Integrating Open-Source Technologies to Build a School Indoor Air Quality Monitoring Box (SKOMOBO)

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***Abstract*—A low-cost, low power consumption indoor environment monitoring instrument, called SKOMOBO (school monitoring box), was developed and tested. SKOMOBO includes sensors to monitor temperature/relative humidity, carbon dioxide, particulate matter (PM) and motions. SKOMOBO was developed using the open source hardware Arduino Pro Mini. This paper describes the process of building SKOMOBO, including sensor selection, printed circuit board design, sensor programming and performance evaluation. Two co-located tests have been undertaken; one in the controlled environment and one in the uncontrolled environment. Results show SKOMOBO measurements have high correlations with their commercial equivalents. In the two different testing environments, the R^2 of temperature measurements for all six SKOMOBOs were 1. The R^2 for relative humidity and CO_2 measurements were above 0.9. The result of this work shows the reliable of SKOMOBO on monitoring indoor air quality.**

Keywords—Arduino Pro Mini, open sourse, low cost sensors, environment monitoring

I. INTRODUCTION

Standard Indoor Air Quality (IAQ) monitoring equipment has a very high capital cost. Continuous and long-term real time monitoring IAQ in a large number of rooms will be costly. Fortuitously, low cost sensor research and remote logging/data transmission equipment are becoming more common. These developments have opened up new horizons for IAQ monitoring and understanding our indoor environment.

Open Source Building Science Sensors (OSBSS) [1], a team from Illinois Institute of Technology, built an indoor environment monitoring device based on Arduino Pro Mini (www.arduino.cc). This device can measure air temperature and air relative humidity, surface temperature, carbon dioxide (CO_2), human occupancy and light intensity. The OSBSS device has been tested alongside the commercial equivalents at student's lab and office for 7 days at 1-min interval. The linear correlation of measurements between OSBSS sensors and their commercial equivalents was strong. For all measurements, the slope ranged from 0.96 to 1.15. R-squared (R^2) was between 0.87 and 0.99 [2].

PiMaa project is based in Kampala, Uganda, aiming to develop an affordable environmental monitoring box to monitor the ambient pollutant in Kampala's most polluted areas. This project used Raspberry Pi as the core, running various environmental sensors (CO_2, sulfur dioxide, nitrogen dioxide, ozone, particulate matter, temperature, relative humidity and noise). They found instruments for the outdoor environment monitoring were most challenging, as fewer sensors were developed for outdoor environmental monitoring compared with the varieties of sensors built for indoor environment monitoring. This project is under development and has not showed any testing result yet [3].

New Zealand National Institute of Water and Atmospheric (NIWA) Research Ltd developed a low cost environmental monitoring box housing five sensors (temperature, relative humidity, carbon dioxide, particulate matter and human occupancy). This environmental monitoring box was named 'PACMAN', standing for Particles, Activity and Context Measurement Autonomous Node. Arduino Pro Mini is the main microcontroller. Co-located test of PACMAN and commercial equivalents showed high agreements of the measurements [4]. In New Zealand (NZ), PACMAN has been used in some research projects for the data collection. PACMAN users included UNITEC (Auckland, NZ), School of Architecture (University of Auckland, NZ) and Wellington School of Medicine (University of Otago, NZ) [5].

In collaboration with NIWA, a research team from Massey University, NZ, is developing a low cost device for monitoring IAQ in schools. This device is named SKOMOBO, standing for SKOol MOnitoring BOx. SKOMOBO will monitor the temperature, relative humidity, particulate matter ($PM_{2.5}$ and PM_{10}), CO_2 and human occupancy in classrooms. SKOMOBO project aims to make monitoring of a large number of classroom environments affordable and achievable. For a fraction of the standard costs, SKOMOBO would allow

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investigations into IAQ in multiple NZ classrooms, assuring children are learning in a healthy environment.

This paper describes the development of SKOMOBO. Test result shows the ability of SKOMOBO to accurately measure indoor IAQ. Section II describes sensors selection, printed circuit board (PCB) design and sensor programming. Section III shows the co-located testing results. Section IV discusses the results, the advantage of this low-cost multi-sensors environmental monitoring instrument.

II. Development of SKOMOBO

This part shows the process of building SKOMOBO, including sensors selection, PCB design, sensors programming and enclosure design.

