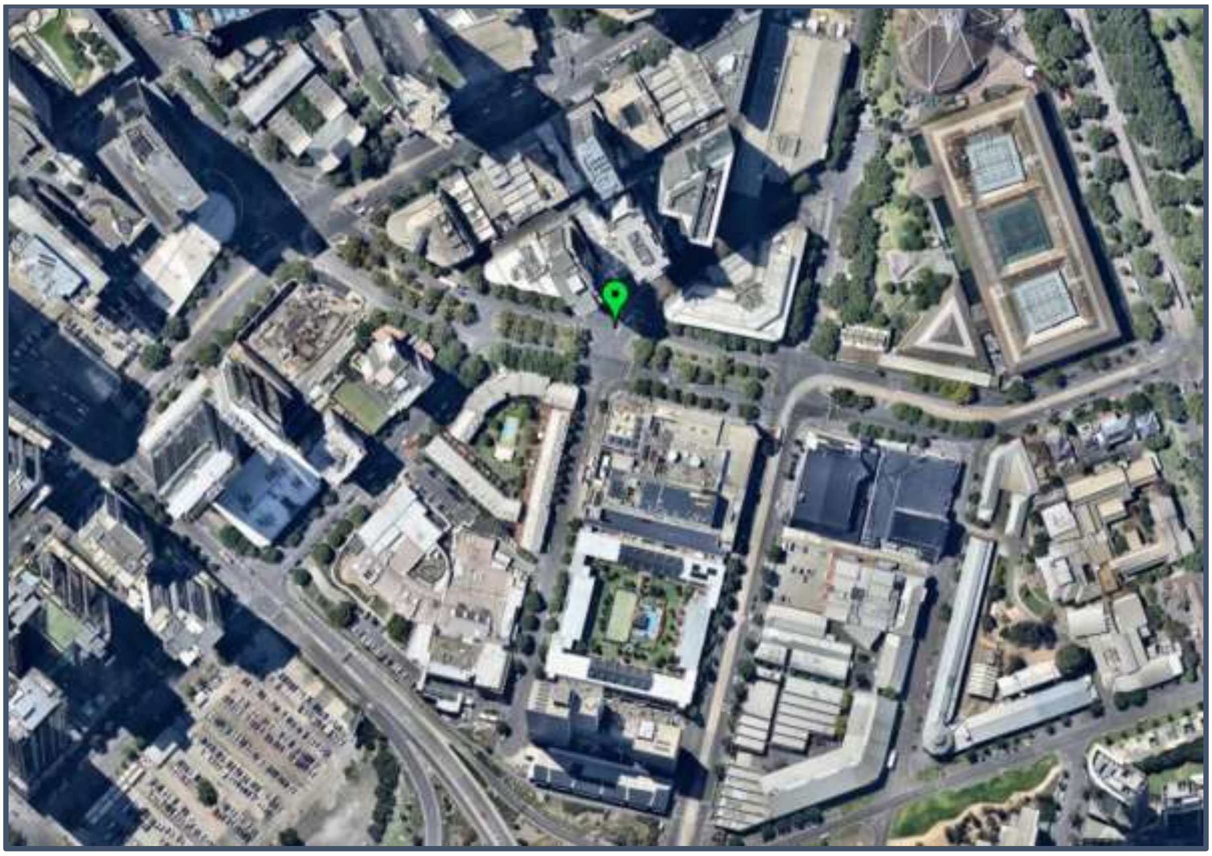
Monitoring Climate, Air Quality and Noise in the South Bank Boulevard Project

Environmental Monitoring Methodology Framework commissioned by the City of Melbourne



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Spatial network of environmental monitoring stations

South Bank Boulevard is a very wide and deep canyon that follows an almost unique orientation within the South Bank precinct. The Boulevard follows a curve west from the National Gallery of Victoria t Dodds Street is a far shallower and narrower canyon on a north-south orientation.

The rationale behind the proposed spatial network of ten environmental monitoring stations is that there are four dominant sections or areas in the South Bank Boulevard redesign.

