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Teachers Teaching with Technology™

Veit Berger, Hans-Martin Hilbig

A Healthy Classroom

Sensor data aquisition & analysis in a classroom environment

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1. Learning objectives and system aspects

a. Learning objective and curriculum

In the fast paced environment we live in today, our thinking often is oriented in the ‘here and now’. Our life is focused on fast context switching between tasks, quick action and decision making and we demand immediate feedback on the results of our actions. In contrast, sustainability mostly has a big long-term impact. Processes are slow but results and changes can be massive over time. In this exercise, students will learn about the latency of some of our key environmental factors, such as temperature, humidity, and air quality. They will learn the concept, requirements, and implementation of an automated environmental measurement system. They will learn about how long it takes for temperature, humidity, and air quality to change in a fully populated classroom and how plants in the classroom or opening the windows affect these parameters.

The activity is expandable by adding more sensors, such as sound level and a counter to detect the number of people and the level of physical activity in a classroom.

b. Science background

A classroom can be viewed as a mini-ecosystem entity, having its own climate. There are external and internal factors influencing the climate of the classroom. External factors include outside temperature and intensity of sunlight falling through the windows, heating up the classroom interior. Internal factors include the temperature of the heating radiators in the room, number of people staying and breathing in the classroom, the presence of plants to regenerate oxygen from ambient air, just to name a few. And there are control mechanisms which influence the classroom’s climate. These include the level of physical activity inside the classroom, the time duration until a window is opened and provisions to shade the interior from direct sunlight. In this project characteristics like temperature, humidity and CO2 content are measured and stored over time. The data is being analyzed, conclusions are drawn and preventive actions are defined to preserve a healthy climate in the classroom.

c. Connection with Sustainability Development Goals

The activity touches several of the 17 Sustainability Development Goals (SDG) established by the United Nations such as:

SDG #3: Good health and well-being: Students will learn that environmental indices like temperature, humidity and air quality will lead to well-being in the classroom.

SDG #11,12: Sustainable cities and communities, responsible consumption, and production: Students will learn that they can make an impact to sustainability by taking responsibility for a balanced climate in the classroom. They will understand the impact of the presence of plants as a source of oxygen. They will see how their personal behavior (e.g. adjusting the time and duration of windows to be opened, based on the individual external and internal factors of the classroom as measured by their Python programs).

Aspect of Sustainability

Comparing air quality in (class)-room situations without and with plants can lead to a key experience for the students, in what way plants are providing us with oxygen. Ideally, they acknowledge that we need plants to stay alive. No plants, no life! This is a thing, which seems to get easily forgotten. This would conclude the Math & Physics aspects of the project.

Next, the project could be expanded to the biology curriculum, starting with the principle of photosynthesis and changing the internal and external factors. What happens if they add more plants? What happens, if they increase the light in the classroom (maybe by using artificial plant-light-spots) or testing the contrary: what if they cut incoming light by half? What happens to the oxygen production if plants do have water-stress?

Eventually, students will get a particularly good and important understanding about the function of plants in each ecosystem and can begin exploring the macro-economic and ecologic impact of the worldwide rate of deforestation for the net production of O_2, in parallel with a rising air pollution and CO_2-level trend.

The healthy classroom is a chance, to grow the awareness of students (and teachers?) beyond the Math & Physics aspect.

2. The actual activity

The experiment:

Key components used in the environmental data monitoring system:

- DHT11 temperature & humidity sensor
- TI-RGB Array (optional)
- Vernier CO2 Sensor (optional)
- TI-Innovator Hub (Firmware 1.4 or better), using the built-in brightness sensor
- TI-Nspire CXII CAS Calculator (Python OS)