A. Sensors Section

Sensors of temperature and humidity, CO_2, PM and human occupancy were housed inside SKOMOBO.

1) Temperature and relative humidity sensor: Research showed enclosure added heat and caused a small lag of the temperature and relative humidity measurement [2]. In this project, the temperature sensor was kept away from the main board, outside the enclosure. This will avoid not only the heat added by enclosure as well as the heat generated by other sensors. In this project, TELAiRE T9602 was selected for temperature and relative humidity measurement. This sensor is based on capacitive polymer sensor chip [6]. This sensor is used in the commercial available Gas Probe IAQ from BW Technologies Ltd, Canada. BW Gas Probe IAQ has been extensively used in our research team since 2005. It showed a reliable long-term measurement. The sensor has flexible cable length (1 meter or 1.8meters), flexible output modes (I^2C digital or PDM analogue) and flexible power supply (3.3VDC or 5.0 VDC). The part number of the sensor selected in this project is T9602-3-D-1.

2) Carbon dioxide sensor: Non-dispersive infrared (NDIR) CO_2 sensor is commercial available and affordable. Three NDIR CO_2 sensors from different manufactures, namely COZIR ambient air CO_2 sensor (accuracy: ±75ppm), Telaire T6615 (accuracy: ±50ppm) and SenseAir K30 (accuracy: ±30ppm) were tested [7]. Results showed the tested sensors were all within the manufacture specified accuracy. SenseAir K30 was found with a reliability and consistency result compared with the observation from the greenhouse gas analyzer based on cavity-enhanced absorption spectrometry. The high accuracy of CO_2 measurement by SenseAir K30 was reported by OSBSS project [2]. OSBSS project selected SenseAir K30 as the CO_2 sensor after testing several CO_2 sensors. Authors did not give any information on make and model of the other tested CO_2 sensors. In this project, SenseAir K30 was selected for CO_2 measurement.

3) Particulate Matter sensor: Co-located tests were carried out to evaluate the accuracy of Sharp GP2Y1010AU0F, Shinyei PPD42NS and Samyoung DSM501A dust monitoring sensors against a commercial available aerosol monitor (SidePak, TSI Incorporated) [8]. Authors found that these sensors were at least with the R^2 of 0.89. However GP2Y1010AU0F reported accuracy deficiencies over long-term monitoring [9], the varieties of measurements among different sensors, low sensitivity response at high PM concentrations and scattered distributed measurements at the low temperature (around 0 °C) [10]. A linear correlation was found between the measurement of Shinyei PPD42NS and TSI Aerosol Particle Sizer model 3321 when $PM_{2.5}$ level was lower than 50 $\mu g/m^3$. However when $PM_{2.5}$ concentration was higher than 800 $\mu g/m^3$, there was no linear regression between the measurement of Shinyei PPD42NS and TSI Aerosol Particle Sizer model 3321 [11]. Similar results were report by [10, 12]. Three different Shinyei PM Sensors (Shinyei models PPD42NS, PPD20V AND PPD60PV) were tested at urban background and on-road locations in India and USA. Correlation results showed the highest R^2 value was 0.30 and the lowest R^2 value was 0.18 [12]. PMS3003 (Plantower, China) was recommended after lab testing by the collaborating team, NIWA [10]. Co-located tests between PMS3003 and SidePak (TSI Incorporation) found a linear correlation between PM_{10} measurements (ranged from 0 $\mu g/m^3$ to 350 $\mu g/m^3$) under the indoor temperature between 18°C and 28°C, with the R^2 of 0.99. Fig. 1 shows the block diagram of PMS3003 dust sensor.

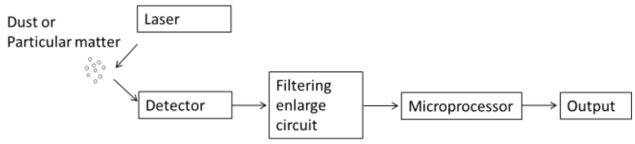

Fig. 1. Block diagram of PMS3003 dust sensor

As shown in Fig. 1, the measurement was based on the laser light. In this project, PMS3003 was selected for PM estimation. PMS3003 can estimate multiple size particulate matter independently, including $PM_{1.0}$, $PM_{2.5}$ and PM_{10}.

