Preliminary Report:

EPSRC IAA Indoor Air quality in Primary Schools

Report produced by

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Contents

1 Summary of EPSRC IAA Indoor Air quality in Primary Schools Project

This EPSRC IAA Indoor Air Quality in Primary Schools Project is an interdisciplinary impact project led by Dr Gabriela Zapata-Lancaster from the Welsh School of Architecture as Principal Investigator, Dr Thomas Smith from the School of Geography and Planning as Co-Investigator and Mr Miltiadis Ionas as research assistant.

This pilot project aims to support Councils and primary schools in maintaining good indoor environmental conditions in classrooms and indoor spaces. A secondary aim is to produce learning resources for children and teachers and guidance for schools and councils to maintain good indoor environmental conditions classrooms and indoor spaces. The project has proposed and deployed a visual monitoring toolkit to measure indoor air quality in school buildings and provide feedback to occupants. Moreover, it will propose supporting guidance to promote good indoor environmental conditions through behaviours and operational practices in buildings.

This research team has partnered with the local council and is working closely with teachers and children in two primary schools towards providing a means for councils and schools to manage the indoor air quality in school buildings. As a secondary aim, it is developing learning resources and engaging in hands-on workshops with pupils to reflect about indoor environmental conditions in schools, focusing on the nexus between behaviours and the resulting indoor environmental conditions.

2 Monitoring approach

This pilot project is testing and fine-tuning a monitoring approach to identify the indoor environmental conditions in different types of spaces in Primary schools (1) Classrooms; and (2) Communal spaces. In order to understand better the context of the monitoring data from the schools, the project is also monitoring outdoor temperature and relative humidity in the school grounds.

2.1. Classrooms

We are monitoring indoor environmental conditions in three classrooms that include different age groups and located in different orientations within the school building in each of the two primary schools (six classrooms in total). The monitoring exercise is measuring the temperature, humidity and CO2 as proxy of air quality. Classrooms were selected on the basis of feedback by Head Teachers and teachers in the schools.

One ‘open/close’ monitoring device has been installed per classroom to understand patterns of use of windows and doors.

2.2. Communal spaces

In addition to monitoring the selected classrooms, the project is monitoring at least one additional ‘communal space’ used for non-educational purposes where different age groups and classes mix: dining hall (School A) and communal reading area (School B). The communal space is primarily a space where non-learning activities take place; thus, is likely to have a different pattern of occupancy than classrooms. In order to provide an additional layer of understanding to characterise the indoor air quality, the project is also measuring ppm 2.5 and 10 in one space to identify exposure to particulate matter (which is associated to outdoor pollution or pollutant activities).

3 Monitoring Plan and Monitoring instrumentation

The monitoring instruments were installed in July 2021. The initial interval of readings is 1 hour. The study is comparing the indoor environmental conditions during unoccupied times (Summer) as a baseline to conditions in Autumn (shoulder season) and in Winter (heating season) with the aim to explore variations due to seasonal differences, changes of occupancy patterns and different regimes of building operation. The understanding of seasonal variations and occupancy patterns variations could inform behavioural based interventions to balance the need to reduce CO2 levels (as proxy of indoor air and ventilation) while maintaining adequate thermal comfort conditions indoors.

The monitoring plans in the figures 1 and 2 represent in a schematic representation the types of sensors installed in each school and their location, which include:

(1) Indoor Temperature and Relative Humidity (T/RH): long term monitoring of three classrooms and one communal space in each school using two types of sensors per classroom (ALTA wireless sensors and tinytags).
(2) Outdoor Ambient Temperature and Relative Humidity long term monitoring using one sensor outdoors in the school grounds, one per school (TinyTag sensor).
(3) CO2 concentration: long term monitoring using one sensor in each one of the three classrooms per school (ALTA wireless sensor). In addition to this long-term monitoring exercise, CO2 concentration is monitored using HOBO sensors to capture more granular data to characterise the patterns of CO2 variations during an in-depth short-term monitoring study. This in-depth short-term study has two

main purposes: (1) to further validate the measurements of the long-term CO2 sensor and (2) to get data with the highest possible resolution (min time interval).

(4) Particulate Matter (PM): one ALTA wireless sensor located indoors on a space nearby the main access point in each school. Particulate matter tends to be exacerbated by activities such as cooking, traffic pollution, smoke. We want to explore to what extent, if any, potential outdoor pollution enters the school premises. This aligns to efforts by the local council to address and limit outdoor pollution. There has been no concern prior to starting the project about pollution risks; however, this sensor is testing a potential approach that can be taken in the future for investigating sites or buildings located nearly heavily polluted areas (i.e., industrial estates) or adjacent to roads with heavy traffic conditions.

(5) Open/close sensor: one ALTA wireless sensor in one window in the classrooms monitored in the project as indication of the natural ventilation of the classrooms. This sensor displays the state of one window, whether they are open or closed.

Figure 1: A schematic of the Monitoring Plan in School A, illustrating the location of sensors deployed

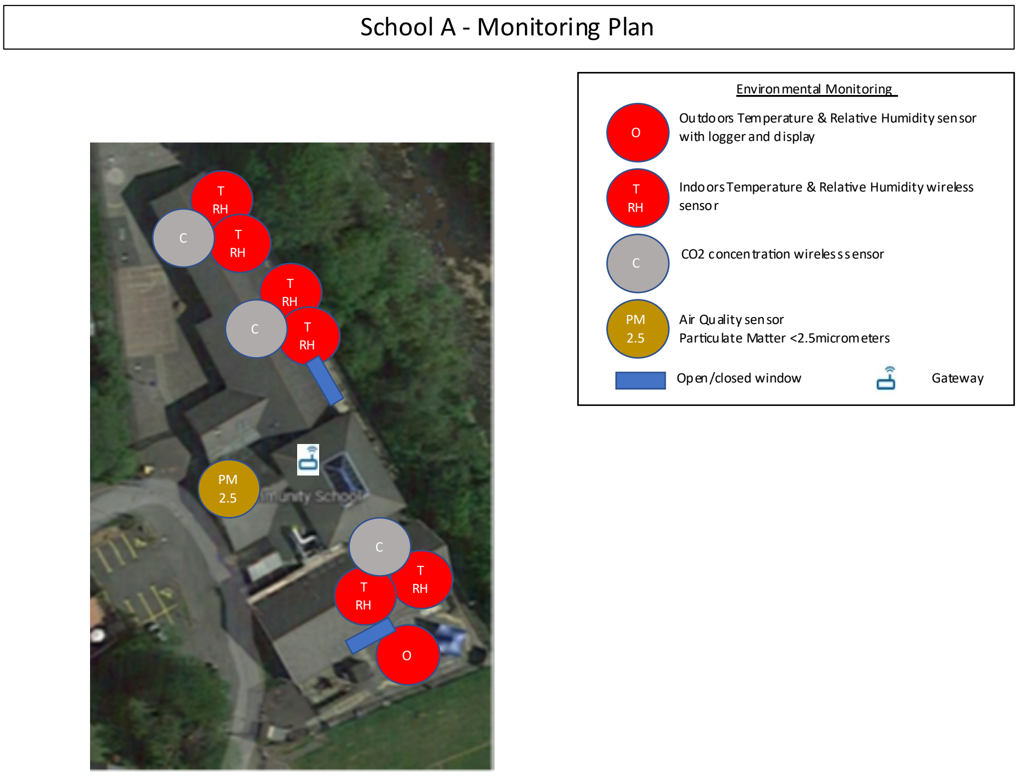
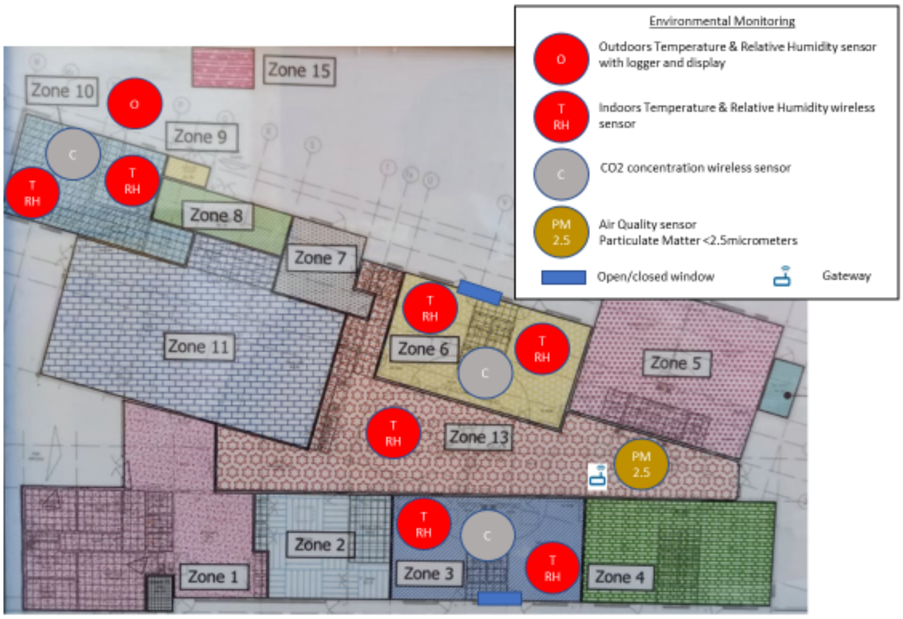


Figure 2: A schematic of the Monitoring Plan in Scool B, illustrating the location of sensors deployed

School B - Monitoring Plan



All the indoor sensors described above are wireless providing the ability for remote monitoring. The sensors transmit the data through a gateway, which needs power supply and internet access, in order to receive the data and transmit it to the main platform, where it can be accessible by the user.

In addition to the sensors used for monitoring purposes to characterise the indoor conditions, the project is deploying 2 types of user-friendly low-cost sensors in the three classrooms per school (1) to measure CO2, temperature and relative humidity indoors (Envisense) and (2) to measure outdoor temperature and relative humidity. These user-friendly devices enable real-time visualisation and feedback for teachers and pupils to identify the indoor conditions in their classrooms and to empower them to adopt behaviours that foster good indoor environmental conditions. Notice that the CO2 Envisense device has similar capabilities and grade than the monitoring sensors issued as part of the Welsh Government initiative to monitor CO2 in educational settings with guidance published in October 2021.

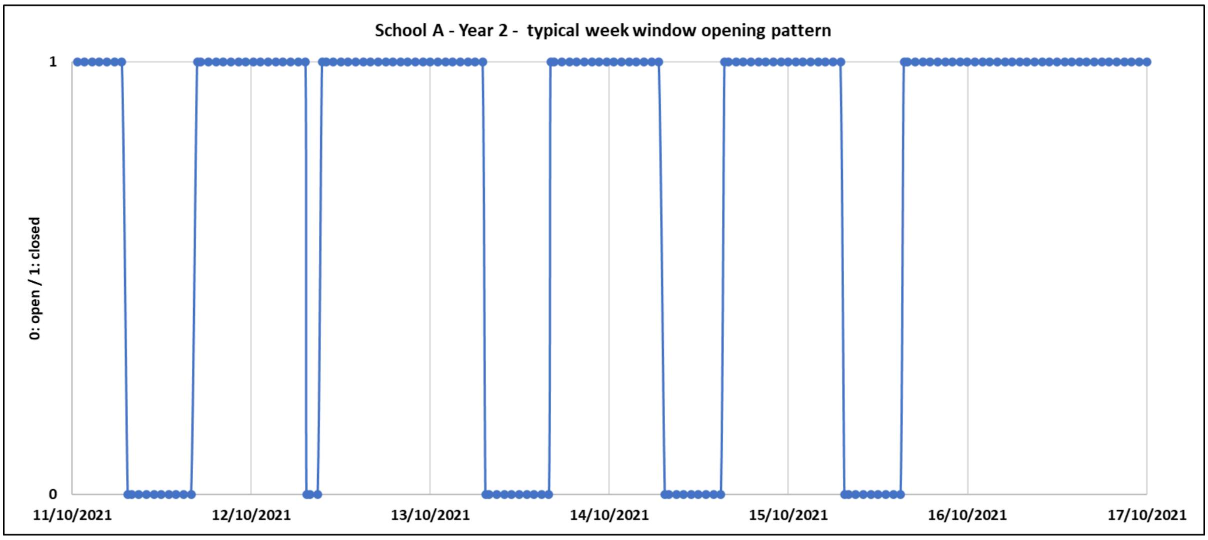
All the sensors, including those located indoors and outdoors, and the wireless transmission system deployed for indoor sensors, and the user-friendly low-cost devices, are further described in Appendix 1: Monitoring Instrumentation. Appendix 2: Monitoring sensor location includes pictures illustrating the location of different types of devices in the participating schools.