1. Dodds Street.
   This street is two lane canyon made up of single storey canyon walls except for the Arts Centre. Traffic flow is very low. Dodds Street currently has very little vegetation. Dodd St. is the only part of the redesign where the whole width of street canyon is converted in to a green space, from wall to wall, akin to a new pocket park.
2. From NGV to City Road
   This section of South Bank Boulevard will have the majority of the impervious asphalt on the southern half replaced with green space, creating a fragmented linear park on the southern half of the Boulevard. There will therefore obviously be considerable potential for different climatic, noise and air quality conditions on the two sides of the Boulevard.
3. The Boulevard and City Road intersection
   This intersection provides a very large and exposed expanse of asphalt that will not be redesigned, other than green space coming to the edges and most importantly the pedestrian crossing points.
4. From City Road to Crown Casino
   This is a part of South Bank Boulevard that has the tallest buildings and then deepest canyon. It receives a great deal of self-shading from these buildings. Traffic flow is low.

Within these four sections different impacts can be estimated from careful comparison of monitoring stations data before and after redesign, or between paired monitoring stations. In some instances, it is possible to strengthen the impact assessment of urban greening redesign through careful comparison to paired control sites, when available (see Figure 1).

- Site A – this site provides a simple before and after assessment of the environmental impact of urban greening in a heavily shaded, deep street canyon situation.
- Sites B1 & B2 – these two sites provide a Before, After, Control, Impact (BACI) opportunity to better assess the urban greening redesign. The monitoring station on the City Road/Power

Street intersection acts as the control (no urban greening) for the urban greening carried out at the South Bank Blvd/City Road intersection. The canyon types are similar, the intersection dimensions are similar (see Figure 2).

- Sites C1 & C2 – these two sites currently differ in that C1 has dense tree canopy over impervious asphalt, whereas C2 has open and exposed impervious asphalt (see Figure 2). However, after the urban greening redesign they will both be very similar green spaces. As such, they provide an opportunity to assess whether tree canopy over asphalt is as good as canopy over permeable green space from a cooling, noise and air quality perspective.
- Sites D1 & D2 – these two sites are both in Dodds Street. They are both very similar now in that they are in an asphalt dominated street canyon, close the eastern side of a north-south street. D2 will be redesigned in to a continuous pocket park, whereas D1 will remain in a part of Dodd Street that is relatively unchanged. As such, these two monitoring sites offer a BACI opportunity to investigate the impact of extreme urban greening from impervious to park at site D2, whereas D1 acts as the control.
- Sites C1 & E1 – these two sites are paired to investigate the impact of uneven street canyon redesign, in that the southern half of South Bank Boulevard will be fragmented green space, and the northern half dominated by asphalt. There may be within-canyon circulation of air that leads to unexpected air quality gradients and cooling-heating differences.
- Sites C2 & E2 – these two sites provide the same opportunity as C1 & E1, but in another section of the urban greening redesign.
- Site F – This site acts a mid-canyon link between C1 & E1 and C2 & E2. This is the only mid-canyon environmental monitoring station.

Location of monitoring stations within the street canyon

It is suggested that environmental monitoring stations are located at a height between 3.0 and 6.0 m. The lower the monitoring stations are, the more representative they are of environmental conditions experienced by ground-level pedestrians. Preferably, the monitoring stations would be attached to poles within the street canyon, rather than attached to building walls.
The monitoring stations, especially the climate sensors, should be situated approximately 1.0 m away from a pole (or building wall) that supports them. This is to reduce support structure interference in wind speed and direction, as well as temperature and radiation measures. Many of the street poles are metal and therefore heat accumulating.