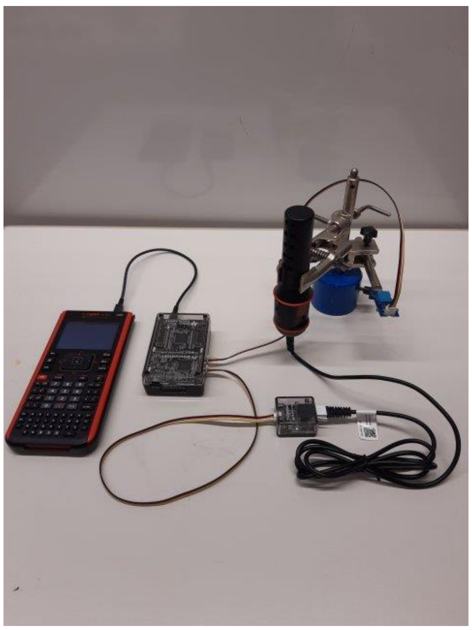


Figure 1 Classroom setup

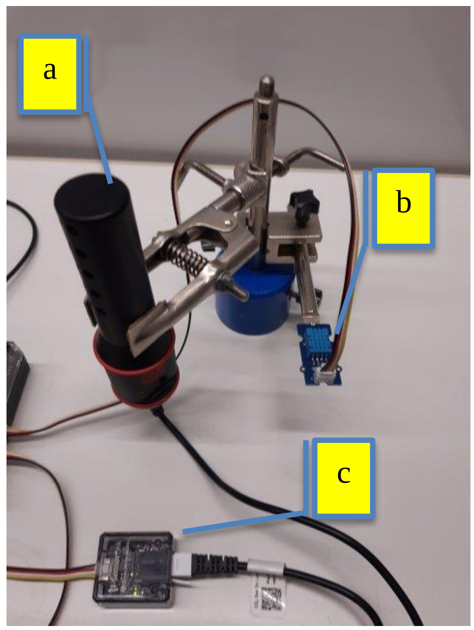


Figure 2 Setup details

Figure 1 shows a typical test setup used for the classroom experiment. The environmental sensors consist of the Vernier CO2 sensor (Fig. 2,a), the DHT11 Temperature & Humidity sensor (Fig. 2,b) and the TI-SensorLink Adapter (Fig. 2,c) connected to the TI-Innovator Hub.

The experiment is divided into two parts: the data logging part and the data analysis part. During data logging, one or more environmental data monitoring systems are placed in dedicated areas of the classroom, e.g. in each of the four corners, plus one near a window. Make sure you carefully keep record of the measurement setup, including internal and external conditions (e.g. # of plants in the room, window shades up or down, radiators on or off, # of people in the room, etc.). Data logging should be started at the same time, ideally in the morning, after fresh air has been led into the classroom before students enter. Allow ample time for the system to adapt to the room's environmental condition (at least 10 mins) and record data for at least 30 mins, while all students are in the classroom for a normal lesson. Towards the end of the data logging part, open the windows and allow the system to continue data logging. Finally, stop the program and save the data for the data analysis part.

During the data analysis part, create a graph from each environmental parameter. Compare the results from each of the environmental data monitoring systems. Create tables of data and add analysis functions, such as creating the mathematical formula from the data acquired, a trend analysis of the data acquired prior to opening the windows, a trend analysis of the data acquired after opening the windows, etc. Discuss and compare observations. Refine your experiment for a possible second run.

The program:

The activity is based on TI-Nspire CXII technology, using Python as the coding language. Object oriented programming is used to define specific object classes tailored to the tasks to be performed in this project. State-of-the-art temperature, humidity, light intensity, and air quality sensors will be used to monitor these key environmental parameters in the classroom in real time. TI-Innovator system will convert the sensor data to allow data analysis in graphical and tabular form.

Program code:

The Python code attached consists of four individual sections:

Section 1, object class definitions: Here, individual classes are defined as needed by the program to perform sensor data acquisition, storage, and graphic display of the results. Special RGB Array classes are defined to perform temperature and humidity data. The classes are based on the built-in TI-RGB class, using the Python inheritance feature to add more functionality. The <try: except:> feature is being used to handle the presence or absence of the TI-RGB Array. A special "timer" class is defined to ensure consistent time stamps of the environmental data recorded. Finally, a couple of text positioning and formatting methods are defined to create a convenient program user interface, using the graphics canvas screen of the CXII calculator.

Section 2, program code: This is the core program to handle input of the brightness range and sample interval, data acquisition using list variables and storage of the data into the TI-Nspire CXII symbol variables.

Section 3, spreadsheet data: sensor data is displayed in numerical form here.

Section 4, graphs: brightness, temperature and humidity data is displayed in graphical (data over time) form.

Sample screenshots:

Fig 3: Sample of the program user interface:

Brightness range was set to 10

Sample interval was set to 5 seconds

At the time of the screenshot, program was running since 6.8 seconds

Current temperature was at 25 DegC, Humidity at 62%, relative brightness at 6.1 (of a maximum of 10)

