Marica Canino NPSE March 15 2024

CO2 monitoring
to enhance digital and green competences in VET

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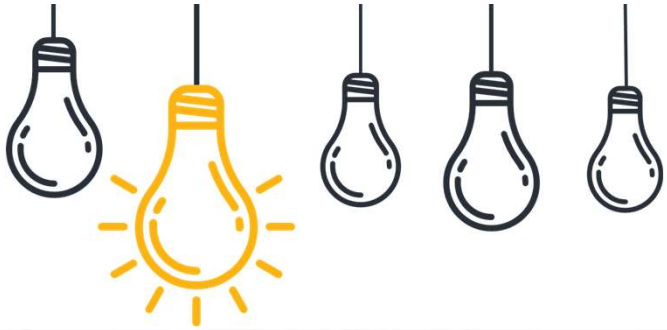
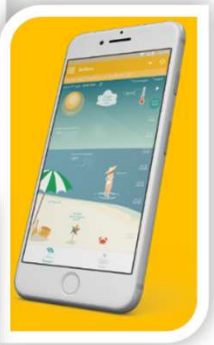
Proambiente Scrl
Carrara, S. Marzocchi, S.Zampolli, M.Canino
CNR IMM Bologna



Idea

End of 2020



IMM BOLOGNA UNIT

PROAMBIENTE innovation & environment

SENSOR FABRICATION + TECHNOLOGY TRANSFER

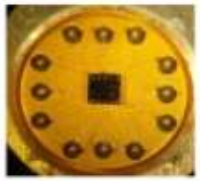
CHANGE CO_2Lab

Research activities @ IMM Bologna - Devices, materials and processes

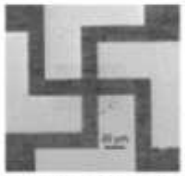
500 m² (250 m² class 100) MEMS and CMOS Clean-Room

Research activities @ IMM Bologna

MICROELECTRONICS



4H-SIC VERTICAL P+-I-N DIODE



GRAPHENE: RELIABILITY-DRIVEN INTEGRATION IN SI TECHNOLOGY

CLEAN ROOM FACILITIES

DEVICES MATERIALS PROCESSES

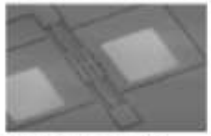
PHOTOVOLTAIC AND OPTOELECTRONIC DEVICES

SILICON PHOTONICS

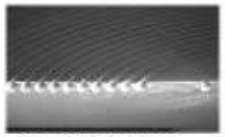
SINGLE PHOTON AVALANCE DIODE

aSi/cSi HETEROJUNCTIONS SOLAR CELL

SENSORS AND MICROSYSTEMS



RESONANT STRAIN SENSORS



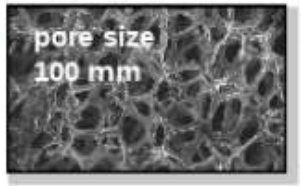
ALL SILICON GAS CHROTOGRAPHIC COLUMN

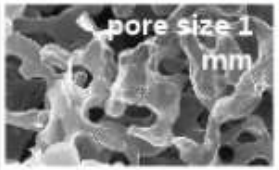
ULTRASOUND EMITTER

ABSOLUTE PRESSURE SENSORS

COMPETENCES

2D MATERIALS





GROWTH OF 3D GRAPHENE

Proambiente Scrl – missione aziendale

Mission of Proambiente is **connecting Research and Industry** through **technology transfer**, industrial research, and advanced services in the frame of **environmentall control and remediation**.

IAQ monitoring

System integration of commercial components

CNR-IMM: know-how on gas sensors
Proambiente: system integration, software, WebApp, Technolgy Transfer

PROAMBIENTE
ricerca industriale e trasferimento tecnologico

www.consorzioproambiente.it

RETE ALTA TECNOLOGIA EMILIA-ROMAGNA HIGH TECHNOLOGY NETWORK
TECNOPOLO BOLOGNA CNR

Why Indoor Air Quality

ENGAGEMENT We spend 90 % of our time in indoor environments

NOVELTY European legislation under construction

Research carried out to identify tolerated vs harmuful human exposure to pollutants

Development of low cost sensors for widespread indoor measurements

SYNERGY Connection to school curricula

Floor tiles (PM, Lead), paintings & coatings (VOCs, Formaldehyde), basements (Radon), sealing materials (VOCs), Cleaning agents (VOCs, Benzene,….), Food cooking, stoves (CO, SO2, PM, PAHs)

Credits to myfreshair.in

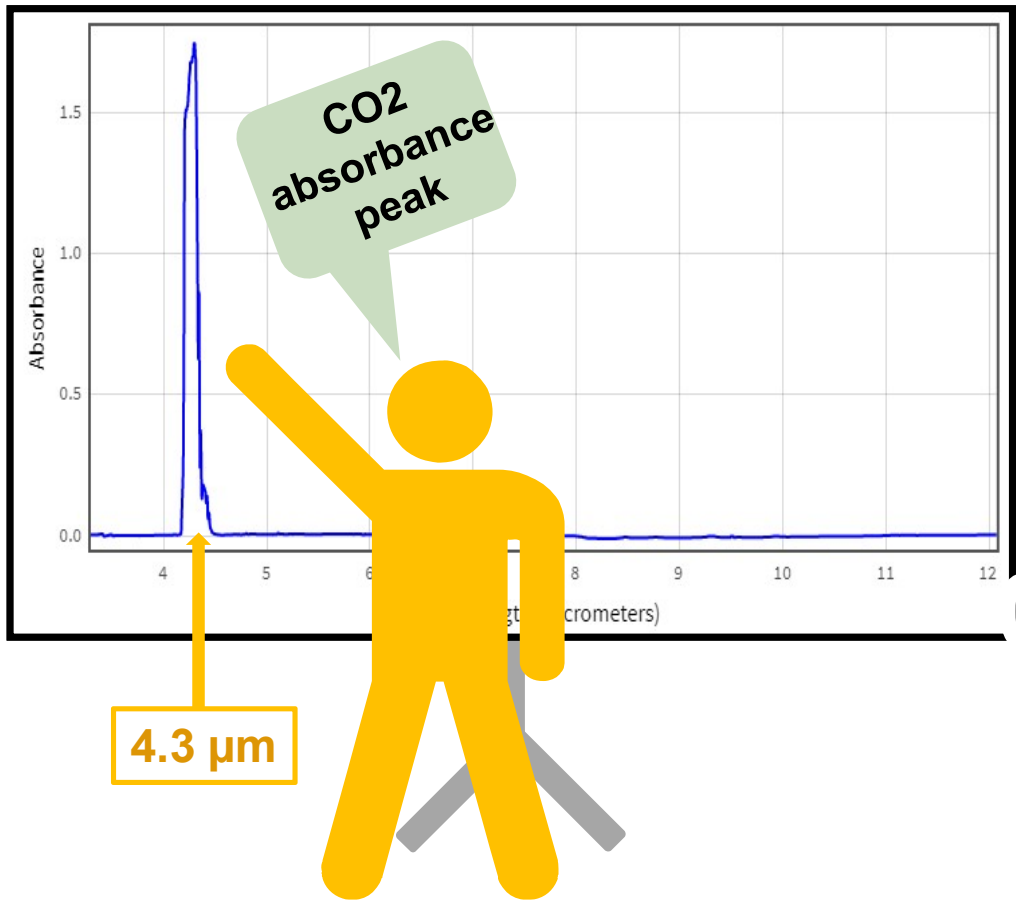
AND….WHAT ABOUT CO_2 ?