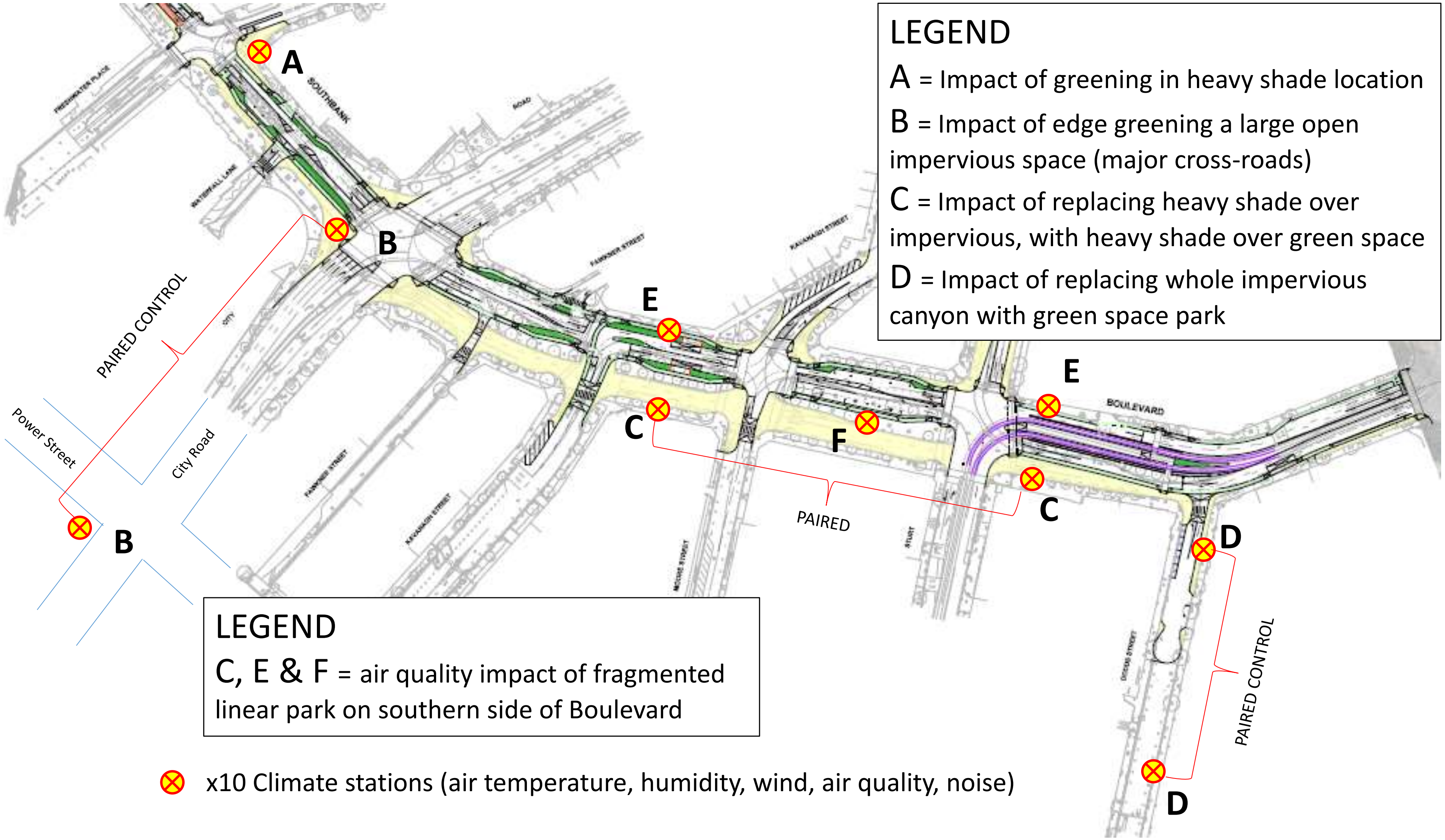

Figure 1. The spatial network of ten environmental monitoring stations in Dodds Street, South Bank Boulevard and City Road