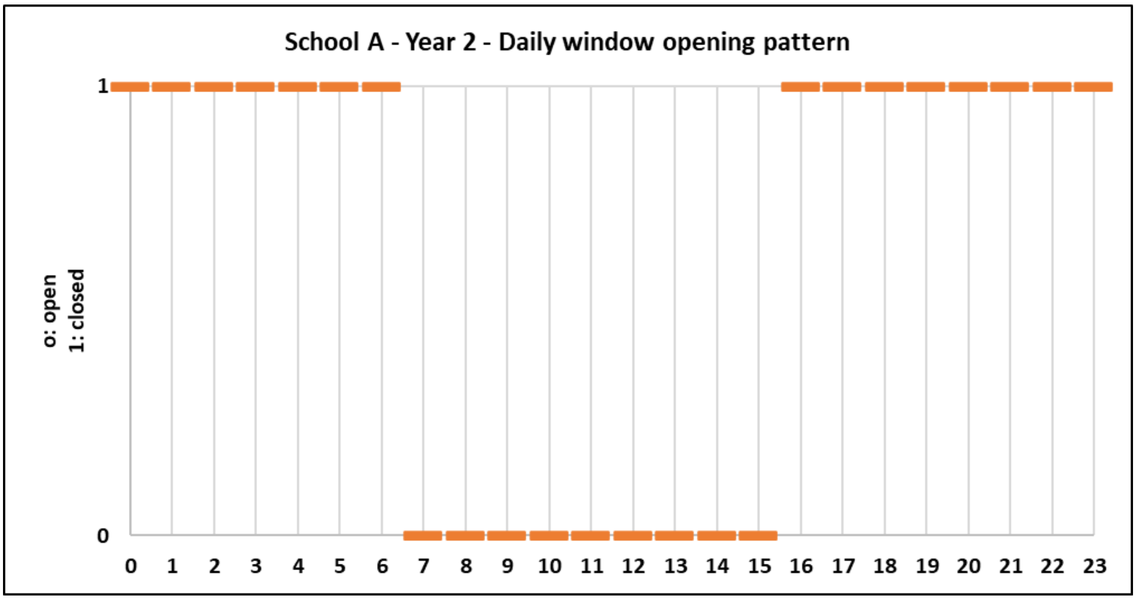
4 Preliminary analysis of monitoring data - Autumn 2021 half term

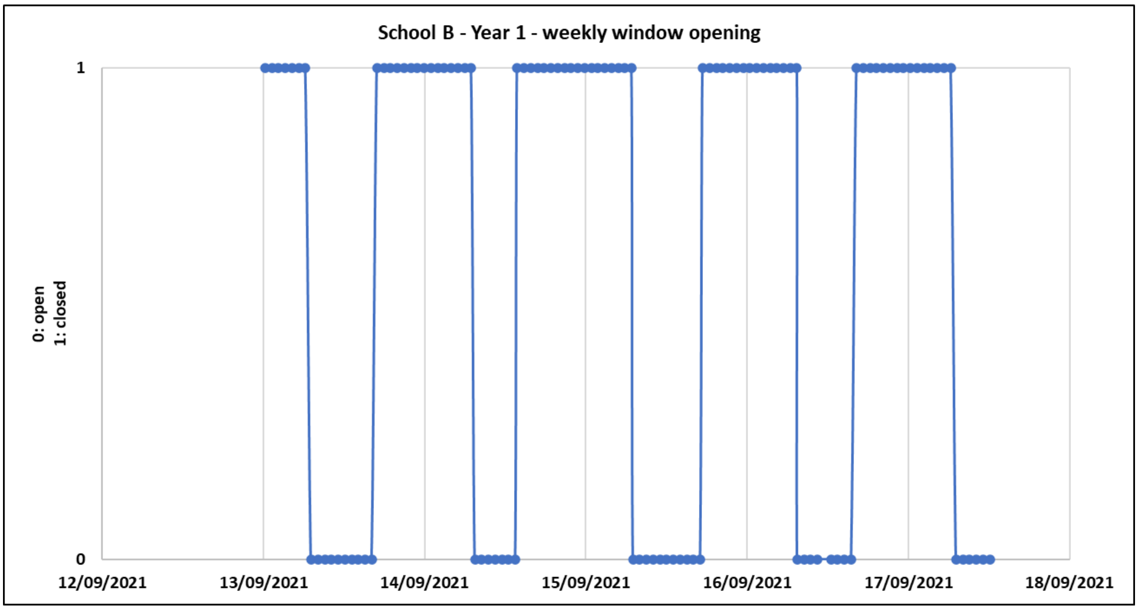
A preliminary analysis has been conducted, based on the monitoring data that has been collected, regarding the period of the first half term of Autumn 2021. The results of the analysis are presented below, grouped in the different features that are monitored.

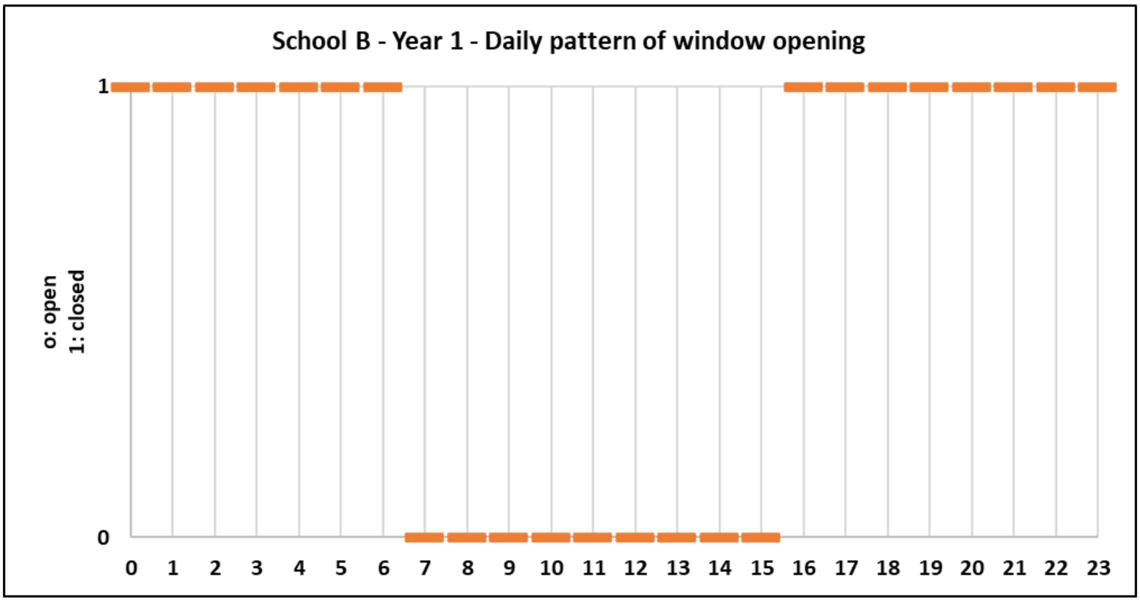
4.1 Natural ventilation (opening windows)

The first category is the natural ventilation of the classrooms. The data shows the consistent regime of keeping open windows during the school hours adopted as a everyday practice of the schools. Two graphs from indicative weeks are presented for each school, as the same pattern has been observed throughout the first two months of the academic year 2021/2022.









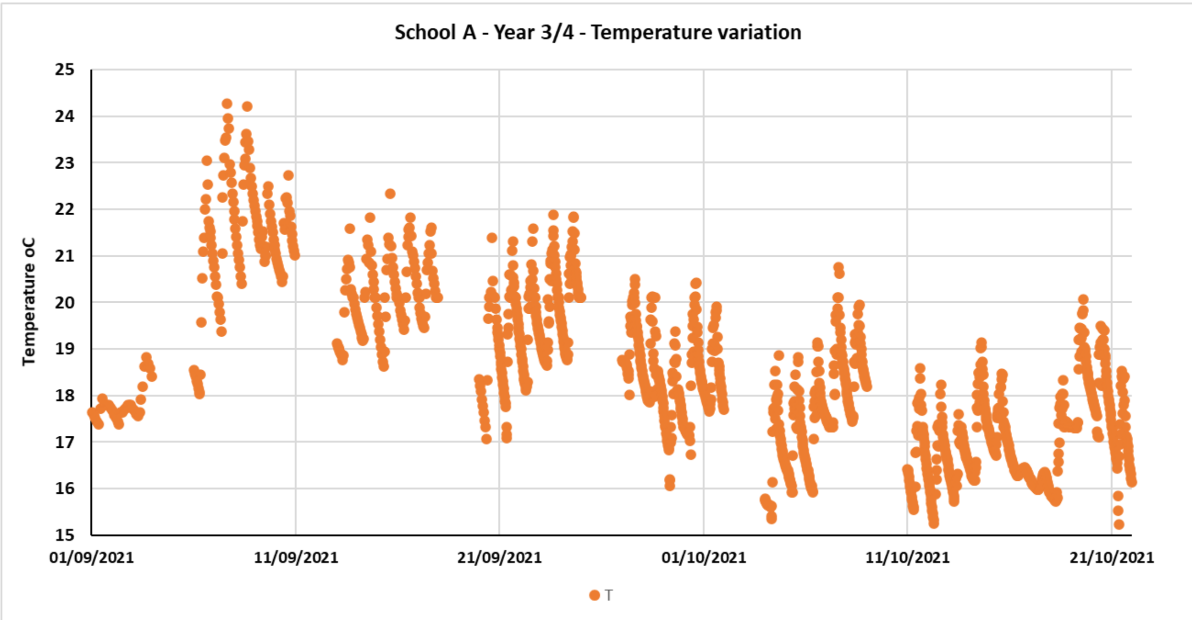
4.2 Air Temperature

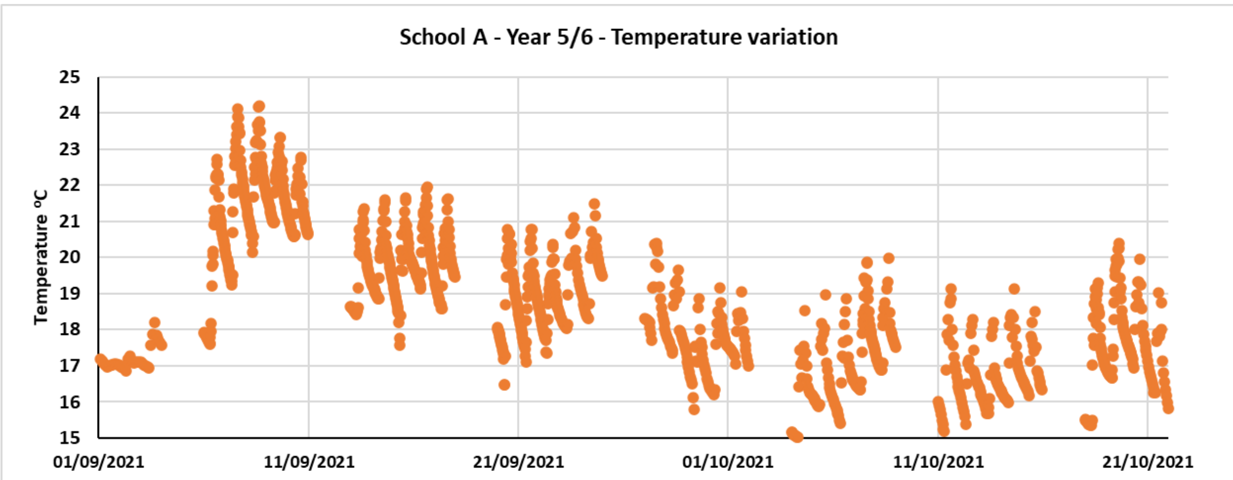
There are two main observations from the data analysis regarding air temperature. Both observations appear as consequences of the requirement for constant natural ventilation of the classrooms. Normally, classrooms are expected to have a constant air temperature, which would be uniform across the classroom. However, due to the need for constant natural ventilation of the spaces, this is not the case.

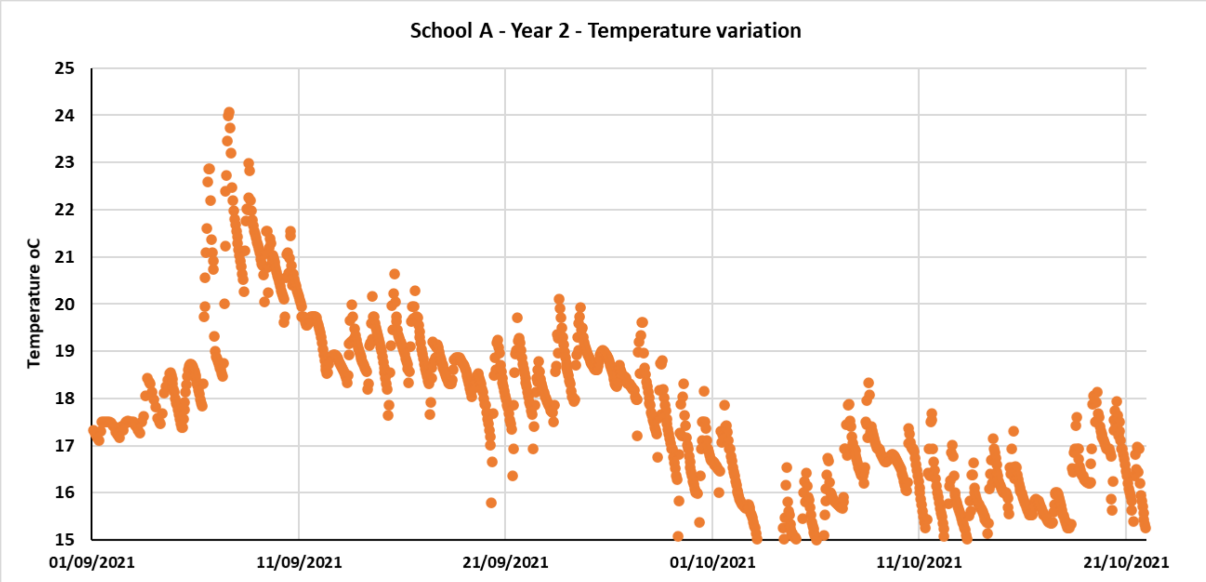
Firstly, the air temperature variation in the classrooms appears to be affected by the ambient air temperature. To illustrate this, the monitoring data has been grouped for each school week. It is apparent that the variation of air temperature of the classroom throughout the day starts from a certain value as the windows have been closed during the night, it drops with the beginning of the lessons, and then it has a tendency to follow the variation of the ambient temperature. However, each week the average temperature is lower, resulting to an air temperature less than 20ºC. Projecting this tendency to the winter months, the indoor air temperature could potentially be too cold and uncomfortable if the opening window regime adopted in autumn is applied in winter.

Moreover, there is a significant temperature difference within the classroom. The graph of an indicative week shows that there is a constant temperature of 1.5-2oC between the location near the window and away from the window.

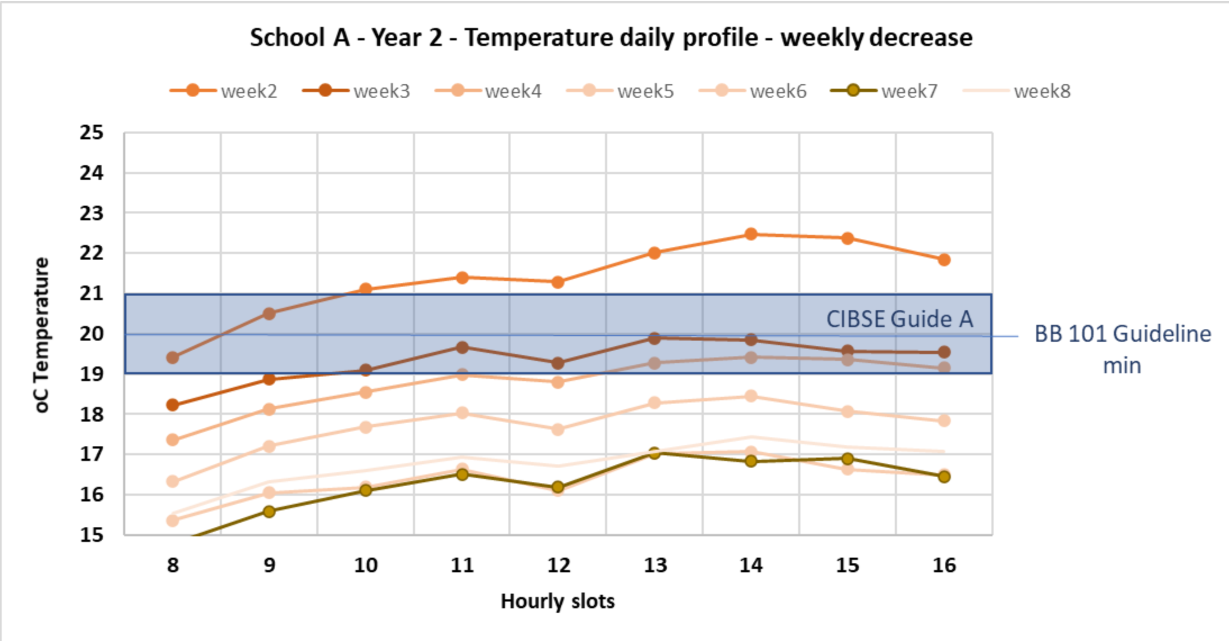
The first three graphs show the temperature variation in the three classroom under study in school A.

