Air quality measurement and logging in taxi ranks and inside of taxis

Willem Cornelis Rossouw

22823700

Report presented in partial fulfilment of the requirements of the module Project (E) 448 for the degree Baccalaureus in Engineering (Electrical and Electronic) in the Faculty of Engineering at Stellenbosch University.

Supervisor: Prof. MJ (Thinus) Booysen

May 2023

Acknowledgements

I would like to thank my supervisor Thinus Booysen for giving me this skripsie topic and for his enthusiasm in his work. I would also like to thank my friend and co-(soon-to-be)-engineer Phillip, for keeping me sane for most of my degree.

Plagiaatverklaring / *Plagiarism Declaration*

1. Plagiaat is die oorneem en gebruik van die idees, materiaal en ander intellektuele eiendom van ander persone asof dit jou eie werk is.
   Plagiarism is the use of ideas, material and other intellectual property of another's work and to present is as my own.

2. Ek erken dat die pleeg van plagiaat 'n strafbare oortreding is aangesien dit 'n vorm van diefstal is.
   I agree that plagiarism is a punishable offence because it constitutes theft.

3. Ek verstaan ook dat direkte vertalings plagiaat is.
   I also understand that direct translations are plagiarism.

4. Dienooreenkomstig is alle aanhalings en bydraes vanuit enige bron (ingesluit die internet) volledig verwys (erken). Ek erken dat die woordelikse aanhaal van teks sonder aanhalingstekens (selfs al word die bron volledig erken) plagiaat is.
   Accordingly all quotations and contributions from any source whatsoever (including the internet) have been cited fully. I understand that the reproduction of text without quotation marks (even when the source is cited) is plagiarism

5. Ek verklaar dat die werk in hierdie skryfstuk vervat, behalwe waar anders aangedui, my eie oorspronklike werk is en dat ek dit nie vantevore in die geheel of gedeeltelik ingehandig het vir bepunting in hierdie module/werkstuk of 'n ander module/werkstuk nie.
   I declare that the work contained in this assignment, except where otherwise stated, is my original work and that I have not previously (in its entirety or in part) submitted it for grading in this module/assignment or another module/assignment.

22823700 Studentenommer / *Student number*	Handtekening / *Signature*
W.C. Rossouw Voorletters en van / *Initials and surname*	April 12, 2023 Datum / *Date*

Abstract

English

The English abstract.

Afrikaans

Die Afrikaanse uittreksel.

Contents

List of Figures

List of Tables

Nomenclature

Acronyms and abbreviations

PM	Particulate Matter
VOC	Volatile Organic Compounds
UART	Universal Asynchronous Receiver / Transmitter
i2c	Inter-Integrated Circuit
UFP	Ultrafine Particle
LPG	Liquefied Petroleum Gas
CNG	Compressed Natural Gas
PPM	Parts Per Million
PPB	Parts Per Billion
NDIR	Nondispersive Infrared
PID	Photoionization Detector
FID	Flame Ionization Detector
MOS	Oxide Semiconductor Sensor
UV	Ultraviolet
AQI	Air Quality Index
IO	Inputs and Outputs
HAT	Hardware Attached on Top

Chapter 1

Introduction

1.1. Background

The majority of South Africa's public sector uses taxis as a means of transport. Millions of commuters use taxis frequently and depend on them for all of their mobility needs [6]. The South African government has recognized the impact of taxi emissions on air quality and has taken steps to address the issue. In 2006, the government gazetted regulations that required taxi operators to convert their vehicles to run on cleaner fuels, such as liquefied petroleum gas (LPG), compressed natural gas (CNG), or diesel with lower sulfur content [4].

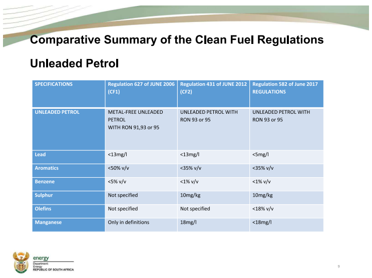

Figure 1.1: Unleaded [4]

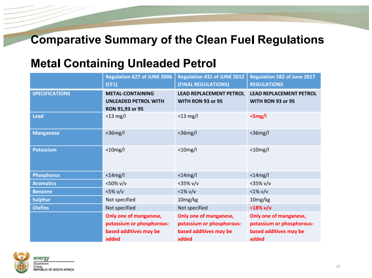

Figure 1.2: Metal+ Unleaded [4]

