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Workplace Environment Data Loggers

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Preface

This report outlines the specifications of a low cost indoor environmental data logging unit for office workstations. The unit collects temperatures (air and radiant), lighting levels (global and directional), RH, air movement, noise and presence or absence of subjects.

Note

This report is intended for the scientific community interested in monitoring various indoor environmental parameters.

Acknowledgments

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Workplace Environment Data Loggers

BRANZ Study Report SR 174

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Reference

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Abstract

This report describes the components of a low cost office environment logger. The objective of the project was to develop simple data logging equipment able to record temperature, RH, sound levels, air movement and a series of spatial light conditions at individual office workstations. This has been achieved by using a series of low cost sensors connected via a data acquisition unit into the office workstation PC. A prototype of the system has been built and successfully tested at a BRANZ office workstation.

Keywords

Indoor environment, data logger, office.

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1. INTRODUCTION

This report outlines the specifications of a low cost environmental data logger which can be used to assess the environmental conditions at office workplaces.

2. DATA REQUIREMENTS

The internal office environment affects a number of outcomes, both for people directly (health, well-being, productivity, etc) and indirectly through its impact on the built construction (mould growth, fading of furniture etc). It is therefore important to understand how changes to the built structure (for example different glazing or insulation) affect the indoor environment.

Many of these impacts are quite location specific and vary over time. It is therefore desirable to be able to conduct measurements at specific workstations over long time frames.

3. PHILOSOPHY OF THE DATA LOGGING SYSTEM

High-tech solutions for similar purposes have been produced for example by UC Berkley (http://arch.ced.berkeley.edu/resources/bldgsci/bsl/cart.html). However, these types of data logging systems are expensive and statistically representative data logging is therefore often not feasible.

A large cost component of the data logging hardware is related to the development and implementation of the hardware controlling the data logging algorithms and the data storage as well as the interface of the data collection units. In the office environment there exists a unique opportunity to tap into the existing hardware i.e. use the already present desktop computers to run the data logging software and to store the collected data.

This project is therefore aimed at developing a data logger set-up, which can be connected to the already existing desktop PC via the USB port. The data logging equipment consists of a series of sensors which are installed on a frame and interface with a National Instrument NI USB-6210 data acquisition system.

In order to allow statistically representative long-term measurements on a large number of workstations, it was critical that the cost of the equipment was kept to a minimum. An initial cost target of NZ$1000 was set.

4. KEY ENVIRONMENTAL PARAMETERS

The following environmental variables are commonly required to conduct a workplace assessment with a focus on worker performance (health and productivity).

Table 1. Relevant office workplace environmental variables

Variable	Importance
Air temperature	High
Radiant temperature	High
Lighting level	High
Directional lighting levels	High
Noise level	High
VOC concentration (via proxy such as CO_2 and/or HVAC system)	High
Subject presence	High
Lighting quality (flicker, colour, etc)	Medium
Air movement	Medium
RH	Medium
Vibration/sway	Low
Smell	Low

Many of the variables listed in the table above can be measured with sensors which are now on the market at very low cost. However, a few require more sophisticated analysis tools. Because the philosophy of the envisaged logging system emphasises low cost, not all of the variables with high importance can be included. On the other hand, all three of the variables with medium importance can be implemented at very low capital cost. The variables not included are the VOC and the lighting quality sensors. The implications and alternative options regarding these two variables are discussed further on in this document (Sections 5.6 and 5.9).

5. SENSORS

5.1 Data acquisition system

The data acquisition system is a NI USB-6210 unit from National Instruments. It features 16-Bit sampling and has 16 analog inputs (16-Bit), 4 digital inputs and a bus-powered USB for high mobility and built-in signal connectivity. It is compatible with the following software: LabVIEW, LabWindows™/CVI, and Measurement Studio for Visual Studio.NET.

We have developed a simple LabVIEW program which can be configured to measure and record at a pre-defined interval. The interval can be set via software to be between 1 minute and 1 hour. The software synchronises the logging intervals with the host computer, making data analysis very convenient. The software starts the logger up automatically once the host computer is started up. This is achieved by placing the shortcut to the LabVIEW programme in the start-up folder of MSWindows. The LabVIEW programme reads several logging parameters such as logging intervals, from a separate ".ini" file, ensuring that multiple logging units can easily be installed at a large number of workstations.

Figure 1. NI USB-6210 data acquisition system connected to a laptop via USB cable.