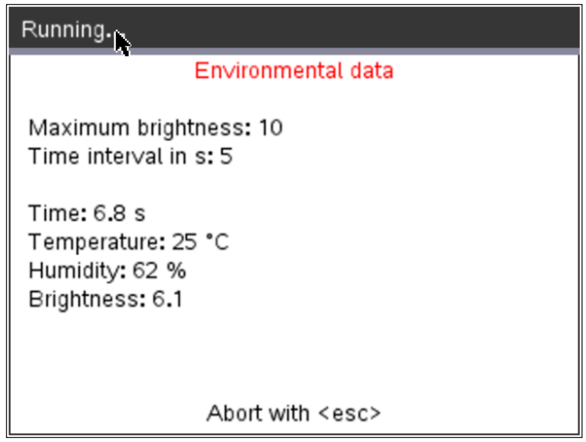
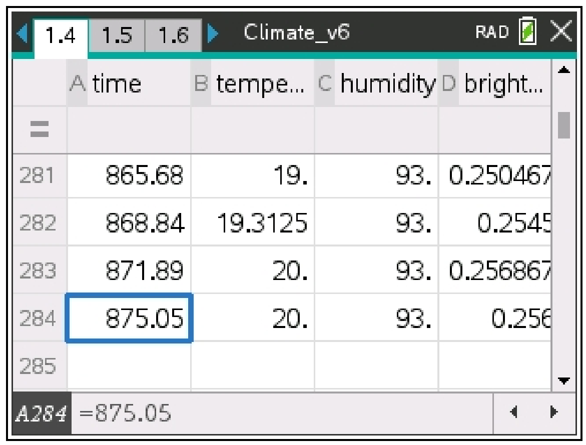


Fig 4: Sample of the variable data spreadsheet:



	A time	B tempe...	C humidity	D bright...
=				
281	865.68	19.	93.	0.250467
282	868.84	19.3125	93.	0.2545
283	871.89	20.	93.	0.256867
284	875.05	20.	93.	0.256
285				

Fig 5: Sample of brightness data recorded for 30 minutes in a refrigerator. Brightness peaks indicate refrigerator door being opened.

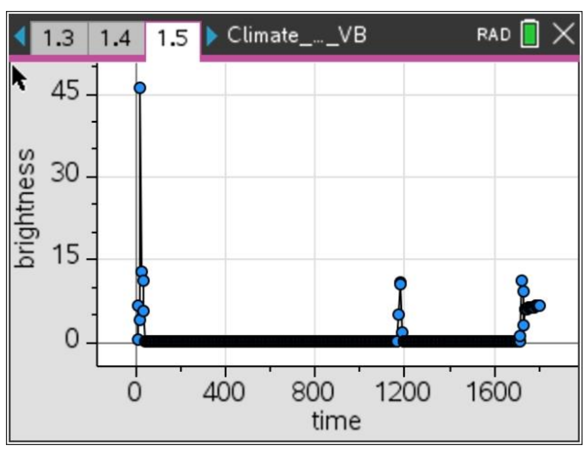


Fig 6: Sample of temperature data recorded for 30 minutes in a refrigerator.

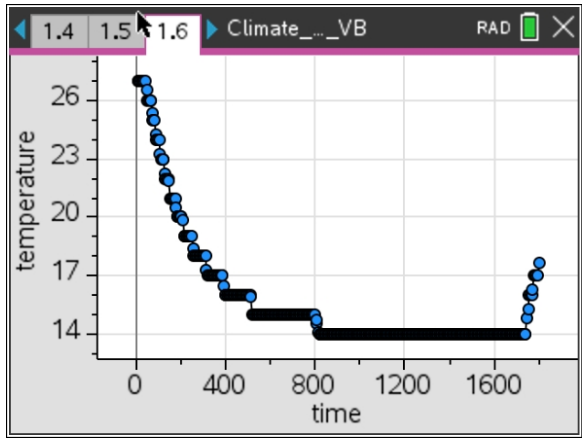
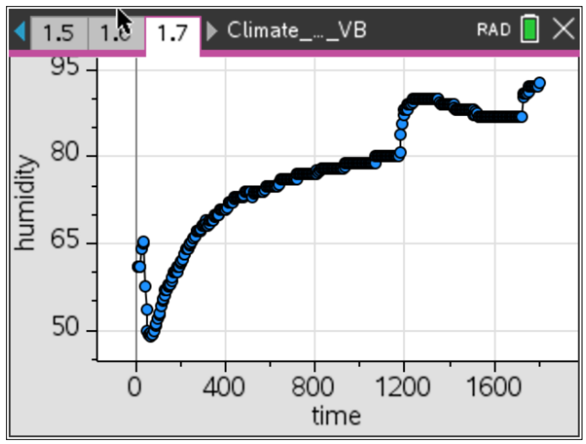


Fig 7: Sample of humidity data recorded for 30 minutes in a refrigerator.