4) Passive Infrared sensor: Passive infrared (PIR) sensor recorded movement in the environment. There is no communication between PIR sensor and the hardware control part. PIR sensor shows binary result; '0' means no movement and '1' means movement in the monitoring environment. After extensively testing, TB-XC4444 PIR sensor was selected in this project. TB-XC4444 PIR sensor recorded results matched the experiments (occupied verse unoccupied office). The testing result showed reliable results. It can measure the movement from 3 meters to 7 meters according to the setup adjustment.

Table 1 shows the summary of the specifications of sensors selected in SKOMOBO. All the information is from sensors datasheet.

TABLE I. SUMMARY OF SENSORS SELECTED IN SKOMOBO

Features	Sensors			
	T9602-3-D-1	*K30 STA*	*PMS3003*	*TB-XC4444*
Measurement	Temperature / Relative humidity	Carbon Dioxide (CO_2)	Particulate Matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10})	Motion
Interface	I^2C, digital	I^2C extension, Serial, UART, Modbus protocol	Serial, UART, Modbus protocol	Digital signal
Range	Temperature: -20C to 70C; RH: 0~100%	0 to 5000 ppm_{vol}	$PM_{1.0}$: 0.3mm to 1.0mm $PM_{2.5}$:1.0mm to 2.5mm PM_{10}:2.5mm to 10mm	3 ~ 7 meters; 100 degree
Accuracy	Temperature: ±0.5C RH: ±2% (20~80% RH) ±3.5% (0% to 20% RH) and (80% to 100% RH)	±30 ppm or ±3% of reading	1 $\mu g/m^3$	NA
Power Supply	3.3 VDC	4.5 to 14.0 VDC; Ripple voltage less than 100mV;	5VDC	5 VDC to 20 VDC
Response time	Temperature: <= 116 sec; RH: <= 29 sec	20 sec	<= 10 sec	0.3-18 sec
Consumption	750µA (typical)	40 mA average	<= 100 mA (working); <= 200 µA (standby)	65 uA (quiescent current)
Manufacture	TELAiRE	SenseAir	Plantower	Duinotech

B. *Printed Circuit Board (PCB) Design*

The printed circuit board (PCB) design in this project was inspired by the PCB from PACMAN [13]. SKOMOBO PCB consisted of temperature and humidity sensor, CO_2 sensor, particulate matter sensor and motion sensor connecting to Arduino Pro Mini (microcontroller). It also contained the connection between Arduino Pro Mini and a real-time clock, SD card module and Wi-Fi module. The circuit board was designed using software Eagle (www.autodesk.com).

Fig. 2 (a) showed connections between sensors/modules and Arduino Pro Mini (including the communication interface and logic level). Fig. 2 (b) showed PCB Eagle design file. As shown in Fig. 2 (a), temperature and humidity sensor had 3.3V logic while the others were all 5V logic. To avoid the malfunction of the I^2C bus caused by the different logic levels, the pull up resistors was connecting with 3.3V logic directly without going through the logic level converter. The Wi-Fi module was 5V tolerant. Therefore Wi-Fi module was directly connected to Arduino Pro Mini without using a voltage divider at its default baud rate of 115200 bits per second. The whole SKOMOBO unit consumes less than 2.5 Watts of power which was around 500mA at 5V.

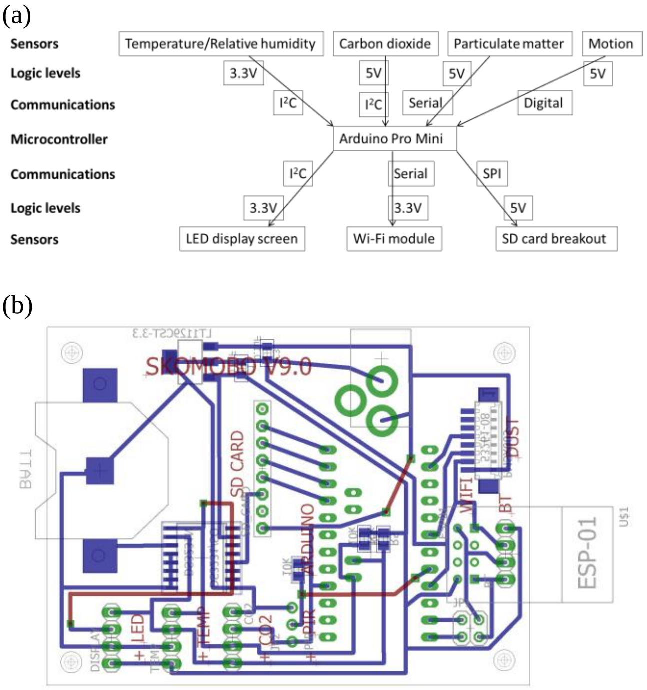

Fig. 2. (a) Block diagram of SKOMOBO printed circuit board (including communication interface and logic levels); (b) SKOMOBO printed circuit board Eagle design file