The following figure (Figure 2) shows the software interface of the unit.

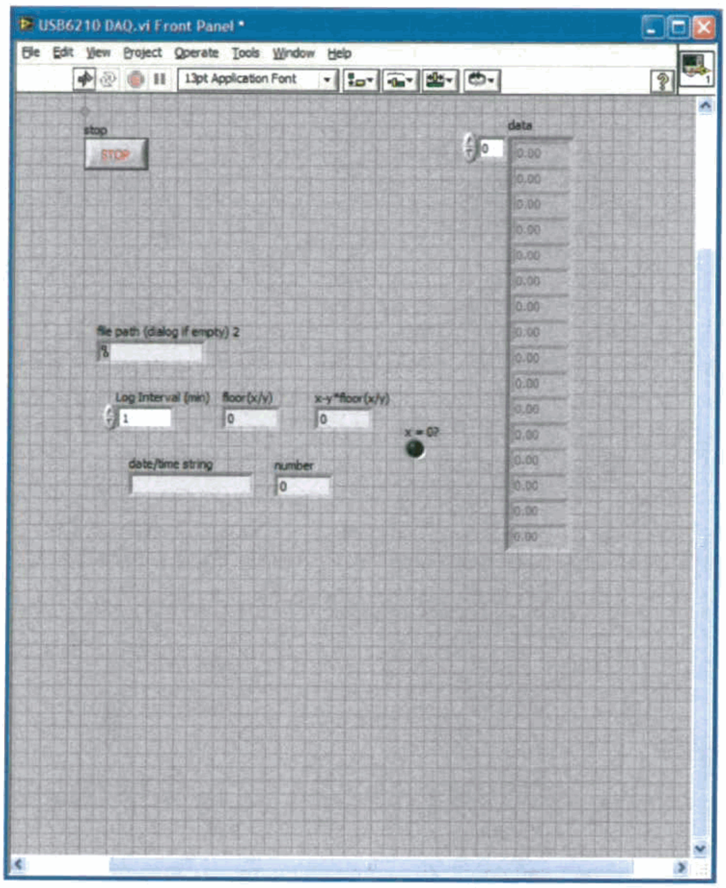

Figure 2. Software interface of the data logging unit.

5.2 Air temperature

For air temperature measurements the system uses glass encapsulated thermistors sourced from EPCOS (B57550/G550). The thermistors in the configuration of the office data logging equipment will have an accuracy after calibration of 0.2°C.

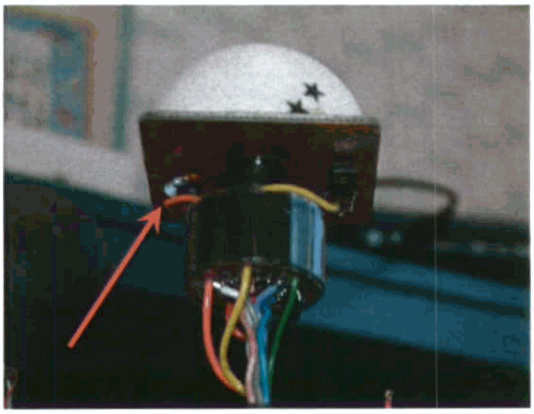

Figure 3. Air temperature thermistor located under the circuit board platform.

5.3 Radiant temperature

In order to measure radiant temperatures a small globe was designed which holds the thermistor. The globe is painted matt black to have an absorptivity close to 1. The mean radiant temperature of the surrounding surfaces (T_s) can be calculated using the theoretical relationship between the temperatures measured by the unshielded thermistor (T_a), which is used for measuring the air temperature and the temperature of the thermistor inside the globe (T_g).

$T_g = h_c/(h_c+h_r)\ T_a + h_r/(h_c+h_r)\ T_s$

h_r and h_c are the surface heat transfer coefficients for radiation and convection respectively. Although h_r and h_c can be calculated based on basic physical properties, literature suggests the use of 0.5 for both of them (Humphreys 1977). This simplifies the above formula to being $T_s = 2T_g - T_a$.

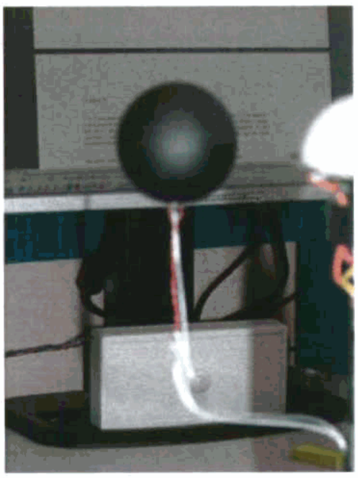

Figure 4. Radiant temperature probe inside the matt black sphere.

