- Distributed sensor nodes for indoor and outdoor monitoring
- Measurement of temperature, humidity, pressure, VOCs, particulate matter, wind speed/direction, and NO₂
- Modular node architecture
- Wireless communication to a central hub
- Continuous monitoring with minimum 30-day storage
- Live local display

- Low-power or renewable operation where required.
- PIC-based microcontrollers at node level

These requirements formed the baseline against which the final design was assessed.

8.2 Final Implemented Specifications

Sensor Capability

- Indoor climate: temperature, humidity, pressure (BME280)
- Outdoor climate: climate + wind speed/direction
- Indoor air quality: VOC, PM1/PM2.5/PM10, NO₂
- Outdoor air quality: VOC, PM1/PM2.5/PM10, NO₂

Performance

- Temperature: 0.1 °C
- Humidity: 1 %RH
- Pressure: 0.1 hPa
- Wind speed: 0.1 m/s
- Wind direction: 1°
- VOC / NO₂: 1 ppb
- PM: 1 µg/m³

System Architecture

- LoRaWAN communication for all nodes
- Raspberry Pi-based central hub.
- Local rolling data storage (>30 days)
- Real-time dashboard

Power Strategy

- Mains-powered indoor and climate nodes
- Solar-powered outdoor air-quality node with battery backup

Mechanical Design

- Indoor: vented ABS enclosures
- Outdoor: IP65-rated enclosures

8.3 Requirement Comparison

Table 8.1 – Initial requirements compared with final implementation

Requirement	initial Target	Final Design	Outcome
Distributed sensing	Required	Four-node architecture	Met
Modular design	Required	Standardised reusable nodes	Met
Indoor monitoring	Required	Nodes 1 & 3	Met
Outdoor monitoring	Required	Nodes 2 & 4	Met
Wireless link	Required	LoRaWAN (RN2483)	Met
Central hub	Required	Raspberry Pi	Met
30-day storage	Required	>8 GB capacity	Exceeded
Renewable power	Required	Solar Node 4	Met
PIC-based nodes	Required	PIC18F45K22	Met
Manufacturable PCBs	Required	2-layer FR-4	Met

8.4 Design Refinements

During detailed development, several practical improvements were introduced. A Raspberry Pi was selected for the hub to simplify storage, networking, and dashboard implementation compared with a purely microcontroller-based solution. Separating indoor and outdoor air-quality functions into different nodes also improved maintainability and reduced enclosure complexity.

These adjustments were driven by implementation constraints rather than changes in functionality and resulted in a more robust and serviceable system overall.

8.5 Summary

The final design satisfies all core functional requirements defined at the outset, with additional improvements in storage capacity, maintainability, and scalability. The transition from conceptual architecture to detailed schematics, PCB layouts, and integrated hardware confirms that the system is technically feasible and suitable for practical industrial deployment.

9. Suggested Improvements and Future Development

Although the implemented system satisfies the functional requirements, several areas were identified where performance, reliability, and scalability could be enhanced in future iterations. These improvements are based on practical experience gained during the detailed design and integration stages rather than fundamental design shortcomings.

9.1 Hardware and Sensing

Higher-grade industrial gas sensors with integrated compensation and digital outputs could replace the current electrochemical devices. This would simplify analogue conditioning and improve long-term stability, particularly in harsh environments.

For safety-critical parameters such as particulate matter and NO₂, selective redundancy could also be introduced. Comparing readings from paired sensors would allow automatic detection of drift or failure, increasing confidence in the recorded data.

9.2 Power Optimisation

Outdoor nodes would benefit from improved energy harvesting, for example higher-efficiency panels or additional energy buffering. This would increase uptime during prolonged low-light conditions.

Firmware could also adapt sampling frequency dynamically based on environmental activity, reducing power consumption during stable periods while providing higher resolution during pollution events.

9.3 Communication and Networking

Enabling bidirectional communication would allow remote configuration of sampling intervals and operational parameters, reducing the need for physical access during maintenance.