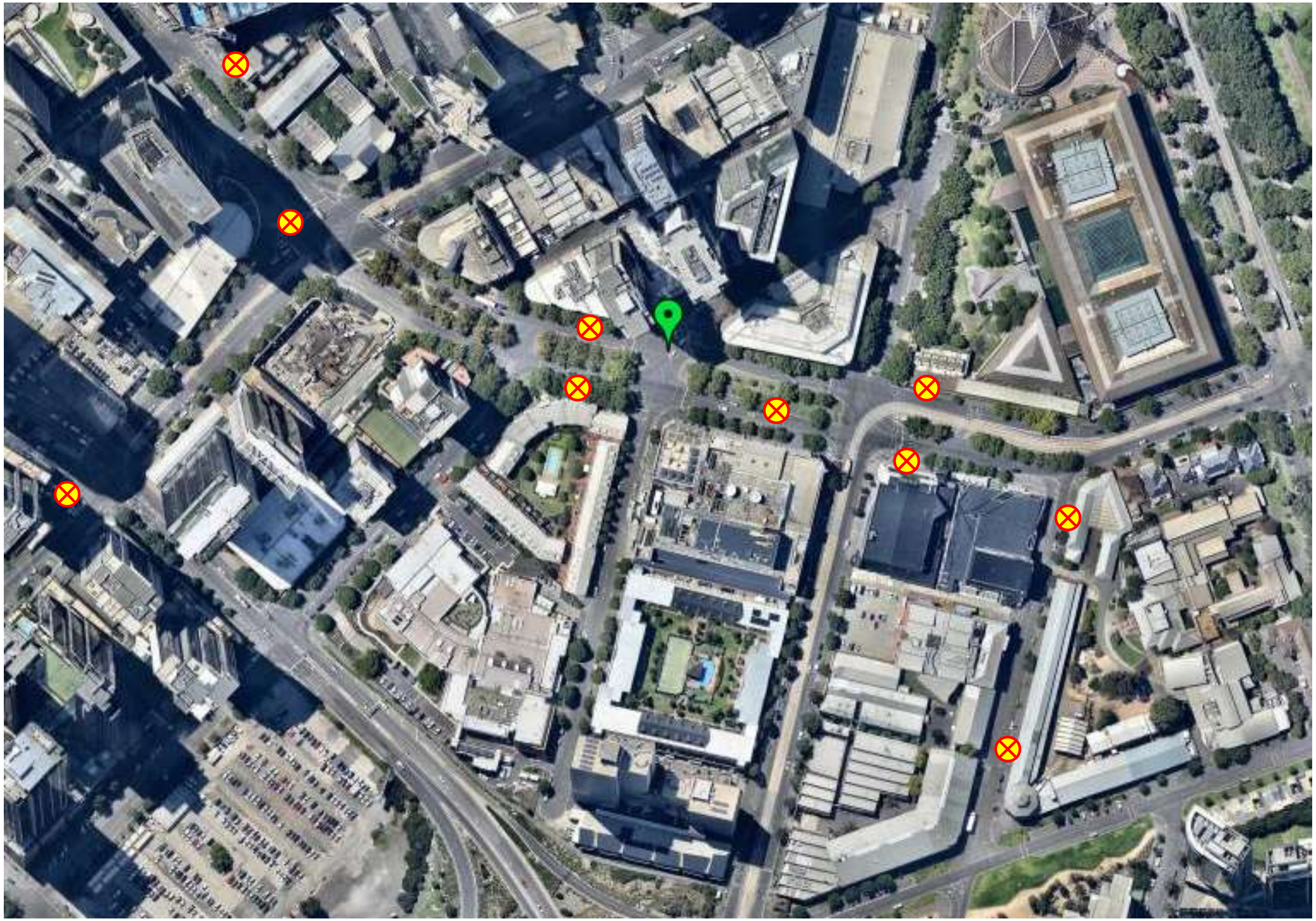

Figure 2. Aerial image of the South Bank Boulevard project and the location of the ten environmental monitoring stations

Environmental parameters to monitor

This sections puts forward a list of environmental parameters that should be monitored, why they should be monitored and provides examples of sensor equipment to monitor them and some of the more important specifications of those sensors and equipment.

This section is divided in to three sections: 1) climate, 2) air quality and 3) noise, with each section communicated as a table.

1. Climate – This includes parameters necessary to assess weather conditions, estimate human thermal comfort, track cloudiness, building shadows or solar exposure (intensity and duration) (Table 1). These climate parameters are also required to interpret and model the air quality data provided by the electro-chemical sensors described below.
   The climate stations described in Table 1 include four standard climate stations of varying sensor quality and precision, as well as two environmental monitoring stations based upon electro-chemical sensors

2. Air quality – This include both particulates, from PM1.0 up to PM40 (when calibrated) and several gases (calibration necessary) all recognised to have deleterious impact upon human health above threshold concentrations (Table 2). Many of the electro-chemical air quality sensors have a short life expectancy of between 1 and 5 years and all suffer from some level of cross-contamination with concurrent gas species. These two factors mean that calibration and careful quality control is critical for the data to reliable. However, the fast response times mean that these electro-chemical sensors are suited to providing real-time air quality information in temporally dynamic urban landscapes, and as they are relatively cost-effective they are suited to larger spatial monitoring networks.