Strictly speaking, carbon dioxide (both indoor and outdoor) cannot be considered as a pollutant. In fact:

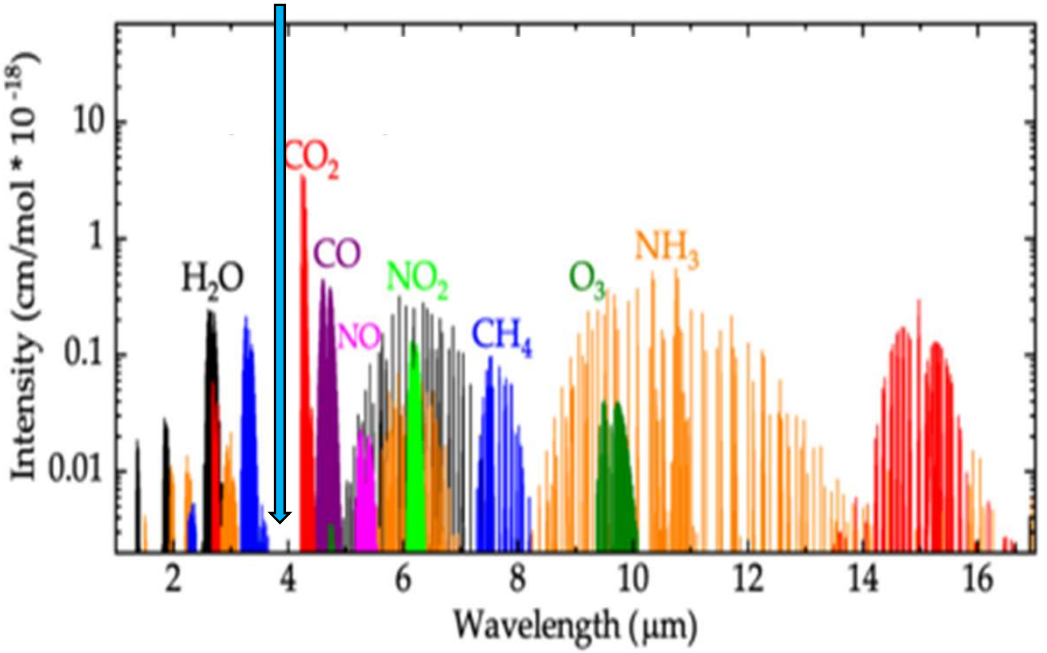
- It is not a carcinogenic compound
- It is not a toxic compound
- It MAY cause headache, sense of fatigue, decrease of attention (2000 ppm < CO2 conc. < 5000ppm)

CHANGE CO_2Lab PA IMM BOLOGNA UNIT

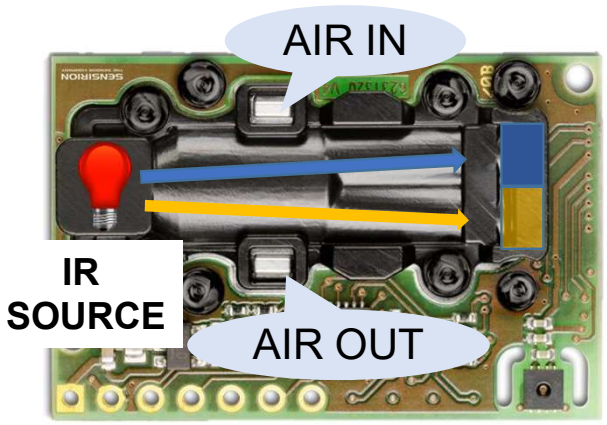
CO2 IR ABSORPTION



CO2 absorbance peak @ 4.3 µm is "isolated" (no gaseous compound has an absorbance line on the left)

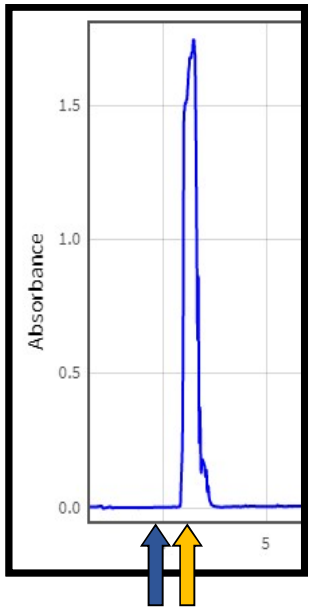


SENSIRION SCD30: WORKING PRINCIPLE

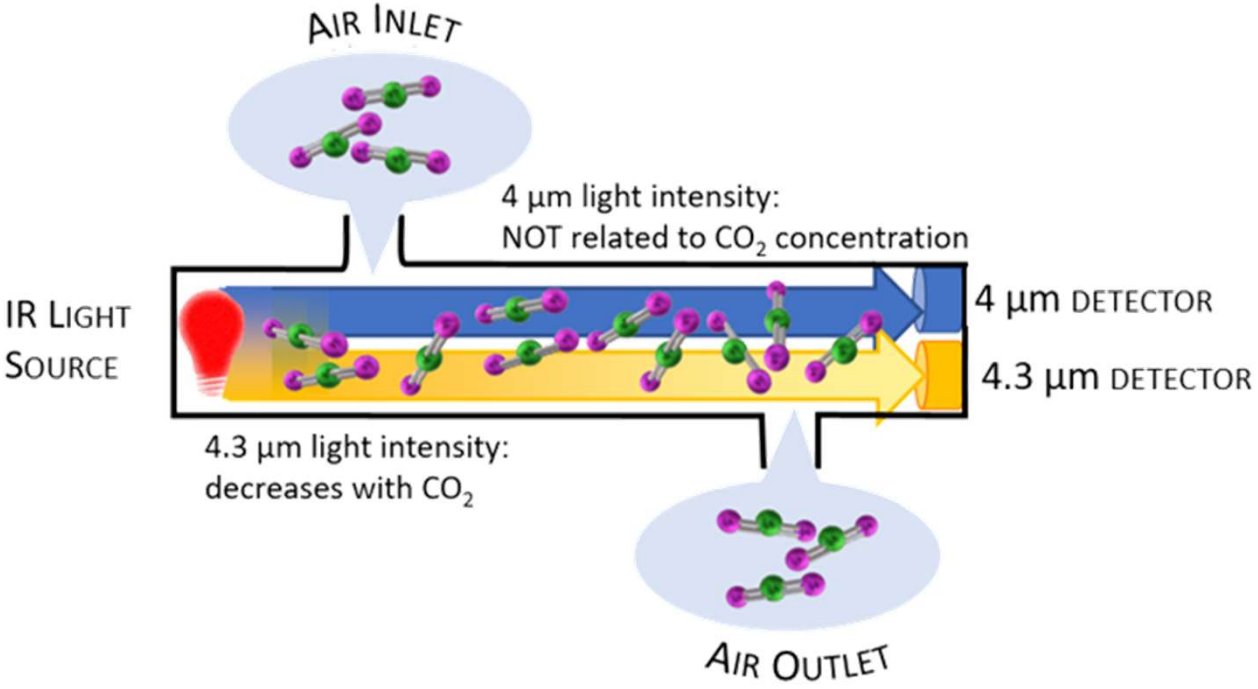


DETECTOR 1 (4µm)

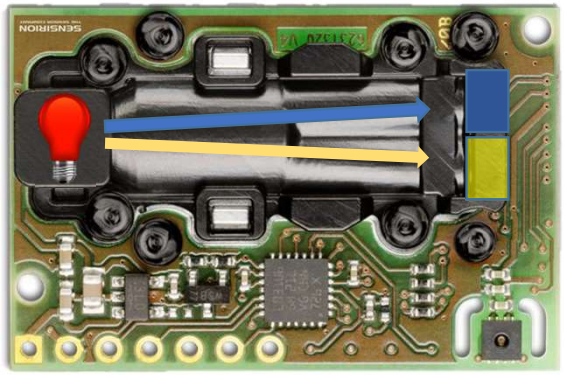
DETECTOR 2 (4.3µm)

