Test Report

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ISO 17025 NADCAP
AAMA Component Testing
CAGE 5HSJ7

Test Report: TR 24580

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Rev A

Revision was made to include an additional 4 graphs displaying concentration reported by all sensors during Accuracy Testing for 50 %LEL Methane, Propane, Pentane, and Hydrogen gases on Pages 13 &14.

Delivered To: **Nevada Nano**

Primary Points of Contact: Graham Harris, Mark Brandemuehl

Purchase Order Number: 1593

Reference Quotation Number: 111918NEVNAN_R1

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Date: 2019.09.04 10:21:17 -05'00'

Mason Schloder, Technical Service Engineer

Background:

Nevada Nano contracted with Assured Testing Services (Assured) to perform six (6) test protocols on three (3) Nevada Nano Molecular Property Spectometer (MPS) flammable gas sensors (B08, B11, B16) and three (3) competitor flammable gas sensors (SGX, Micropel, Dynament). The test protocols were:

1. Accuracy
2. Repeatability
3. Stability
4. Humidity Sensitivity
5. Temperature Sensitivity
6. Poison Resistance, on final test day only

Assured performed Nevada Nano's test protocol saving the data from each run to the PC and USB drive.

During times when active testing was not being performed, the sensor setup was removed from the thermal humidity chamber and remained operational in ambient laboratory environment while the PC recorded data with no gas flow through the Nafion/PTFE tubing/sensor gas train. The sensors were connected in series by short lengths of tubing, outlet to inlet.

Before starting each test protocol, competitor samples were calibrated using 50% LEL Methane for 5 minutes followed by Zero Air gas flowing through the sample train for 2-5 minutes.

At the end of all testing Assured "poisoned" the sensor chain with 100 ppm H_2S, balance Zero Air, at 0.3 l/min flow and the PC recorded the sensor response to 50% LEL Methane before and after H2S flow.

Testing was performed, on the same day each week four times in accordance with the following schedule:

Day 0, Accuracy, Repeatability, Stability, Humidity Sensitivity
Day 1, Temperature Sensitivity
Days 2-13: Ambient dwell time
Day 14, Accuracy, Repeatability, Stability, Humidity Sensitivity
Day 15, Temperature Sensitivity
Days 16-27: Ambient dwell time
Day 28, Accuracy, Repeatability, Stability, Humidity Sensitivity
Day 29, Temperature Sensitivity
Days 30-59: Ambient dwell time
Day 60, Accuracy, Repeatability, Stability, Humidity Sensitivity
Day 61, Temperature Sensitivity
Day 62, Poison Resistance

Scope of Sample and Equipment Supply:

Nevada Nano provided all sensors, USB cabling and hubs, laptop PC, microcontroller, and data acquisition software.

Assured provided:

- Bottled analyte gases, 15% and 50% LEL Methane, 15% and 50% LEL Propane, 50 % LEL Hydrogen, 50% LEL Pentane, and "Zero Air" purge gas.
- "70 series" 0.3 l/min fixed volume flow rate regulators for gas pressure and flow control.
- 48" of Nafion humidity transfer tubing assembly (Permapure ME-110-48COMP-4 Rev B) to humidify the analyte gases in Assured's thermal humidity chamber, and PTFE tubing for interconnection between analyte bottles and the various sensors in series.
- Exposure chamber; CSZ-2

Data Collection Method

Upon completion of testing each test day, the data was saved and the sensors powered off. Then the sensors were moved to a bench top in ambient laboratory environment and powered back up again and off-test data collection started. On the next day of testing, the off-test data was saved, sensors powered off, and moved back to the exposure chamber with Zero Air running over them for 5 minutes before powering the sensors back on.

Test Setup Schematic:

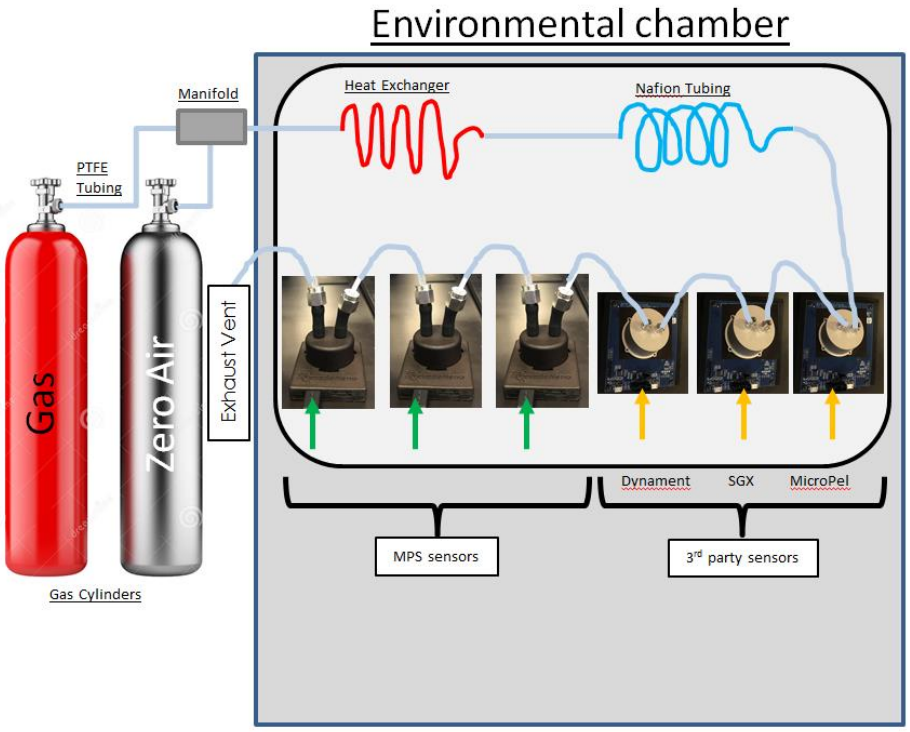


Illustration courtesy Nevada Nano

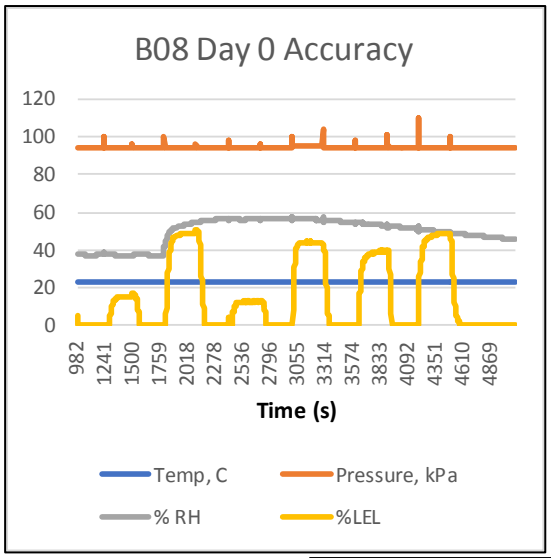
Test Procedures and Graphical Results

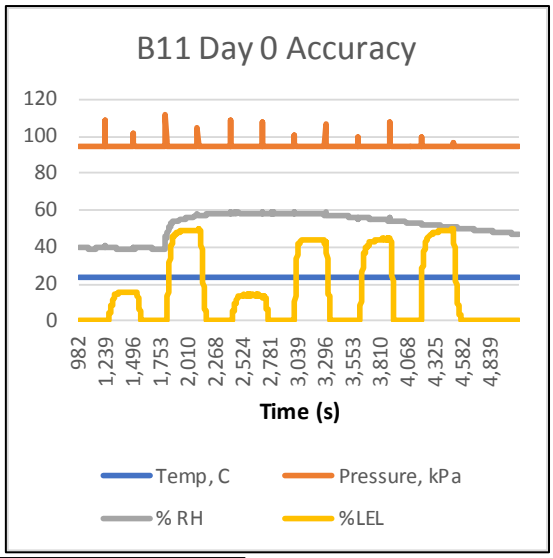
Accuracy Test Procedure

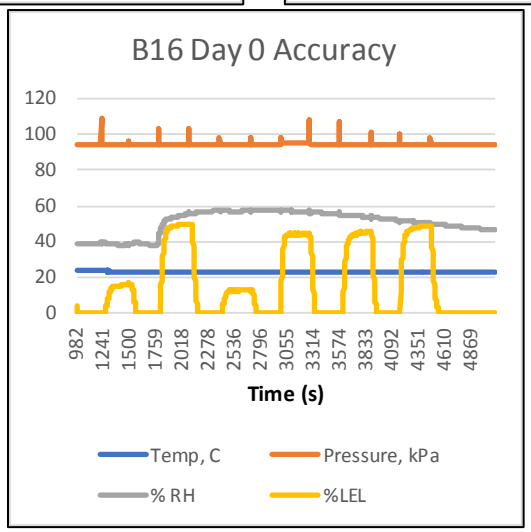
Protocol Number	Gases Required	Chamber Settings	Timing
1	15% LEL Methane 50 % LEL Methane 15% LEL Propane 50% LEL Propane 50% LEL Pentane 50% LEL Hydrogen Zero Air Purge Gas	20C 50% RH	Sequential introduction of test gases for 5 minutes each with zero air purge between test gases. 1 hour 5 minutes total

Gas Flows: Zero Air 5 minutes, 15% Methane 5 minutes, Zero Air 5 minutes, 50% Methane 5 minutes, Zero Air 5 minutes, 15% Propane 5 minutes, Zero Air 5 minutes, 50% Propane 5 minutes, Zero Air 5 minutes, 50% Pentane 5 minutes, Zero Air 5 minutes, 50% Hydrogen, Zero Air 5 minutes, end.

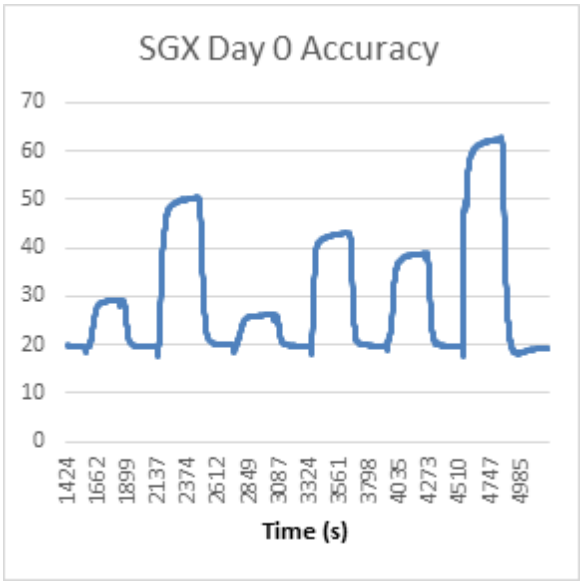
Accuracy Results; MPS Sensors, Day 0:

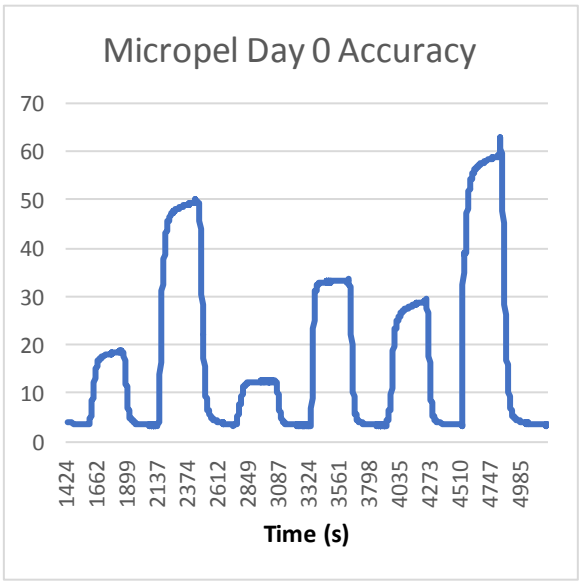


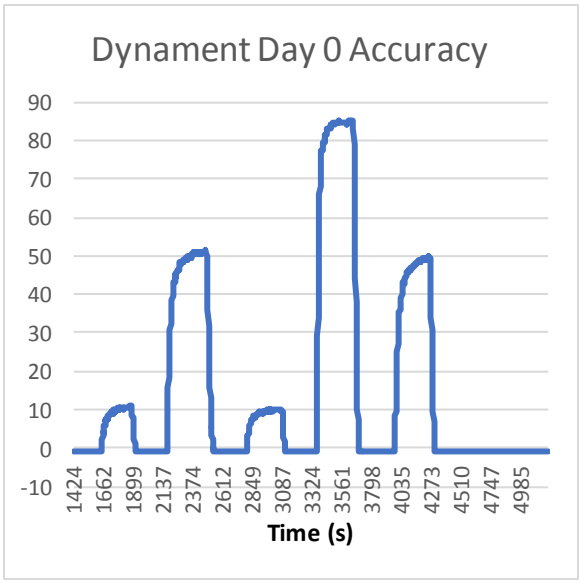




Accuracy Results; Competitor Sensors, Day 0:



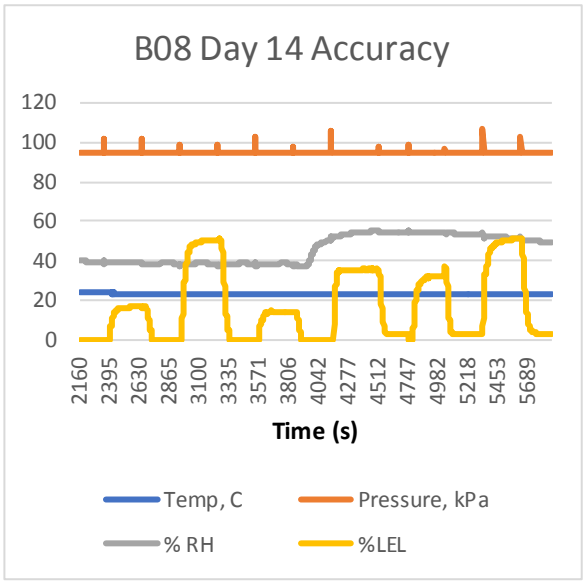


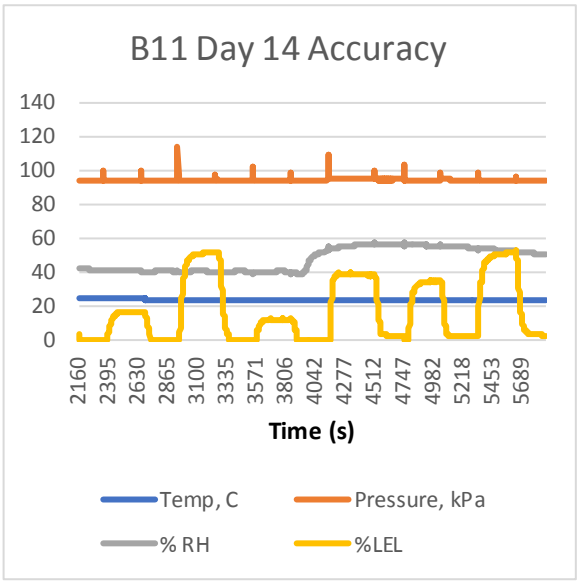


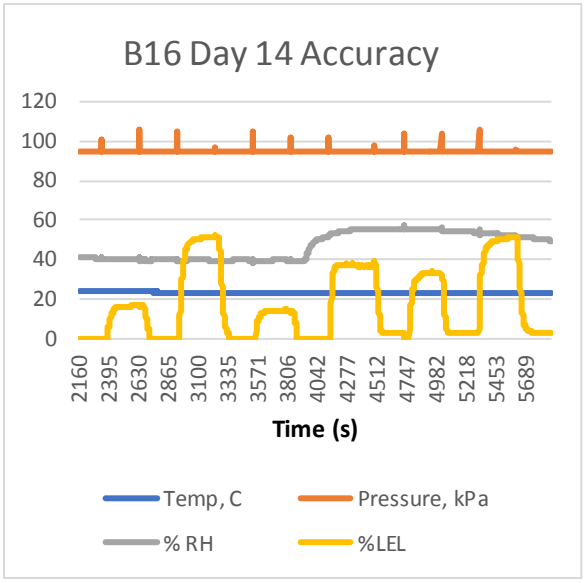
Observations:

- SGX sensor consistently exhibited offset from zero by ~ 18-20 %LEL which continued throughout test program. Peaks for 50% LEL Propane and 50% Pentane were appeared low, and 50% LEL Hydrogen appeared to be over 60%.
- Micropel sensor also exhibited offset from zero by ~ 4-5 %LEL which continued throughout test program. Peaks for 50% LEL Propane and 50% Pentane appeared low, and 50% LEL Hydrogen appeared high.
- Dynament sensor was not capable of sensing the presence of 50% LEL Hydrogen as seen in the above graph showing only presence of the first 5 test gases. The peak for 50% Propane appeared disproportionately high as well.

Accuracy Results, MPS Sensors, Day 14:



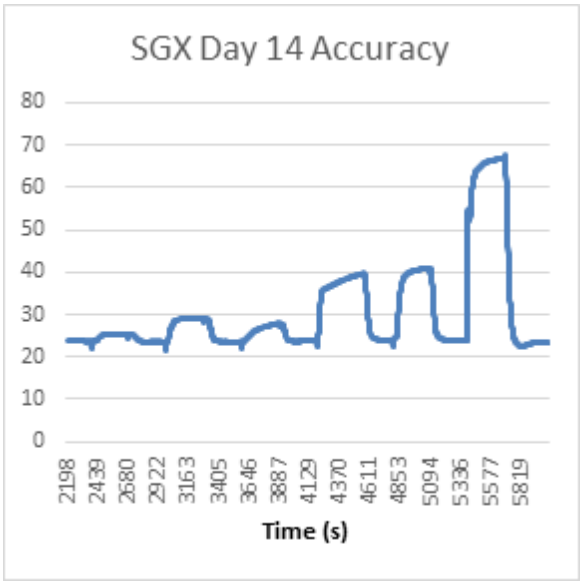


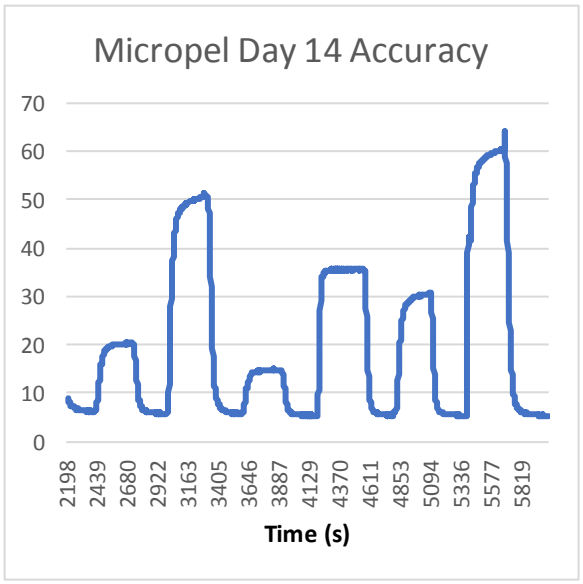


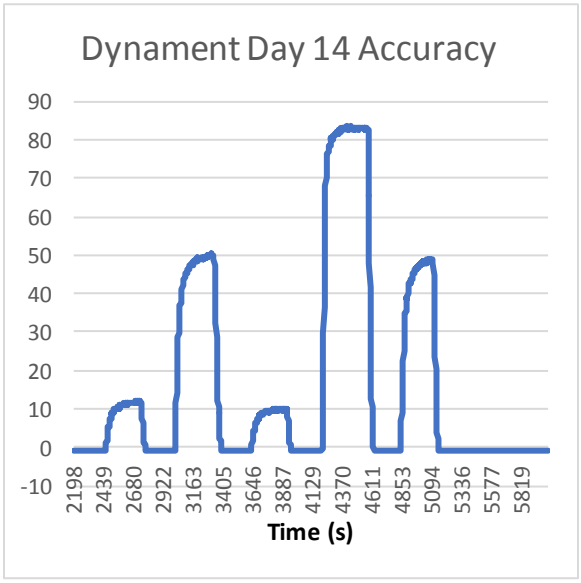
Observations:

- MPS sensors continue to provide the most accurate and consistent results at Day 14.