5.4 Lighting level

Overall lighting levels are measured via TSL257 high-sensitivity light-to-voltage-converters from Texas Advanced Optoelectronics Solutions. The sensors are built of monolithic silicon IC containing photodiodes, operational amplifiers and feedback components. The sensitivity of the sensors broadly aligns with the sensitivity perception of the human eye.[1]

The sensor detecting the overall light level is placed facing upward and is covered by a small diffuser hemisphere made out of a ping-pong ball.

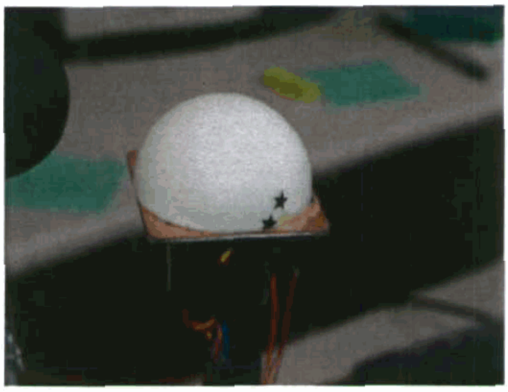

Figure 5. Lighting level sensor hidden under the diffuser hemisphere (two star ping-pong ball).

5.5 Directional lighting levels

Directional light levels are also measured by a set of TSL257 sensors. In the current assembly they are mounted in a circle, each of them spaced at a horizontal angle of approximately 70°. The view angle of the sensors is also approximately 70° (see Figure 6). As discussed in Section 7.1.2 an alternative arrangement is proposed for future assemblies with the five directional light sensors all facing forward in line with the subject's main field of view.

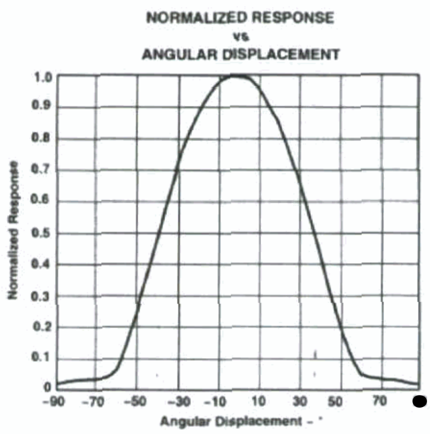

Figure 6. Angular distribution of light sensor response.

Testing of the light sensors showed that the sensors are too sensitive for normal daylight brightness. In order to reduce the sensitivity three layers of both a neutral density filter and an IR filter are wrapped around the light sensor assembly.

[1] We have recently sourced a different light sensor which is even better aligned with the spectral sensitivity of the eye. The sensor is also low cost and could replace the currently used one in future developments.

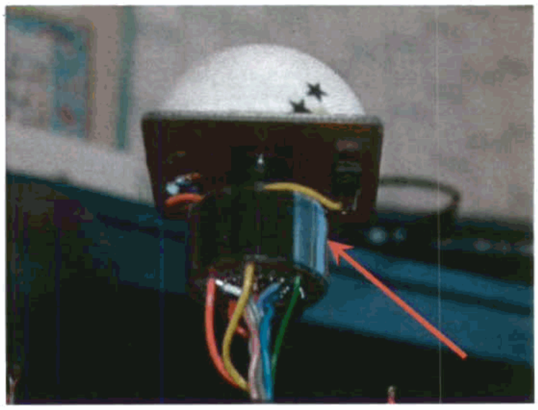

Figure 7. Cylinder containing five directional light sensors covered by three layers of neutral density filters.

5.6 Lighting quality (flicker, colour etc)

Lighting quality measurements require high frequency data recording and sophisticated processing. After investigating the issues involved it was decided that such an arrangement would be too complex to implement on a low cost data logging arrangement.

Light quality issues like flicker and colour tones are generally associated with artificial lighting. Therefore it is likely that one-off measurements of these values will be representative of light quality levels over longer periods making is superfluous to conduct long-term measurements. This is in contrast to general lighting levels, which will change throughout the day and season, thus requiring long-term logging.