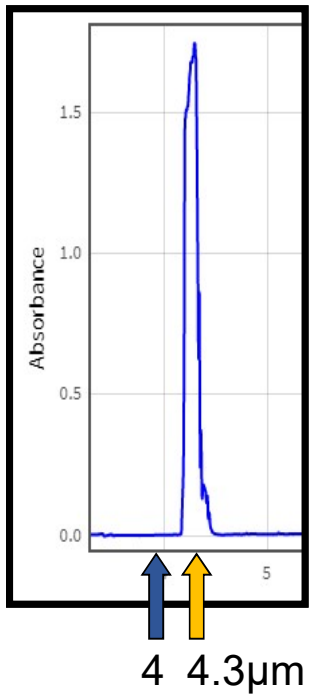


The IR light covers the distance between source and detectors, eventually hitting CO2 molecules



Marica Canino NPSE March 15 2024





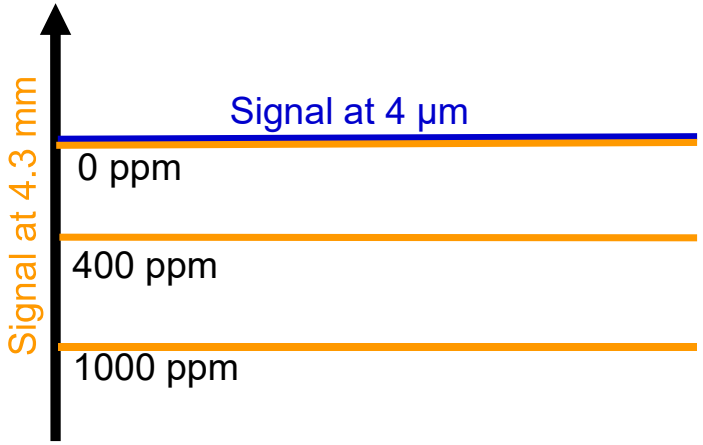
WORKING PRINCIPLE

CO2 molecules absorb 4.3µm light.

The light intensity read by the detector at 4.3µm decreases as the amount of CO2 molecules in the chamber increases

The light intensity read by the detector at 4µm is not affected by the CO2 presence in the chamber

This signal difference provides the CO2 concentration value



CHANGE CO_2Lab

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CONTROL SBC

Pin#	NAME		NAME	Pin#
01	3.3v DC Power		DC Power 5v	
03	GPIO02 (SDA1 , I²C)		DC Power 5v	
05	GPIO03 (SCL1 , I²C)		Ground	
07	GPIO04 (GPIO_GCLK)		(TXD0) GPIO14	08
09	Ground		(RXD0) GPIO15	10
11	GPIO17 (GPIO_GEN0)		(GPIO_GEN1) GPIO18	12
13	GPIO27 (GPIO_GEN2)		Ground	14
15	GPIO22 (GPIO_GEN3)		(GPIO_GEN4) GPIO23	16
17	3.3v DC Power		(GPIO_GEN5) GPIO24	18
19	GPIO10 (SPI_MOSI)		Ground	20
21	GPIO09 (SPI_MISO)		(GPIO_GEN6) GPIO25	22
23	GPIO11 (SPI_CLK)		(SPI_CE0_N) GPIO08	24
25	Ground		(SPI_CE1_N) GPIO07	26
27	ID_SD (I²C ID EEPROM)		(I²C ID EEPROM) ID_SC	28
29	GPIO05		Ground	30
31	GPIO06		GPIO12	32
33	GPIO13		Ground	34
35	GPIO19		GPIO16	36
37	GPIO26		GPIO20	38
39	Ground		GPIO21	40

Rev. 2

www.element14.com/RaspberryPi

CHANGE CO_2Lab

PA

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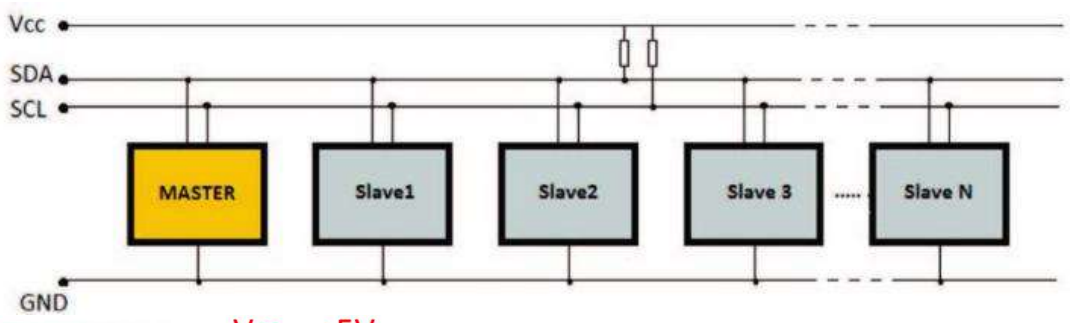
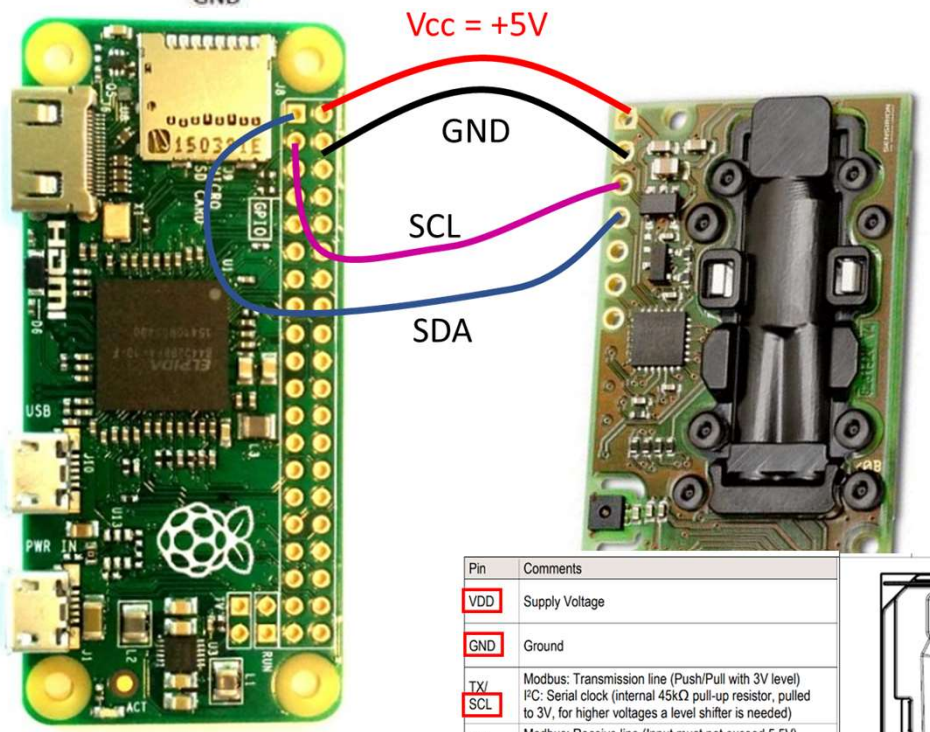
Communication