Accuracy Results, Competitor Sensors, Day 14:



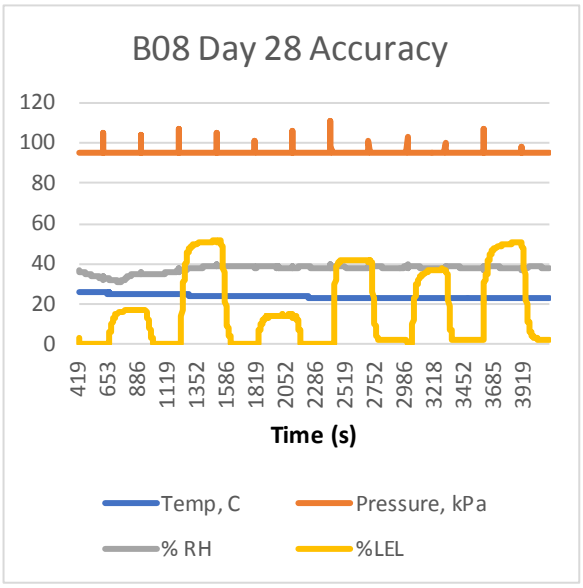


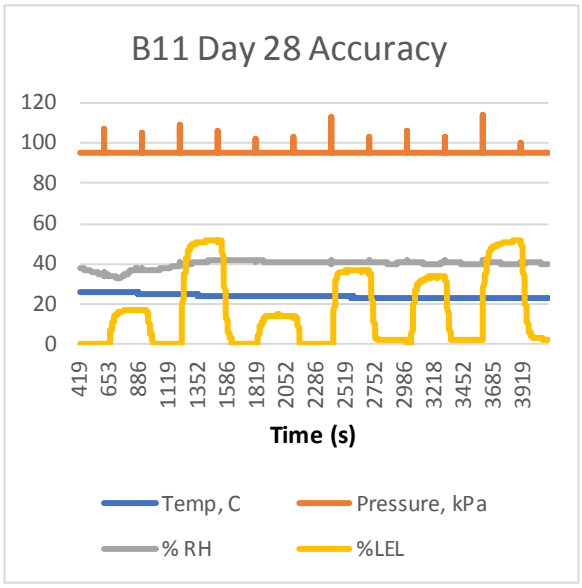


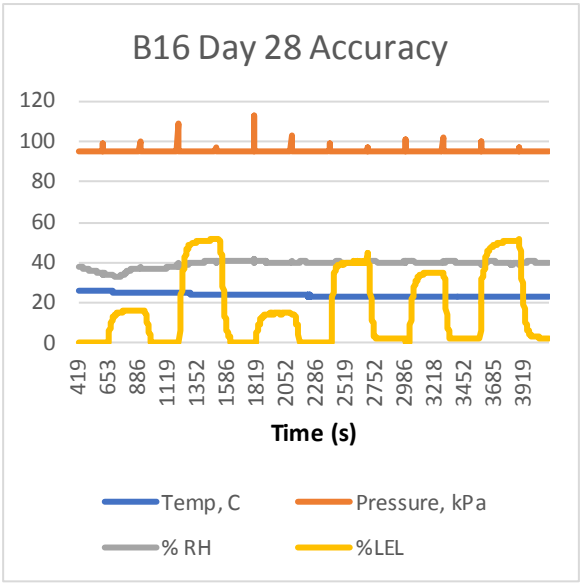
Observations:

- SGX sensor consistently exhibited offset from zero by ~ 18-20 %LEL. SGX sensor also showing signs of degradation as indicated by the lack of accuracy and responsiveness during Accuracy Testing.
- Micropel sensor also exhibited offset from zero by ~ 4-5 %LEL and peak inaccuracies consistent with previous data.
- Dynament sensor results were consistent with previous and sensor was not capable of sensing the presence of 50% LEL Hydrogen as seen in the above graph showing only presence of the first 5 test gases.

Accuracy Results, MPS Sensors, Day 28:



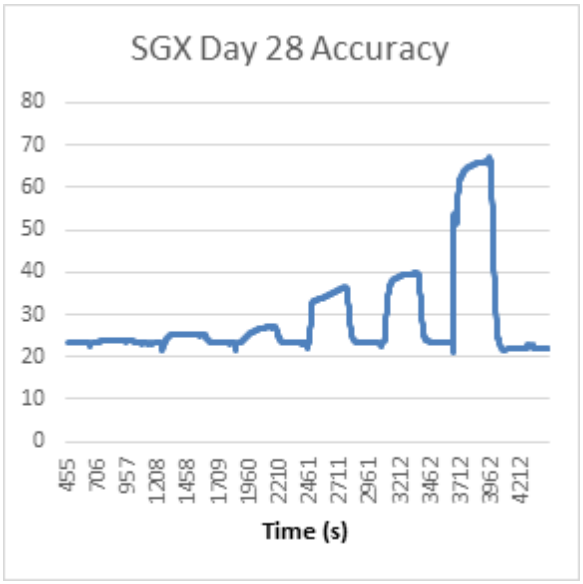


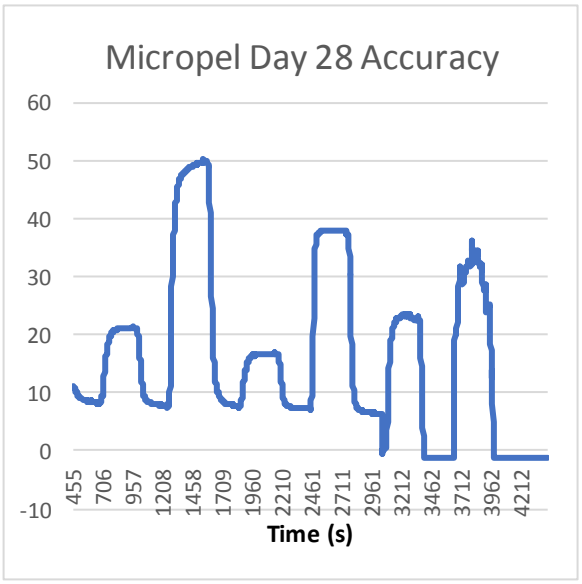


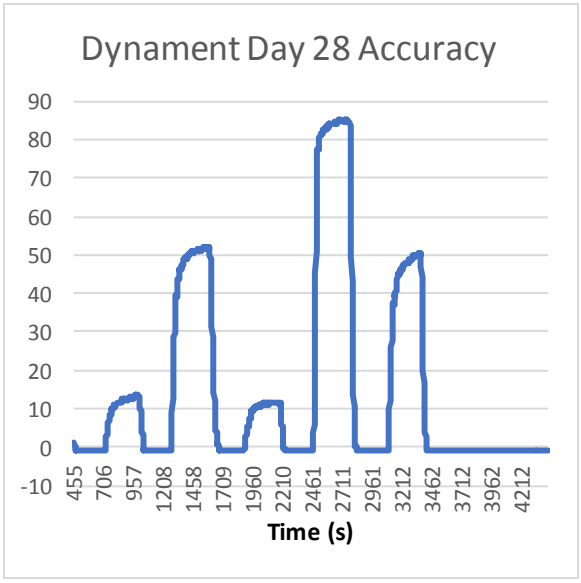
Observations:

- MPS sensors continue to provide the most accurate and consistent results at Day 28.

