

Submission ID #: 69307

Scriptwriter Name: Poornima G

Project Page Link: <https://review.jove.com/account/file-uploader?src=21138683>

Title: Façade-Level Monitoring of CO₂ Variability Under Urban Heat Island Conditions Using Low-Cost Sensor Data Loggers

Authors and Affiliations:

Visvanathan Girish R¹, Kailas Patil¹, Prawit Chumchu², Alfa Nyandoro³

¹Vishwakarma University

²Prawit Chumchu Kasetsart University

³Alfa Nyandoro, Regent University

Corresponding Authors:

Alfa Nyandoro anyandoro@regent.edu

Kailas Patil kailas.patil@vupune.ac.in

Email Addresses for All Authors:

Visvanathan Girish R girish.visvanathan-795@vupune.ac.in

Prawit Chumchu prawit@eng.src.ku.ac.th

Alfa Nyandoro anyandoro@regent.edu

Kailas Patil kailas.patil@vupune.ac.in

Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **NO**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **YES, all done**

*Videographer: Please record the computer screen for the shots labeled as **SCREEN** as back-up*

3. Filming location: Will the filming need to take place in multiple locations? **NO**

4. Testimonials (optional): Would you be open to filming two short testimonial statements **live during your JoVE shoot**? These will **not appear in your JoVE video** but may be used in JoVE's promotional materials. **YES**

If **Yes**, please provide the **full name and position** (e.g., Director of [Institute Name], Senior Researcher [University Name], etc.) of the author willing to participate.

Current Protocol Length

Number of Steps: 25

Number of Shots: 55 (22 SC)

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

NOTE: The clip numbers are added as indicated by the videographer in **red font** after each shot description throughout the script

INTRODUCTION:

~~What is the scope of your research? What questions are you trying to answer?~~

- 1.1. **Girish Visvanathan**: This research examines how urban microclimates influence outdoor–indoor CO₂ dynamics and ventilation performance in real buildings.
 - 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera **10178**

~~What are the current experimental challenges?~~

- 1.2. **Girish Visvanathan**: The main challenge in the field is the lack of data correlating the urban heat island effect and air quality whilst designing buildings for energy performance and health.
 - 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera **10180**

CONCLUSION:

~~What significant findings have you established in your field?~~

- 1.3. **Girish Visvanathan**: Our studies highlight that urban heat and outdoor CO₂ variability directly accelerate indoor CO₂ buildup, even in naturally ventilated buildings.
 - 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera **181**

~~What advantage does your protocol offer compared to other techniques?~~

- 1.4. **Girish Visvanathan**: The protocol is low-cost, scalable, field-ready, and visually reproducible across climates and building typologies.
 - 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera **184**

~~What questions will future research focus on?~~

- 1.5. **Girish Visvanathan**: Our future studies will focus on community-level AQI, energy use, cognitive performance, and climate-adaptive ventilation strategies.
- 1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera **187**

Videographer: Obtain headshots for all authors available at the filming location.

Testimonial Questions (OPTIONAL):

Videographer: Please capture all testimonial shots in a wide-angle format with sufficient headspace, as the final videos will be rendered in a 1:1 aspect ratio. Testimonial statements will be presented live by the authors, sharing their spontaneous perspectives.

- Testimonial statements will **not appear in the video** but may be featured in the journal's promotional materials.
- **Provide the full name and position** (e.g., Director of [Institute Name], Senior Researcher [University Name], etc.) of the author delivering the testimonial.
- Please **answer the testimonial question live during the shoot**, speaking naturally and in your own words in **complete sentences**.

How do you think publishing with JoVE will enhance the visibility and impact of your research?

- 1.6. **Girish R Visvanathan, PhD Scholar**: (authors will present their testimonial statements live) 191

Can you share a specific success story or benefit you've experienced—or expect to experience—after using or publishing with JoVE? (This could include increased collaborations, citations, funding opportunities, streamlined lab procedures, reduced training time, cost savings in the lab, or improved lab productivity.)

- 1.7. **Girish R Visvanathan, PhD Scholar**: (authors will present their testimonial statements live) 191

Authors: Could you please also deliver the above statements in any regional language comfortable to you?

Videographer: Please film the testimonials in both English and (if possible,) any regional language the author wishes to deliver in

Protocol

2. Sensor Calibration and Setup

Demonstrator: Girish Visvanathan

2.1. To begin, assemble the sensor module using a non-dispersive infrared carbon dioxide sensor [1] and a combined temperature and humidity probe [2]. Secure both sensors together as a single functional module [3].

2.1.1. WIDE: Talent showing the sensor set-up consisting of CO₂, temperature and humidity sensors. 192

2.1.2. Showcasing/pointing to readily available sensors from the market that can be used for logging. 194 and 195

2.2. Configure the microcontroller-based data logger by connecting a real-time clock module [1] and installing the secure digital card shield [2]. Ensure that all components are firmly seated on the microcontroller [3].