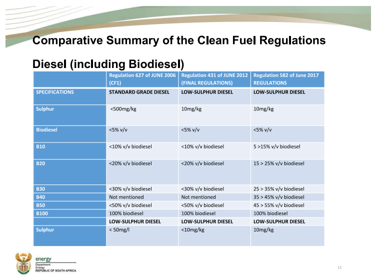

Figure 1.3: Diesel [4]

However, the implementation of these regulations has been slow and often ineffective as seen in figures 1.1, 1.2 and 1.3, resulting in continued poor air quality in many areas. As a result, the effects of air quality in taxis on human health and the impact of taxi exhaust emissions are issues unique to South Africa.

The main sources of air pollution in South Africa are industrial activities, power generation, vehicle emissions, biomass burning, and domestic fuel use [7]. Among these sources, vehicle emissions are particularly relevant for taxi commuters, who are exposed to high levels of pollutants such as particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOCs) [8]. These pollutants can have adverse effects on respiratory, cardiovascular, neurological, and immune systems, as well as increase the risk of cancer and premature death [9].

1.2. Problem Statement

Despite the popularity and importance of taxis in South Africa, there is a lack of research on the air quality inside these vehicles and at taxi ranks. Air quality is a crucial factor for human health and well-being, especially for commuters who spend long hours in taxis exposed to various pollutants. Moreover, taxi emissions contribute to the overall air pollution in crowded spaces(in this case taxi ranks), which affects the environment and the quality of life of the passers by. The closest studies being that of inside single cab taxis [2], road based pollution [10] and general pollution [3]. Therefore, there is a need for a comprehensive study on the air quality in taxis and taxi ranks and its impacts on human health and the environment.

1.3. Objectives

The objective of the study will be as follows:

- To measure and compare the levels of CO2, VOC, particulate matter and NOx both inside taxis and in taxi ranks to that of a known baseline.
- Identify the primary sources of air pollution in taxi ranks and within taxis and evaluate the impact of environmental factors, such as traffic congestion and weather conditions(optional- time limited).
- To investigate the potential health risks associated with exposure to air pollution in taxi ranks and within taxis, particularly for passengers, drivers and potential third parties.
- To evaluate the effectiveness of current measures in place to reduce air pollution from taxis, such as emission standards and regulations.
- Propose potential strategies to mitigate the impact of from taxis on public health and the environment such as implementing new technologies.

1.4. Scope

The scope of the project encompasses only the following:

- Building of base station and portable sensor module
- Development of communication network for satellite module and base station as well as data storage and backup

- Deployment of sensor and network
- Analysis of data gathered

1.5. Report Overview

NEED TO DO THIS

Chapter 2

Background Study

2.1. Related Work and Existing Solutions

2.1.1. Related Work

2.1.1.1. Air quality at bus stops [1]

This article was a case study of air quality monitoring at a bus stop in an underpass on the campus of Lancaster University. The bus stop was suspected to have high levels of air pollution due to the large number of vehicles passing through the tunnel. They used an Aeroqual AQY Micro Air Quality Station to measure the concentrations of NO_2, PM_{10} and $PM_{2.5}$ at the bus stop.

2.1.1.2. Exposure to traffic air pollutants in taxicabs [2]

This study reviewed the level of pollutants present inside taxi cabs(American style taxis). The article reports that the exposure studies show that traffic related air pollutants concentrations inside taxicabs are higher than their urban background. This was a research based study.

2.1.1.3. An investigation into the environmental impact of the taxi industry in Butterworth [3]

This study analysed the environmental impact of the taxi industry in South Africa, by surveying a fleet of taxis in Butterworth, they do simple analogue measures such as dust gauges and soil and water analysis.

2.1.2. Existing Solutions

2.1.2.1. Aeroqual AQY

This sensor was used in a similar study done to determine the air quality at bus stops [1]. The sensor solution used consists of sensors for the following along with provided ranges [11]:

- Particulate matter ($PM_{2.5}$ & PM_{10}) 0-1000 µg
- Ozone
- Nitrogen Dioxide 0-500 ppb
- Temperature and Relative Humidity
- Dew point

This sensor lacks Carbon Dioxide measuring and lacks detailed specification on ranges' error.