3. Noise – These are both electro-chemical sensors that require careful calibration for the data to reliable (Table 3).

Table 1. Climate parameters, their purpose and examples of propriety systems that can measure them and their performance specifications

Parameter	Purpose	Campbell Scientific	Thomson Lufft	Hobo U30-NRC	Davis Vantage Pro	Array of Things	Libelium
Air temperature (°C)	Key indicator of UHI. Required to estimate human thermal stress	±0.2° @ 25°C	±0.2° @ 25°C	±0.2°C from 0° to 50°C	±0.5° > 20°C ±1.0° < 20°C	±0.5°C @ 25°C ±1°C <or>25°C BMP180 ±0.5°C HIH6100	±0.5°C @ 25°C ±1°C < or > 25°C BME280
Relative humidity (%)	Required to estimate human thermal stress Higher humidity = greater discomfort.	±1% (0-90%) ±1.7% (90-100%)	±2% (0-100%)	±2.5% (0-90%) up to ±3.5%	±3% (0-90%), ±4% (90-100%)	±3.5% HIH4030 ±4% HIH6100	±3% RH BME280
Wind speed ($m\ s^{-1}$)	Required to estimate human thermal stress Essential to model air quality.	Min. 0.45 $m\ s^{-1}$ Max. 45 $m\ s^{-1}$ ±0.11 $m\ s^{-1}$ or 1.5%	Min. 0 $m\ s^{-1}$ Max. 75 $m\ s^{-1}$ ±0.3 $m\ s^{-1}$ or 3%	Min. 1.0 $m\ s^{-1}$ Max. 75 $m\ s^{-1}$ ±1.1 $m\ s^{-1}$ or 4%	Min. 0 $m\ s^{-1}$ Max. 75 $m\ s^{-1}$ ±1.1 $m\ s^{-1}$ or ±5%	X	X
Wind direction (360°)	Essential to model air quality.	±5°	<±3°	±5°	±3°	X	X
Solar radiation ($W\ m^{-2}$)	Overshadowing, tree canopy interception. Urban energy balance.	± 5%	± 5%	±10 W m-2 or ±5%	± 5%	Lux (high error) APDS-9006-020 Lux (high error) Si1145 $\mu W\ cm^{-2}$ (error) MLX75305	Lux (high error) APDS-9006-020

Parameter	**Purpose**	**Campbell Scientific**	**Thomson Lufft**	**Hobo U30-NRC**	**Davis Vantage Pro**	**Array of Things**	**Libelium**
Rainfall (mm)	Building rain-shadows, Impervious evaporation potential	0.1 or 0.2 mm ±2%	0.1 mm	0.2 mm ±1%	0.2 mm	X	X
Mean radiant temperature (°C)	Required to estimate human thermal stress. More sensitive than air temp.	*External temp. probe possible* e.g. thermistor ±0.1°C	*External temp. probe possible*	*External temp. probe possible*	*External temp. probe possible*	X	X
Data storage		CR1000 (16 single or 8 differential)	e.g. ML-315, e.g. MMP1000 e.g. DT82-EM	RX3000 (10 channel)	Vantage Connect (cloud storage)	(cloud storage)	(cloud storage)
Comms		Radio, 3G, WiFi	3G	3G or Wi-Fi	3G	3G	3G, WiFi, LoraWan, etc
Power		Solar panel & battery	Solar panel & battery	Solar panel & battery	Solar panel & battery	Mains power (lighting pole)	Solar panel & battery

Table 2. Air quality parameters, their health implications and examples of propriety systems and their performance specifications

Parameter	Health implications	Array of Things	Libelium (Waspmote Plug and Sense)[1]
Particles	Linked to cancer, cardiovascular, reproductive, breathing, respiratory and central nervous system diseases. Irritant. In Australia estimated 3400 deaths per year in 2015[2,3].	OPC-N2 (PM1, PM2.5, PM10 up to PM40) Precision ? Expected operating lifetime >1 year. High correlation of particle counts with gold standard, requires calibration for respirable profiling.	OPC-N2 (PM1, PM2.5, PM10 up to PM40) Precision ? Expected operating lifetime >1 year. High correlation of particle counts with gold standard, requires calibration for respirable profiling.
Ozone	Linked to cardiovascular and breathing diseases. Irritant[2]. In Australia estimated 30 deaths per year in 2015[1].	SPEC Sensors 3SP-O3-20. Measurement range: 0.02 to 20 ppm. Precision ±3 %. Resolution <15 seconds. Expected Operating Life > 5 years. Cross contamination from H_2S, NO_2, Cl.	O3-A4 (calibrated) Measurement range 0 to 5 ppm Precision ±0.005 ppm Resolution 30 seconds Expected Operating Life: > 18 months Cross contamination unknown
NO	Liver, spleen, blood, breathing diseases and irritant[2]. Also controls ozone concentrations in urban setting.	Not measured	4-NO-250 for NO (calibrated) Measurement Range: 0 to 250 ppm Precision at best ±0.5 ppm Resolution <30 seconds Expected Operating Life 2 years Cross contamination??