C. *Sensor Programming*

The default language of Arduino Pro Mini (C++) was used to program SKOMOBO. During the initial development, each sensor was tested and developed in isolation. All individual codes were combined together at the end of development.

Arduino Pro Mini was connected to a Node.js server (www.nodejs.org) via an ESP8266 01-S wireless module. The server was hosted inside a virtual machine on Windows 2016 server. Microsoft Internet Information Server (Microsoft IIS), being a reverse proxy, was run by the virtual machine to allow the virtual machine to response HTTP requests. The virtual machine was also running MariaDB for the database management. TypeScript (a programming language) was used to program the Node.js server. All codes are freely accessible to the public at https://github.com/SKOMOBO/arduino.

D. *Enclosure design*

The enclosure was designed by product development students and engineering students, using software SOLIDWORKS (www.solidworks.com). The material used for enclosures is 3mm thick clear acrylic. Fig. 3 shows the appearance of SKOMOBO.

Fig. 3. The appearance SKOMOBO

There is an inner plate inside the SKOMOBO. The inner plate was fixed by slots on the two sides and bottom enclosure. All sensors were mounted on the inner plate. On both sides of CO_2 sensor, the enclosure was designed as net stock, making sure adequate air circulate through it. This enclosure had no influence on the measurement results of all sensors.

III. Validation of Skomobo Measurements

SKOMOBO (N=6) and commercial monitors (TSI Q-trak 7575, N=2 and TSI DustTrak 8530, N=2) were exposed to the same environment for a 2-day period in a controlled environment office and for a 3-day period in an uncontrolled environment office.

A. *Controlled environment office*

1) Experiment design

SKOMOBO and TSI equipment were placed on the same desk in a controlled environment office. The office had a volume of 16.83m^3. The data were recorded at 1-minute interval during the 2 day test. The office occupancy was logged. Some activities had been carried out in the office to evaluate the sensor response. Fig. 4 shows SKOMOBO and TSI equipment co-located test in the controlled environment office.

Fig. 4. SKOMOBO (N=6) and TSI equipment (N=2) co-located test in a uncontrolled environment office common area

Table II shows the date, time, activities undertaken in the controlled environment office and the sensors been evaluated under each activity.

TABLE II. Time and Activities Undertaken During Tests

Date	Time	Activity	Sensor evaluated
2017/07/11	13:00	• Walking around the office for 1 minute; • window and door close;	Motions
	14:00	• Packing and unpacking a dusty suitcase; • Window and door kept close; • Left the office at 14:05;	Particulate matter
	15:30	• Release CO_2 with CO_2 fire extinguisher; • Left the room at 15.35;	Carbon dioxide
	17:00	• Walking around the office for 5 minutes. • Window and door kept open.	Motions; Temperature
2017/07/12	08:00	• Turn on the heater for 30 minutes; • Walking around the office for the first 15 minutes; • Stand in front of the middle of desk, waving arms only for the second 15 minutes; • Left the office at 8:30;	Temperature; Motions
	09:30	• Walking around the office for 5 minutes; • Window and door kept close;	Motions
	11:00	• Vacuum the carpet for 5 minutes; • Windows and door kept close; • Leave the office at 11:05;	Particulate matter
	14:30	• Release CO_2 with CO_2 fire extinguisher; • Left the room at 14.35;	Carbon dioxide
	16:30	• Walking around the office for 5 minute; • Windows kept close but the door was open. • Left the room at 16.35.	Motions; Temperature
2017/07/13	08:00	• Turn on the heater for 30 minutes; • Windows and door were kept close; • Walking around the office for the first 25 minutes; • Stand in front of the middle of desk, waving arms only for the second 5 minutes; • Left the room at 8:30.	Temperature; Motions
	11:35	• Walking around the office for 5 minute; • Windows and door were kept close; • Left the office at 11:40.	Motions

2) Experiment results

a) Temperature, relative humidity and carbon dioxide

Fig. 5 showed results of SKOMOBO and TSI Qtrak co-located test under the controlled environment. 'TSI08' and 'TSI20' inside plot legends are the results from two TSI Qtraks.