Student questions and potential answers:

a) Analyze environmental data of the same parameter, different stations:

   a. How does the slope and time differ amongst stations? What might be the root cause of any differences (placement, different air flow, exposure to sun light from the window, etc.)? Try to prove your assumptions (e.g. by looking at the light intensity sensor data of different stations, there was direct sunlight from the window exposed to one station while the other being in the shadow, etc.)

b) Comparing the slope of different parameters, same station:

   a. What would be a method to graphically compare slope and shape of temperature data against humidity or air quality or brightness? (Ans: by normalizing the sensor data and display all graphs into one graphical window)

   b. What are your observations? (Ans: temperature gradient leads humidity, brightness leads temperature, etc.)

   c. How is air quality affected? How can you prove your assumptions by repeating the experiment under different conditions?

c) Comparing data prior to opening the window against data after opening the window:

   a. Is the underlying mathematical formula the same or different? If the mathematical function is the same, how does slope change?

d) Summary and conclusions:

   a. Summarize the findings about the behavior of each individual sensor data and how they inter-relate with each other.

   b. Come up with a recommendation by when and for how long windows should be opened. Which sensor triggers this decision? What should be the trigger level? Should the decision be based on just one sensor or a combination of many?

e) Tips & Tricks:

a. Use some fixtures to fix the DHT11 and the Vernier CO2 sensor in a repeatable setup. If needed, borrow equipment from the physics or chemistry lab (see figure 8).

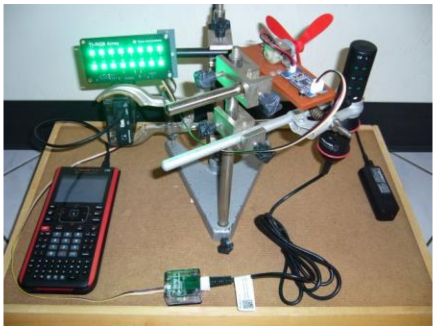


Figure 8 Typical test fixture

b. Do a dry run of your complete environmental measurement system. Consider latencies of the individual sensors (see section 3c below).

c. If multiple systems are available, place them deliberately in different locations of the classroom. E.g., one system near the window, close to sunlight, another system on the floor, in a shaded area, a third system close to the ceiling. Precisely record the place where data was recorded. Let the students compare the data recorded and let them discuss what might be the root caus(es) of any differences seen across systems.

d. If only one system is available, repeat the experiment under similar conditions, but different places. Precisely record the place where each data set was recorded.

e. Figures 9 through 14 show measurements taken in a real classroom environment.

Scenario 1:

Large classroom, low population (19 students), 65 mins, room well ventilated, CO2 sensor was warmed up before

Observation: temperature and humidity remain flat (18-19 DegC, 43-46% rel.hum.) across entire student session. CO2 concentration increases slightly, but still acceptable

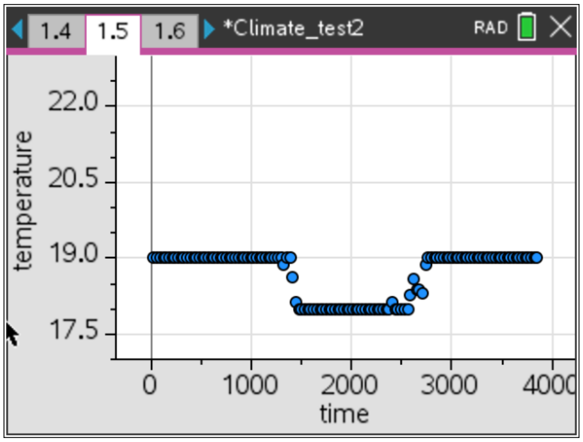


Figure 9 Classroom temperature, scenario 1

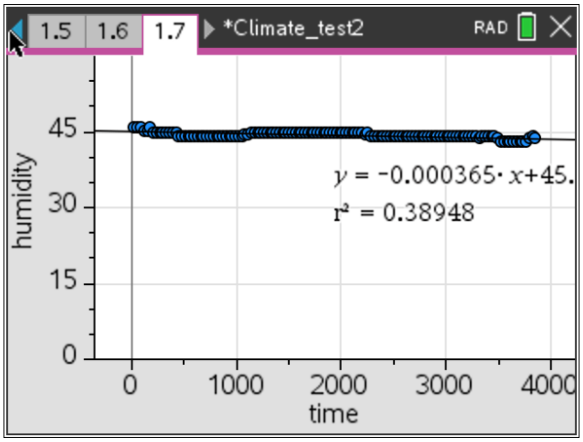


Figure 10 Classroom humidity, scenario 1

Scenario 2:

small classroom, 13 students, 98 mins, CO_2 sensor and system were **not** warmed up before

Observation: Temperature remains flat, after an initial soak. Humidity increases, after an initial soak period. CO_2 concentration remains flat, after an initial soak period.