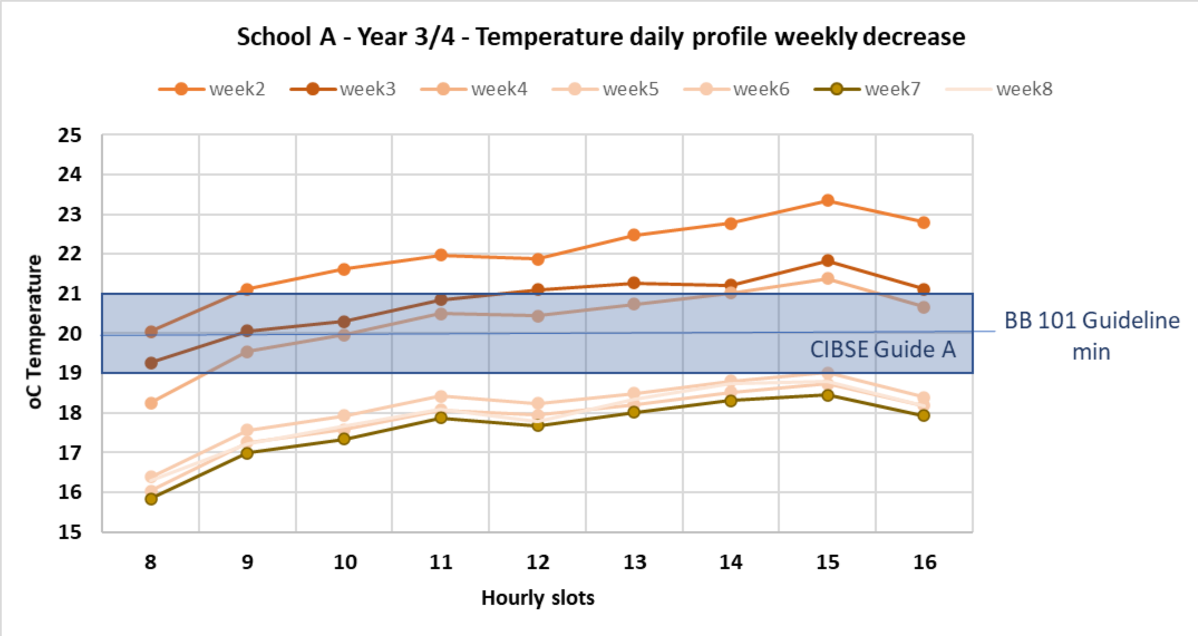


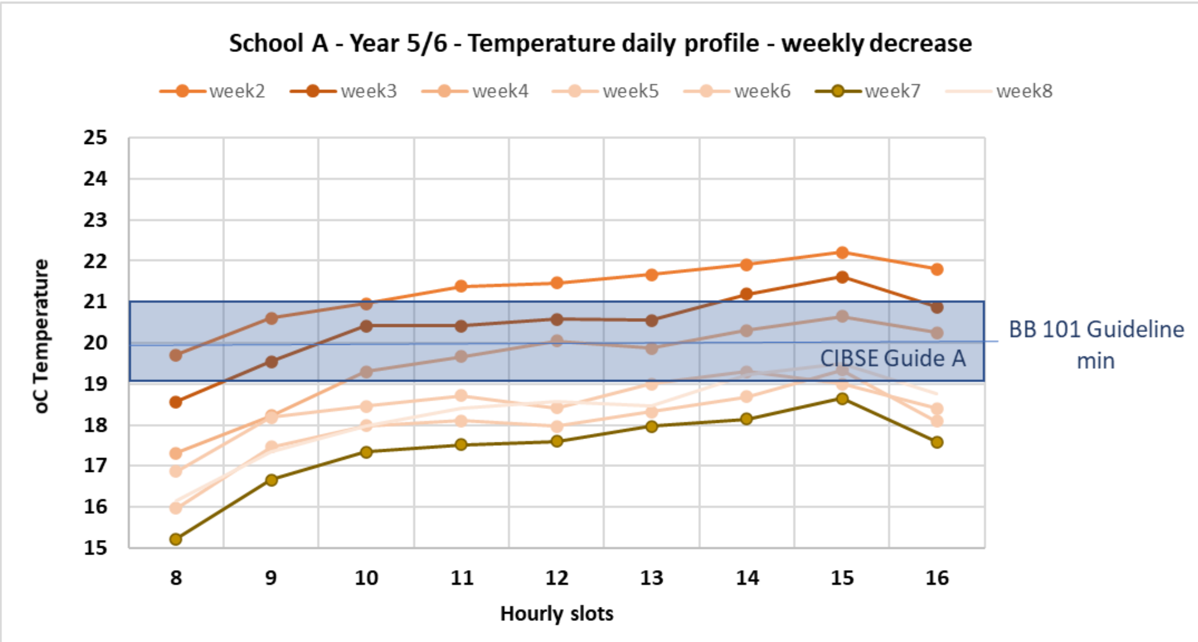




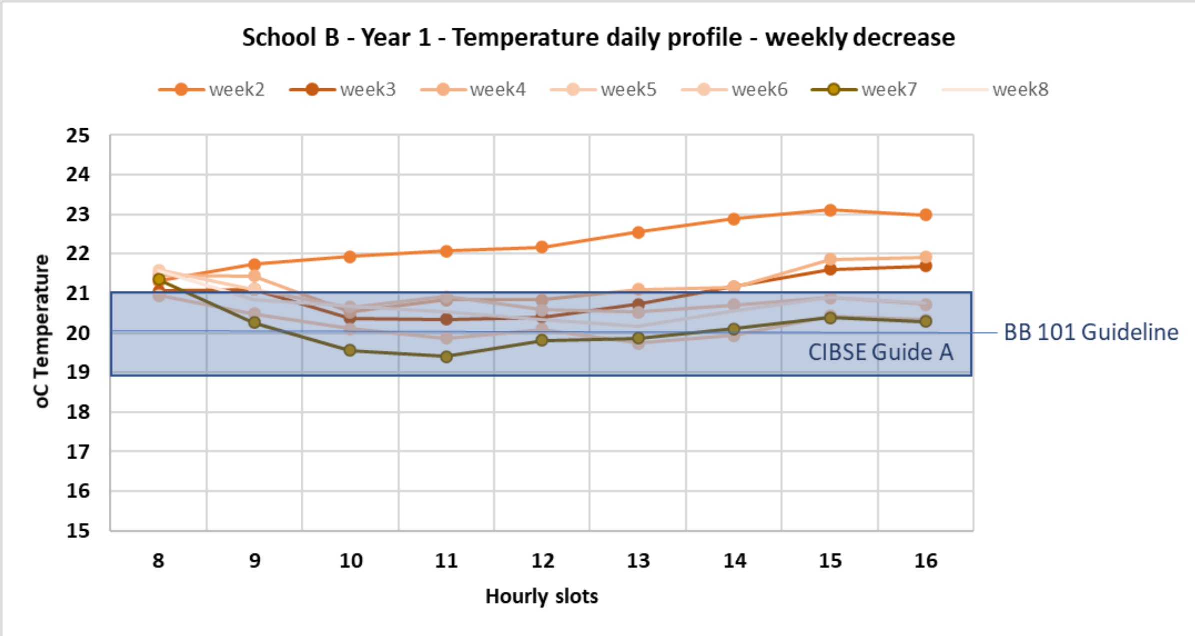
The next three graphs show the daily profile of the temperature for every week. There is a distinct temperature drop week by week. Moreover, the temperature drops below the acceptable range by the CIBSE Guide A for classrooms and the minimum threshold from the Building Bulleting Guideline.



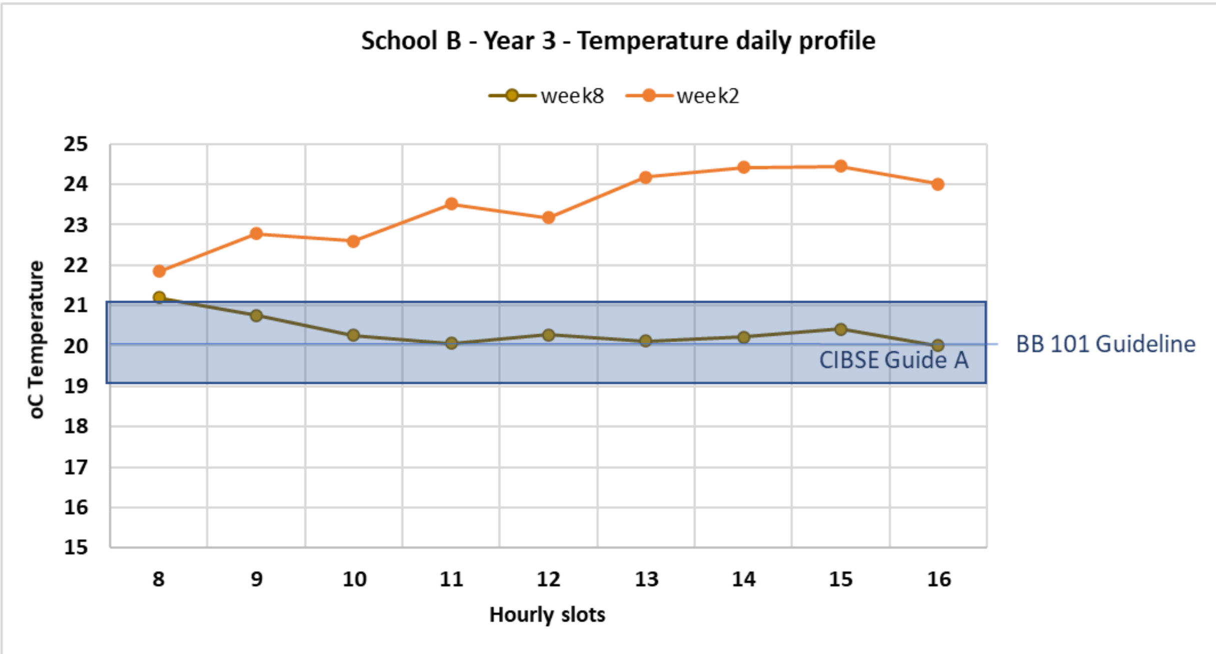




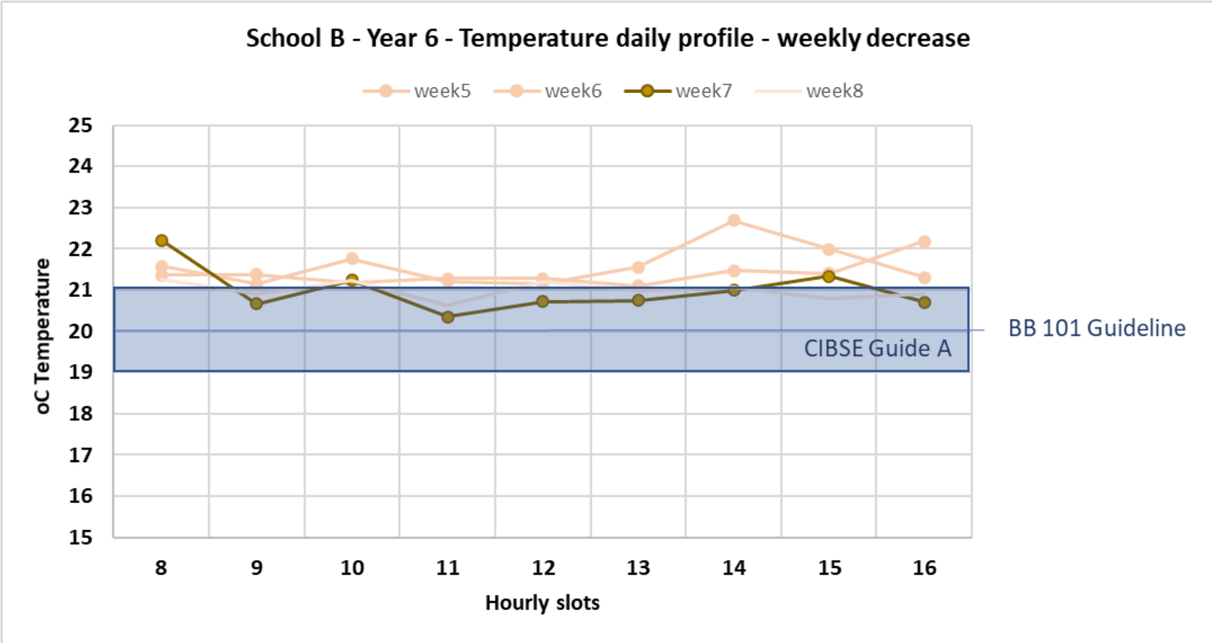
Following the same analysis, the next graph shows the temperature profile in the classroom of Year 1 for every week, in school B. Similarly to the first school, the decrease of the temperature is again apparent for every week.



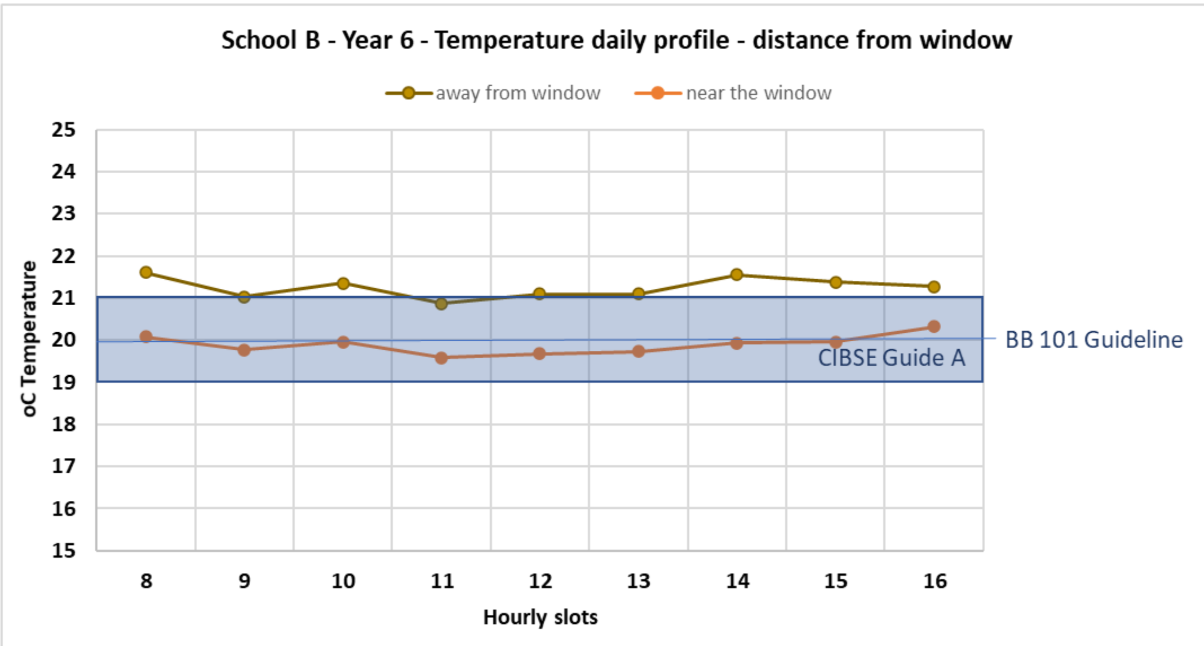
Similarly, the next graph shows the temperature daily profile in Year 3 classroom of the same school. There is a similar significant trend, and the temperature difference reaches 4°C.