2.1.2.2. Airthings View Plus

This sensor suite was designed for home use, it features:

- Particulate matter ($PM_{2.5}$ 0-200µg
- Carbon dioxide 400–5000 ppm
- VOC
- Radon

This sensor was not intended to be extremely accurate and seems to be more for sensing danger than accurate measuring. It does include a handy chart for what should be considered normal levels for the different sensors as seen in Figure C.1

2.2. Air Quality Monitoring Methods

2.2.1. Sensors

2.2.1.1. Carbon Dioxide (CO_2)

There are two main types of CO2 sensors: infrared gas sensors (NDIR) and chemical gas sensors. [12] The most common and more accurate sensor type is the NDIR sensor. Chemical sensors typically use less power and can be smaller but are less accurate and are more prone to aging effects.

2.2.1.2. VOC

VOC sensors measure volatile organic compounds in the air, such as what is found in petroleum fuels. There are three main types of sensors used to detect VOC [13] [14]:

- photoionization detector (PID)
- flame ionization detector (FID)
- metal oxide semiconductor sensor (MOS)

PID sensors uses ultraviolet light to ionize the VOC molecules and measure the electric current. They are typically used for low concentrations. FID sensors, are similar to PID sensors, but use a flame instead of UV light. A MOS sensor uses a heated metal oxide film that reacts with VOC and measures the change in resistance. This sensor is typically used from low to medium concentration. [13] [14]

2.2.1.3. PM

Particulate matter sensors measure the concentration and size of airborne particles. They use different methods to detect particles, such as:

- light scattering
- light obscuration
- direct imaging

Light scattering is used for smaller sized particles(¡1 µm), while obscuration is used for larger particles [15]. Direct imaging depends on the resolution and size of the sensor, but is usually prohibitively expensive.

2.2.1.4. NO_x

NO_x sensors measure Nitrogen Oxides typically found in exhaust gases of diesel engines [16]. There are different types of NO_x sensors [17]:

- Electrochemical
- Zirconia

Electrochemical uses an electrolyte to create a current proportional to the concentration. Zirconia sensors use ceramic material and changes resistance based on concentration. Zirconia sensors typically run at lower temperatures and are more customizable. [18]

2.2.2. Air Quality Reporting

Air quality is usually reported as an index taken from various sources. We can use this standard to measure our perceived air quality of each contributing gas or particulate mater. [19]

IAQ Index			
PM2.5	**VOC**	**CO2**	
$\mu g/m^3$	$\mu g/m^3$	ppm	Hazard Level
<12	100	700	Good
35	200	800	Moderate
56	300	1100	Poor
150	400	1500	Unhealthy
250	500	2000	Very Unhealthy
300	600	3000	Hazardous
500	700	5000	Extreme

Figure 2.1: Air Quality index [5]

Typically the gases used to estimate the air quality form part of an index and are weighted. The AQI was developed by the US to communicate levels of air pollution to the public [20]. It is based on the levels of different pollutants in the air, such as particulate matter (PM), ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2) and carbon monoxide (CO). The AQI is calculated for each gas separately so it is logical to measure each and take the highest(worst) as the index value. [21]

2.3. Effects of Pollutants

2.3.1. CO_2

Exposure to CO_2 in concentrations as low as 1000 ppm can lead to adverse effects [22], this is enhanced by prolonged exposure, as would likely be experienced by the driver or passenger.
Adverse effects include [23]:

- inflammation
- reduced cognitive performance
- kidney and bone problems

2.3.2. Particulate Matter

Short-term exposure to particulate matter in the 2.5 and 10 µg range seems to to aggravate pre-existing conditions, such as respiratory and cardiovascular conditions [24], long term exposure is irrelevant in this context, as it is not measurable in the span of this study.

2.3.3. Volatile Organic Compounds

Short term exposure to VOCs can lead to eye and respiratory tract irritation, headaches, nausea and cancer [25]. The Environmental XPRT article on acceptable VOC levels in the air (2019) [26] suggests that acceptable ranges for VOC would be between 300 to 500 µg .