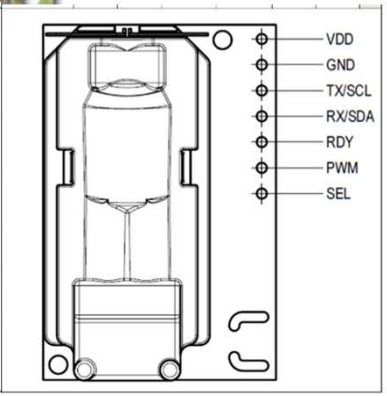
Pin#	NAME		NAME	Pin#
01	3.3v DC Power		DC Power 5v	02
03	GPIO02 (SDA1 , I²C)		DC Power 5v	04
05	GPIO03 (SCL1 , I²C)		Ground	06
07	GPIO04 (GPIO_GCLK)		(TXD0) GPIO14	08
09	Ground		(RXD0) GPIO15	10
11	GPIO17 (GPIO_GEN0)		(GPIO_GEN1) GPIO18	12
13	GPIO27 (GPIO_GEN2)		Ground	14
15	GPIO22 (GPIO_GEN3)		(GPIO_GEN4) GPIO23	16
17	3.3v DC Power		(GPIO_GEN5) GPIO24	18
19	GPIO10 (SPI_MOSI)		Ground	20
21	GPIO09 (SPI_MISO)		(GPIO_GEN6) GPIO25	22
23	GPIO11 (SPI_CLK)		(SPI_CE0_N) GPIO08	24
25	Ground		(SPI_CE1_N) GPIO07	26
27	ID_SD (I²C ID EEPROM)		(I²C ID EEPROM) ID_SC	28
29	GPIO05		Ground	30
31	GPIO06		GPIO12	32
33	GPIO13		Ground	34
35	GPIO19		GPIO16	36
37	GPIO26		GPIO20	38
39	Ground		GPIO21	40

Rev. 2
29/02/2016

www.element14.com/RaspberryPi

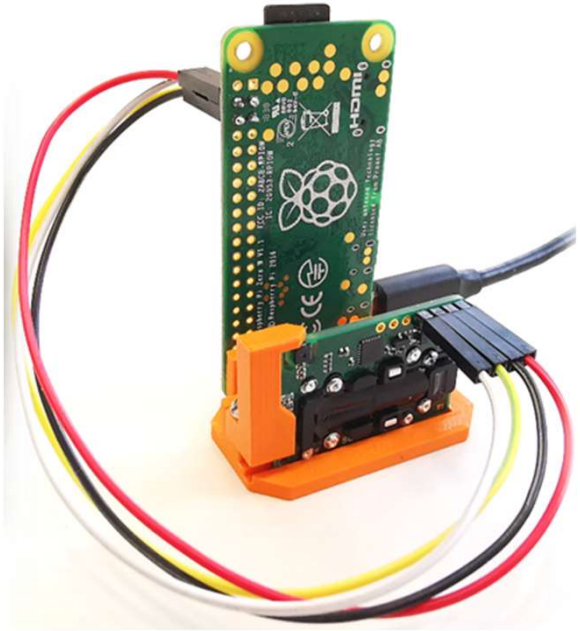


Pin	Comments
VDD	Supply Voltage
GND	Ground
TX/ SCL	Modbus: Transmission line (Push/Pull with 3V level) I²C: Serial clock (internal 45kΩ pull-up resistor, pulled to 3V, for higher voltages a level shifter is needed)
RX/ SDA	Modbus: Receive line (Input must not exceed 5.5V) I²C: Serial data (internal 45kΩ pull-up resistor, pulled to 3V, for higher voltages a level shifter is needed)
RDY	Data ready pin. High when data is ready for read-out
PWM	PWM output of CO_2 concentration measurement
SEL	Interface select pin. Pull to VDD (do not exceed 4V, use voltage divider in case your VDD is >4V) for selecting Modbus, leave floating or connect to GND for selecting I²C.

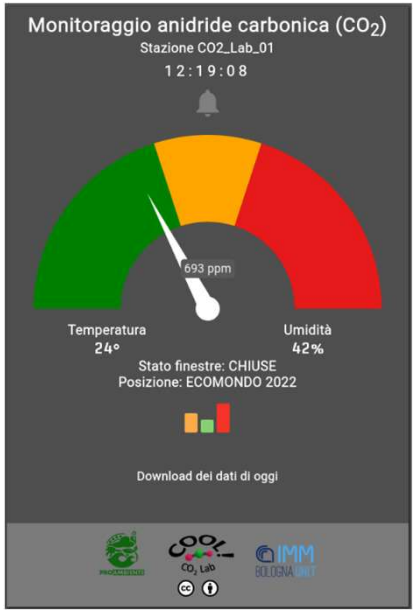


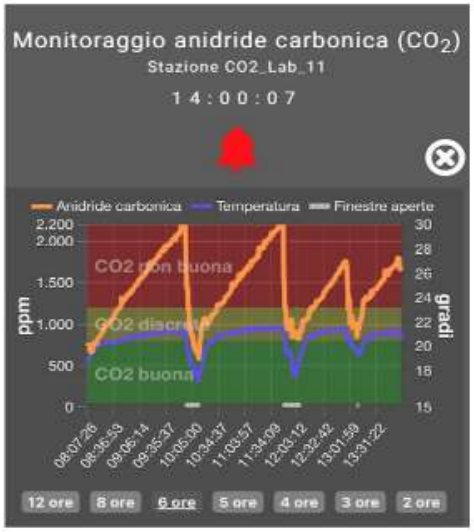
Operation

1. Data acquisition and local storage



2. Data sent to a server via wifi





3. WebApp for data visualization, alert threshold, data plot, data download, acquisition settings

OPEN SOURCE software
Commercial components
Can be customized

→ Use as a didactic tool

CO2 concentration as an indicator of ventilation (2h)

Station assembly and CO2 measurement within experiments inducing CO2 variations (2h)

CO2 monitoring in classroom, data elaboration, report

Theory

Guided practical activity

Autonomous activity

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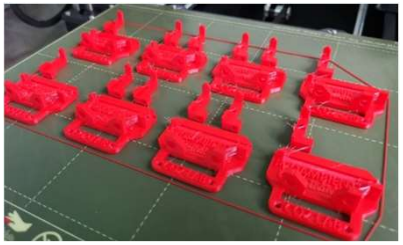
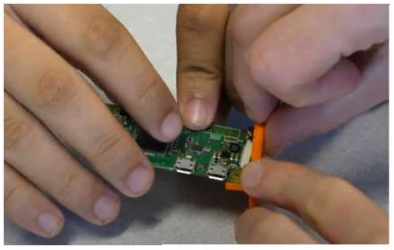
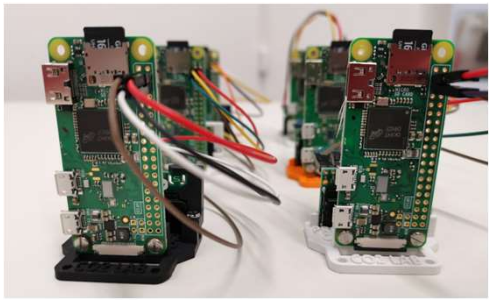
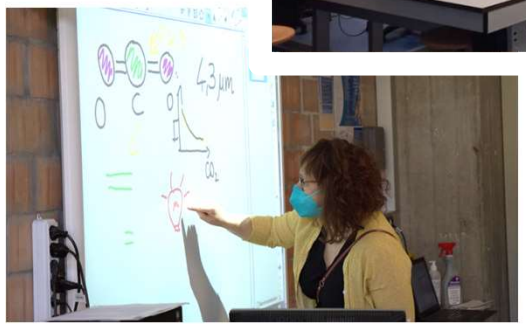
2021-2024 CO_2 Lab in Italy









11 Schools

>20 Teachers

>20 Reports

>18 Stations installed in schools

>1000 h monitoring

IIS Belluzzi - Fioravanti
Bologna (Italy)

CIPFP Valle de Elda
Elda, Alicante (Spain)

Profesionalna Gimnazia po Elektronika "John Atanasoff"
Stara Zagora (Bulgaria)

Liceul Tehnologic Mirsa
Mirsa-Avrig (Romania)

CHANGE
CO_2Lab

Co2 monitoring in scHools for digitAl aNd Green compEtences

Training courses for high school teachers (2 on Italian SOFIA platform)