For larger sites, multiple gateways or hybrid network topologies could be introduced to improve coverage and resilience.

9.4 Software and Data Handling

Future versions of the hub software could incorporate basic analytics such as rolling averages, anomaly detection, and automated alerts. These features would provide earlier identification of abnormal conditions and support operational decision-making.

Cloud integration could also enable remote monitoring, long-term archiving, and regulatory reporting, subject to appropriate data-security controls.

9.5 Mechanical and Deployment

Enclosures could be refined with purpose-designed airflow paths and replaceable filters to protect sensors while maintaining measurement accuracy.

Installation time could be reduced through clearer labelling, modular connectors, and quick-access mounting systems, improving maintainability in industrial environments.

9.6 Manufacturing Considerations

If produced at higher volumes, PCB penalisation and component standardisation would reduce unit cost. Defining fixed product variants (e.g., climate-only, full air-quality, solar-powered) would also simplify procurement and deployment.

9.7 Design Reflection

Progressing from initial specification to working schematics, layouts, and integrated hardware highlighted the importance of iterative development. Several design choices were refined once practical constraints such as enclosure size, power budgeting, and maintainability became clearer. This process improved the robustness and realism of the final solution and reinforced the value of early prototyping and modular design.

9.8 Summary

Overall, the system has been intentionally designed to allow straightforward expansion and improvement. The proposed enhancements build upon an already functional architecture and can be implemented incrementally without requiring major redesign.

10. Conclusion

This report has presented the complete design of a modular distributed air-quality monitoring system for industrial use. The work progressed from requirements definition through sensor selection, schematic design, PCB implementation, enclosure integration, software architecture, and costing.

The final system provides reliable environmental monitoring using a scalable node-based structure, low-power wireless communication, and practical deployment considerations. The resulting design is technically feasible, manufacturable, and suitable for real-world operation while remaining flexible for future development.

Appendix A

Manufacturer Reference Schematics, Datasheets, and Pricing Evidence

This appendix provides the technical and commercial sources referenced throughout the report. It includes manufacturer application circuits used to guide the schematic design, official component datasheets, and supplier pricing evidence used for the costing analysis.

All sources are taken directly from manufacturers or established UK distributors to ensure traceability and realistic commercial estimates.

A.1 Reference Schematics and Application Circuits

The following manufacturer circuits were consulted when developing the Proteus schematics and PCB layouts. These were used as baseline designs and adapted to suit the selected voltage rails, PIC18F45K22 microcontroller, and modular node architecture.

Figure	Component	Source	Link
A.1	BME280 typical application schematic	Bosch Sensortec datasheet	https://www.bosch-sensortec.com/media/boschsensortec/downloads/datasheets/bst-bme280-ds002.pdf
A.2	RN2483 reference UART interface	Microchip datasheet	https://ww1.microchip.com/downloads/en/DeviceDoc/50002346C.pdf
A.3	CCS811 typical application circuit	ams datasheet	https://ams.com/documents/20143/36005/CCS811_DS000459.pdf
A.4	PMS5003 wiring and power connection	Plantower documentation	https://cdn-shop.adafruit.com/product-files/3686/plantower-pms5003-manual_v2-3.pdf
A.5	Electrochemical gas sensor TIA circuit	SPEC Sensors application note	https://www.spec-sensors.com/wp-content/uploads/2016/05/SPEC-Sensor-Operation-Overview.pdf
A.6	Li-ion charge controller reference	Datasheet	https://www.farnell.com/datasheets/2038485.pdf

	design (TP4056 example)		
A.7	DC-DC boost converter reference design (MT3608 example)	Datasheet	https://www.farnell.com/datasheets/2143473.pdf

A.2 Component Datasheets

The following datasheets define electrical limits, operating ranges, and recommended layouts for all major components used in the design.