[1] Smart environment pro sensors http://www.libelium.com/downloads/documentation/waspmote_plug_and_sense_sensors_guide.pdf (accessed 3 April 2017)
[2] https://www.stateofglobalair.org/data (accessed 3 April 2017)
[3] EEA Signals 2013 — Every breath we take. Improving air quality in Europe http://www.eea.europa.eu/publications/eea-signals-2013/at_download/file (accessed 3 April 2017)

Parameter	Health implications	Array of Things	Libelium (Waspmote Plug and Sense)[4]
NO_2	Liver, spleen, blood, breathing diseases and irritant[2]. Also controls ozone concentrations in urban setting.	SPEC Sensors 3SP-NO2-20. Measurement Range 0 to 20 ppm. Precision < +/- 3 %. Resolution: 200 seconds. Expected Operating Life > 5 years. Cross contamination with H_2S.	4-NO2-20 for NO_2 (calibrated) Measurement range 0 to 20 ppm Precision ±0.1 ppm Resolution <30 seconds Expected Operating Life 2 years
Volatile organic compounds (VOCs)	Controls ozone concentrations in urban setting. Natural (trees) and anthropogenic (vehicles, petrol bowsers) emissions.	Not measured	MiCS-5524 Measurement Range 30 to 400 ppm Resolution 30 seconds Careful calibration required.
CO	A VOC and a product of incomplete combustion. Fatal in high doses, headaches / dizziness. Forms ozone.	SPEC Sensors 3SP-CO-1000 Measurement Range 0 to 1,000 ppm. Precision: < ± 2 %. Resolution < 100 ppb. Resolution < 30 seconds. Expected Operating Life > 5 years. Cross contamination low, only to H_2.	CO-A4 (low concentration calibrated) Measurement Range 0 to 25 ppm Precision ±0.1 ppm Resolution ? Resolution 20 seconds. Expected Operating Life 3 years
NH_3	Tailpipe product of new efficient catalytic converters, forms nitric acid and particles.	Not measured	4-NH3-100 (calibrated) Measurement range: 0 to 100 ppm Precision ±0.5 ppm Resolution ≤ 90 seconds Expected Operating Life >1 year

[4] Smart environment pro sensors http://www.libelium.com/downloads/documentation/waspmote_plug_and_sense_sensors_guide.pdf (accessed 3 April 2017)

Parameter	Health implications	Array of Things	Libelium (Waspmote Plug and Sense)[5]
SO_2	Linked to cardiovascular and breathing diseases. Irritant, anxiety and headaches. Forms sulfuric acid and particles.	SPEC Sensors 3SP-H2S-50 Measurement Range 0 to 50 ppm Precision < +/- 3 %. Resolution < 15 seconds. Expected Operating Life > 5 years. SO_2, NO_2 and NO cross contamination. Not a direct SO_2 measurement, but H_2S	4-SO2-20 (calibrated) Measurement Range 0 to 20 ppm Precision ±0.1 ppm Resolution <45 seconds Expected Operating Life 2 years in air
H_2S	Fatal in high doses, irritant, headaches / dizziness.	SPEC Sensors IAQ-100. Measurement Range 0 to 100ppm. Precision ? Resolution ? Expected Operating Life > 5 years. Cross contamination: CO, H_2S, Ozone, Nitrogen Dioxide, Sulfur Dioxide, Ethanol, Nitric Oxide (NO), Chlorine.	4-H2S-100 (calibrated) Measurement Range 0 to 200 ppm Precision ±0.1 ppm Resolution <20 seconds Expected Operating Life 2 years Cross contamination?
CO_2	Climate forcing. Indicator of respiration, combustion, concrete and photosynthesis. Used in smart buildings to control ventilation.	Not measured.	INE20-CO2P-NCVSP (calibrated) Measurement Range 0 to 5000 ppm Accuracy ±50 ppm **Not high enough accuracy for ambient conditions.*
O_2	Required for respiration.	Not measured.	4-OL (calibrated) Measurement range 0 to 30%. Accuracy ± 0.1 % Resolution ~30 seconds. Expected Operating Life 2 years

[5] Smart environment pro sensors http://www.libelium.com/downloads/documentation/waspmote_plug_and_sense_sensors_guide.pdf (accessed 3 April 2017)