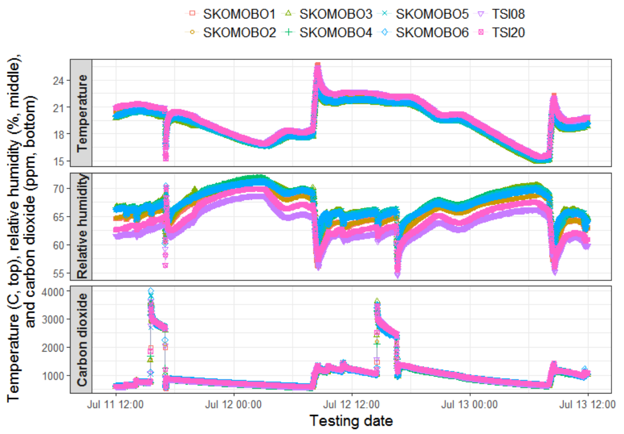

Fig. 5. SKOMOBO (N=6) and TSI Qtrak (N=2) co-located test for temperature, relative humidity and carbon dioxide measurements under the controlled environment

Results showed good agreements for temperature, relative humidity and CO_2 measurements between the six SKOMOBOs and the two TSI Qtraks. These three sensors housing inside SKOMOBO responded to the environment change as same as TSI Qtrak did. Temperature decreased when the window and door kept open (Table II activities happened at 17:00, 2017/07/11 and 16:30, 2017/07/12), while it increased when turning the heater on in the morning (Table II activities happened at 08:00, 2017/07/12 and 08:00, 2017/07/13). The linear regression showed strong correlations between SKOMOBO and TSI Qtrak temperature measurement. The minimum R^2 was 0.98. The slope ranged between 0.9 and 0.98, and the intercept ranged from 0.115 to 1.48.

Strong correlations between SKOMOBO relative humidity and TSI Qtrak relative humidity measurements were found. The R^2 was between 0.92 and 0.97. SKOMOBO relative humidity measurements were higher than TSI relative humidity measurements. But the differences were less than 5%. This difference can be offset adjusted in codes.

All CO_2 sensors immediately responded to the CO_2 level increased (from 800ppm to 3000ppm) when CO_2 was released from CO_2 fire extinguisher (Table II activities happened at 15:30, 2017/07/11 and 14:30, 2017/07/12). They responded to CO_2 gradually increases as well, as in the morning (Table II activities happened at 08:00, 2017/07/12 and 08:00, 2017/07/13) CO_2 measurements were slowly increased when the activity was carried out in the office. Fig. 6 showed the correlations between each SKOMOBO CO_2 measurements and TSI Qtrak CO_2 measurements (the average value of two TSI Qtrak).

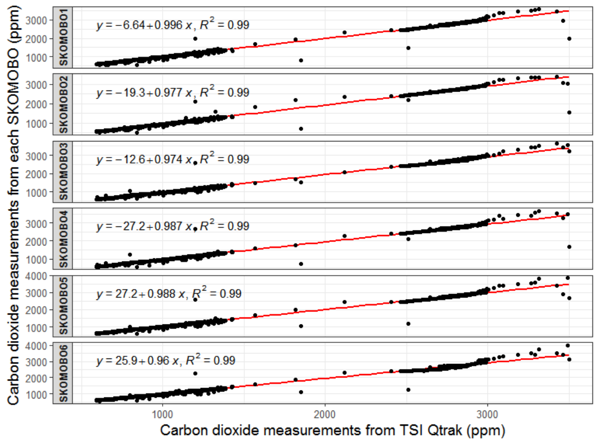

Fig. 6. Correlations between SKOMOBO and TSI carbon dioxide measurement, results in the unoccupied office

Correlations of CO_2 measurements between SKOMOBO and TSI Qtrak were strong with the R^2 of 0.99 for all the six SKOMOBOs. The slopes were between 0.96 and 0.99, meaning good linear relationships between SKOMOBO and TSI Qtrak CO_2 measurement. The intercept ranged from -27.2ppm to 27.2ppm. This level was within the manufacture reading accuracy (± 30ppm). In conclude, results showed that SKOMOBO gave a reliable measurement of temperature, relative humidity and CO_2. Sensors quickly responded to the environment change in the same way that TSI Qtrak (commercial parts) did.

b) Particulate matter

Two activities (Table II activities happened at 14:00, 2017/07/11 and 11:00, 2017/07/12) had been done to test the dust sensor estimation. Fig. 7 shows the estimated PM results from SKOMOBO and TSI DustTrak.