5.7 Noise meter

The sound level meter is a Center 320 meter. It has three level ranges (30-80dB, 50-100dB and 80-130dB). The frequency range is 31.5Hz to 8KHz. This covers the auditable spectrum. The meter gives DC output at 10mV/dB, suitable for the data acquisition system.

The meter records instantaneous sound levels rather than aggregated or peak levels. It has been investigated whether it is feasible to develop integrating and filtering electronics to determine non-uniform noise levels, but this would require quite complex processing and data recording algorithms as well as additional hardware on the data logging unit itself. Due to the high development and final equipment cost this idea was therefore discarded. Even if such a configuration were to be developed, the interpretation of any filtered and integrated results would be quite complex and was considered to be outside the scope of this project.

If there is an expectation that intermediate noise levels are of interest in a particular work environment (passing trucks, phone rings etc) separate high frequency sound level logging is recommended to capture these events. Again it is likely that these events are often more uniform across the whole office plan, which makes it more efficient to collect only one or two samples across a larger office space rather than for each individual workplace.

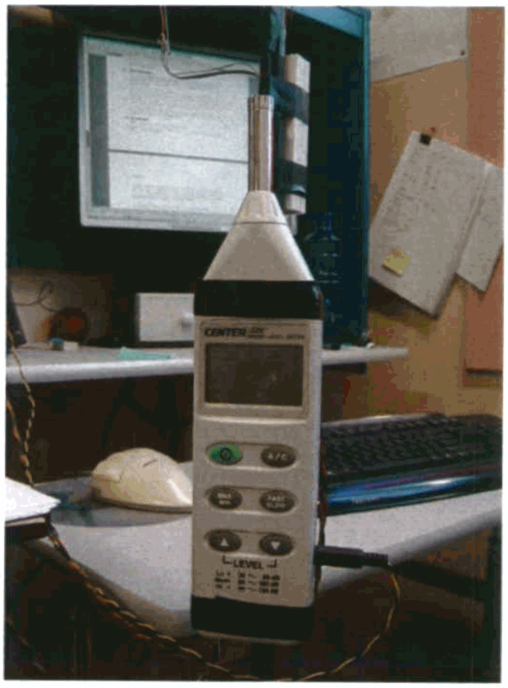

Figure 8. Sound level meter mounted to the post of the assembly array.

5.8 Air movement

Human comfort can be affected by relatively slow airflows. A typical target threshold for the airflow meter sensitivity is approximately 0.2 m/s.

Three air movement sensor options were investigated:

- hotwire anemometer
- solid state sensors
- ultrasonic.

There are a number of off-the-shelf sensors available. One of them is an instrument offered by Fluke which also includes a number of other instruments in one unit (temperature, RH, CO and CO_2). However, the Fluke 975 Airmeter is expensive ($5500)[2] and the airflow sensor is not able to record low flow rates in the 0-0.25m/s range.

Prices for systems able to measure lower airflows are even higher.

It was therefore decided to explore whether a simple device could be built from existing low cost components. The approach taken was similar to the hotwire anemometer. The assembly consists of a set of two thermistors placed in close proximity to each other. One of the thermistors is heated to a higher temperature via its supply voltage. Initial tests have shown that the arrangement detects differential temperatures for relatively low wind speeds (gentle blowing past the sensors). However, the arrangement still needs to be tested and calibrated against a range of ambient temperatures and air speeds.

[2] The Fluke airflow meter can be hired from Betacom for about $180/month.

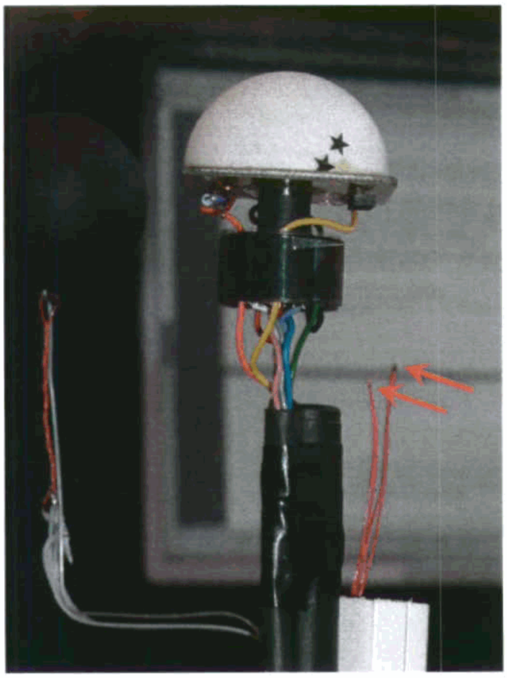

Figure 9. Thermistor pair to measure air velocity (the sensors have a separate circuit board which is hidden in the small conduit below but can for production line equipment be mounted on the main circuit board platform).