Table 3. Noise, possible sources of noise and thresholds to human impact and examples of propriety systems and their performance specifications

Pararmeter	Equivalent source and human impact	Array of Things	Libelium
Noise	50 dBA is constant urban background noise, 90 dBA is heavy traffic, 100 dBA is factory or pneumatic hammer noise. Threshold to human discomfort is 120 dBA, Threshold to pain is 130 dBA (NOTE: scale is logarithmic).	Spectrum range 100 Hz to 10 kHz *(Performance unkown)*	Spectrum range 20 Hz to 20 kHz Measurement range 50 to 100 dBA Microphone sensitivity: 12.7 mV / Pa Precision +/-0.5dBA (1KHz) Omni-directional microphone

Calibration, replacement and maintenance

Calibration of air quality sensors

Calibration of all air quality sensors is necessary before installation. This is to assess sensor performance against specified performance by the manufacturer or supplier.
Calibration for the air quality sensors can be provided by three recognised institutions:

- CSIRO (Aspendale)
- Environmental Protection Agency (EPA-Vic)
- Queensland University of Technology (QUT)

Calibration can also be facilitated by several private consultancies, who will sub-contract CSIRO, EPA or QUT to provide calibration.
It is strongly suggested that in the first year of sensor installation that they are removed and recalibrated at 6 months and at 12 months. This will enable the drift in sensor performance to be understood under the urban atmospheric conditions of inner-Melbourne.
After this first year, the frequency of calibration can be reviewed and adapted as necessary.

Replacement of air quality sensors

Each time of sensor calibration is also an opportunity for sensor replacement and instrument cleaning, maintenance and repair.
Many of the electro-chemical air quality sensors have a short life expectancy of between 1 and 5 years. All of the electro-chemical air quality sensors have some level of cross-contamination, which means that the measured quantity may be a response to some other trace gas, so multiple sensors, calibration and careful quality control will be required for the data to reliable.
Deterioration with environmental stressors; such as temperature and relative humidity, is known. However, the response times are fast and they lend themselves to real-time city sensor networks. The shortest life expectancy being the Optical Particle Sensor (OPS) that detects PM1.0, PM2.5, PM10 and can be calibrated to detect larger (pollen sized) PM40. The calibrated OPS sensors from Libelium are recommended to be replaced every 6 months to achieve specified accuracy. This dictates the suggested frequency of recalibration in the first year.

Calibration, replacement and maintenance of climate sensors

For the climate sensors it may be possible to calibrate in-situ using portable and comparable – laboratory-calibrated sensors that are placed in direct proximity to the monitoring stations. However, there are several station elements that require annual cleaning:

- Some climate sensor heads (e.g. solar radiation, sonic anemometer) require annual cleaning with deionised water; and
- 3-cup anemometers, rainfall gauge funnels and tipping bucket gauges should be cleaned annually, and
- Solar panels should be cleaned annually and batteries tested and replaced where necessary.

As such, it is suggested that it would be more cost, and time, efficient to remove the climate stations calibrate, replace and maintain at the same time as the air quality sensors.

Data communication, archiving and quality control protocols

Security of data and quality control of data streams is vital in a real-time environmental monitoring framework.

It is essential that the entity responsible for managing the sensors establishes themselves, or sub-contract data infrastructure (communication and archiving) services, so that all data is secured continuously and instantly in raw data format .

Checks and balances should be put in place to assess the quality of data being produced so that faults or errors can be identified early, and remotely rectified where possible, or manual intervention for repair, replacement or maintenance flagged.

Possible utility of the environmental monitoring framework

The stream of complementary data on climate, air quality and noise gathered from this network can be combined to produce a series of high-level products of direct benefit. These would initially be research products but could be made operational once tested and deemed useful.

Some examples:

- Combining the microclimate information one can produce real-time series of human thermal comfort and its spatial variation.

- Using the network of air quality and meteorological information to determine air quality of an urban environment.

- Combining measurements of air quality and noise with aggregated pedestrian information it is possible to calculate the pollutant and noise exposure and its change within the target area.

- The size-resolved particle counters may well be able to distinguish increases in airborne pollen from other aerosol changes. This would need to be tested against an in-situ pollen counter.

- The feasibility of using the particle counter network to determine if an alert system for poor air quality can be established for the City of Melbourne due to fire influences, thunderstorm pollen events, stable meteorological conditions etc.