2.3.4. NO_x

Symptoms from exposure to NO_2 include inflammation of the airways, increase susceptibility to respiratory infections and to allergens as well as aggravating pre-existing lung or heart conditions. The safe amount that should not me exceeded regularly is 200µg. [27]

Chapter 3

System Design

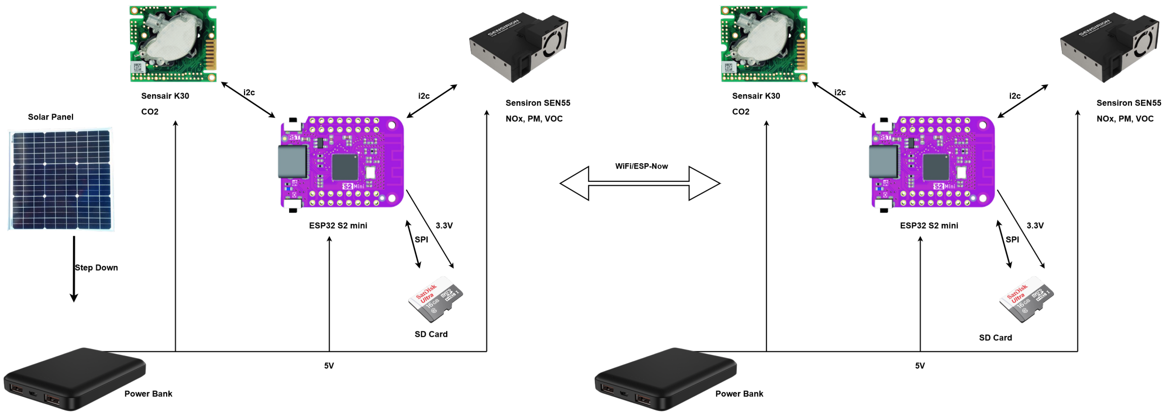

Figure 3.1: Hardware and Interface Overview
(Base station on the left and Satellite station on the right)

3.1. Hardware Overview

3.1.1. Microcontroller

An essential part of this project is the microcontroller, since it contains and controls many of the aspects needed for the project to work. Choosing a microcontroller comes down to it's features. For this project the features considered were:

- Speed
- Communication capabilities
- Expandability / IO
- Storage
- Power draw
- Size

- Cost

A few common microcontroller boards available at the time of writing are compared in the table below along with their respective specifications:

		ESP32-S2 lolin mini	ESP8266 NodeMCU	Raspberry Pi Zero W
Speed		Tensilica Xtensa LX7 32 bit Single-Core @ 240Mhz	Tensilica LX106 32 bit @ 80 MHz (up to 160 MHz)	BCM2835 1GHz
Communication	Wifi	802.11b/g/n	802.11b/g/n max 65mbps	802.11b/g/n
Expandability / IO	I2C	2	1	2
	ADC	20 x 12bit	1 x 10 bit	8 x 17 bit
	CAN/TWAI	X		Needs HAT
	GPIO	43	17	40
	UART	X	X	X
Storage		Micro SD and USB OTG	Needs module	Micro SD and USB OTG
Power draw		190mA peak when sending WiFi	250mA peak	260mA at idle
Size		34.3*25.4mm	49*26mm	60*30mm
Cost		R99	R94	R320.85

Table 3.1: Microcontroller option and Specifications

From table 3.1 the ESP32 s2-mini is power efficient, contains enough expandability to implement the necessary sensors, has wireless capabilities and is more affordable than the alternatives.

3.1.2. ESPNow/WiFi

When considering data transfer between the basestation and satellite station, speed, power consumption and range need to be accounted for. According to an article done by Dani Eichhorn from thingpulse, the runtime of a typical ESP32 running on a standard 2.5A h battery can be increased from an estimated 6.9 months on a WiFi gateway to up to 3.7 years on esp-NOW, a sixfold increase [28].

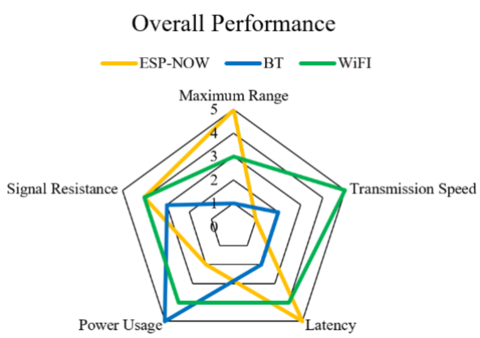

Figure 3.2: Overall Performance of each Protocol

In figure 3.2 extracted from a study done regarding the performance of the various wireless aspects of the esp32 [29] it can be seen that the transmission range of esp-NOW is superior to that of WiFi making it a valid option for transmission, while also keeping power consumption low. Tests will have to be done to see if the transmission speeds are fast enough to enable transmission of data when the satellite station reaches base.