5.9 VOC concentration (via proxies such as CO_2)

In December 2006 NIWA announced that they are developing a low cost indoor air quality logger. The philosophy behind the logger is similar to the BRANZ project in that it focuses on low cost components which can be installed in large numbers. The NIWA logger is a small self-contained unit measuring aerosols, NO_2, VOCs, CO, particulates, temperature and humidity. The target cost of the unit start from about $2000.

Some of the sensor technology in the NIWA data logger is not yet completely developed (particle sensors) and the project manager has applied for further internal NIWA funding to complete the development. The intention is to install the data loggers in a number of houses in the following year (Marsden funding) to study their performance in situ.

The BRANZ project team just recently became aware of the NIWA activities and we could therefore not explore the possible opportunities further. However, we had initial discussions with the NIWA project manager Guy Coulson[3]. He expressed interest in exploring whether the BRANZ and the NIWA data logging systems could be integrated.

Since we have not been able to find a low cost air quality sensor so far we recommend to hold some further discussions and possibly trial some of the relevant sensors with the data acquisition system which is used in the BRANZ logger. Since the data acquisition system is very flexible, accepting most common sensor voltage signals, this would be a relatively simple exercise.

[3] G.Coulson@niwa.co.nz, 09 375 4503

Figure 10. NIWA indoor air quality logger.

5.10 Relative humidity

The relative humidity sensor is a Honeywell HIH-4000-002 integrated circuit humidity sensor. The sensor has an accuracy of +/-3.5%, sufficient to investigate normal indoor moisture issues.

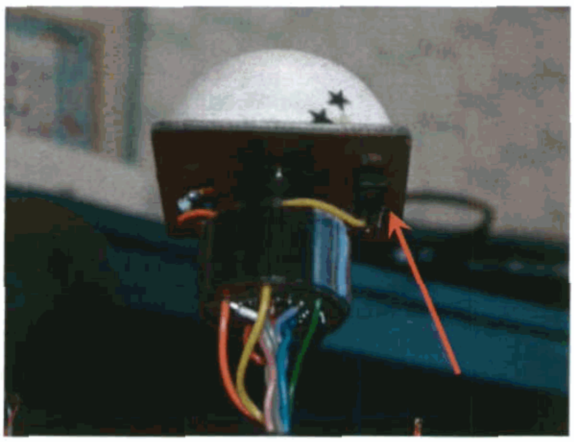

Figure 11. Relative humidity probe located at the bottom of the circuitry platform.

5.11 Subject presence

When studying health and productivity issues in the workplace it is obviously important to identify the exposure times of the subjects i.e. when they present in the measured environmental conditions which are recorded. A very simple assumption suitable for office places is to detect when the office workplace PC is switched on. However, many computer users leave their PCs on overnight and this method would also not detect periods when people are at meetings away from their workstations.

Several options were explored including mechanical sensors in the office chair. However this particular solution would have required wireless data transmission from the sensor to the data acquisition board because wires would inevitably get entangled in the chair.

Therefore the preferred solution is an infrared sensor which is placed in front of the subject either on the desk or attached to the PC monitor. The sensor was developed by modifying an existing IR security system sensor. The circuit board had to be modified to supply a persistent "on signal" to the acquisition board rather than instant short-term pulse signals when the sensor is triggered, because the acquisition board inquires of the sensors only at fixed intervals rather than continuously recording switching events. This "persistent signal" logic has been implemented in the sensor electronics. It can be varied via a small dial between different time interval settings and should ideally be matched to the logging interval setting of the whole system.

IR security sensors have been reported to be quite insensitive to small movements, missing minor activity events such as finger movements for keyboard entry. However, initial evaluations of the sensor sensitivity are encouraging. Because the sensor is placed in close proximity to the workstation (rather than the usual security sensor placement in the corner of a room), the relative angle of movement in the view field is much larger. It is therefore likely that the sensor will be sufficiently sensitive to record most subject movements.