The sensors in Year 6 have not been placed since the beginning of the term, so the differences are smaller. However, the same trend is still noticeable.



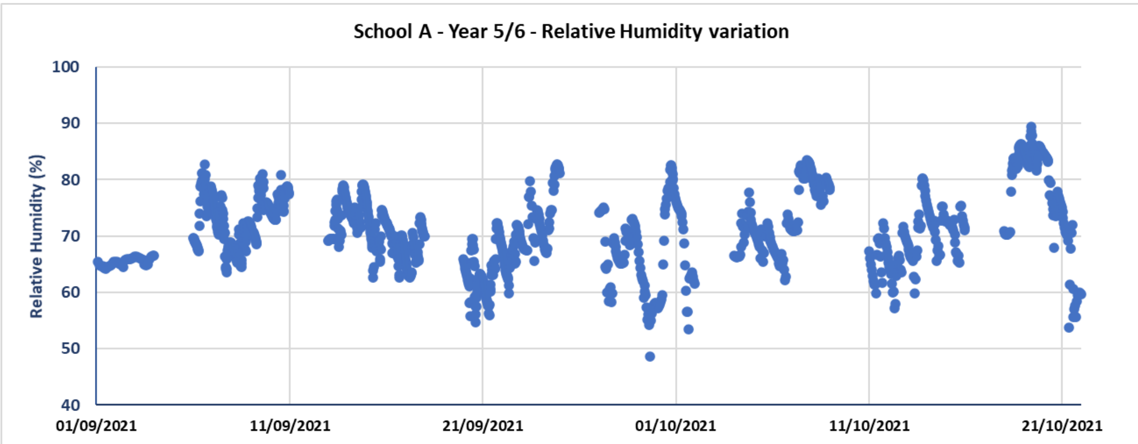
In addition to the temperature decrease depending on the weather, there is a significant temperature difference inside each classroom. The following graph compares the temperature daily profile of an indicative week, for two spots in the same classroom, close to the window and away from the window. A constant temperature difference of 1.5-2^{o}C between the locations near the window and away from the window has been recorded.

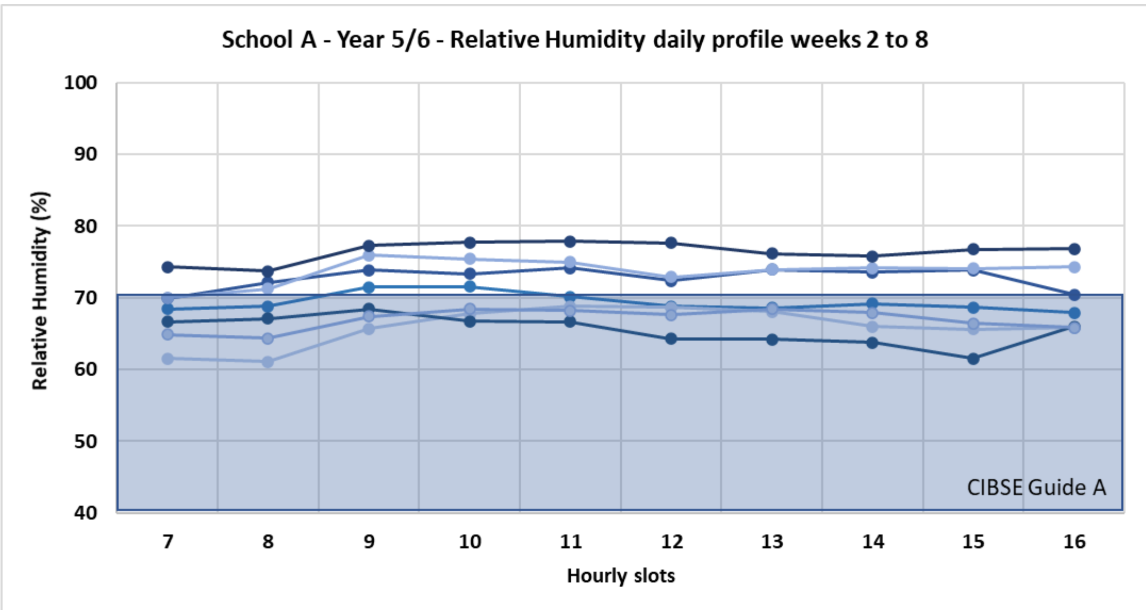


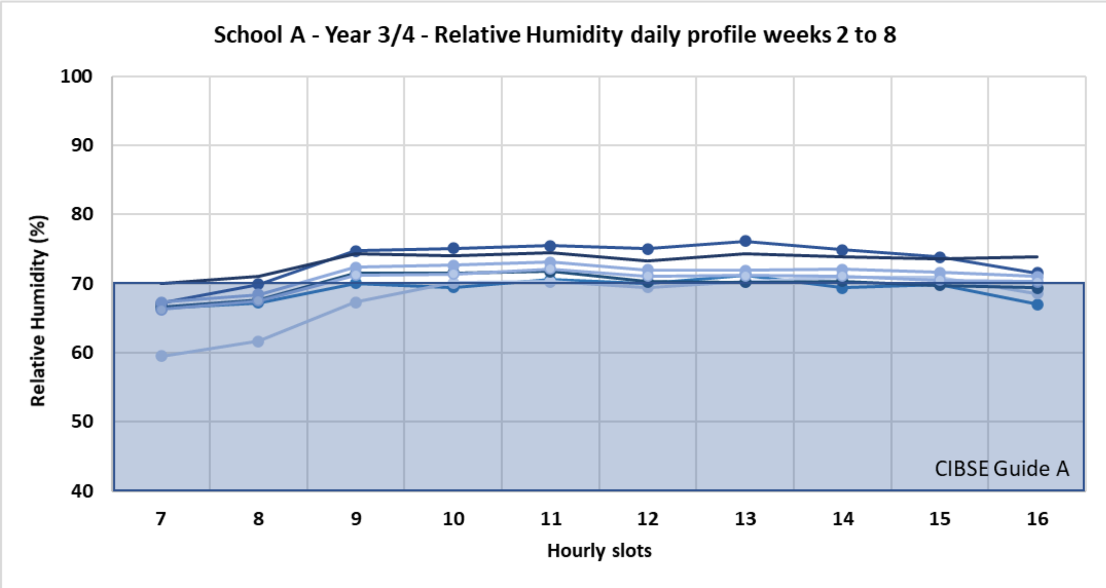
Simple behavioural interventions to balance the need of increased natural ventilation and thermal comfort could include (1) reducing the number of hours windows are open to match times when CO2 levels are likely to be higher during the occupancy hours; (2) locate sitting and learning areas, if possible, farther away from windows so occupants using the spaces are primarily located towards the inner end of the classrooms. This strategy, however, could compromise efforts to maintain social distance or bubble arrangements within classrooms adopted as safety provision in the light of COVID-19 guidance.

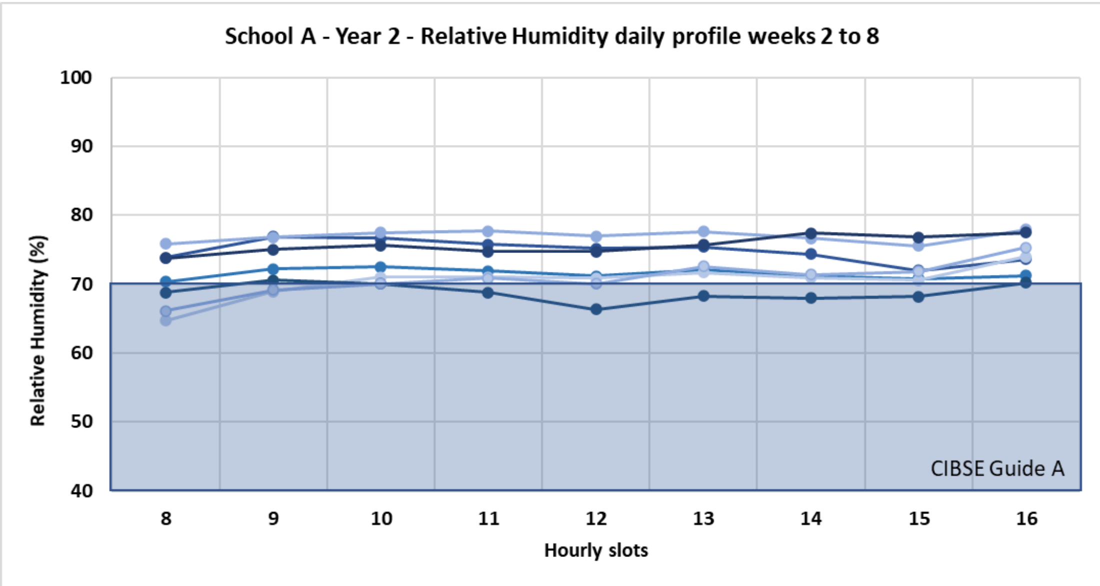
4.3 Relative Humidity

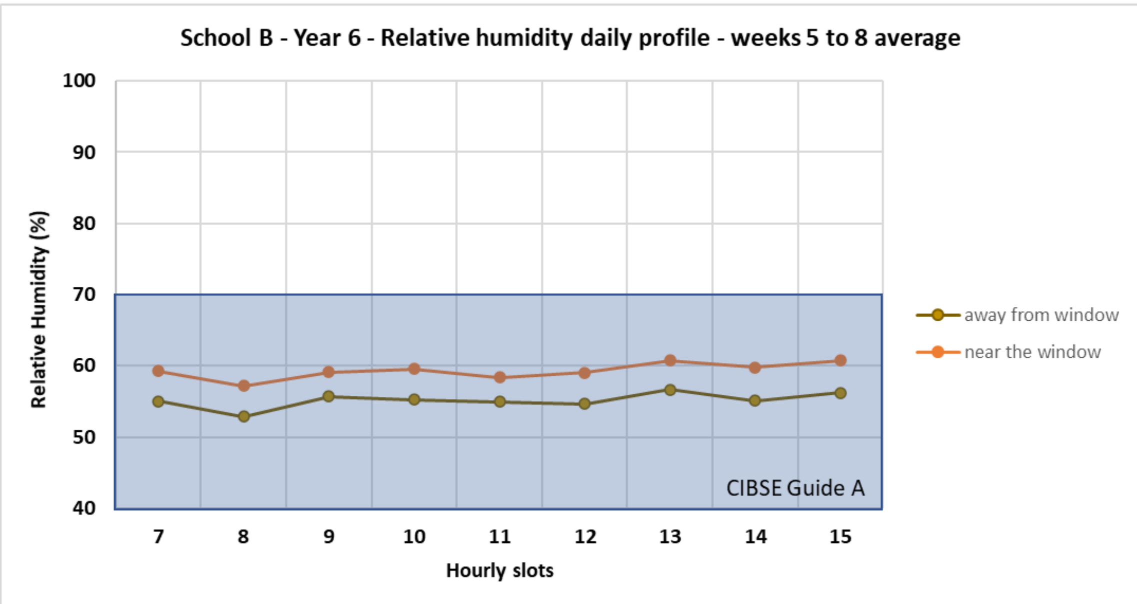
The variation of the relative humidity follows the same tendency as described before, due to the constant natural ventilation. The fresh air that enter the building is critical to ensure the ventilation of the space. However, the humidity of the air cannot be controlled, resulting to an increased humidity in the classroom. The levels of humidity keep increasing every week, following the seasonal change of the weather. Moreover, the areas next to the window appear to have higher relative humidity, as the fresh air that enters the building is colder and more humid than the indoor air. An indicative example shows a constant 5% higher relative humidity difference on average from the week 5 to week 8 of the academic school year 2021/2022.