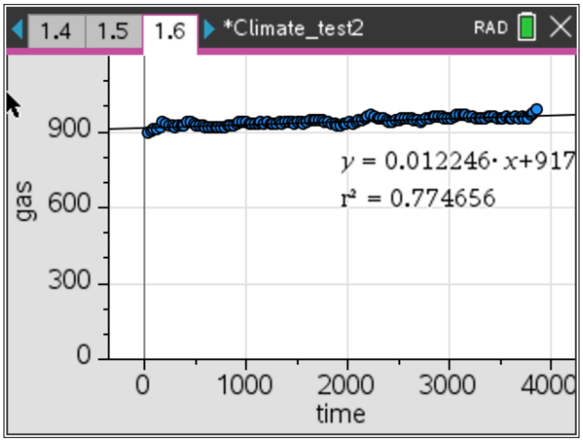


Figure 11 Classroom CO2, scenario 1

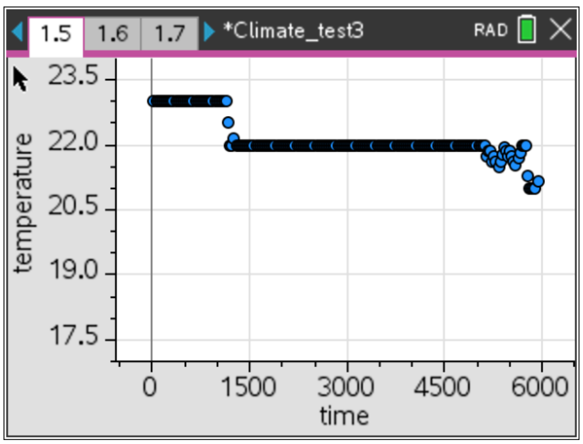


Figure 12 classroom temp, scenario 2

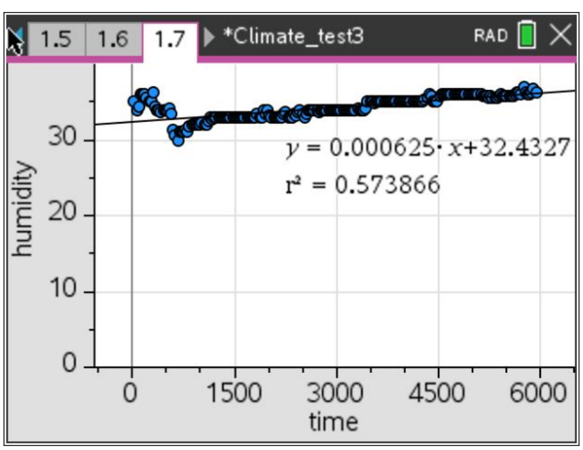


Figure 13 classroom humidity, scenario 2

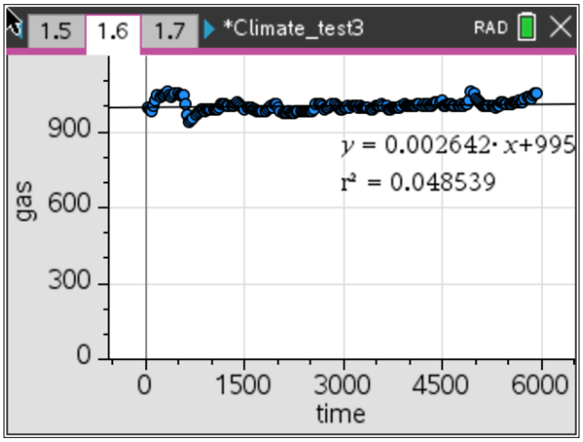


Figure 14 classroom CO2, scenario 2

Conclusions: A large, well ventilated classroom environment ensures all three parameters (temp, humidity, CO2 concentration) remaining in a healthy range, with none of the three increasing within a normal student lesson's period. Humidity seems to be the first leading indicator of a changing classroom air environment. Interestingly, there are no absolute maximum CO2 concentration limits quoted in German and Austria by law. Official publications recommend 1000-1400ppm as a threshold to improve air quality in rooms, by opening the windows or by adding air conditioning/ventilation equipment.

3. Further project ideas and exercises

a) **Introduce the terms 'leading indicators' and 'lagging indicators**.
Leading indices are metrics that help to predict a certain state/condition happening in the future. Leading indicators can be used to define preventive action to avoid a certain situation. Lagging indicators are metrics that reflect the current status quo. Lagging indicators can be used to define corrective action to change an existing situation. Let the students come up with leading and lagging indicators of the healthy classroom activity. (Ans: All three, temperature, humidity and air quality are lagging indicators (as they reflect the status quo at a given time. Brightness level is a leading indicator, as higher brightness is caused by increasing sunlight heating up the inside of the classroom over time, making people to start sweating, etc.).