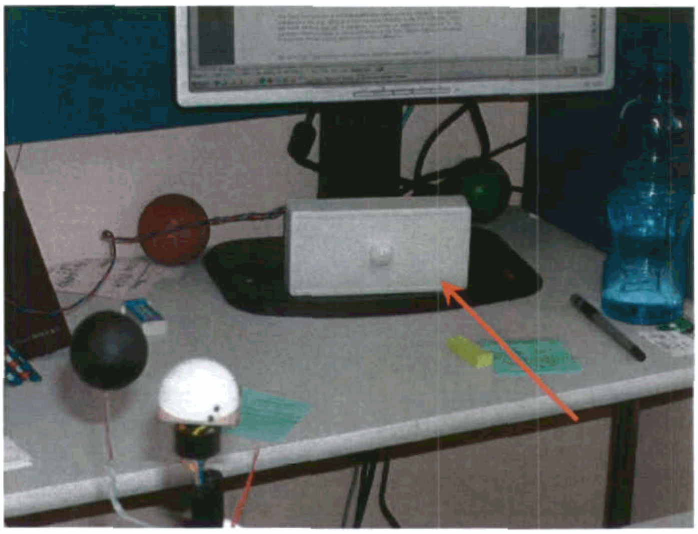

Figure 12. Subject presence sensor (can be mounted anywhere suitable to record subject movement at the workstation – table, on top of PC screen etc).

5.12 Vibration/sway

Vibration and sway effects are usually quite small and it is therefore difficult to access low cost sensors which are sensitive enough to capture these events. Vibration events are also often very temporary (trucks passing the building for example). Any sensor arrangement would therefore need to include electronics or processing logic to capture these one-off events (an issue similar to the ones discussed for noise levels). This makes any sensor arrangement complex and costly.

Since it is believed that vibration and sway have little influence on worker well-being and productivity, it was decided to not pursue this further.

5.13 Smell

Smell has sometimes been quoted as an important factor for well-being. However, to our knowledge there are no small low cost sensors on the market at this stage which would be suitable for the applications investigated here. The most common sensors use gas chromatograph technology requiring mains power supply, and are far beyond the $1000 target budget for the environmental office data logger.

Figure 13. zNose GC analyser.

It is therefore recommended to use, when required, a separate unit on a case-by-case basis such as the one shown above by zNose©.

6. EQUIPMENT COST

One of the main drivers for this project was to develop a low cost solution for the data logging equipment. An arbitrary target cost of approximately $1000 was set initially. The final system cost exceeds this cost but is still extremely economical, making it feasible to study a large number of office workstations over long periods of time.

The following table lists the cost of the individual components:

Table 2. Logger cost

Equipment	Use	Units	Cost
TA DAQ data acquisition system		1	$910
EPCOS Thermistor (RS#4840133)	Air temperature	1	$13
EPCOS Thermistor (RS#4840133)	Radiant temperature	1	$13
TSL257 High Sensitivity Light-to-Voltage Converter from TAOS	Lighting level	1	$6
TSL257 High Sensitivity Light-to-Voltage Converter from TAOS	Directional lighting level	5	$30
Center 320	Noise level	1	$220
Honeywell HIH-4000-002 Humidity sensor	RH	1	$68
IR Movement Sensor	Subject presence	1	$25
Mounting unit (stand etc)	Sensor placement	1	$50
Electronics and other small parts		1	$70
Labour (assembly) (depending on volumes ordered)[4]		1	$200
Approximate total			**$1600**
Additional sensors			
NIWA Unidata Crossramp logger	CO_2, aerosols, NO_2, temperature, RH, VOCs, CO	1	from $2500
Example: Fluke 975 Airmeter	Air movement (incl. temperature, RH, CO and CO_2)	1	$5500
Example: zNose	Smell	1	

[4] Some additional BRANZ time will be required to detail the specifications should the assembly be out-sourced. Additional one-off costs for circuit board assembly set-up will be incurred (a few hundred dollars).

7. SENSOR PLACEMENT

Two aspects are mainly influencing the possible placement of the various sensors: relevance of the measured data and practicality.

The team has considered a number of alternatives for the different variables:

7.1.1 Air temperature and radiant temperature

Temperatures must be collected close to the subject and must not be distorted by other localised factors. Temperature sensors could therefore not be mounted too close to the computer or the monitor, because the waste heat would result in unrepresentative readings. The ideal location is close to the subject body. Placing removable small sensors on the subjects clothing would, however, be too intrusive and unreliable. The most practical solution is therefore to place the temperature sensors on a stand close to the subject's office chair.