2.2.1. Talent showing the configuration of the sensor setup on screen. **NOTE: If a clip for this is not available then use clip from 2.2.2**

2.2.2. Talent mounting the secure digital card shield onto the data logger. 196 and 197

2.2.3. Close-up shot of the fully assembled microcontroller-based data logger. 199

2.3. Set the logging frequency to one reading every 10 minutes using the data logger configuration interface [1]. Confirm that the selected interval is correctly saved in the system settings [2].

2.3.1. SCREEN: 69307_screenshot_1.mp4 00:00-00:13

2.3.2. SCREEN: 69307_screenshot_1.mp4 00:14-00:19.

NOTE: Show step 2.5 here and then show 2.4

2.4. Now, place the assembled sensor module and data logger inside a weather-resistant housing made of polypropylene [1]. Ensure that all wiring is fully insulated and that all connectors are firmly secured [2].

2.4.1. Talent placing the assembled electronics into the polypropylene enclosure. 202

and 204

2.4.2. Close-up shot of insulated wiring inside the housing. 212

NOTE: Move step 2.5 before 2.4

2.5. To test sensor function and perform calibration, place all carbon dioxide and temperature-humidity sensors in a well-ventilated outdoor area [1]. Arrange the sensors so that they are equally exposed to ambient air [2].

2.5.1. Talent positioning multiple sensor modules outdoors in an open, ventilated area. 214

2.5.2. Shot showing sensors evenly spaced and exposed to open air. **NOTE: This was combined with 2.5.1**

2.6. Now, connect the sensor modules to a stable power source, such as a 230-volt alternating current to direct current adapter [1-TXT]. Allow the sensors to stabilize for 10 minutes [2], then record the baseline carbon dioxide concentration of approximately 410 parts per million to verify consistency across devices [3].

2.6.1. Talent connecting the sensor module to the power source. **TXT: Alternatively, use a battery bank rated for continuous 24 h operation** 216

2.6.2. ~~Close-up shot of the power connection in place.~~ **NOTE: Not filmed, VO merged with previous shot**

2.6.3. Talent placing the powered sensors in a stationary position outdoors. 217

2.6.4. Display recorded baseline carbon dioxide readings and compare values across devices. 233

3. Site Selection and Deployment of Sensor Modules

3.1. Identify contrasting thermal zones within the locality around the building or zone of interest [1].

3.1.1. TEXT ON PLAIN BACKGROUND:

Select two or more urban typologies, such as:

- Adjacent low-density green or shaded area
- Façade with outdoor HVAC heat-rejection units

3.2. Install sensor modules on multiple façades where applicable to capture thermal and

pollutant variation [1].

3.2.1. Talent mounting sensor modules on different façades of the building. 219, 229, 230

3.3. After mounting the sensor module, confirm that it is securely attached to the façade [1].

3.3.1. ~~Talent securing the sensor module with harness ropes to a window grill or wall hook.~~ **NOTE: Not filmed, VO merged in concise format**

3.3.2. Close-up shot of the firmly mounted sensor module on the façade. 220

3.4. Maintain a mounting height between 1 and 2 meters above the local floor level for each façade [1]. Adjust the exact height as needed based on accessibility, available supporting infrastructure, and façade geometry [2].

3.4.1. Talent measuring the mounting height from the local floor level. 221

3.4.2. Talent adjusting the sensor position to suit façade geometry and access constraints. 221, combined with 3.4.1

3.5. Now, record the directional orientation of each sensor location, such as an east-facing façade adjacent to a road [1], and document nearby obstructions, including heating, ventilation, and air conditioning units or walls [2-TXT].

3.5.1. Talent noting the compass orientation of the mounted sensor. 225

3.5.2. ~~Shot showing the sensor relative to a road facing façade.~~

3.5.3. Talent noting down in a notebook. **TXT: Connect the sensor module to a continuous power source** 226

3.6. ~~To configure the power supply, [1] using a 230 volt alternating current to a 12 volt direct current adapter with surge protection [2].~~

3.6.1. ~~Talent connecting the power adapter to the sensor module.~~ **NOTE: Not filmed, VO moved as on screen text to the previous shot**

3.6.2. ~~Close-up shot of the surge-protected power connection.~~

3.7. Verify sensor output by observing live readings on the display or logger interface [1]. Confirm that the connection is stable and that active data recording is underway [2].