b) **Let the students come up with ideas for additional leading indicators not being used in the current activity.**
(Ans: counting the students might be a good leading indicator to predict the slope of air quality decreasing. Measuring body temperature and heart rate of the students might be a good leading indicator to predict the slope of temperature and humidity. Measuring sound level in the classroom and adding a motion sensor might be good indicators for the physical activity in the classroom, leading to increased temperature and humidity).

c) **Spend time to let students get familiar with the term 'latency'.**
Expose the sensor assembly (or the entire measurement setup, including TI-Nspire CXII

Calculator and TI-Innovator Hub) to a different 'climate', such as inside a fridge (do not use the deep freezer compartment, as it may harm the electronics). Start taking measurements before you expose sensors to the fridge. Monitor brightness level, as it will indicate open door/closed door (see figure 5). Let the system soak and adapt to the different temperature and humidity. Let students determine the temperature gradient of the DHT11 Sensor. Looking at figure 6, it takes almost 12 minutes for the DHT11 to adapt to the low temperature inside the refrigerator.

d) **Let the students come up with preventive actions to avoid air quality go down below critical level in the classroom.**
(Ans: Add shades to the windows before the classroom is exposed to direct sunlight. Add big plants in the classroom to produce oxygen. Prove the effectiveness of plants in the classroom by comparing the initial air quality in a classroom in the morning prior to school starting vs. the same classroom without plants.

e) **Add more features to the activity.** Introduce the term 'sensor fusion'. Modern technology like cars or smart phones use sensor fusion techniques to validate measurement trends or to augment accuracy. Combining data from the built-in GPS receiver with signal strength data from more than one cell phone base station (triangulation) in a mathematical algorithm will improve location accuracy of the cell phone.
Adding a sound level sensor such as the Vernier sound level meter will add another data component to the experiment. Along with temperature, humidity, number of people in the classroom data, it will improve the predictability of when air quality may go below a certain level.

f) **Add warning devices** (such as the RGB Array, sound alarm) to the system or actuators to influence classroom climate, like a fan to increase air flow or a servo motor to automatically open the window.

g) **Build a small scale house** as a model for the big classroom. Discuss the advantages and disadvantages of this model. (Ans: possible advantages: Easy to add shades, servo operated door, shorter latency of 'climate' changes. Possible disadvantages: difficult to model the effects humans have in the experiment, i.e. consumption of oxygen, increase of humidity, temperature.

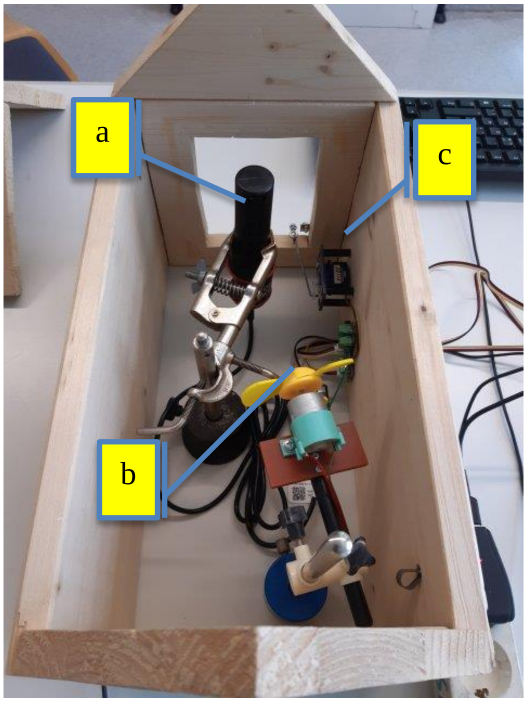


Figure 15 mini house model

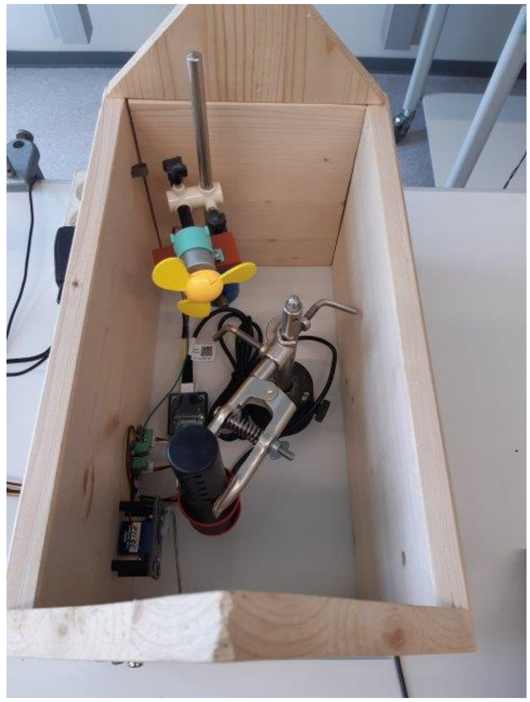


Figure 16 mini house model

Figure 15 & 16 show pictures of a mini house with its roof removed, created by one of the authors, Veit Berger. A Vernier CO_2 sensor (a) is held in a fixed position. Fan (b) is creating an airstream to evenly distribute CO_2 concentration within the mini house. Servo (c) is connected with the plastic door of the mini house. CO_2 sensor, fan and actuator are operated by a TI-Nspire CXII Calculator and a TI-Innovator Hub, running a Python program.