Care has to be taken that the radiant temperature sensor is not shielded by other instruments or office equipment. The subject itself will obviously have a distorting affect on the sensor readings i.e. it will shield the sensor from radiant heat but also function as a radiant heat source.

7.1.2 Lighting

The average lighting level and lighting quality has an impact on worker well-being and also on degradation of furniture, for example. It can be measured anywhere in the proximity of the workplace.

However, directional lighting levels have been shown to have a significant impact on productivity and processing effectiveness. It is therefore important to reproduce as closely as possible the directional lighting levels the subject sees when working at the workstation. In this case we have arranged five directional light sensors to capture a 360° view of the light intensity from these directions. An alternative option would be to locate the directional light sensors facing forward, with each covering an approximately cone shaded field of view as shown below. This option will be trialled in a future version of the instrument.

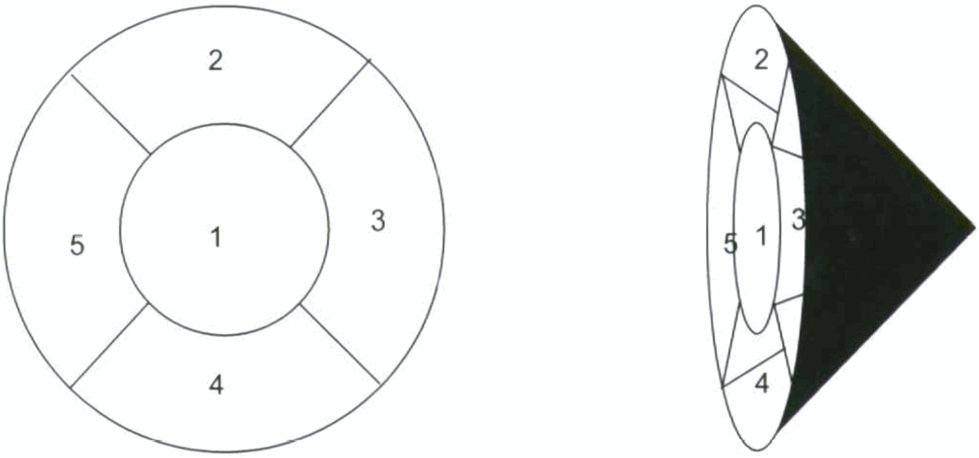

Figure 14. Frontal and side view of alternative directional light sensor.

Other placement options were also considered. Options included mounting of the directional light sensors at the back of the office chair, integrated into a set of specially designed glasses and on a flexible arm mounted onto the computer screen. Although the final assembly on a separate stand has some limitations in respect to light being shielded by the subject him/herself and accidental misdirection of the sensors, it was considered the most practical solution.

7.1.3 Noise level

The location of noise level sensors needs to be suitable to capture general office noise, but must not be distorted by low level equipment noise produced by office equipment such as computer fans. It is therefore important to place the noise level sensors as close to the subject's head as possible. Location on the workstation itself might lead to over-representation of equipment noise and possible vibration of tables and equipment. It was therefore decided that the best location for placing noise level sensors was also on a separate floor stand.

7.1.4 VOC/CO_2

As discussed previously the level of volatile organic compounds (VOCs) is not very sensitive to precise locations within an open plan floor. When using CO_2 as a proxy for VOCs, there is an advantage to move the sensors somewhat away from the subject in order to avoid a distorted reading from exhaled air.

7.1.5 Air movement

It is well accepted that air movement can have an important effect on comfort perceptions. The options to measure air movements have therefore been explored. Choosing an appropriate location for any air movement sensors proved very difficult. Draught perceptions may relate to any part of the body, most commonly around the feet and the lower back or the neck. Because of the practical difficulties in developing a suitably sensitive sensor, and the practical issues of placing it at the required location in a robust and reproducible manner, it was found that it is not feasible to collect this particular data stream.

7.1.6 Overall set-up

The following photos show the overall set-up of the environmental monitoring arrangement.