Modular and multilingual didactic material

Open platform for CO2 monitoring data sharing according to FAIR principles

Dissemination for citizen made by steudents

Erasmus+

CHANGE CO_2Lab

IMM BOLOGNA UNIT

Topics

SCIENCE
CITIZENSHIP

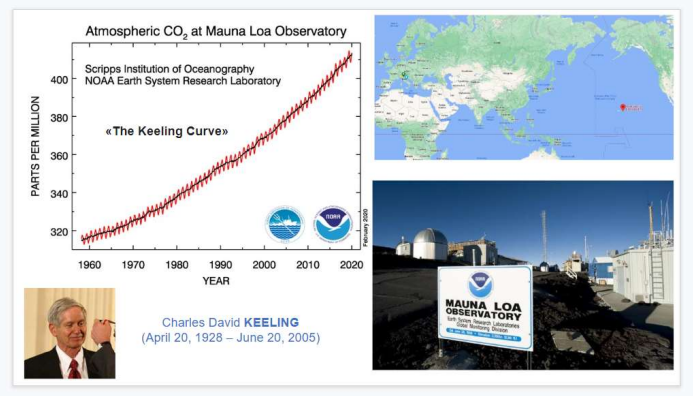
Meaning of CO2 concentration in air
pollutants in air, CO_2 concentration along the last decades, greenhouse effect
Open Source
FAIR Data (Findable, Accessible, Interoperatable, Reusable)

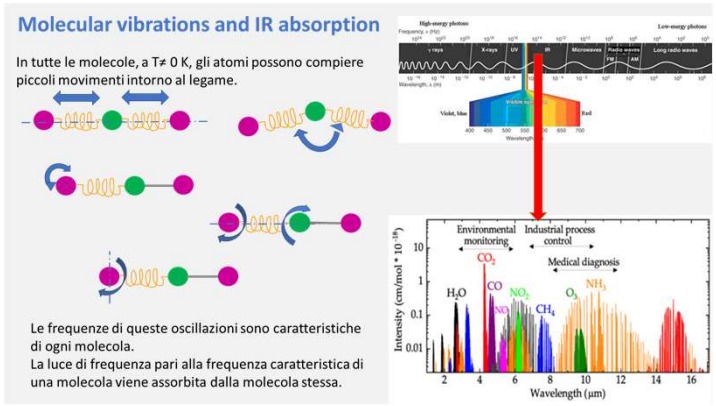
CHEMISTRY
PHYSICS

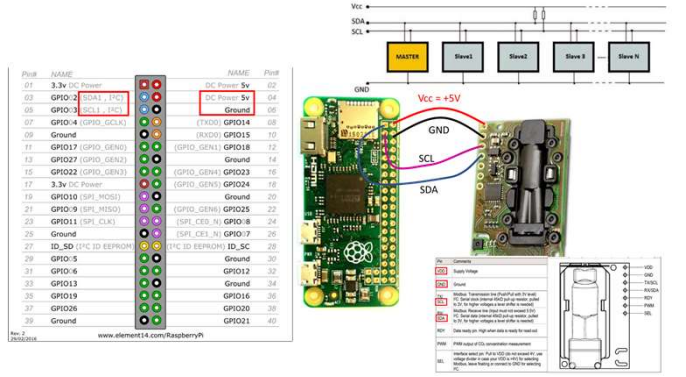
CO2 concentration measurement technique
Measurement units (ppm,ppb), molecular vibration modes in the IR, absorption lines, CO_2 sensing technique, low-cost approach
Materials in electronic devices; planned obsolescence

ELECTRONICS
INFORMATICS

Sensor-electronics interface
Python
Data management
3D- printing

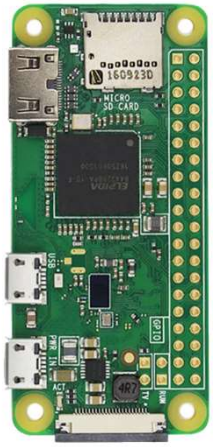






Marica Canino NPSE March 15 2024

Assembly



‘MINI-PC’

Raspberry Pi Zero

Python language and libraries

40 GPIO pin

ACCESSORIES

Sensirion SCD 30

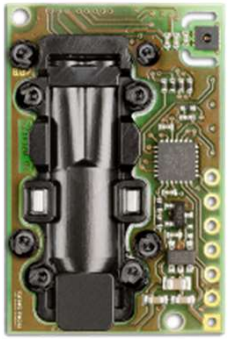
NDIR 400 – 1000 ppm range

±30 ppm accuracy

Integrated CO2, T and RT% sensors

Open libraries for interface

Possibility to force a baseline



SENSOR

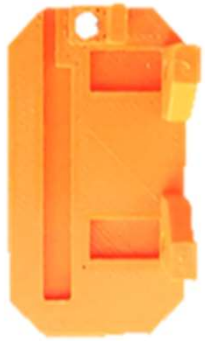
3D-PRINTED BASE

Recycled plastics

PLA & PET

8g material consumption

Open and customizable design



CHANGE CO_2Lab

PA

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Assembly

'MINI-PC'

Sensirion SCD 30

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±30 ppm accuracy

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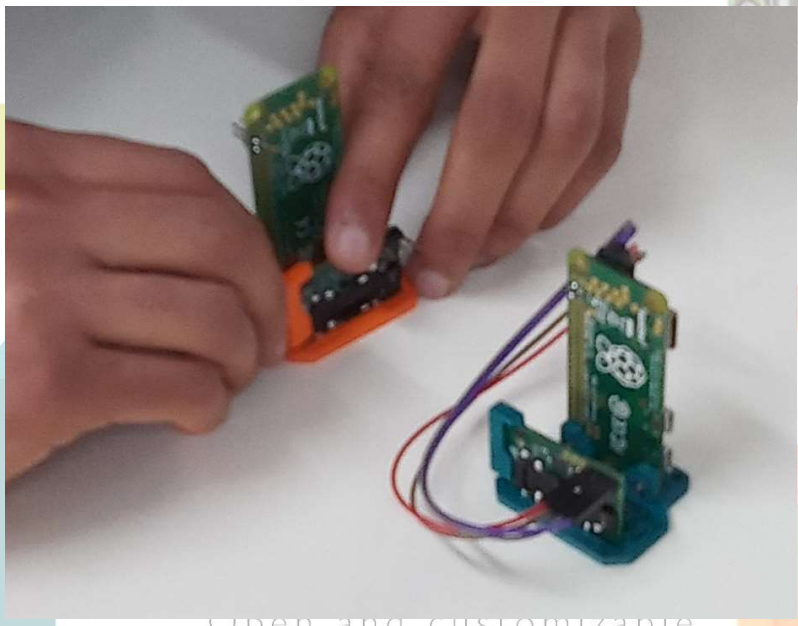


Open and customizable design

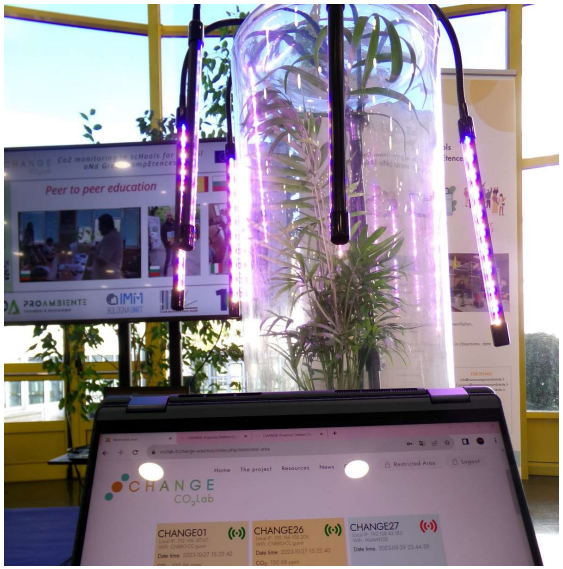
Guided Experiments

Aim

Familiarize with :

- the WebApp for station management,
- data management and analysis

CO_2 production
through bicarbonate-vinegar reaction



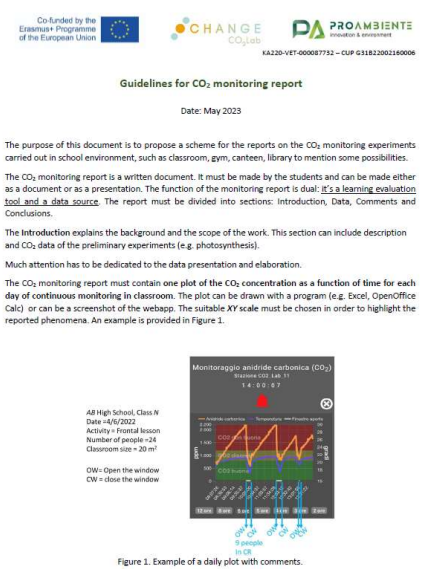
CO_2 capture
by plant photosynthesis

Monitoring in class

Event annotation

- Paper
- WebApp

Guidelines



Co-funded by the Erasmus+ Programme of the European Union

KA220-VET-000087732 – CUP G31B22002160006

Guidelines for CO_2 monitoring report

Date: May 2023

The purpose of this document is to propose a scheme for the reports on the CO_2 monitoring experiments carried out in school environment, such as classroom, gym, canteen, library to mention some possibilities.