Figure 17 shows the entire setup, including TI-RGB Array as a warning indicator. Warning limits have been set to 2000ppm, respectively 3000ppm. Mini house roof is attached, CO2 sensor is measuring 1893ppm gas concentration. RGB Array shows ‘green’ status.

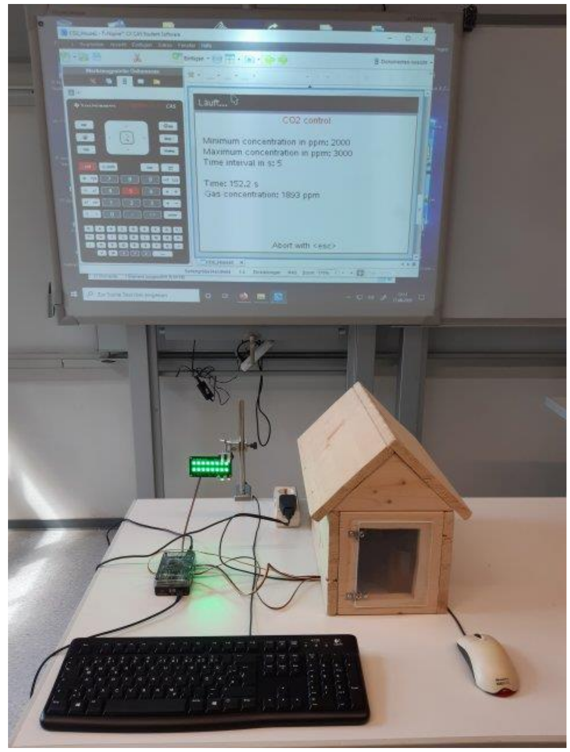


Figure 17

In figure 18, an effervescent tablet was immersed into water inside the mini house, increasing CO2 concentration to 2652ppm. As this value is exceeding the first warning limit, RGB Array switches to ‘yellow’.

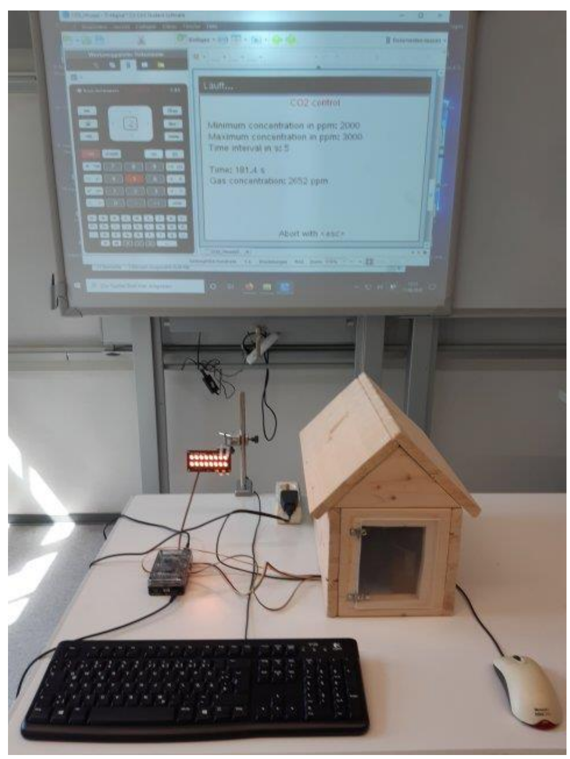
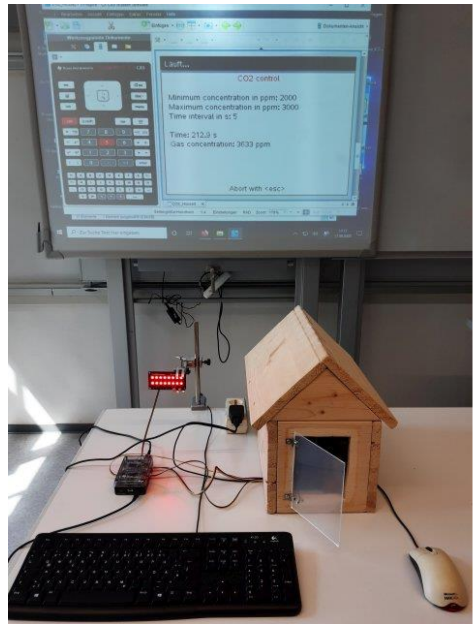


Figure 18



With the tablet continuing to decay, freeing up more CO2 gas, in figure 19 the CO2 sensor is measuring 3633ppm, exceeding the second warning threshold. RGB Array turns to red, and servo and fan motor are operated to open the door of the mini house and ventilate air.