Accuracy Results, Competitor Sensors, Day 28:



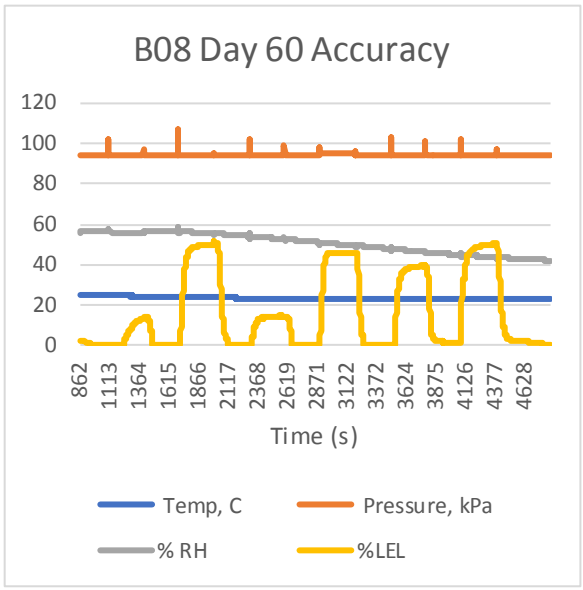


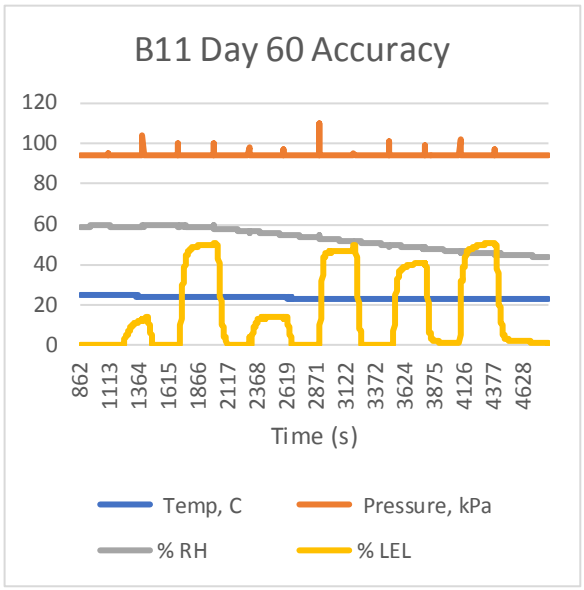


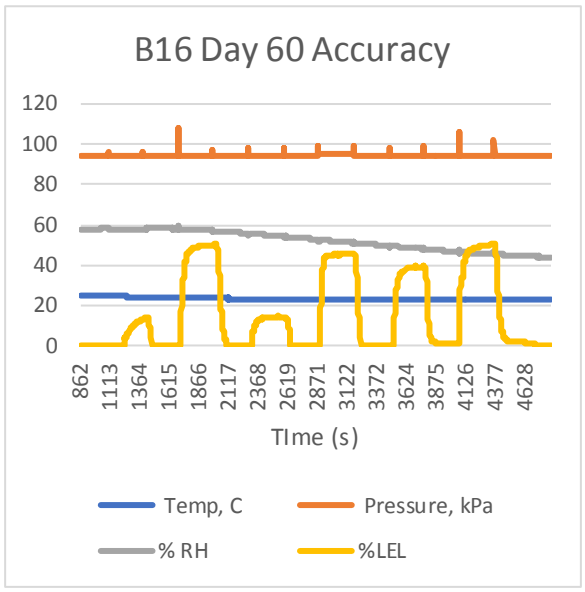
Observations:

- SGX sensor consistently exhibited offset from zero by ~ 18-20 %LEL. SGX sensor continued to show signs of degradation as indicated by the lack of accuracy and responsiveness during Accuracy Testing.
- Micropel sensor also exhibited offset from zero and begins to show signs of erratic measurement.
- Dynament sensor was not capable of sensing the presence of 50% LEL Hydrogen as seen in the above graph showing only presence of the first 5 test gases.

Accuracy Results, MPS Sensors, Day 60:



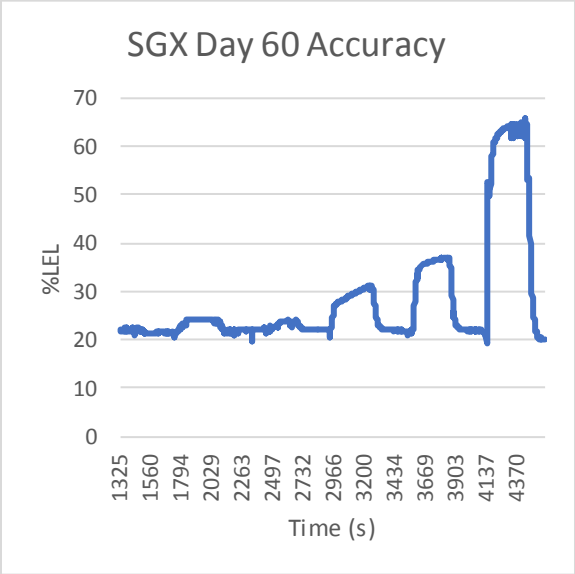


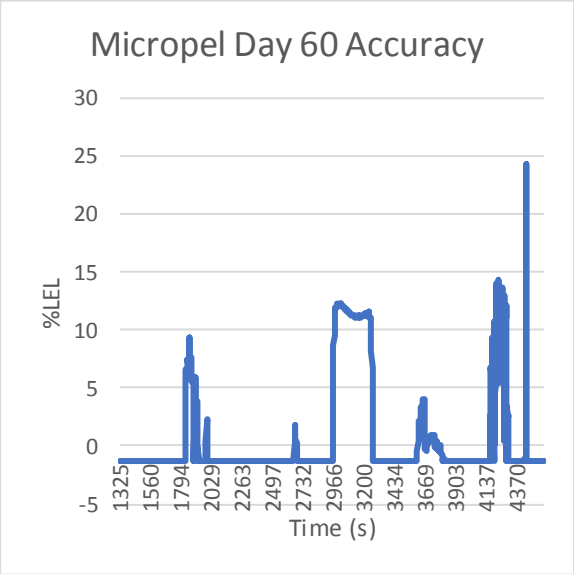


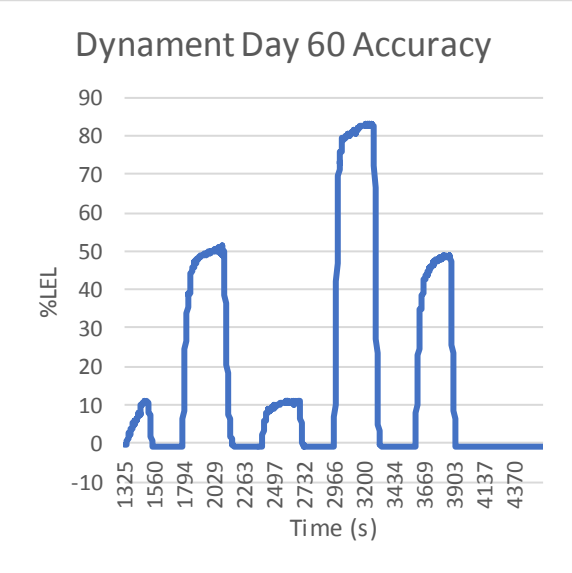
Observations:

- MPS sensors continue to provide the most accurate and consistent results at Day 60
- 15 %LEL Methane gas beginning to run empty explaining the sharp spikes at the beginning of Accuracy Testing

Accuracy Results, Competitor Sensors, Day 60:

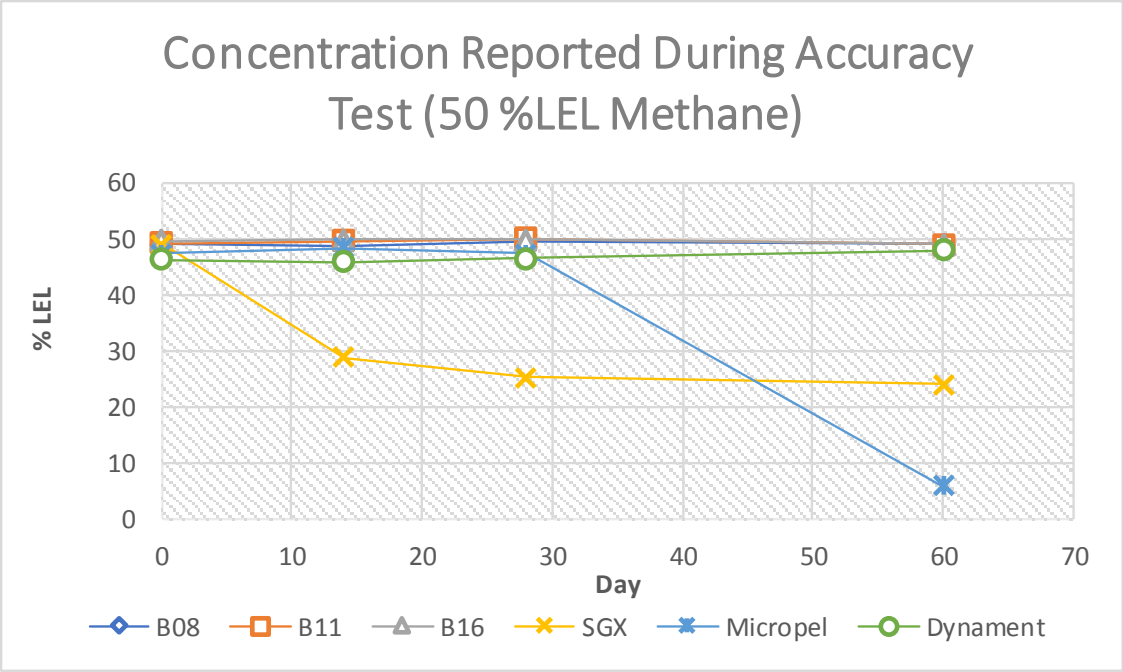


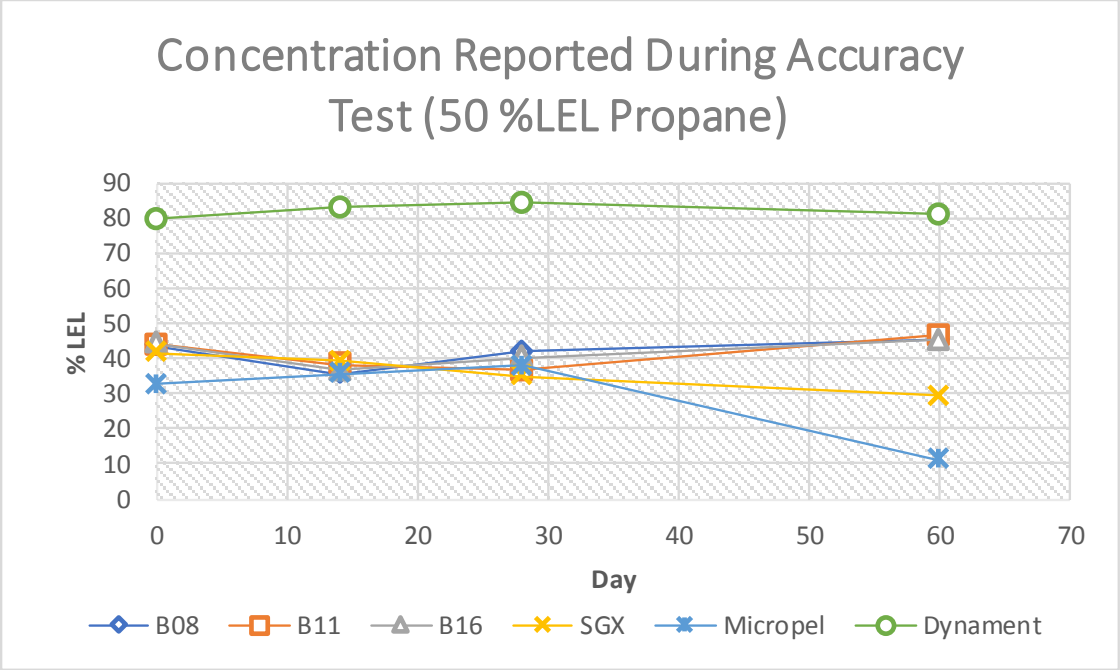




Observations:

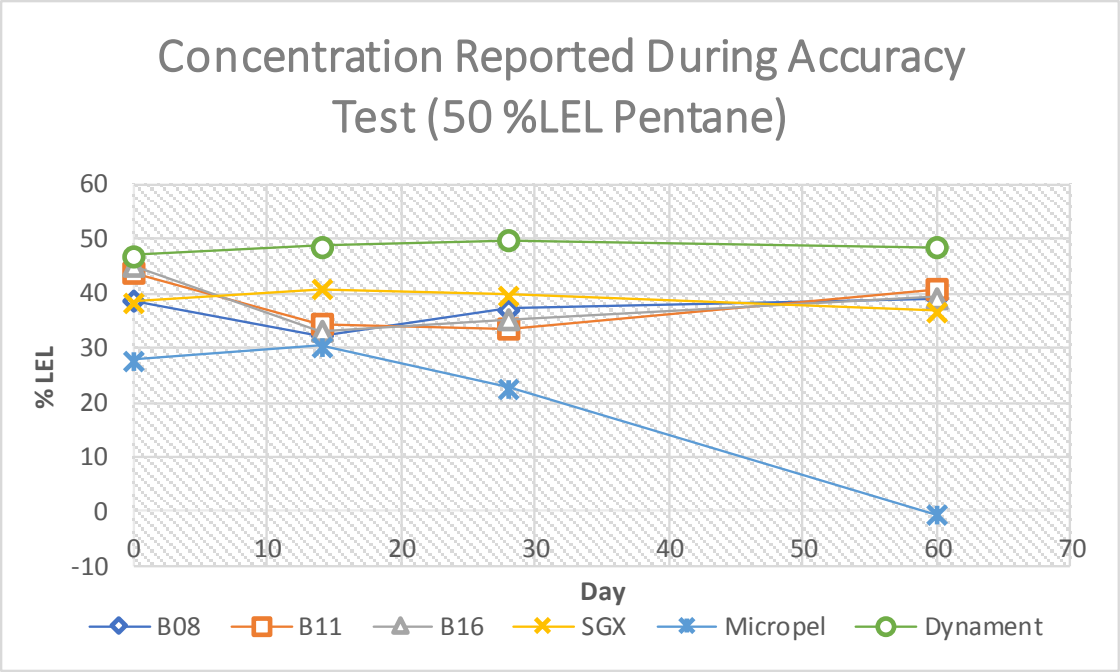
- SGX sensor consistently exhibited offset from zero and continued notable loss in accuracy and responsiveness.
- Micropel sensor exhibited negative drift from zero, and substantial loss of accuracy at Day 60.

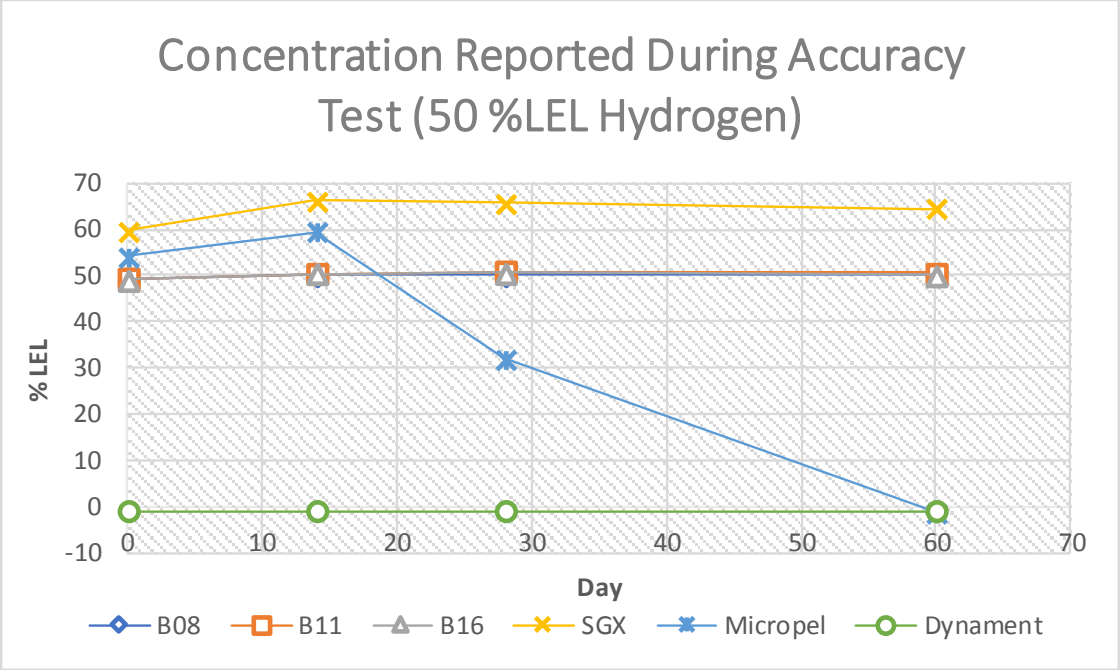




Observations:

- All MPS sensors (B08, B11, B16) give the most reliable and repeatable measurements for both 50 %LEL Methane and 50 %LEL Propane throughout the test program.





Observations:

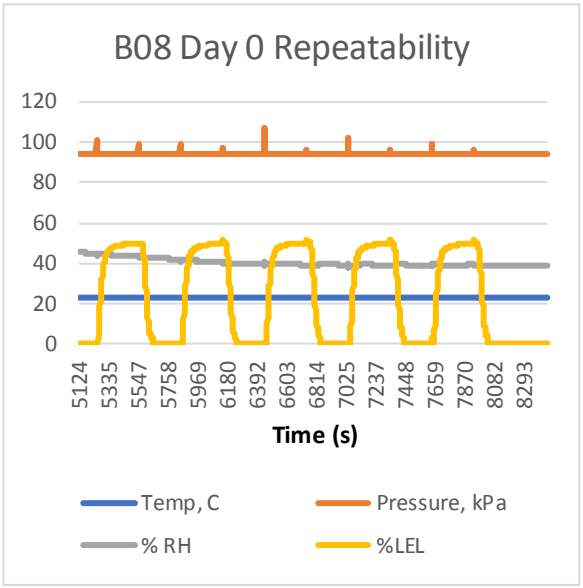
- Dynament sensor appears to be most accurate sensor for 50 %LEL Pentane however was completely unable to sense the presence of 50 %LEL Hydrogen on all testing days.