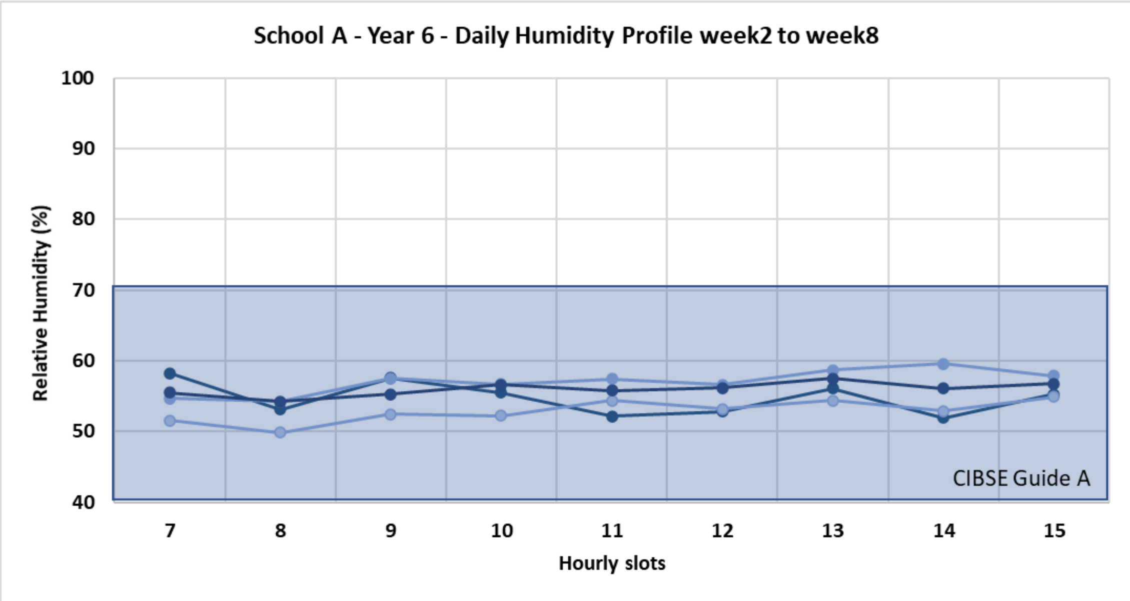


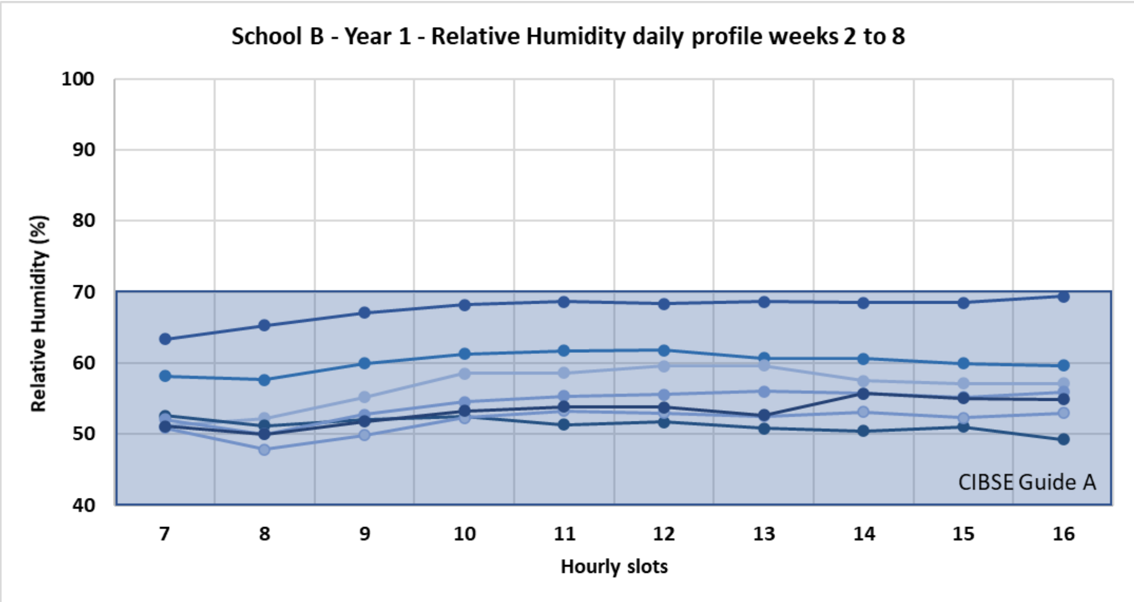


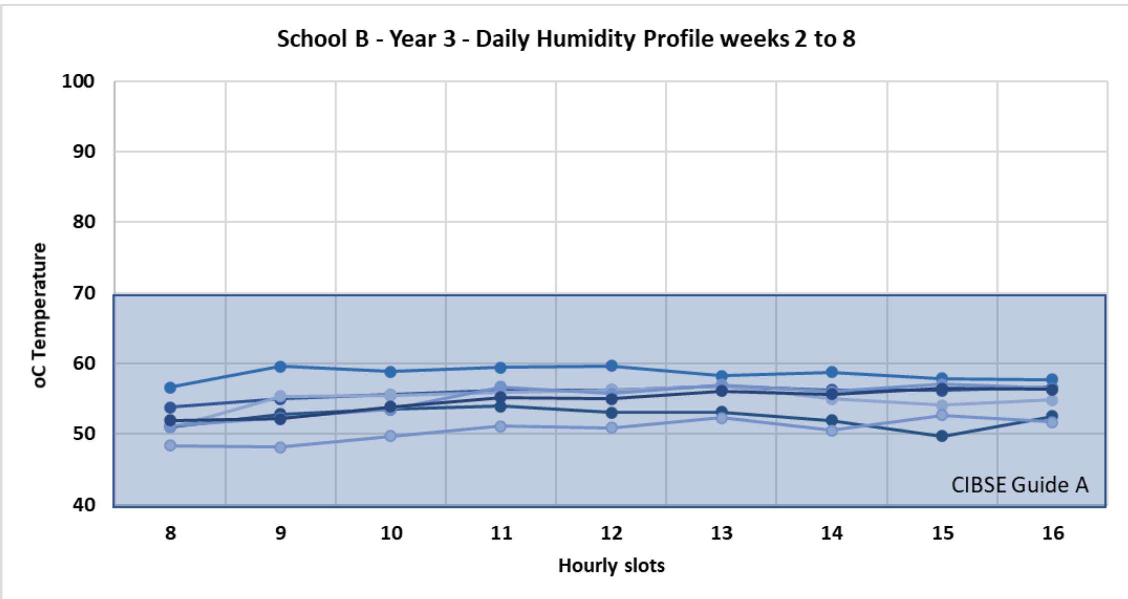

School A - Year 3/4 - Relative Humidity daily profile weeks 2 to 8
Relative Humidity (%)
100
90
80
70
60
50
40
CIBSE Guide A
7
8
9
10
11
12
13
14
15
16
Hourly slots


School A - Year 2 - Relative Humidity daily profile weeks 2 to 8
Relative Humidity (%)
100
90
80
70
60
50
40
CIBSE Guide A
8
9
10
11
12
13
14
15
16
Hourly slots


School B - Year 6 - Relative humidity daily profile - weeks 5 to 8 average
Relative Humidity (%)
100
90
80
70
60
50
40
CIBSE Guide A
7
8
9
10
11
12
13
14
15
Hourly slots
away from window
near the window


School A - Year 6 - Daily Humidity Profile week2 to week8
Relative Humidity (%)
100
90
80
70
60
50
40
CIBSE Guide A
7
8
9
10
11
12
13
14
15
Hourly slots

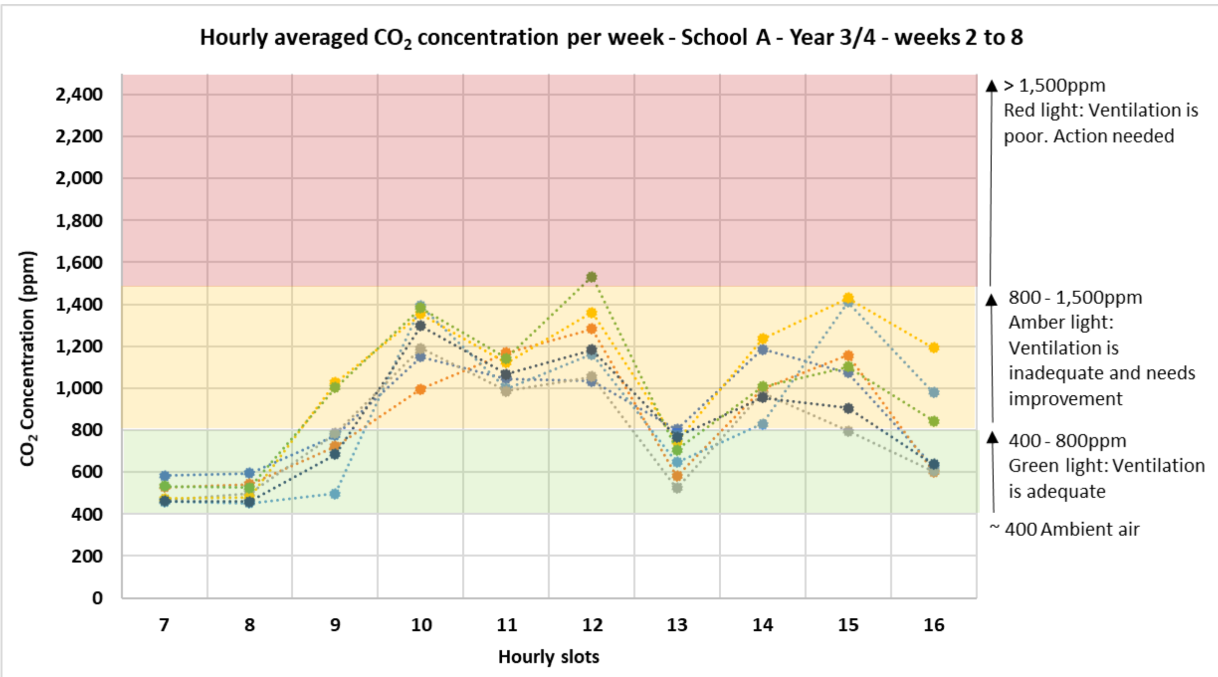

School B - Year 1 - Relative Humidity daily profile weeks 2 to 8
Relative Humidity (%)
100
90
80
70
60
50
40
CIBSE Guide A
7
8
9
10
11
12
13
14
15
16
Hourly slots

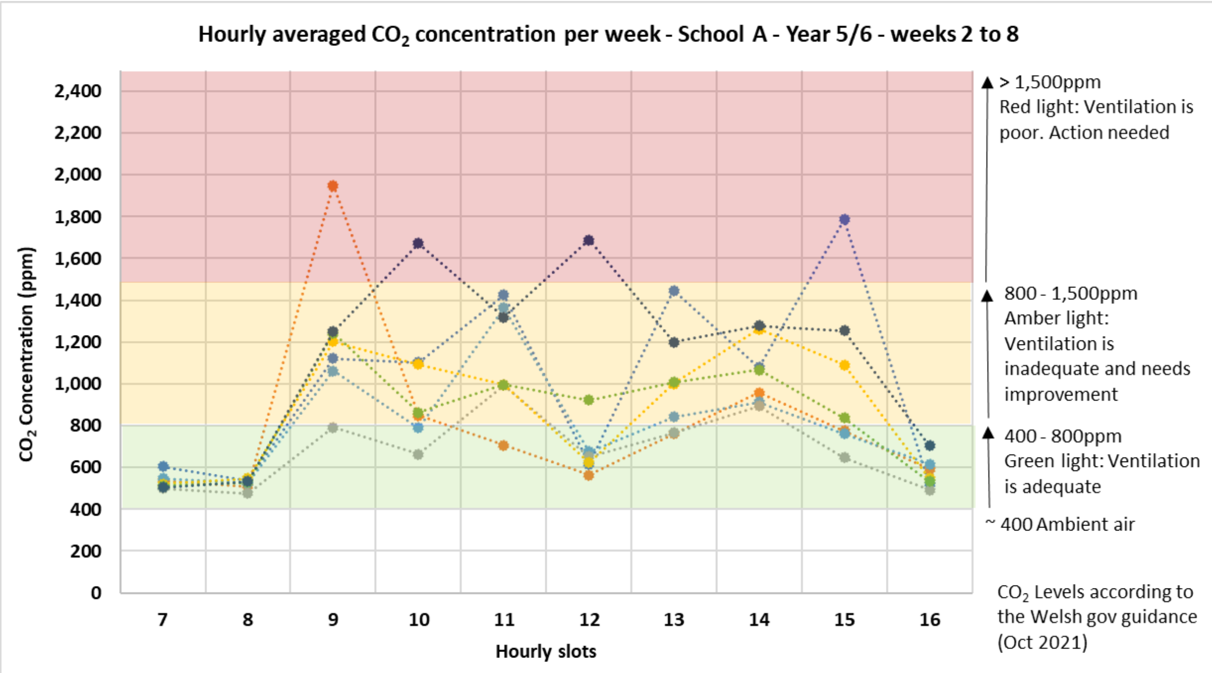

School B - Year 3 - Daily Humidity Profile weeks 2 to 8
oC Temperature
100
90
80
70
60
50
40
CIBSE Guide A
8
9
10
11
12
13
14
15
16
Hourly slots

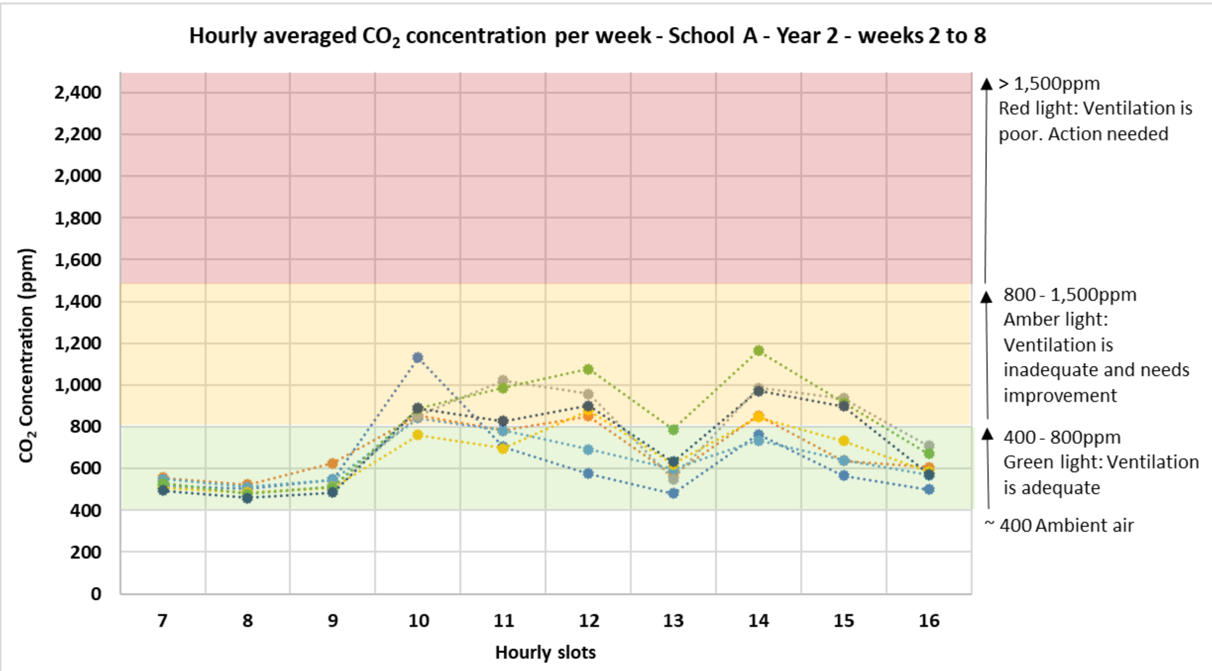
4.4 CO2 concentration

In the graphs below the analysis of the preliminary data from the 8 first weeks of the school year is presented, illustrated the data for the 3 monitored classrooms in each school.