3.7.1. SCREEN: 69307_screenshot_2.mp4 00:02-00:09.

3.7.2. SCREEN: 69307_screenshot_2.mp4 01:25-01:37.

~~3.8. Power the data logger to start recording and capture the diurnal measurement cycle [1].~~

~~3.8.1. Talent switching on the data logger and confirming power activation. NOTE: Not filmed~~

3.9. Allow the data logger to operate continuously for 24 hours with a data-logging interval of 10-minutes to capture full-day variations in carbon dioxide concentration, temperature, and humidity [1].

3.9.1. SCREEN: 69307_screenshot_3.mp4 00:02-00:15.

3.10. Verify that timestamps remain synchronized across all sensors before deployment and again after deployment [1].

3.10.1. SCREEN: 69307_screenshot_4.mp4 00:17-00:37.

3.11. Now, record the start time and stop time [1] manually in a field logbook to provide redundant backup documentation [2].

3.11.1. Close-up shot of the field logbook as the talent writes the start time. 244, might be screen capture

3.11.2. Shot of the completed logbook entry with date and times recorded. NOTE: This was combined with 3.11.1

4. Data Retrieval, Visualization and Quality Control

4.1. For wireless fidelity-enabled loggers, connect to the local service set identifier [1] and download the log files through the Internet Protocol-based dashboard [2].

4.1.1. SCREEN: 69307_screenshot_5.mp4 00:02-00:27, *please speed up*.

4.1.2. SCREEN: 69307_screenshot_6.mp4 02:10-02:20.

4.2. Process the retrieved data using a spreadsheet or data analysis software to prepare it for visualization [1].

4.2.1. SCREEN: 69307_screenshot_6.mp4 02:13-02:33.

- 4.3. Next, generate a multi-variable line plot showing carbon dioxide concentration and temperature on the primary vertical axis [1], and relative humidity on the secondary vertical axis, to allow direct trend comparison [2].

4.3.1. SCREEN: 69307_screenshot_7.mp4 00:10-00:30.

4.3.2. SCREEN: 69307_screenshot_7.mp4 01:07-01:15.

- 4.4. ~~Label the horizontal axis as Time [1]. the primary vertical axis as carbon dioxide parts per million and temperature degrees Celsius, and the secondary vertical axis as relative humidity percent [2].~~

~~4.4.1. SCREEN: 69307_screenshot_7.mp4 01:25-01:35.~~

~~4.4.2. SCREEN: 69307_screenshot_7.mp4 00:10-00:30.~~

~~4.4.3. SCREEN: Show the secondary vertical axis label being edited and confirmed.~~

- 4.5. Add a legend to distinguish variables [1] and annotate peak values, typically between 11 and 15 hours, for inter-site comparison [2].

4.5.1. SCREEN: 69307_screenshot_8.mp4 00:08-00:10.

4.5.2. SCREEN: 69307_screenshot_8.mp4 00:45-00:55.

- 4.6. Perform data validation by reviewing the collected dataset for anomalies [1]. Identify and remove outliers or data points flagged due to timestamp irregularities or device communication errors [2].

4.6.1. SCREEN: 69307_screenshot_8.mp4 00:04-00:05.

4.6.2. SCREEN: 69307_screenshot_9.mp4 00:20-00:35.

- 4.7. Finally, recalibrate sensors if post-experiment analysis indicates sensor drift exceeding 3 percent or a variation of more than 10 parts per million [1]. Repeat the baseline calibration procedure in open-air conditions and reacquire data under identical environmental conditions [2].

4.7.1. Talent placing the sensor modules outdoors for baseline calibration. 217

4.7.2. Shot of sensors operating in open air during recalibration. **NOTE: This was combined with 4.7.2**

Results

5. Results

5.1. External carbon dioxide concentrations were significantly higher at concrete-dominant façades [1] compared to adjacent green façades across all monitored cities [2].

5.1.1. LAB MEDIA: Table 1. *Video editor: Highlight the “average CO2” for “High Concretization” rows in Chennai, Pune, Mumbai and Hyderabad*

5.1.2. LAB MEDIA: Table 1. *Video editor: Highlight the “average CO2” for “Green area north” rows in Chennai, Pune, Mumbai and Hyderabad*

5.2. In Chennai, elevated carbon dioxide levels at the east façade coincided with higher local temperatures near the sensor compared to the shaded façade [1].

5.2.1. LAB MEDIA: Figure 5. *Video editor: Highlight the CO2 (concrete side) line and the temperature (concrete side) line*

5.3. In Pune, the difference in carbon dioxide concentration between façades occurred despite only a 1 degree Celsius increase in temperature at the concrete façade [1].

5.3.1. LAB MEDIA: Figure 6. *Video editor: Highlight the CO2 (concrete side) line.*

5.4. Green zones consistently exhibited lower temperatures, higher humidity, and faster carbon dioxide dispersion rates compared to concretized façades across all sites [1].