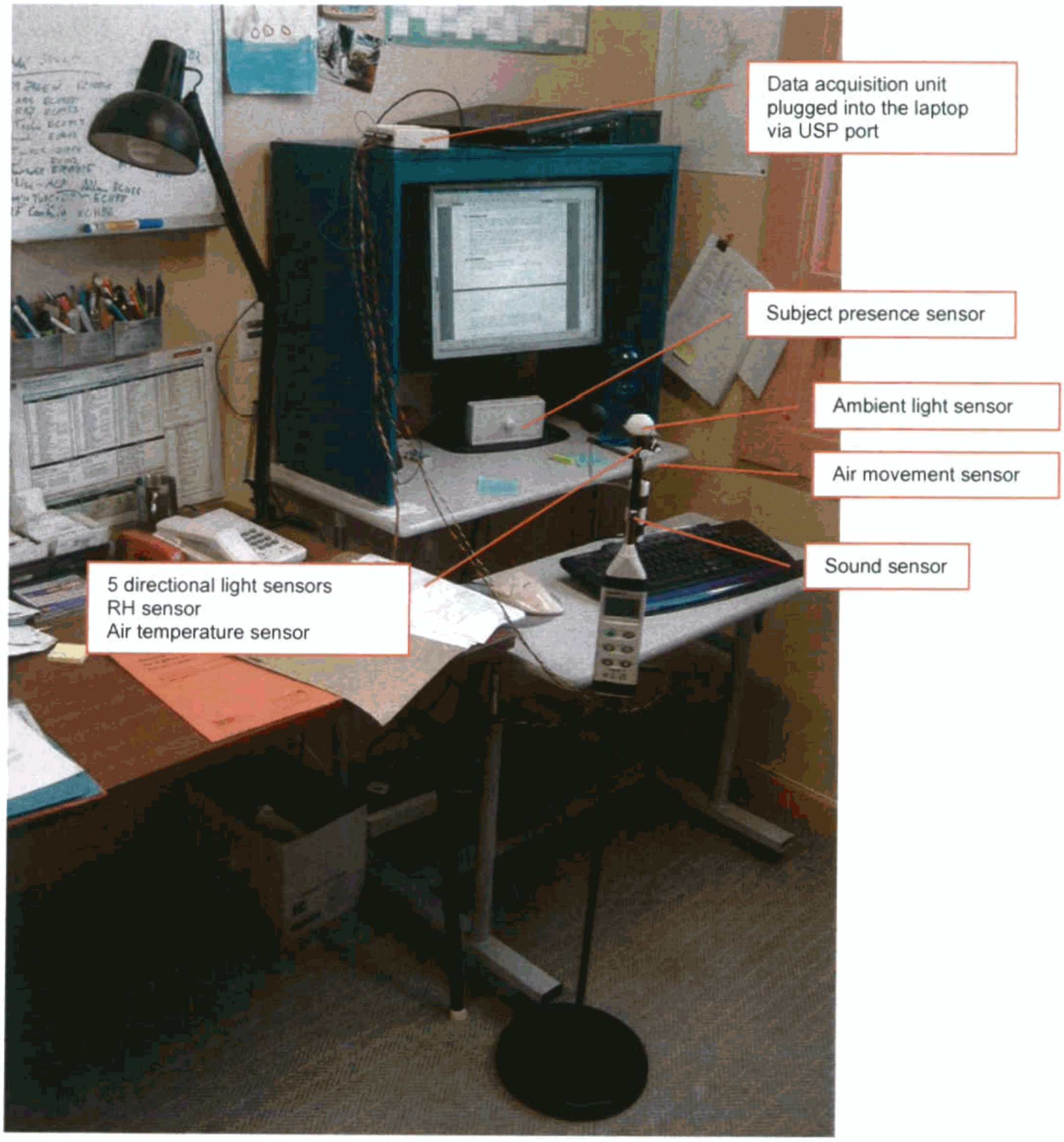

Figure 15. Placement of the sensor arrays around the workstation.

8. CONCLUSION AND RECOMMENDATION

This project successfully developed a low cost environmental workplace station metering system. Potential applications of the system are the building energy end-use project, research activities into health and productivity of office workplaces and as a tool for general consulting work on office environment performance.

The potential of this system could be further increased by a number of elements. The following activities are recommended:

1. Improve the directional light sensor arrangement as described in section 7.1.2
2. Conduct a full calibration of all the sensors

3. Develop a schedule for maintenance and re-calibration of the equipment

4. Investigate the option to combine the NIWA air quality metering system with the office environment metering system

5. Explore the potential of intellectual property protection and commercialisation of the system

9. REFERENCES

Humphreys M. 1977. *The Optimum Diameter for a Globe Thermometer for Use Indoors: Report CP9/78*. Building Research Establishment, Watford, UK.