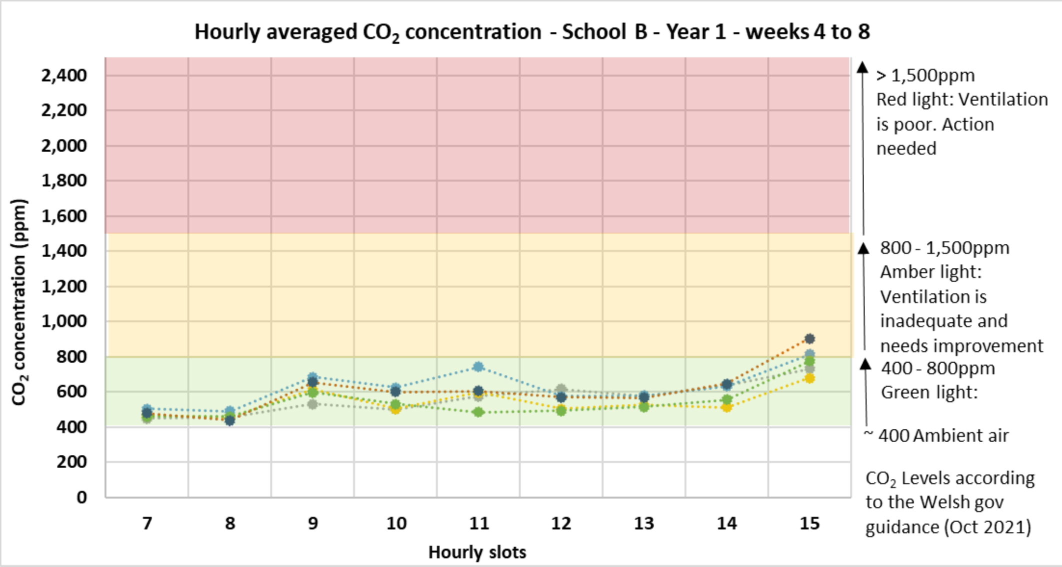
In School A, the data suggests that the CO2 concentration in the classrooms needs some improvement as per ALTA wireless instruments. The majority of occupied hours the classrooms are within amber light zone (800-1000ppm) as per Welsh Government Guidance issued in October 2021. There are instances where the CO2 concentration is within the red light zone; however, these seem to be short-lived instances. The CO2 concentration will be further investigated using the in-depth short-term monitoring approach with HOBO CO2 instruments with higher reading interval for an intense sample period of CO2 concentration evaluation to determine if the data collected by ALTA wireless instruments is characterising correctly the existing conditions of the classroom and evaluate how the existing conditions compare to traffic light system by Welsh Government.

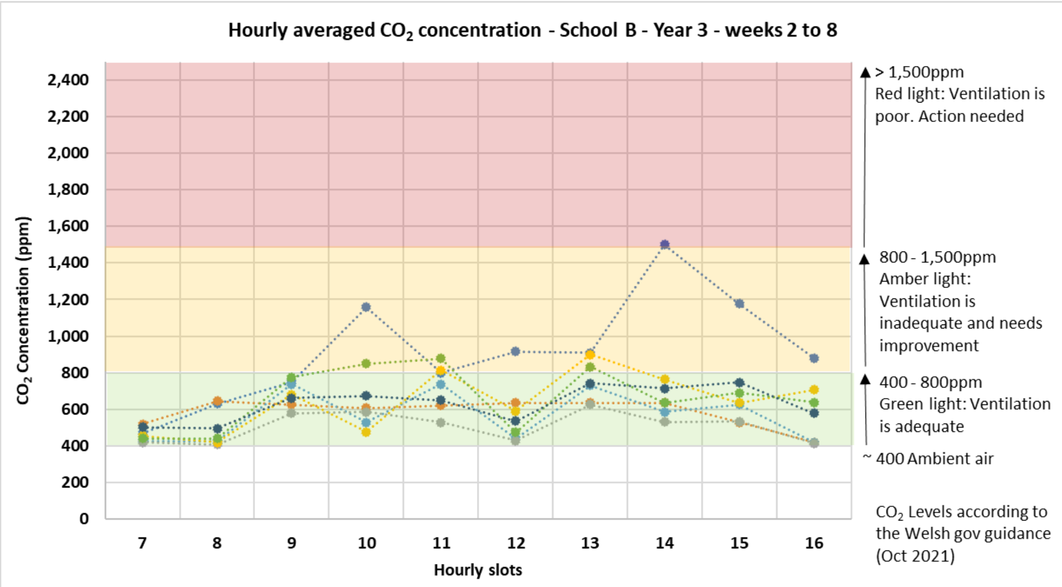


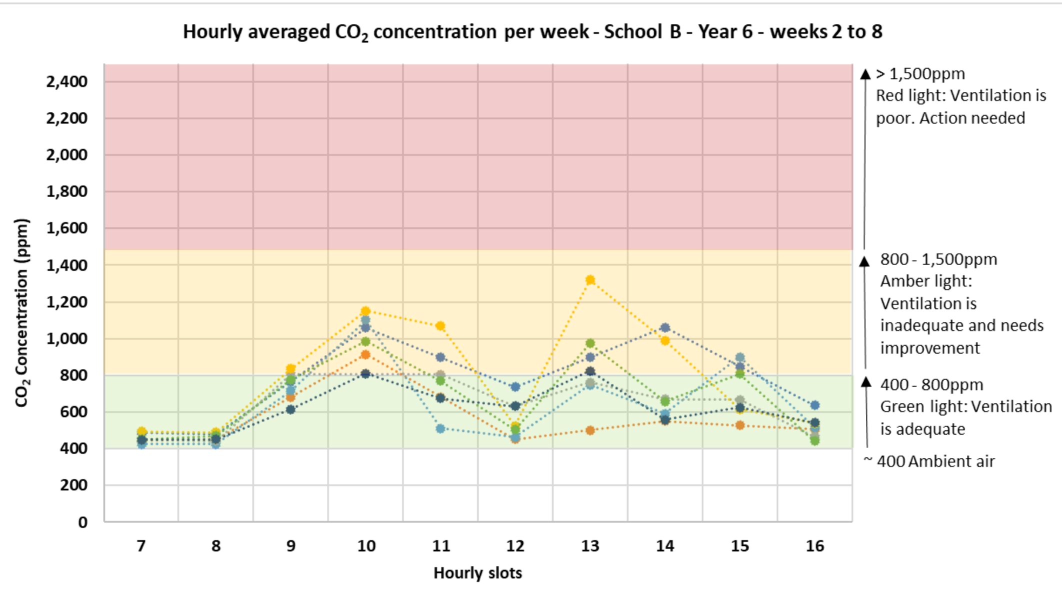




In School B, the data suggests that the CO2 concentration in the classrooms is generally adequate. The vast majority of occupied hours the classrooms are within good range of CO2 concentrations (400-800ppm), which corresponds to 'green light' zone as per Welsh Government Guidance issued in October 2021. There are very infrequent instances with short-lived peaks where the CO2 concentration is in the lower end of the amber light zone (800-1000ppm).

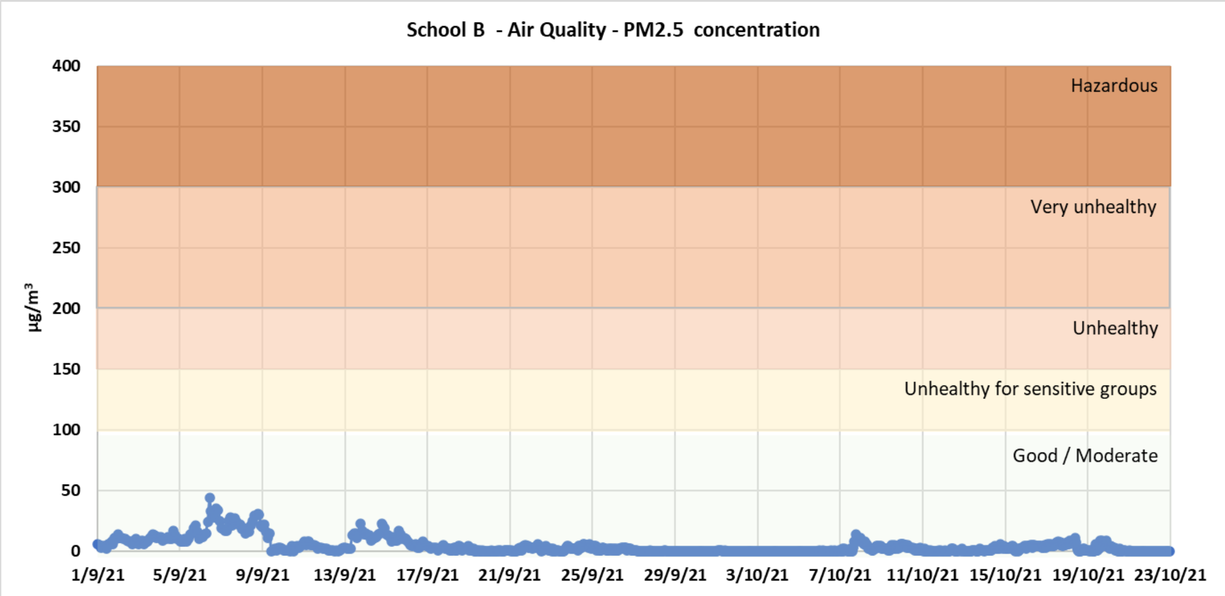

Hourly averaged CO_2 concentration - School B - Year 1 - weeks 4 to 8
CO_2 concentration (ppm)
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
7
8
9
10
11
12
13
14
15
Hourly slots
> 1,500ppm Red light: Ventilation is poor. Action needed
800 - 1,500ppm Amber light: Ventilation is inadequate and needs improvement
400 - 800ppm Green light:
~ 400 Ambient air
CO_2 Levels according to the Welsh gov guidance (Oct 2021)

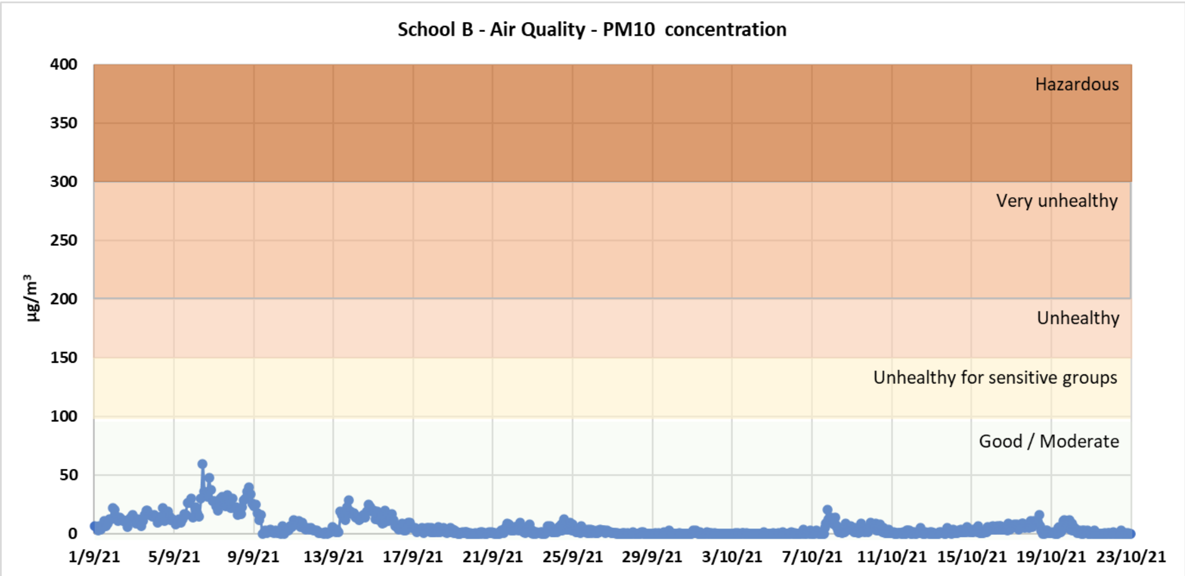

Hourly averaged CO_2 concentration - School B - Year 3 - weeks 2 to 8
CO_2 Concentration (ppm)
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
7
8
9
10
11
12
13
14
15
16
Hourly slots
> 1,500ppm Red light: Ventilation is poor. Action needed
800 - 1,500ppm Amber light: Ventilation is inadequate and needs improvement
400 - 800ppm Green light: Ventilation is adequate
~ 400 Ambient air
CO_2 Levels according to the Welsh gov guidance (Oct 2021)

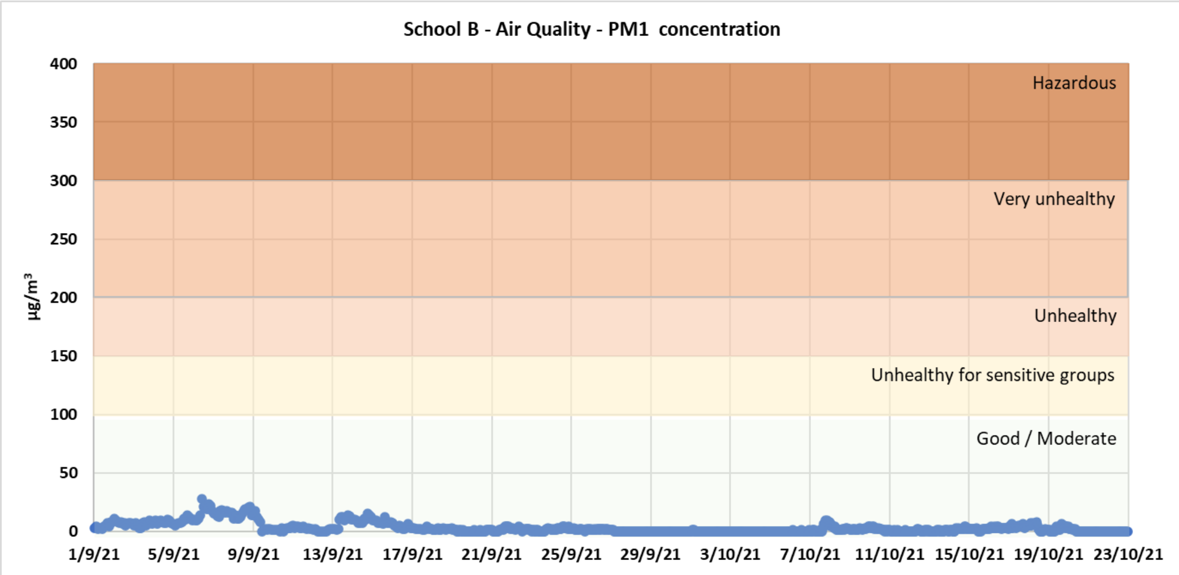

Hourly averaged CO_2 concentration per week - School B - Year 6 - weeks 2 to 8
CO_2 Concentration (ppm)
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
7
8
9
10
11
12
13
14
15
16
Hourly slots
> 1,500ppm Red light: Ventilation is poor. Action needed
800 - 1,500ppm Amber light: Ventilation is inadequate and needs improvement
400 - 800ppm Green light: Ventilation is adequate
~ 400 Ambient air

4.5 Air Quality

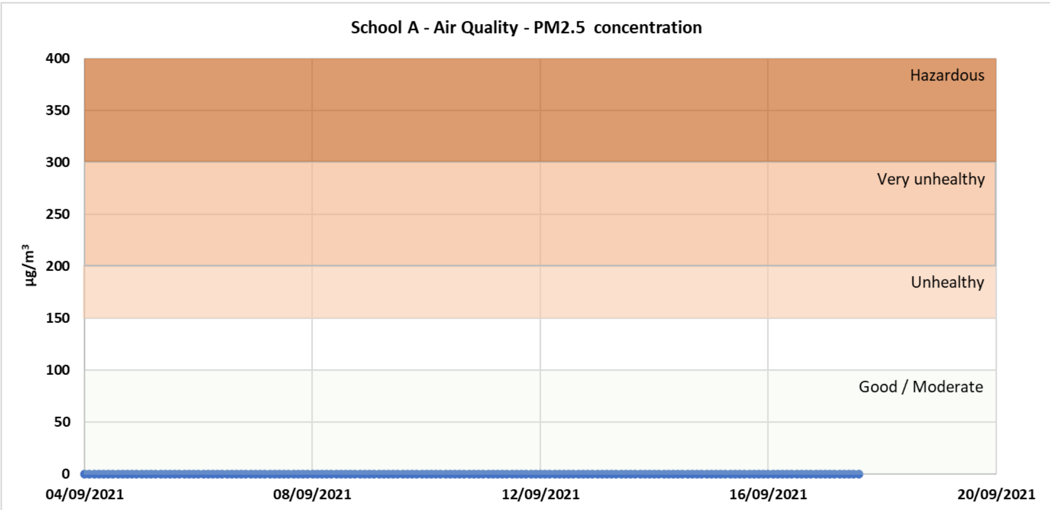
Preliminary results of ppm 2.5 and 10 suggest that school B is within a good air quality zone. This suggests that possible pollutants, if any, from outdoor sources such as nearby road are not entering the school. This result was expected as both schools are located in relatively safe non-polluted outdoor zones.