Fig. 7. SKOMOBO (N=6) and TSI DustTrak (N=2) co-located test for particulate matter (PM2.5 and PM10) estimations under the controlled environment

In Fig. 7, 'PM10DT' and 'PM2.5DT' inside plot legends mean PM_{10} estimated results and $PM_{2.5}$ estimated results from TSI DustTrak. SKOMOBO estimated results were on the left-hand axis. DustTrak measurements were on the right-hand axis with the unit of mg/m^3. The different scale of measurements can be offset adjusted in the coding. As shown in Fig. 7, SKOMOBO and DustTrak all immediately responded to changes of particulate matter levels. Linear regression of $PM_{2.5}$ estimated results from SKOMOBO and TSI DustTrak showed for the $PM_{2.5}$ measurements, the R^2 ranged from 0.82 to 0.9. For PM_{10} measurements, PM_{10} measurements correlations were less strong than $PM_{2.5}$. The R^2 ranged from 0.68 to 0.89. In conclude, particulate matter estimations from SKOMOBO and DustTrak were in a good agreement.

c) Motions (occupancy)

Fig. 8 showed motion test results in the controlled environment office. Except for activities described in Table II, there were no other motions in this office. Results showed in the first day (from 12pm July 11 to 00am July 12), all SKOMOBOs recorded the same result. The results matched the activities in this office. For the rest 18 hours of the test, except SKOMOBO5, all other five SKOMOBOs recorded same results, matching the activities. For example, in the morning, when the researcher was walking around for 30 minutes, the dense bars indicated more motions at this time than others.

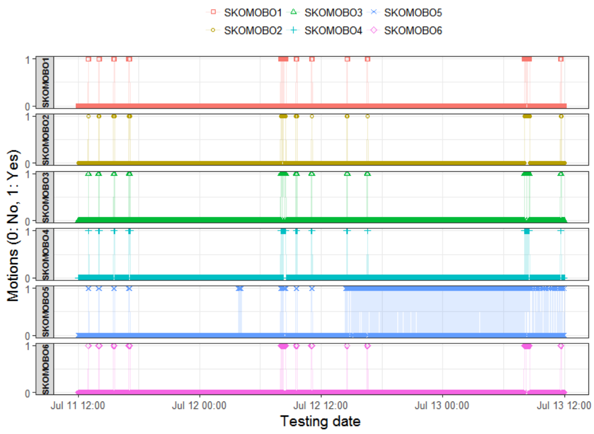

Fig. 8. Motion testing result in the controlled environment office

The inaccurate motion recording result from SKOMOBO5 was caused by the loose connection between PIR sensor and the PCB board. SKOMOBO PIR sensor was working accurately after tight the connection. In conclude, the co-located test between six SKOMOBOs, two TSI Qtrak and two TSI DustTrak under the controlled environment office showed a reliable result of the SKOMOBO measurements for temperature, relative humidity, CO_2, $PM_{2.5}$, PM_{10} and occupants motions.

B. Uncontrolled environment office

1) Experiment design

The sensors response in an uncontrolled environment office was tested as well. There were no windows in the uncontrolled environment office common area. The main door kept open during the weekdays from 8am to 6pm. The office was air conditioned from 7am to 7pm during weekdays. Seven small offices are located around the common area. Normal office activities were conducted during the test. Fig. 9 shows SKOMOBO and TSI equipment co-located test in the uncontrolled environment office common area.