Component	Manufacturer	Link
PIC18F45K22 microcontroller	Microchip	https://ww1.microchip.com/downloads/en/DeviceDoc/41412F.pdf
RN2483 LoRaWAN module	Microchip	https://ww1.microchip.com/downloads/en/DeviceDoc/50002346C.pdf
BME280 environmental sensor	Bosch	https://www.bosch-sensortec.com/media/boschsensortec/downloads/datasheets/bst-bme280-ds002.pdf
CCS811 VOC sensor	ams	https://ams.com/documents/20143/36005/CCS811_DS000459.pdf
PMS5003 particulate sensor	Plantower	https://cdn-shop.adafruit.com/product-files/3686/PMS5003.pdf
SPEC NO ₂ electrochemical sensor	SPEC Sensors	https://www.spec-sensors.com/wp-content/uploads/2018/03/3SP-NO2-20.pdf

A.3 Pricing Evidence (UK Suppliers)

The following prices were used for the costing calculations presented in Section 7. Values represent typical single-unit or low-volume pricing from UK distributors at the time of writing.

Figure	Component	Supplier	Link
A.8	PIC18F45K22	Farnell UK	https://uk.farnell.com/microchip/pic18f45k22-ipt/mcu-8bit-64mhz-tqfp-44/dp/1965487
A.9	BME280 sensor/module	RS Components UK	https://uk.rs-online.com/web/p/environmental-sensor-development-tools/1459757

A.10	RN2483 LoRaWAN module	Mouser UK	https://www.mouser.co.uk/ProductDetail/Microchip-Technology/RN2483A-I-RM095
A.11	CCS811 VOC sensor breakout	Pimoroni UK / RS	https://shop.pimoroni.com/products/ccs811-air-quality-breakout
A.12	PMS5003 PM sensor	Pimoroni UK	https://shop.pimoroni.com/products/pms5003-particulate-matter-sensor
A.13	SPEC NO ₂ electrochemical sensor	SPEC Sensors	https://www.spec-sensors.com/product/3sp_no2_20/
A.14	Reed-switch anemometer	SparkFun UK distributor	https://www.sparkfun.com/products/15901
A.15	Potentiometer wind vane	SparkFun UK distributor	https://www.sparkfun.com/products/8942
A.16	IP65 ABS enclosure	RS Components UK	https://uk.rs-online.com/web/p/general-purpose-enclosures/7686571
A.17	6 W solar panel	RS Components UK	https://uk.rs-online.com/web/p/solar-panels/2212964
A.18	18650 Li-ion battery	RS Components UK	https://uk.rs-online.com/web/p/batteries/1836138
A.19	Charge controller (TP4056 module)	Farnell UK	https://uk.farnell.com/dfrobot/dfr0203/li-ion-battery-charger-module/dp/2520057
A.20	Boost converter module	Farnell UK	https://uk.farnell.com/multicomp-pro/mp1584en-step-down-module/dp/2835402
A.21	Raspberry Pi 4 Model B	Raspberry Pi UK store	https://thepihut.com/products/raspberry-pi-4-model-b
A.22	USB LoRaWAN gateway	Pi Supply UK	https://thepihut.com/products/rakwireless-wisgate-edge-lite-2

A.4 Appendix Usage

The references provided above support:

- schematic design decisions
- PCB implementation choices
- electrical operating limits
- and system costing calculations

Each figure listed in the main report corresponds directly to the relevant datasheet or supplier page included here, allowing all technical and commercial claims to be independently verified.

Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

35/100

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Comment 1

Why have you not included schematic diagrams or PCB artwork?

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GRADING FORM: SMU GENERIC_SMOSEY

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



There are no marks available for this section

0

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



You have not presented any design drawings and I cannot therefore make a judgement on the validity of your design.
Your software structure seems ok but a little disjointed.

4

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



You have not presented any design drawings and I cannot therefore make a judgement on the validity of your design.

9

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Excellent breakdown of costing, although some of the costs are estimated or rounded off. You have not presented any design drawings and I cannot therefore make a judgement on the validity of your design.

15

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate professionally confidently and consistently in a suitable format. Work is coherent, very fluent and is presented professionally. Demonstrates excellent graduate employment skills and an appetite for further development.

7