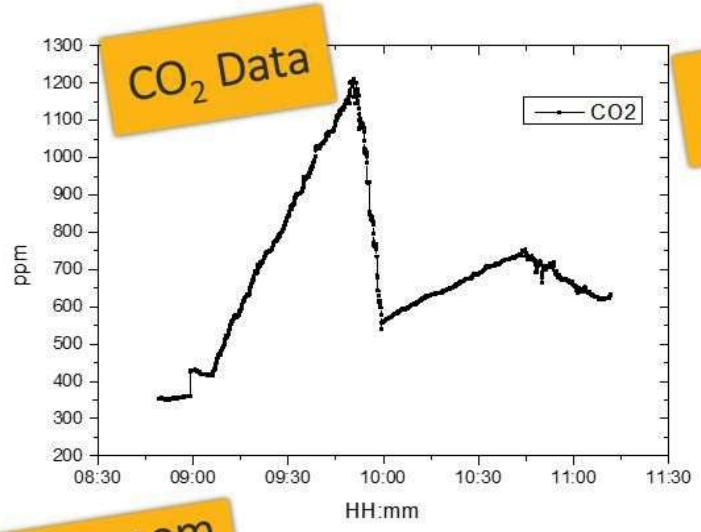
The CO_2 monitoring report is a written document. It must be made by the students and can be made either as a document or as a presentation. The function of the monitoring report is dual: it's a learning evaluation tool and a data source. The report must be divided into sections: Introduction, Data, Comments and Conclusions.

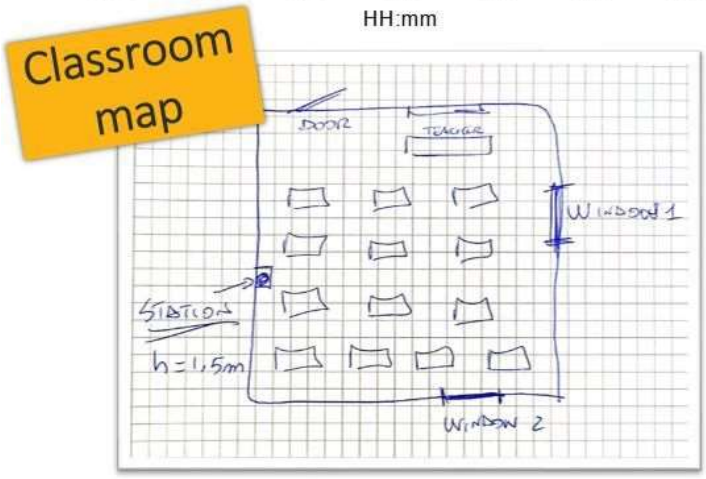
The **Introduction** explains the background and the scope of the work. This section can include description and CO_2 data of the preliminary experiments (e.g. photosynthesis).

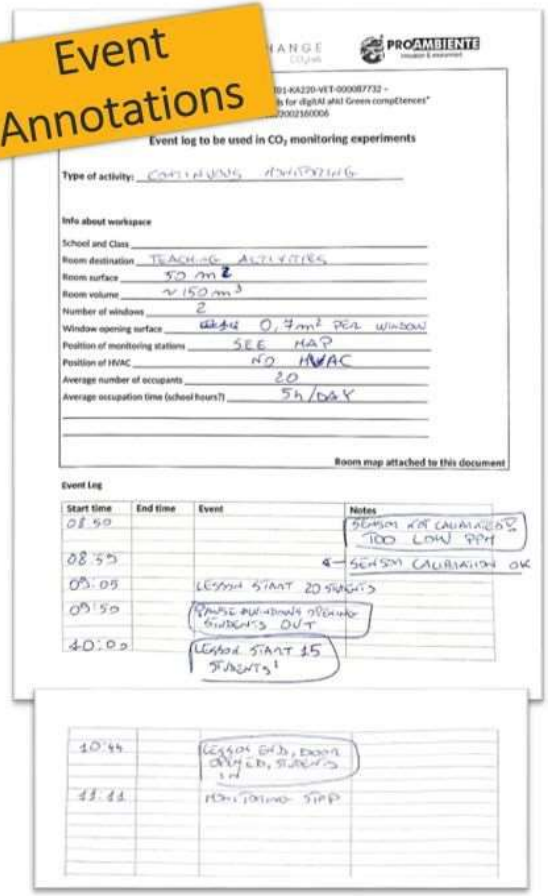
Much attention has to be dedicated to the data presentation and elaboration.

The CO_2 monitoring report must contain **one plot of the CO_2 concentration as a function of time for each day of continuous monitoring in classroom**. The plot can be drawn with a program (e.g. Excel, OpenOffice Calc) or can be a screenshot of the webapp. The suitable ***XY* scale** must be chosen in order to highlight the reported phenomena. An example is provided in Figure 1.

Figure 1. Example of a daily plot with comments.

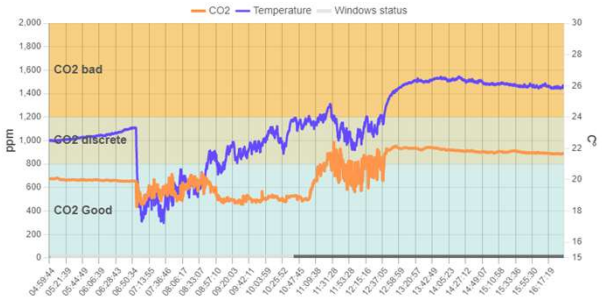




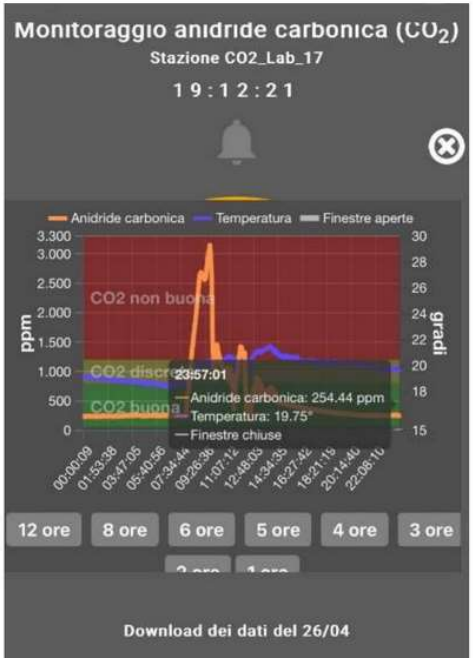


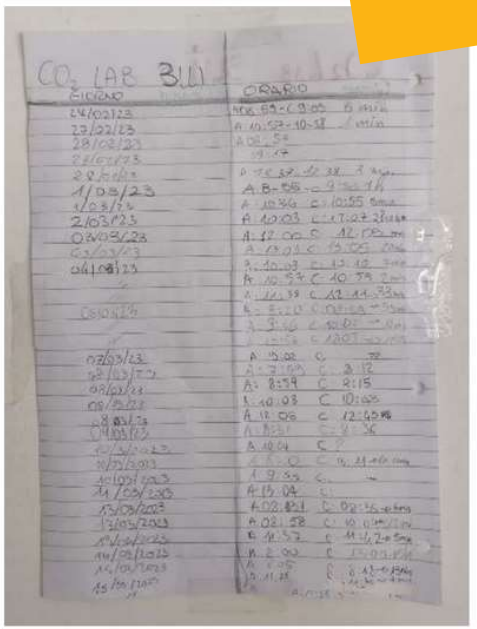
Examples of event log

On-line window opening log



Paper log





EVENT LOG

Event Log

Start time Начален час	End time Краен час	Event събитие	Notes Бележки
8:00	12:00	Window is open	10:35 – 11:00 no students
12:00	14:30	Window is closed	