Figure 19

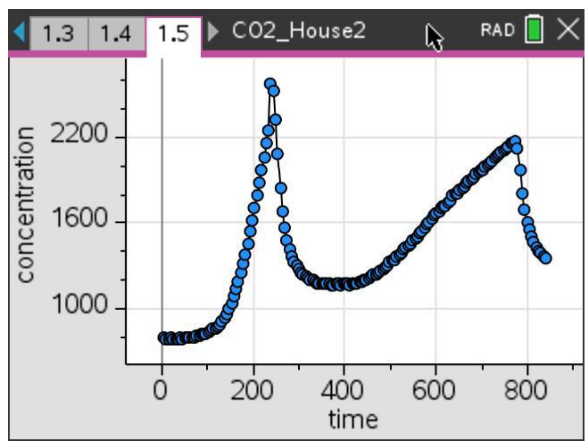


Figure 20 shows the CO2 concentration data recorded during the experiment. CO2 concentration exceeded the threshold of 2200ppm after approx. 225 seconds, the servo was actuated to open the mini house door and the fan motor was turned on to ventilate air. After CO2 concentration fell below 1200ppm, fan motor was turned off and door was closed. Consequently, gas concentration increased again, repeating the alarm-door open-fan on sequence a second time.

Figure 20

h) Pick up the classroom plant idea mentioned under d) above and include plants in the mini house, with the wooden roof replaced by a glass roof. Add an oxygen sensor from Vernier to monitor O2 and CO2 concentration over time, along with recording brightness sensor data from a brightness sensor inside the house. Discuss the results and see how brightness, oxygen concentration and CO2 concentration all relate to each other.

Appendix: System & code FAQs:

Q: Which version of Python is the CXII implementation based upon?
A: To ensure compatibility between the TI-Nspire Desktop software running on MAC or Windows PCs and the TI-Nspire CXII Handheld Calculator, Python is based on MicroPython 1.11.0, which has its roots from Python 3.4.0.

Q: When the TI-RGB Array is not connected, why is there a beep coming from the TI-Innovator Hub, indicating an error?
A: The absence of the TI-RGB Array is first flagged at run time by the TI-Innovator Hub firmware, causing the beep. A program stop, though, is avoided by using the <try: except:> feature of Python. So you can discard this run time error beep.

Q: Why is the DHT11 sensor being sampled continuously, independently of the programmed sample interval?
A: When not being polled for a certain period of time, the DHT11 sensor enters a ‘power saving’ mode. It takes a couple seconds to revoke DHT11 from power save mode, which would cause erroneous reads by the TI-Hub. Hence, the DHT11 is polled continuously.

Q: What is the longest program run time the TI-Nspire CXII would support?
A: With a fully charged TI-Nspire CXII calculator and just the DHT11 sensor connected (no additional sensors or TI-RGB Array), the entire system will support at least the usual class hour (45-60 mins).
To extend system battery life, connect a separate power supply (battery pack) through the small USB PWR connector of the TI-Innovator Hub. This would free up the CXII battery from powering the TI-Innovator Hub and its sensors and should extend the system up time to about 4-5 hours at least.

Q: Why is the temperature gradient so slow when the system is exposed into the fridge?
A: The DHT is designed for an ambient air environment, where quick and large temperature changes are not likely to happen. The thermal capacity of the DHT11 package is much bigger than that of a normal silicon sensor such as the LM19. If your experiment requires short sample intervals, you should use temperature sensors with low latency like the LM19, a thermistor or the Vernier temp sensor.

Q: I don’t see much change in my classroom environmental data over time. Why?
A: At first, check for latency effects like soak time needed for temperature, humidity and gas sensors to adapt to the current classroom environment being accounted for. Place the system running in the classroom at least 10 minutes ahead of student lesson starting. Another latency is the thermal capacity of the classroom. Cross air ventilation will make the room refresh its air much quicker than opening a single window. Number of people in the room is the third latency factor. You won’t see a big change in CO_2, Temperature & Humidity over time with only a few people sitting in a large classroom. If your classroom environment does not support meaningful data trends over time, rather switch to experiments like the mini house model mentioned above.