5.4.1. LAB MEDIA: Table 1. *Video editor: Highlight the “average temperature and average humidity” columns for “Green area north” rows in Chennai, Pune, Mumbai and Hyderabad.*

1. Non-dispersive

Pronunciation link: <https://www.merriam-webster.com/dictionary/nondispersive>

IPA: /ˌnɑːn.dɪˈspɜːsɪv/

Phonetic Spelling: non·di·spur·siv

2. Infrared

Pronunciation link: <https://www.merriam-webster.com/dictionary/infrared>

IPA: /ˌɪn.fraɪˈrɛd/

Phonetic Spelling: in·fruh·red

3. Carbon dioxide

Pronunciation link: <https://www.merriam-webster.com/dictionary/carbon%20dioxide>

- IPA: /ˌkɑːr.bən dɑː'ɑːk.sɑɪd/
Phonetic Spelling: kar·buhn dye·ok·side
4. Microcontroller
Pronunciation link: <https://www.merriam-webster.com/dictionary/microcontroller>
IPA: /ˌmaɪ.kroʊ.kən'troʊ.lə/
Phonetic Spelling: my·kroh·kuhn·troh·ler
 5. Real-time clock
Pronunciation link: <https://www.merriam-webster.com/dictionary/real-time>
IPA: /'rɪr.tɑɪm/
Phonetic Spelling: reer·time
 6. Secure Digital
Pronunciation link: <https://www.merriam-webster.com/dictionary/secure>
IPA: /sɪ'kjʊr/
Phonetic Spelling: si·kyur
 7. Polypropylene
Pronunciation link: <https://www.merriam-webster.com/dictionary/polypropylene>
IPA: /ˌpɑː.li.prəʊ.pə'liːn/
Phonetic Spelling: pah·lee·proh·puh·leen
 8. Calibrate
Pronunciation link: <https://www.merriam-webster.com/dictionary/calibrate>
IPA: /'kæl.ə.brɪt/
Phonetic Spelling: ka·luh·brate
 9. Alternating current
Pronunciation link: <https://www.merriam-webster.com/dictionary/alternating%20current>
IPA: /'ɔːl.təˌneɪ.tɪŋ 'kɜː.ənt/
Phonetic Spelling: awl·ter·nay·ting kur·uhnt
 10. Direct current
Pronunciation link: <https://www.merriam-webster.com/dictionary/direct%20current>
IPA: /də'rekt 'kɜː.ənt/
Phonetic Spelling: dih·rekt kur·uhnt
 11. Parts per million
Pronunciation link: <https://www.merriam-webster.com/dictionary/part%20per%20million>
IPA: /'pɑːrts pə 'mɪl.jən/
Phonetic Spelling: parts per mil·yun
 12. Façade
Pronunciation link: <https://www.merriam-webster.com/dictionary/facade>
IPA: /fə'sɑːd/
Phonetic Spelling: fuh·saad
 13. Diurnal
Pronunciation link: <https://www.merriam-webster.com/dictionary/diurnal>
IPA: /daɪ'ɜː.nəl/
Phonetic Spelling: dye·ur·nuhl
 14. Wireless fidelity
Pronunciation link: <https://www.merriam-webster.com/dictionary/Wi-Fi>

- IPA: /'waɪ faɪ/
Phonetic Spelling: why·fye
15. Internet Protocol
Pronunciation link: <https://www.merriam-webster.com/dictionary/internet%20protocol>
IPA: /'m.təˌnet 'proʊ.təˌkɑ:l/
Phonetic Spelling: in·ter·net proh·tuh·kaal
16. Visualization
Pronunciation link: <https://www.merriam-webster.com/dictionary/visualization>
IPA: /ˌvɪʒ.u.ə.lə'zeɪ.ʃən/
Phonetic Spelling: vij·oo·uh·luh·zay·shuhn
17. Multi-variable
Pronunciation link: <https://www.merriam-webster.com/dictionary/multivariable>
IPA: /ˌmʌl.ti'veɪ.i.ə.bəl/
Phonetic Spelling: mul·tee·vair·ee·uh·buhl
18. Relative humidity
Pronunciation link: <https://www.merriam-webster.com/dictionary/relative%20humidity>
IPA: /'rɛl.ə.tɪv hjuː'mɪd.ə.t̬i/
Phonetic Spelling: reh·luh·tiv hyoo·mi·duh·tee
19. Recalibrate
Pronunciation link: <https://www.merriam-webster.com/dictionary/recalibrate>
IPA: /ˌriː'kæl.əˌbreɪt/
Phonetic Spelling: ree·ka·luh·brate
20. Spreadsheet
Pronunciation link: <https://www.merriam-webster.com/dictionary/spreadsheet>
IPA: /'spredʃi:t/
Phonetic Spelling: spred·sheet