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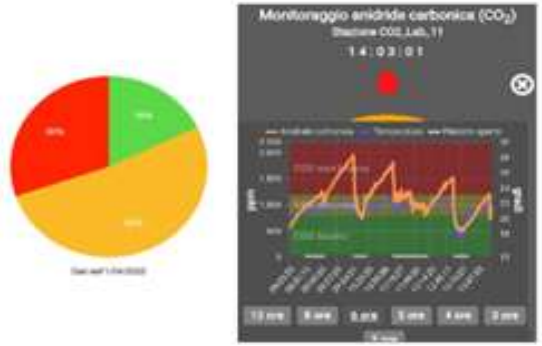
Irregular window opening vs 10 min opening every hour

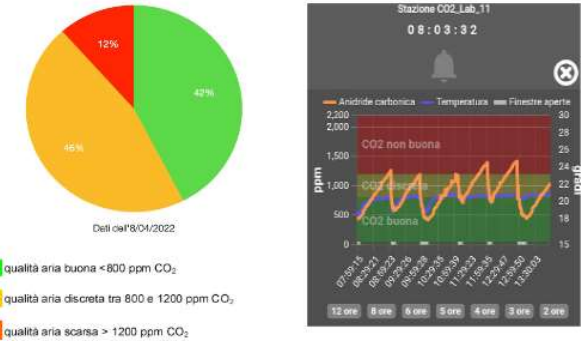
TEST 1

IRREGULAR WINDOW OPENING



VS

10 MIN OPENING EVERY HOUR



Figures 1B and 2B show how by changing the air irregularly, low or discrete CO2 levels are recorded during most of the time of the day.

On the 8th of April, both windows were kept open completely for 10 minutes each hour and for 15 minutes during the two breaks and, as it can be seen from the graph, the level almost never exceeded 1200 ppm of CO_2. The temperature did not show significant variations as it was a particularly mild day.

The data were also analyzed from a mathematical point of view, calculating the average slope in the lines that describe the increase in CO_2 values with the windows completely closed on different days (table 1).

DATA	people present in the room	surface (m^2)	m^2/person	volume (m^3)	m^3/person	line with average gradient (y=final ppm; b=initial ppm)
1 Apr	22	63,2	2,9	345	15,7	y=**3,97** x + b
4 Apr	22	63,2	2,9	345	15,7	y=**3,79** x + b
8 Apr	20	63,2	3,2	345	17,2	y=**3,48** x + b

The time spent in good CO_2 conditions halves upon regular window opening

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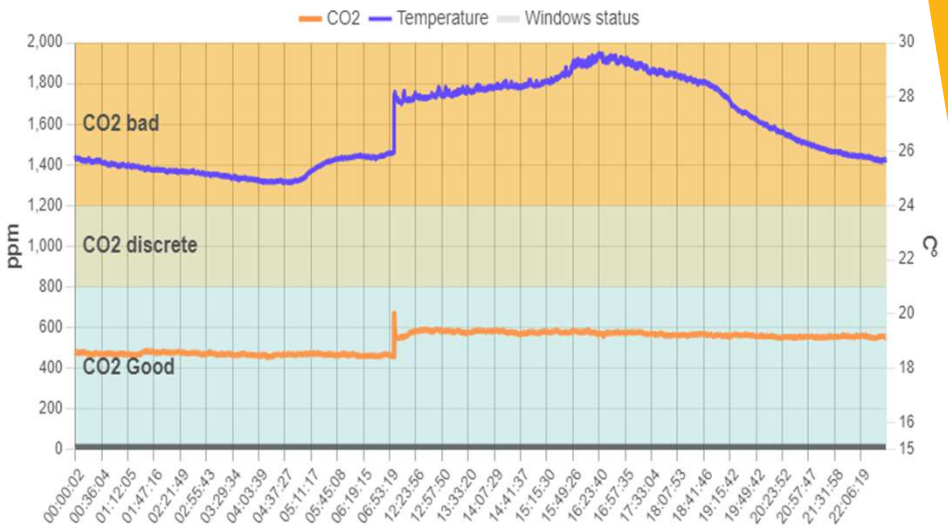
Big room low student density

TEST II

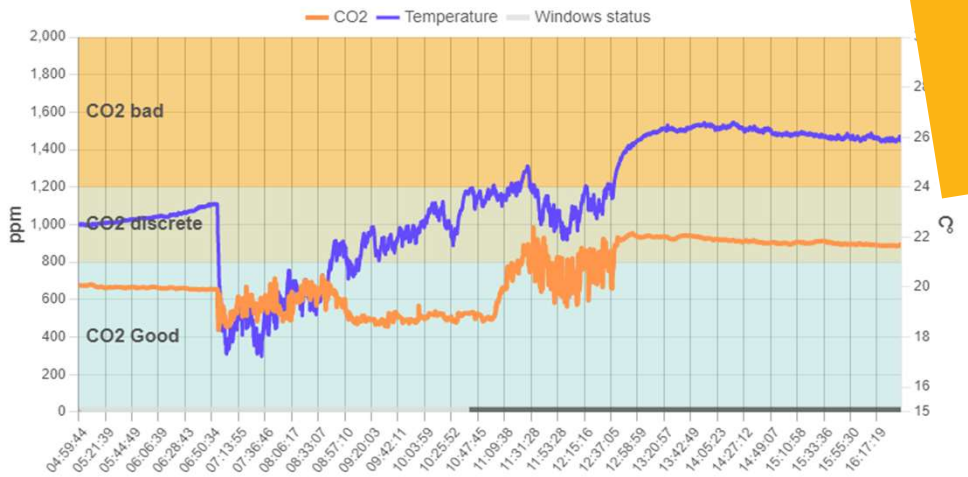


Room surface (площ на стаята) - 63 m²
Room volume (обем на стаята) - 190 m³
Number of windows (брой прозорци) - 4
Window opening surface (площ отваряеми прозорци) – (0,8 x 4) m²
Position of monitoring stations (разположение на устройството) – on a ledge next to an opening window
Position of HVAC - three radiators 1.5m² away
Average number of occupants (среден брой на хората) -15
Average occupation time (school hours?)(учебни часове: начален час-краен час) - 08:00 – 14:30

Коментари (Comments): There is construction work outside so the windows remain closed all day. The CO2 concentration is in the good zone due to ventilation through the door and the size of the room.