3.1.3. Sensors

3.1.3.1. CO_2

For the CO_2 sensor a sensor with at least 5000ppm measuring capability was needed, as that was the top end of exposure for AQI. It also needed a suitable interface and an acceptable power consumption and fast enough response time. After looking at a few options on the market, the Senseair K30 FR(Fast response) NDIR sensor was chosen. This sensor features both UART and I2C communication, has a 70mA average power consumption when powered, has a 0-5000ppm sensing capability and is a fast response sensor, meaning it does not need a fan and can the fan from the other sensor is plenty to provide the diffusion needed to enable accurate and fast sensing.

3.1.3.2. PM, NO_x, VOC

The sensor chosen for the various needed values needed to comply to the various parameters needed to determine air quality. For the air quality index, the values indicated are VOC and PM2.5, these values needed to have a range of at least 100-700 µg/cm^3 and 0-1200 µg/cm^3 respectively.

The sensor chosen is an all in one sensor, the Sensiron SEN55, it measures Temperature, Humidity, Particulate matter in the anges 1, 2.5, 4, and 10 µm

3.2. Metrics

Chapter 4

Detailed System Design

4.1. ESP32

4.2. Sensors

4.2.1. CO_2

4.2.2. PM, NO_x, VOC

Chapter 5

Results

Chapter 6

Summary and Conclusion

Bibliography

[1] F. S. B. McGann, “Air quality monitoring at bus stops – lancaster university case study,” Mar 2020. [Online]. Available: https://www.linkedin.com/pulse/air-quality-monitoring-bus-stops-lancaster-university-francine

[2] M. Hachem, N. Saleh, A.-C. Paunescu, I. Momas, and L. Bensefa-Colas, “Exposure to traffic air pollutants in taxicabs and acute adverse respiratory effects: A systematic review,” *Science of The Total Environment*, vol. 693, p. 133439, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0048969719333595

[3] M. NOAH, “An investigation into the environmental impact of the taxi industry in butterworth,” p. 13, 01 2002. [Online]. Available: https://repository.up.ac.za/bitstream/handle/2263/7888/090.pdf?sequence=1&isAllowed=y

[4] “South africa clean fuels strategy,” https://www.samsa.org.za/Other%20Forms/Workshop%20Presentations/Marpol%20Sulphur%20Cap%202019%20Presentations/South%20Africa%27s%20Clean%20Fuels%20Strategy.pdf, 2019, accessed: 2023-04-04.

[5] M. S. Davies, “3 metrics to guide air quality health and safety,” [Online; accessed 8-April-2023]. [Online]. Available: https://greenecon.net/3-metrics-to-guide-air-quality-health-safety/carbon-footprint.html

[6] “Public transport,” https://www.transport.gov.za/public-transport, 2023, accessed: 2023-03-12.

[7] “Air quality management - open by-laws south africa,” https://openbylaws.org.za/za-cpt/act/by-law/2016/air-quality-management/eng/, 2023, accessed: 2023-04-09.

[8] C. J. Venter, A. D. Venter, M. Naidoo, and N. Naicker, “The impact of transport emissions on the health of johannesburg residents: A preliminary assessment,” *Journal of Transport and Health*, vol. 9, p. S33–S34, 2018.

[9] “Ambient air pollution: A global assessment of exposure and burden of disease,” 2016, accessed: 2023-04-09. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/250141/9789241511353-eng.pdf?sequence=1

[10] Y. Sun, P. Brimblecombe, P. Wei, Y. Duan, J. Pan, Q. Liu, Q. Fu, Z. Peng, S. Xu, Y. Wang, and Z. Ning, “High resolution on-road air pollution using a large

taxi-based mobile sensor network," *Sensors*, vol. 22, no. 16, 2022. [Online]. Available: https://www.mdpi.com/1424-8220/22/16/6005

[11] AQMD, "Aeroqual aqy v1.0." [Online]. Available: http://www.aqmd.gov/aq-spec/sensordetail/aeroqual-aqy-v1.0

[12] D. Technologies. (2022) What is a co2 sensor and how does it work? - disruptive technologies. [Online; accessed 7-April-2023]. [Online]. Available: https://www.disruptive-technologies.com/blog/what-is-a-co2-sensor-and-how-does-it-work

[13] OurPCB. (2021) Voc sensors: Everything you need to know - ourpcb. [Online; accessed 7-April-2023]. [Online]. Available: https://www.ourpcb.com/voc-sensors.html

[14] Utmel. (2021) Introduction to voc sensor - utmel. [Online; accessed 7-April-2023]. [Online]. Available: https://www.utmel.com/blog/categories/sensors/introduction-to-voc-sensor