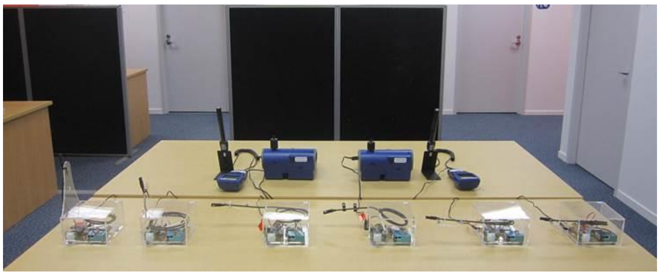

Fig. 9. SKOMOBO (N=6), TSI Qtrak (N=2) and TSI DustTrak (N=2) co-located test in an uncontrolled environment office common area

In the middle of the common area, SKOMOBO and TSI equipment were placed on desks. All the data were recorded at 1-minute interval during the 3 days testing.

2) Experiment results

a) Temperature, relative humidity and carbon dioxide

Fig. 10 shows temperature, relative humidity and CO_2 results under the uncontrolled environment test.

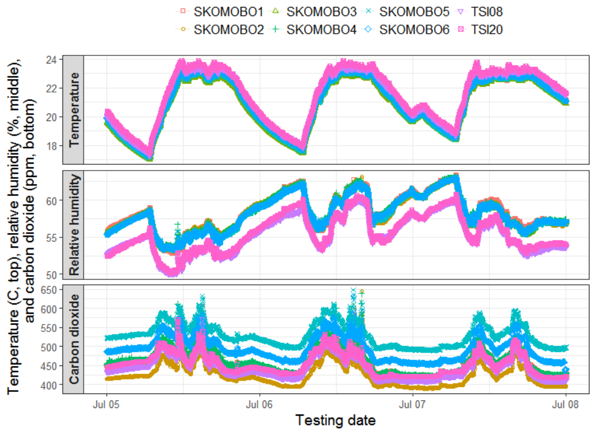

Fig. 10. SKOMOBO and TSI Qtrak co-located test for temperature, relative humidity and carbon dioxide measurements under a uncontrolled environment

As shown in Fig. 10, temperature measurements from SKOMOBO and TSI Qtrak were in a very good agreement. The slopes ranged between 0.957 and 0.973, with the R^2 of 1 for all the SKOMOBOs. The intercept ranged from 0.05 to 0.42. This level was within the manufacture reading accuracy (± 0.5 °C). SKOMOBO relative humidity measurements were in average 5.88% (4.68% to 6.44%) higher than TSI relative humidity measurements but they had the same trends. This measurement difference can be offsite adjusted in the coding. The slopes were from 0.932 to 0.966. The R^2 was between 0.96 and 0.98. The CO_2 measurements from SKOMOBO and TSI Qtrak ranged had the R^2 from 0.89 to 0.94. The slope ranged from 0.953 to 1.13, having intercepts between -47.8ppm and 48.6ppm.

b) Particulate matter

Fig. 11 shows $PM_{2.5}$ and PM_{10} estimated results from SKOMOBO and TSI DustTrak. Fig. 11Fig. was generated with the raw data using generalized additive model.

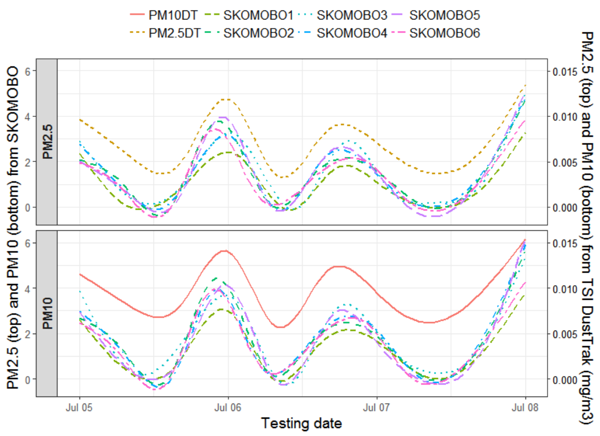

Fig. 11. SKOMOBO and TSI DustTrak co-located test results under the uncontrolled environment

The meaning of 'PM10DT' and 'PM2.5DT' inside plot legends, the estimated results on left-hand axis and right-hand axis are as same as they are in Fig. 7. Figure 11 shows SKOMOBO and TSI DustTrak responded to the particulate matter change in the same way. Linear regression between $PM_{2.5}$ measurements from SKOMOBO and TSI DustTrak showed between 76% and 83% of data can be presented with SKOMOBO estimations.

c) Motions (occupancy)

Fig. 12 shows the occupancy measurement in the uncontrolled environment.