Window opening with pollution outside

TEST III



Room surface (площ на стаята) - 30 m²
Room volume (обем на стаята) - 90 m³
Number of windows (брой прозорци) - 2
Window opening surface (площ отваряеми прозорци) – (0,8 x 2) m²
Position of monitoring stations (разположение на устройството) – On the teacher's desk, adjacent of an openable window
Position of HVAC (Отоплителни , вентилационни системи) - Radiator 3m² away
Average number of occupants (среден брой на хората) - 13
Average occupation time (school hours?)(учебни часове: начален час-краен час)- - 8:00 – 14:30

4. Заключения (Conclusions):

ıcentration of CO2 is high most of the day and the reason for his is the intensive flow of students through the m and the polluted air coming from outside due to construction activities. In this case the mechanical ventilation ɔpening the window is not effective

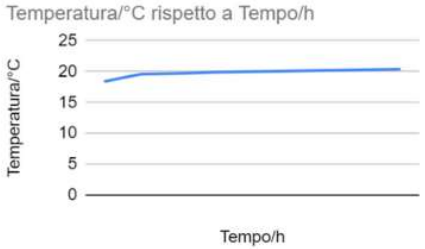
Elevator lubrication

/V\icrosistemi

TEST IV

ANALISI DATI DEL 02/04/2023

Tempo/h	CO2/ppm	Temperatura/°C
7	2053	18,4
8	1978	19,6
9	2012	19,7
10	2040	19,9
11	2001	20,0
12	1936	20,1
13	1907	20,2
14	1830	20,1
15	1850	20,3



Il 02/04/2023 il livello di CO2 è notevolmente alto in quanto i cavi dell'ascensore del piano erano stati lubrificati ed hanno inciso sui livelli di CO2. Nonostante la classe tenesse le finestre aperte , il livello di anidride carbonica non scendeva.

On 04/02/2023 the CO2 concentration was significantly high as the elevator cables on the floor were been lubricated and affected CO2 levels. Although the classroom kept the windows open, the carbon dioxide level did not decrease.

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Output

What we don't know

La quantità di CO_2 nell'aria delle aule aumenta in base al numero di persone presenti, numero che è stato stabilito negli ultimi due anni in modo da rispettare le regole per il distanziamento

Non conoscevamo tuttavia la situazione di partenza nella nostra scuola e quanto rapidamente crescono i valori di CO_2 misurati in ppm a finestre chiuse, in funzione ad esempio della superficie a disposizione per ciascuna persona presente nell'aula

La valutazione dell'impatto di questi fattori è importante per la salute della popolazione scolastica e per le possibili scelte future

Assemblaggio centralina

1 Inserimento degli inserti filettati nelle sedi presenti nella base

Inserire due viti nei 2 fori ed inserire gli inserti filettati avvitandoli sulle viti. Poi avvitare con cacciavite fino a che gli inserti non saranno inseriti totalmente nei fori.

2 Posizionare l'he… Raspberry Pi …

Inserire gli header nei 4 pin Raspberry Pi Zero W (3-4-5-6).
I pin sono da orientare verso l'alto.

Discussione e Conclusioni (1)

Il nostro esperimento pone le basi per una scuola più sostenibile. Trascorrere un quarto delle proprie giornate esposti a livelli di CO_2 scarsi o al limite discreti non agevola la vita studentesca. Il nostro intento era innanzitutto quello di raccogliere i dati, fondamentali per i seguenti motivi: per valutare la qualità dell'aria durante le ore scolastiche, per verificare l'efficacia delle indicazioni di sicurezza messe in atto durante la pandemia, per rafforzare le scelte future.

Dai risultati dei nostri esperimenti è emerso che l'apertura delle finestre è sufficiente a garantire un buon ricambio di aria solo se effettuata in modo regolare, ogni ora, spalancando entrambe le finestre per almeno 10 minuti.

Tuttavia, soprattutto in inverno questo determina un importante calo della temperatura interna, esponendo i presenti al rischio di raffreddamento e comportando un notevole spreco in termini energetici.

Sommario

In questo progetto ci siamo proposti di misurare i livelli di anidride carbonica (CO_2) in alcune classi della sede centrale del Liceo Galvani. Gli obiettivi erano di monitorare mediante una centralina la qualità dell'aria in luoghi chiusi e affollati come gli ambienti scolastici, e di valutare se le indicazioni fornite durante la pandemia, rispetto ai tempi necessari per un adeguato ricambio dell'aria, fossero coerenti con i risultati sperimentali.

I dati raccolti mostrano che, quando il ricambio dell'aria non è svolto in modo regolare e per tempi prolungati, la maggior parte del tempo in classe trascorre in condizioni di scarsa qualità dell'aria, mentre se si rispettano le indicazioni fornite in emergenza pandemica, si mantengono livelli discreti. Tuttavia non sempre è possibile rispettare le tempistiche e le modalità previste dall'emergenza per un ricambio di aria efficace, soprattutto durante la stagione invernale.

I nostri risultati mostrano quindi come sia necessaria una riflessione più ampia per garantire la salubrità degli ambienti scolastici

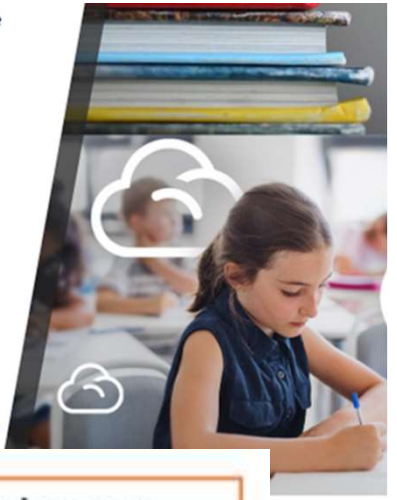
Output

I nostri risultati mostrano quindi come sia necessaria una riflessione più ampia per garantire la salubrità degli ambienti scolastici

What we don't know

Non conoscevamo tuttavia la situazione di partenza nella nostra scuola e quanto rapidamente crescono i valori di CO_2 misurati in ppm a finestre chiuse, in funzione ad esempio della superficie a disposizione per ciascuna persona presente nell'aula

La valutazione dell'impatto di questi fattori è importante per la salute della popolazione scolastica e per le possibili scelte future



Tuttavia, soprattutto in inverno questo determina un importante calo della temperatura interna, esponendo i presenti al rischio di raffreddamento e comportando un notevole spreco in termini energetici.

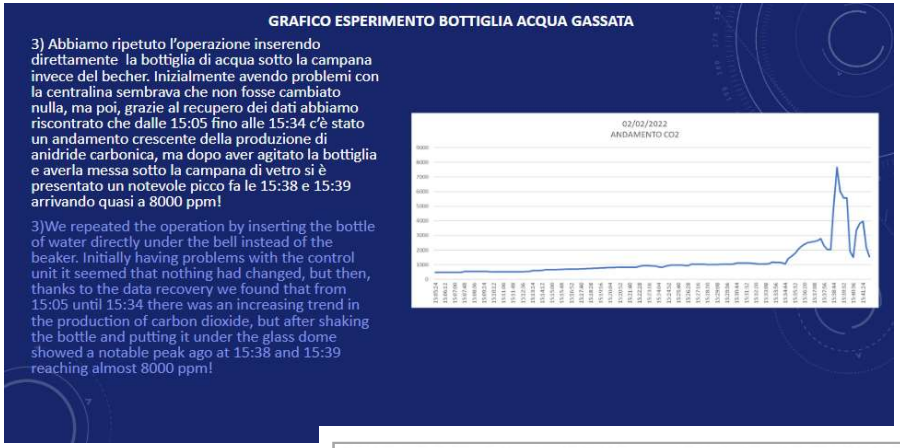
un notevole spreco in termini energetici.

Output

Report on the experiments → TEACHERS ☺

Survey on the level of knowledge about IAQ and health among parents and peers → OUTREACH ☺

Custom 3D-printed base



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Scientific activity

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Optimization & perspectives

Pathway delivery mode

Direct from researchers →
Teacher training for independent delivery → Researcher intervention at monitoring stage

Monitoring report

Teacher engagement
Explain the importance of annotations
Guidelines for monitoring

Room for improvement

Open to collaborations in the analysis of the impact of the project on students learning

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Istituto Tecnico e Professionale - Catanzaro

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Thank you
for your attention

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CO2 LAB:

un percorso didattico STEM per il monitoraggio della CO2 in ambienti scolastici

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