The initial results from school A show that particle matter concentration is very low, at the point of being hardly traceable in the graph.



6. Lessons learnt from installation and preliminary analysis

Monitoring CO_2 as a proxy of the ventilation level is crucial for maintaining the desired level of indoor air quality in schools. To make sure that the monitoring process produces meaningful data there are a few parameters that should be taken in consideration.

Depending on the type of the monitoring devices they might need calibration before their use. This process should be done carefully and following the manufacturer's instructions.

The choice of monitoring equipment should take this into consideration as they should be able to provide the ability to be used by non-specialists, such as teachers.

Baseline ambient CO_2 levels should be monitored before the actual monitoring of the CO_2 of the classrooms. The ambient CO_2 levels might be different depending on the area where the school is located, so initial measurements give reference points for the monitoring process.

The location of the CO_2 sensors should be changed periodically to give more indicative mapping of the room. Especially due to the requirement for open windows, the air inside the classroom is not homogenous and the CO_2 percentage is not the same throughout the whole room. Moreover, the sensors collect air from a certain area around them, depending on their technology and quality. By changing the location of the sensors, the measurement is more indicative.

In case of logging CO_2 meter data, the interval is very important. For example, an interval of 60min would give an indicative value only when the levels of CO_2 are steady and will track long-term changes. In the case of classrooms, the changes are often and an interval of at least 10min should be used.

5 Further work related to monitoring study

5.1. In-depth monitoring studies

The research team will undertake an in-depth short-term monitoring study to investigate in further detail the CO2 concentrations in the classrooms as a way to interrogate the long-term data collected via ALTA CO2 sensors using higher grade devices. We will explore if the current locations of the CO2 sensors or their calibration have an effect on the resulting data to characterise with better confidence the CO2 concentration profile in the monitored classrooms. It should be noted that the current guidance and state of art research related to measuring and monitoring ventilation is very complex and requires careful attention to confounding factors as ventilation cannot be directly monitored using a single metric such as CO2. CO2 is a proxy to indicate indoor air quality levels but if used in isolation, it can lead to misinterpretation of the indoor environmental conditions. Therefore, the research team will further explore this aspect in alignment to current industry guidance, Welsh Government and UK Government advice and ongoing research developments.

5.2. Qualitative study with teachers and pupils on perceptions of indoor environment and adaptations to enhance monitoring data understanding

The research is also undertaking a supplementary qualitative study that includes questionnaires and interviews with teachers and pupils to identify their perceptions about indoor environmental conditions and perceived comfort in the schools and to explore with teacher's adaptations taken in response to health and safety concerns with the aim to identify possible behavioural interventions that can foster good indoor environmental conditions in the schools. The qualitative study will enable the team to integrate the monitoring data with the everyday use of school buildings, adding a layer of understanding in relation to the experience of school occupants in their buildings.

6 School's engagement: development of educational resources and hands-on workshops with pupils

A second strand of this project is focused on developing learning resources and engaging in hands-on workshops with pupils to reflect about indoor environmental conditions in schools, focusing on the nexus between behaviours and the resulting indoor environmental conditions.

A series of workshops are being developed with the support of teachers of monitored classrooms which include a mix of age groups from Foundation Phase and Key Stage 2. The resources are tailored to the knowledge and skills of different age groups and the complexity of concepts related to building performance, indoor environment and comfort in buildings and energy in buildings. We are designing practical STEM workshops with children to discuss concepts related to temperature, indoor air and building parameters while practicing numeracy skills. Children are producing materials such as drawings, tables, crafts and charts as part of the workshop activities and encouraged to use monitoring devices to understand concepts about building performance using their own schools as Living Labs.

As a result of our work on engagement we have developed two lesson plans (one for Foundation phase and one for Key Stage 2) to support hands-on participatory workshops of 60-75 minutes duration. The learning resources used during these workshops are being developed with the feedback of teachers and in response to pupils' interest, needs and knowledge about the topics discussed. We are encouraging hands-on participation to offer an opportunity for kids to discuss what they know about buildings and sustainability as a way to empower them to take actions that foster good indoor environment in sustainable ways. The workshops include hands-on activities where kids use monitoring instruments to develop numeracy skills and explore concepts about building performance.

Sections 6.1. and 6.2 summarise the topics and aims of the lesson plans for the workshops for Foundation Phase and for Key Stage 2. Appendix 3 illustrates the monitoring devices used by pupils during the workshops.

6.1. Lesson Plan Foundation phase

Topic: What do children understand about 'temperature', 'thermal experience' and 'thermal comfort'?

Aims of workshop 1-*what Cardiff team and teachers can learn as result of the workshop:*

1) To explore children's understanding of building performance concepts (thermal comfort).

2) To identify children's perception of thermal comfort in their classroom in the light of monitoring data.

3) To compare differences/similarities of understanding of concepts per age groups which can inform learning materials/instruments to collect data about perception/experience in buildings (cross comparison of data collected, specific 'research aim exploration' per age group/key stage)

Learning aims of visit 1 (foundation phase)- what the pupils learn as result of the workshop:

1. To understand how you feel now in the building, and when you are hot or cold, and what you would do if you were too hot or too cold when inside a building.

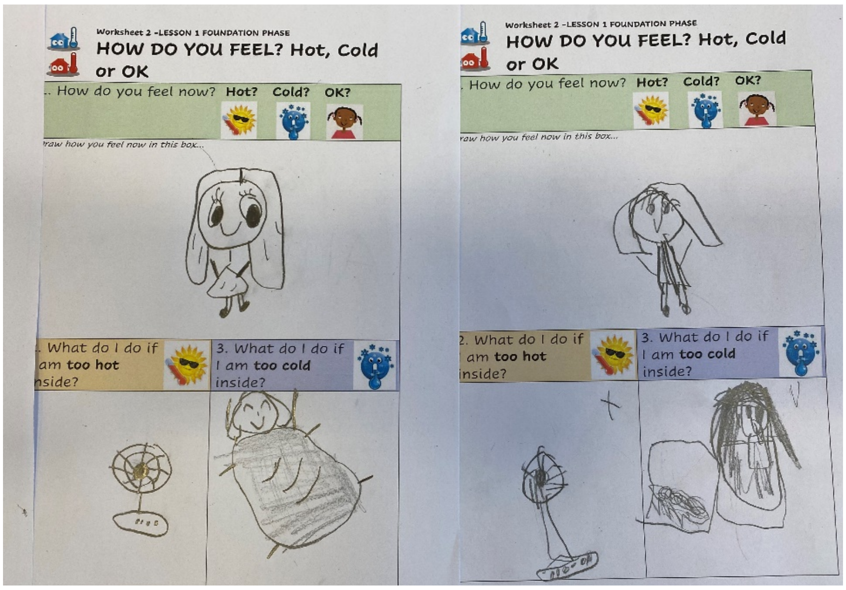
2. Building doctors and Feverish buildings: how to take the temperature of the air inside and outside a building, how to record it and compare the temperature in different locations (hands-on activity by pupils using monitoring instruments).

3. To understand how buildings use energy to keep you warm, and how you can do to make your classroom comfortable

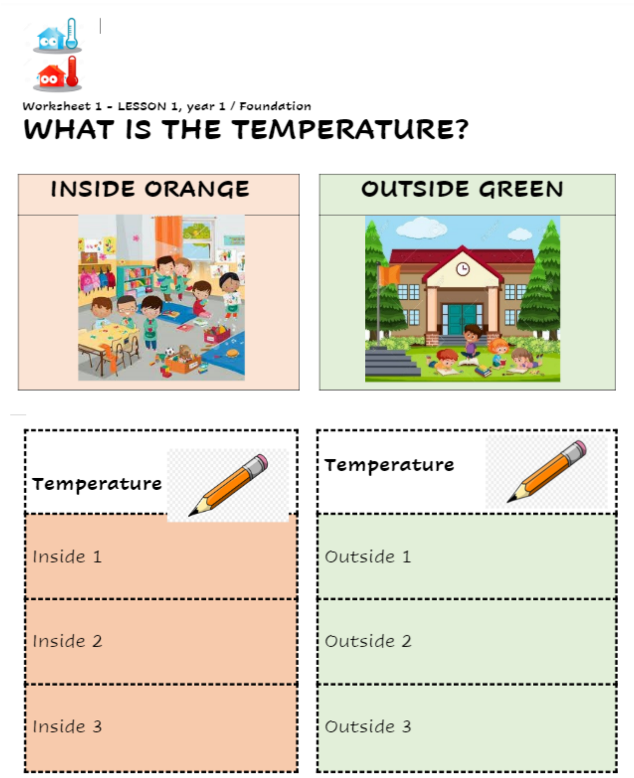
Extension activity (after the workshop)

Making buildings warm or cold: Monitoring the temperature - Can we measure the temperature over time? – Looking at monitoring device left in the classroom and demonstrating what they can do. – Recording the temperature at different times of day –

do they notice any difference (e.g. morning of schools day, and home-time?) - Do they notice the classroom being a different temperature when it is hotter or colder outside?



Example of Worksheet used in Workshop 1 completed by Foundation Phase pupils



Example of Worksheet used in Workshop 1 for Foundation Phase pupils to record data about their school using monitoring devices

6.2. Lesson Plan Key Stage 2 phase

Topic What do children understand about 'temperature', 'thermal experience' and 'thermal comfort' AND indoor ventilation?

Aims of workshop 1 *-what Cardiff team and teachers can learn as result of the workshop:*

1) To explore children's understanding of building performance concepts (thermal comfort, ventilation/CO_2).

2) To identify children's perception of thermal comfort and ventilation in their classroom in the light of monitoring data that they collect in hands-on workshop.

3) To compare differences/similarities of understanding of concepts per age groups which can inform learning materials/instruments to collect data about perception/experience in buildings.

4) Optional aim for upper Key Stage 2 level: to identify children's understanding of energy in buildings and sustainability impact of energy sources in buildings.

Learning aims of visit 1 (Key Stage 2 phase)- what the pupils learn as result of the workshop:

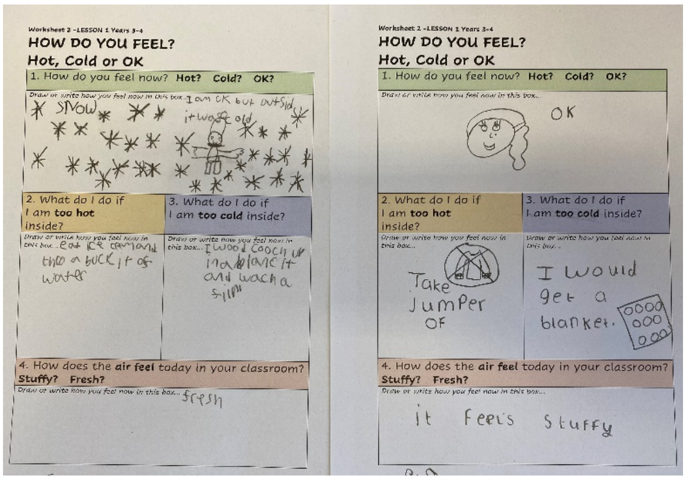
1. To understand how you feel now in the building, and when you are hot or cold, and what you would do if you were too hot or too cold when inside a building. With upper Key stage 2 children the concept of ventilation is also explored - how does the classroom feels now in terms of ventilation, what do you do if it feels airy, if it feels unfresh?.

2. Building doctors and and Feverish buildings:: how to take the temperature of the air inside and outside a building, how to record it and compare the temperature in different locations. (hands-on activity by pupils using monitoring instruments). With upper Key stage 2 children the concept of ventilation is also explored- how to record CO_2 and compare it in different locations.

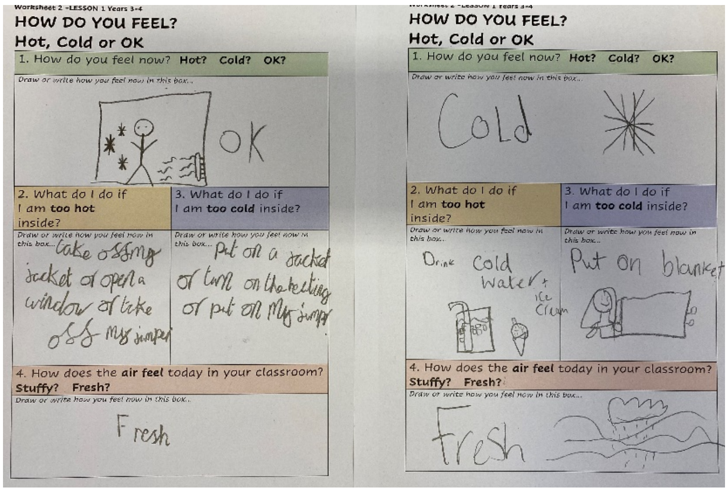
3. To understand how buildings use energy to keep you warm, and how you can do to make your classroom comfortable With upper Key stage 2 children the concept sustainable energy in buildings is also explored- discussion about energy in buildings and sustainability impact of energy sources in buildings.

Extension activity (after the workshop)

Making buildings warm or cold: Monitoring the temperature - Can we measure the temperature over time? – Looking at monitoring device left in the classroom. – Recording the temperature and CO_2 concentrations at different times of day – do you notice any differences (e.g. morning of schools day, and home-time?) - Do you notice the classroom being a different temperature when it is hotter or colder outside? Do you notice how CO2 changes if you open windows? At different times of the day? During school days and during weekends?