[15] Thomasnet. (2023) All about particle sensors - thomasnet. [Online; accessed 7-April-2023]. [Online]. Available: https://www.thomasnet.com/articles/instruments-controls/all-about-particle-sensors/

[16] Autolintec. (2022) The types of nox sensors - autolintec.com. [Online; accessed 7-April-2023]. [Online]. Available: https://www.autolintec.com/news/the-types-of-nox-sensors.html

[17] DriveArchive. (2020) Nox sensors: What they are and how they work - drivearchive. [Online; accessed 7-April-2023]. [Online]. Available: https://drivearchive.co.uk/articles/article-nox-sensors-what-they-are-and-how-they-work.php

[18] N. Miura, T. Koga, M. Nakatou, P. Elumalai, and M. Hasei, "Electrochemical nox sensors based on stabilized zirconia: comparison of sensing performances of mixed-potential-type and impedancemetric nox sensors," *Journal of electroceramics*, vol. 17, no. 2-4, p. 979–986, 2006.

[19] W. A. Q. I. project team. (2022, May) World's air pollution: Real-time air quality index. [Online; accessed 8-April-2023]. [Online]. Available: https://aqicn.org/

[20] Airly, "Airly - air quality monitoring solutions," https://airly.org/en/, accessed: 2023-04-08.

[21] IQAir, "World air quality index (aqi) ranking," 2021. [Online]. Available: https://www.iqair.com/world-air-quality-ranking

[22] T. Jacobson, J. Kler, M. Hernke, R. Braun, K. Meyer, and W. Funk, "Direct human health risks of increased atmospheric carbon dioxide," Aug 2019. [Online]. Available: https://doi.org/10.1038/s41893-019-0323-1

[23] Chrisodgen. (2019, July) Co2 affects human health at lower levels than previously thought. [Online; accessed 9-April-2023]. [Online]. Available: https://airqualitynews.com/2019/07/10/co2-affects-human-health-at-lower-levels-than-previously-thought/

[24] N. M. of Health, "Particulate matter (pm10 and pm2.5)," 2019. [Online]. Available: https://www.health.nsw.gov.au/environment/air/Pages/particulate-matter.aspx

[25] U. E. P. Agency, "Volatile organic compounds' impact on indoor air quality," Aug 2022. [Online]. Available: https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality

[26] C. Bugayong, "Understanding voc's and its effects on health," Apr 2022. [Online]. Available: https://getuhoo.com/blog/home/understanding-vocs-and-its-effects-on-health/

[27] N. statistics, "Concentrations of nitrogen dioxide," Apr 2022. [Online]. Available: https://www.gov.uk/government/statistics/air-quality-statistics/ntrogen-dioxide

[28] D. Eichhorn. (2021, July) Esp32 – ultra-long battery life with esp-now. [Online; accessed 12-April-2023]. [Online]. Available: https://thingpulse.com/esp32-ultra-long-battery-life-with-espnow/

[29] D. Eridani, A. F. Rochim, and F. N. Cesara, "Comparative performance study of esp-now, wi-fi, bluetooth protocols based on range, transmission speed, latency, energy usage and barrier resistance," in *2021 International Seminar on Application for Technology of Information and Communication (iSemantic)*, 2021, pp. 322–328.

Appendix A

Project Planning Schedule

This is an appendix.

Appendix B

Outcomes Compliance

This is another appendix.

Appendix C

Appendix

Threshold levels

Radon (pCi/L)
- ≥4 pCi/L
- ≥2.7 and <4 pCi/L
- <2.7 pCi/L

Radon (Bq/m^3)
- ≥150 Bq/m^3
- ≥100 and <150 Bq/m^3
- <100 Bq/m^3

Particulate matter ($PM_{2.5}$)
- ≥25 μg/m^3
- ≥10 and <25 μg/m^3
- <10 μg/m^3

Carbon dioxide (CO_2)
- ≥1000 ppm
- ≥800 and <1000 ppm
- <800 ppm

Humidity
- ≥70 %
- ≥60 and <70 %
- ≥30 and <60 %
- ≥25 and <30 %
- <25 %

Temperature (°F)
- >77 °F
- ≥64 and ≤77 °F
- <64 °F

Temperature (°C)
- >25 °C
- ≥18 and ≤25 °C
- <18 °C

Airborne chemicals (VOC)
- ≥2000 ppb
- ≥250 and <2000 ppb
- <250 ppb

Figure C.1: Airthings table