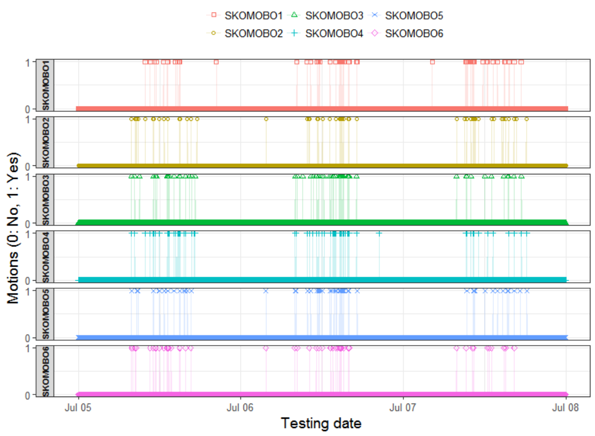

Fig. 12. Motion test results in the open plan office space

The result of the motions was consistent with the actual activity. No movement was recorded during the night time. This result illustrated SKOMOBO can correctly record motion in the uncontrolled environment (office common area).

IV. Discussion

Six SKOMOBO prototypes had been co-located tested with their commercial equivalents under two different environments; controlled environment and uncontrolled environment. In the two different testing environments, the R^2 of temperature measurements for all six SKOMOBOs were 1. The R^2 for relative humidity and CO_2 measurements were above 0.9. The particulate matter sensor inside SKOMOBO can estimate 80% of the TSI DustTrak particulate matter measurements. Office occupancy results matched room activities. Results show SKOMOBO can estimate temperature, relative humidity, CO_2, particulate matter and motions levels.

SKOMOBO is affordable compared to the market available equipment. Table III shows the price of all sensors, components, enclosure, assessory included in SKOMOBO. The sensors and components house inside SKOMOBO totally cost 245 USD. This price does not include the labor cost and all the development time.

TABLE III. Price of Sensors and Components of SKOMOBO

Sensor or components	Table Column Head	
	Sensor or component make and model	***Price (USD)***
Temperature and relative humidity	Telaire T9602-3-D-1	38.56
CO_2	SenseAir K30	91.5
Particulate matter	Plantower PMS3003	15.34
Motion	Duinotech XC-4444	5.12
Microcontroller board	Arduino Pro Mini	9.95
Printed Cricurt Board with components	PCB GoGo	9.98
MicroSD card breakout board	Adafruit	7.50
WiFi module	SparkFun-ESP8266	6.95
Micro SD card	SanDisk 8GB	9.52
Internet data	Vodafone Internet data	4.68 (per month)
USB dongle	Kuwfi 7.2Mbps WiFi dongle	20.99
USB dongle adapter	PowerTech 5VDC, 1.0A	9.52
Power adapter	PowerTech Plus MP-3144 5VDC, 1.0A	9.52
Enclosure	3mm clear acrylic	5 (roughly estimated)
Total		245

This price does not contain time cost in manufacturing SKOMOBO.

SKOMOBO is a multi-sensors IAQ monitoring device, including temperature, relative humidity, CO_2, particulate matter and motion measurement. The hardware and software are flexible. It is easier to add extra sensors. SKOMOBO has the customized enclosure. This benefits the fieldwork setup. The level of noise generated by SKOMOBO was lower than a computer does. This level would not drive the occupants to distraction, making it easier to blend into the fieldwork. The wireless data collection makes remote data checking available, reducing the physically fieldwork.

V. Conclusion and Future Study

The design and development of an environmental monitoring box with multi-sensors are discussed in this paper. The result of this work shows the reliability of SKOMOBO on estimating indoor air quality. In the future, up to eight infra-red sensors located on classroom windows will monitor how often the windows are open to bring fresh air into classrooms. In addition, three sound level sensors will measure the noise levels at three different points around the classroom (teacher area, back of the classroom and by the window to capture the outdoor noise pollution). This will provide the information on the speech quality. The next generation of SKOMOBO (SKOMOBO plus) will add a screen, showing the IAQ monitoring result (figures or graphs) simultaneously. This will investigate the impact of engagement on IAQ. SKOMOBO project engages with the science, technology, engineering and education as advised by New Zealand Ministry of Business, Innovation and Employment. SKOMOBO project responded to improve the ventilation and learning environment in New Zealand primary school as advised by New Zealand Ministry of Education.

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