Example of Worksheet Workshop 1 completed by Key Stage 2 Phase pupils (Year 3)



Example of Worksheet Workshop 1 completed by Key Stage 2 Phase pupils (Year 6)

ENVIRONMENTAL DATA LOG BOOK					
		CLASSROOM /INDOORS			OUTDOORS
Week 1	Time	Classroom Temperature (oC)	Relative Humidity (%)	CO2 concentration (ppm)	Outdoor Temperature (oC)
Monday date :	Morning ________				
Tuesday date :	Morning ________				
Wednesday date :	Morning ________				
Thursday date :	Morning ________				
Friday date :	Morning ________				

Example of 'Environmental Data Log book' to be used as extension activity of Workshop 1 for Key Stage 2 Phase pupils to record data about their school using monitoring devices

6.3. Further work on engagement

The research team will undertake a follow-up workshop to build upon concepts and further test and trial resources that the kids can used to learn about sustainable building use and operation.

7 References

[1] CIBSE, 2015. Environmental design: CIBSE Guide A. London: The Chartered Institution of Building Services Engineers.

[2] Building Bulletin 101, 2018: Guidelines on ventilation, thermal comfort and indoor air quality in schools, Education and Skills Funding Agency.

Appendix 1: Monitoring instrumentation- Technical information

Wireless Temperature and Humidity Sensor - Coin Cell Powered

- These sensors are perfect for monitoring ambient temperatures around the sensors physical location.
- Scientific grade sensor
- +/- 2% humidity accuracy (between 0% – 100% RH)
- +/- 0.5°C temperature accuracy (between 0°C–100°C)

Wireless Carbon Dioxide (CO_2) Sensors - AA Battery Powered

The ALTA Wireless Carbon Dioxide Sensor uses an ultra low-power, high-performance CO2 sensor to measure the amount of carbon dioxide in ambient air.

Monnit wireless CO2 sensors allow monitoring the level of carbon dioxide (CO2) gas in the surrounding air.

The ALTA Wireless Carbon Dioxide Sensor measures the amount of CO2 in the ambient air surrounding the element. It is programmed to take readings at a set interval to accurately calculate CO_2 levels, then send the time-stamped data to the iMonnit Online Sensor Monitoring and Notification System at user-specified time intervals.

- Measures 0 to 10,000 ppm CO_2
- Accurate to +/- 45 ppm + 3% of reading
- Sensor produces instantaneous CO2 readings and 8-hour time weighted average reading
- Operating temperature ranges: 0°C to 50°C
- Operating humidity range: 0% to 95%
- Commercial grade sensors are designed for applications in ordinary environments (normal room temperature, humidity and atmospheric pressure).

ALTA Wireless Open-Closed Sensors - Coin Cell Powered

Monnit wireless open/closed sensors provide information on the status of doors, windows, cabinets, etc.

- Sense immediate door or window access.
- Sense if a door, window, drawer is opened or has been left open

- Monitor access to specific areas of buildings.
- Sensor Magnet with Mounting Flange

ALTA Monnit Wireless Air Particulate Meter AA

The ALTA wireless PM2.5 sensor measures PM1, PM2.5 and PM10 concentrations in the air and transmits the measurement to iMonnit.

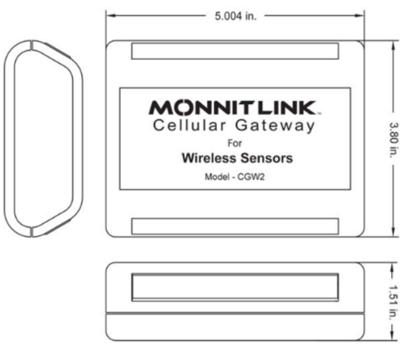
The PM2.5 sensor works by turning on a small fan at the beginning of a measurement cycle to bring in a volume of ambient air and measuring the particulate matter (PM) content of that sample volume.

The sensor measures PM content using a laser that scatters based on the number and size of particles suspended in the air. It is important to keep the inlet ports of the sensor clear to ensure proper readings.

ALTA Ethernet Gateway

The MonnitLink™ Ethernet gateway allows your Monnit Wireless Sensors to communicate with the iMonnit™ Online Wireless Sensor Monitoring and Notification System without the need for a PC.

AC power supply, Existing Internet connection required,
No PC required for operation, Real time TCP interface,
SNMP poll and trap interface, MODBUS TCP interface,
FCC, IC and CE certified.



Enclosure Material ABS

Storage Temperature: -20 to +60°C

Operating Temperature: +5 to +45°C

Operating Frequency: 868 MHz Operating Frequency

Certifications: CE Certified. Tested and found to comply with: EN 300 220-2 V3.1.1 (2017-02), EN 300 220-2 V3.1.1 (2017-02) and EN 60950.

Integrated on-board data storage allows ALTA sensors to store data messages if communication to a wireless gateway is disrupted (power outage, Internet outage, or out of range).

Tinytag TGU-4500

Indoor temperature and relative humidity data logger with built-in sensors (Brand: Gemini).

The TGU-4500 monitors temperatures ranging from -25 to +85°C, and relative humidity from 0 to 95% using built-in sensors. It is primarily suited to indoor monitoring.

- Built-in temp/RH sensor
- 32,000 reading capacity
- Delayed start option
- Low battery monitor
- User-replaceable battery
- Splash-proof case (IP53)
- High reading resolution
- Fast data offload
- User-programmable alarms

Tinytag Plus 2 – TGP-4500.

Rugged, waterproof outdoor temperature and relative humidity logger with built-in sensors.

The TGP-4500 monitors temperatures from -25 to +85°C, and relative humidity from 0 to 100% using built-in sensors. The coated RH sensor offers good resistance to moisture and condensation, and like the rest of the Plus 2 range, this accurate and reliable unit is ideal for monitoring in outdoor and industrial applications.

Certifications: IP68 rated, CE certified

Telaire 7001 CO_2 Sensor and Hobo Datalogger

The Telaire 7001 handheld carbon dioxide sensor features patented absorption infrared technology. Each sensor measures CO2 and temperature and can calculate and display real-time ventilation rates. When combined with the HOBO MX1104, MX1105, or UX120-

006M, it can record CO2. When connected to analog inputs on a HOBO H22, RX3000, or U30 series logger, it can record temperature and CO2. The Telaire comes with a power adapter, but also operates up to 70 hours on 4 AA batteries.

The Telaire T7000 series CO2 Monitor is an use-to-use temperature and carbon dioxide monitor designed for use in residential or commercial applications. With the ability to display CO2 readings in less than 30 seconds, it is ideal for identifying energy saving opportunities in over-ventilated spaces, determining if air quality complaints are due to insufficient ventilation, or locating the presence of combustion fumes generated from vehicles and appliances.

The data logging kit option combines the easy-to-use T7001 with a pocket-sized Hobo logger from Onset Computer Corporation. The T7001D kit has the ability to calculate and display the cfm/person ventilation rate as well as record CO2, temperature, and RH data over time making it useful for indoor air quality (IAQ) applications. The kit includes software and cables.

Applications for the Telaire T7000 Series CO_2 Monitors:

- Identify areas with low or substandard ventilation
- Identify hidden energy savings in over-ventilated spaces
- Determine if ventilation is a factor in air quality complaints
- Locate the presence of combustion fumes from vehicles and appliances
- Use as a reference to calibrate wall mounted CO_2 sensors

EnviSense CO_2 Monitor and data logger

- Measuring range CO2 — 0 - 5000 ppm
- Measuring range humidity — 5 - 95% RH
- Measuring range temperature — 0 - 50 °C
- Sensor — NDIR
- Width — 120 Millimeter
- Depth — 35 Millimeter
- Height — 90 Millimeter
- Suitable for — Rooms < 100 m^2

The CO_2 meter should be placed at table height in a place where it is not directly breathed into, at least 1.5 metres from an open window or door, or hanged it on the wall.

Appendix 2: Monitoring sensor location

Monitoring devices have been installed since July 2021 to provide a baseline of data regarding empty classes before the beginning of the school year. Following the Monitoring Plan, the following equipment has been installed:

In each one of the three classrooms under study per school:

- 1 CO_2 concentration sensor (remote monitoring).
- 1 Temperature and Relative Humidity sensor (remote monitoring).
- 1 sensor to record whether the window is open/closed (remote monitoring).
- 2 Temperature and Relative Humidity sensors/data loggers

In chosen communal areas of the schools:

- Temperature and Relative Humidity sensors at the entrance, dinning and gym.
- PM2.5 concentration sensor at the entrance.

Below are presented some indicative photos of the installed sensors.

Figure 3: T/RH sensor in School A - Year 3

Figure 4: T/RH and CO2 sensors in School A - Year 3

Figure 5: T/RH and CO2 sensors in School A - Year 6

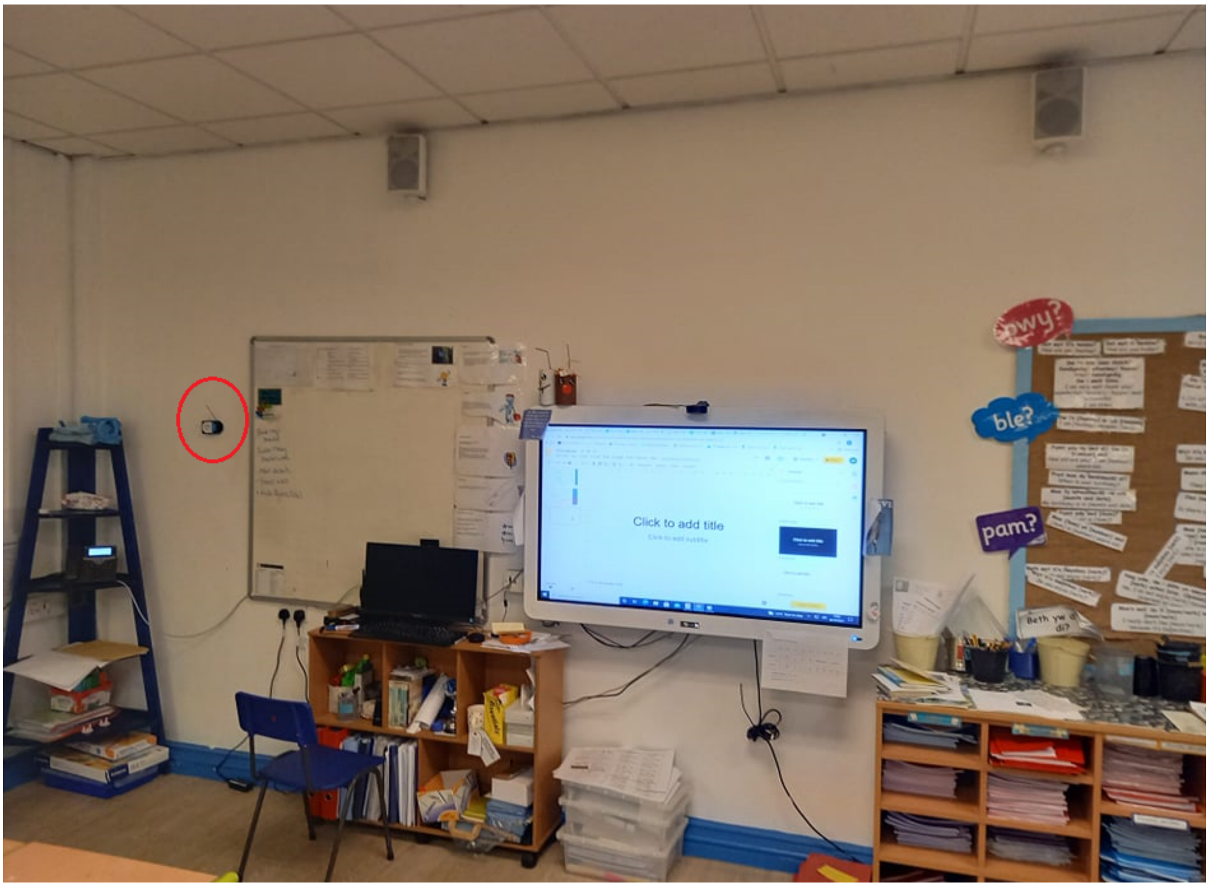


Figure 6: CO_2 sensor in School B - Year 6

Figure 7: T/RH sensors in School A

Figure 8: Outdoor T/RH sensors in School A (left) and School B (right)

Figure 9: Window open/closed status installed sensor in School B

Figure 10: The gateway for receiving and transmitting the monitoring data

Figure 11: Particulate Matter sensors at the entrance of the School B

Appendix 3: Monitoring instruments used by pupils during Workshop 1 'Building doctors and Feverish Buildings'

EnviSense CO_2 Monitor and data logger

- Width 120 mm
- Height 90 mm
- Depth 35 mm
- Connection Mini-USB to USB with 230V adapter
- Cable length 1 meter
- Startup time 30 seconds countdown
- Operating humidity Between 0% – 95% (not-condensed)
- Suitable for CO2 measurement Yes
- Suitable for humidity measurement Yes
- Suitable for temperature measurements Yes
- Measuring range CO2 0 – 5.000 ppm
- Measuring range humidity 5% – 95% RH
- Measuring range temperature 0°C – 50°C
- Operating temperature 0°C – 50°C
- Storage temperature -20°C – 60°C
- Power supply 5 V DC via USB-port
- Weight 170 grams
- Warranty 3 years

Indoor/Outdoor RH/T

- Max/Min Temperature Memory
- 2 sensors for Indoor/outdoor (or 2 different temperature environments)
- Indoor Temp Range: 14 to 122 degF (-10 to 50 degC)
- Outdoor Temp Range: -58 to 158 degF (-50 to 70 degC)

DIGITAL THERMO-HYGROMETER W/TEMP AND RH (Pen Style Hygrometer)

- Temperature in °F or °C (14 - 122°F / -10 to 50°)
- 5 to 95% Relative Humidity (RH)
- Fast, accurate electronic sensor
- Displays relative humidity and temperature at the same time
- MIN/MAX record
- Data hold
- Auto power-off

Surface T sensor

The infrared laser thermometer is very robust and is well suited to applications where contact measurement is not possible or desirable.

The HL-550 is very easy to use: simply point and measure. The measurement is read within 1 second and the laser pointer helps to precisely identify your measurement point.

The units are best suited to the measurement of matt, non-reflective surfaces. The temperature readouts are backlit making them easy to read, even in the dark.

- Laser targetting
- 0.95 emissivity (fixed)
- °C/°F selectable
- Automatic data hold
- Auto power off
- Low battery indication
- Backlit LCD display
- Over range indication
- Supplied with 9V battery and soft case
- 160mm x 82mm x 42mm