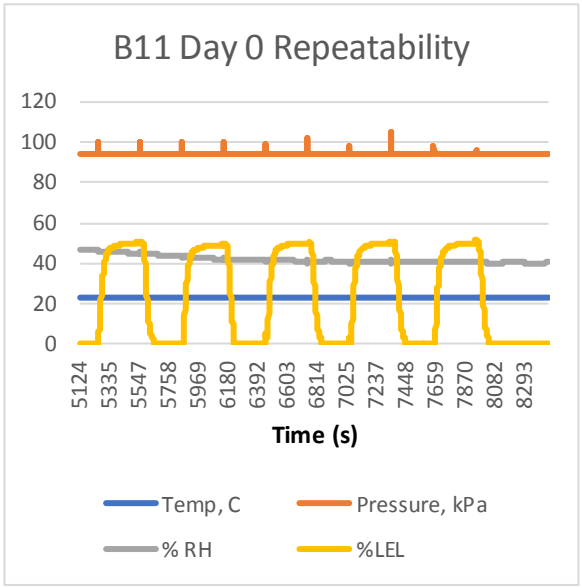
Repeatability Test Procedure

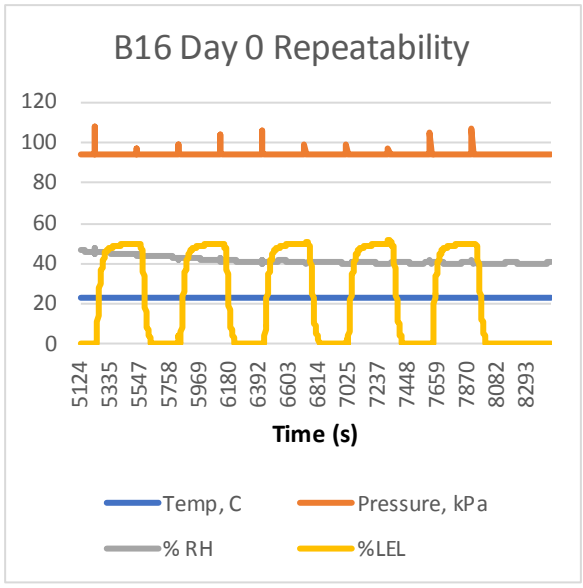
Protocol Number	Gases Required	Chamber Settings	Timing
2	50 % LEL Methane Zero Air Purge Gas	20C 50% RH	Five (5) minutes on and off, repeating five (5) times 1 hour total time

Gas Flows: Zero Air 5 minutes, 50% Methane 5 minutes, Zero Air 5 minutes, 50% Methane 5 minutes, Zero Air 5 minutes, 50% Methane 5 minutes, Zero Air 5 minutes, 50% Methane 5 minutes, Zero Air 5 minutes, 50% Methane 5 minutes, end.

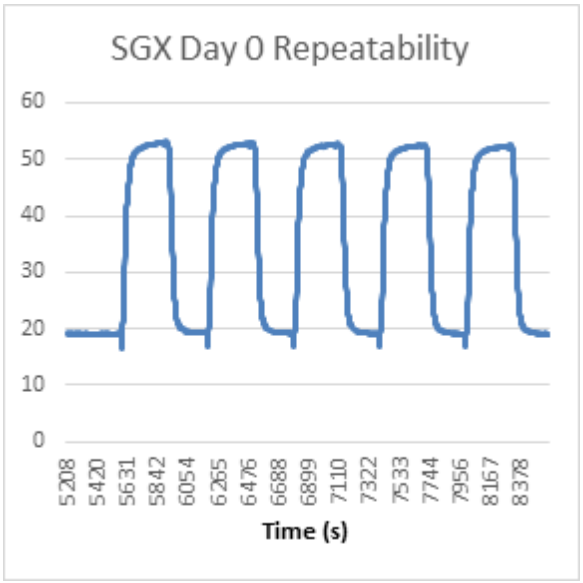
Repeatability Results; MPS Sensors, Day 0:

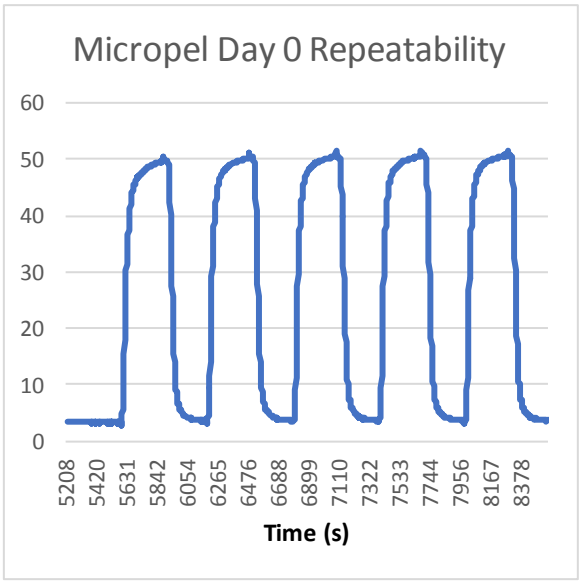


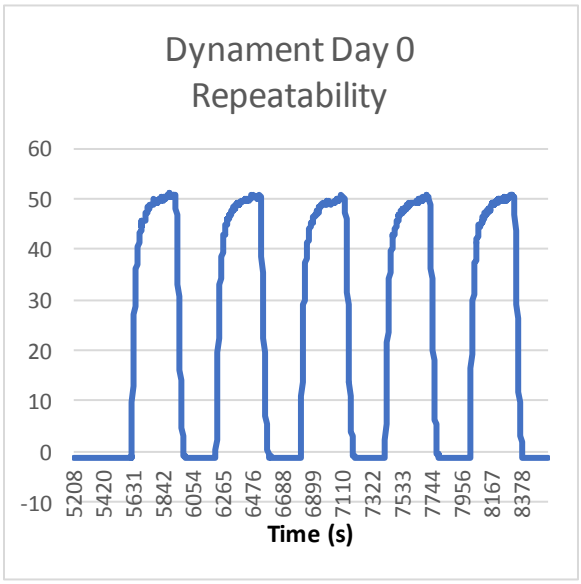




Repeatability Results; Competitor Sensors, Day 0:



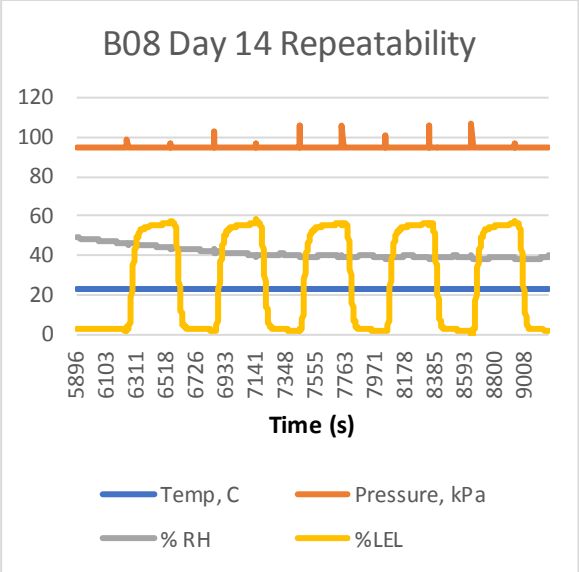


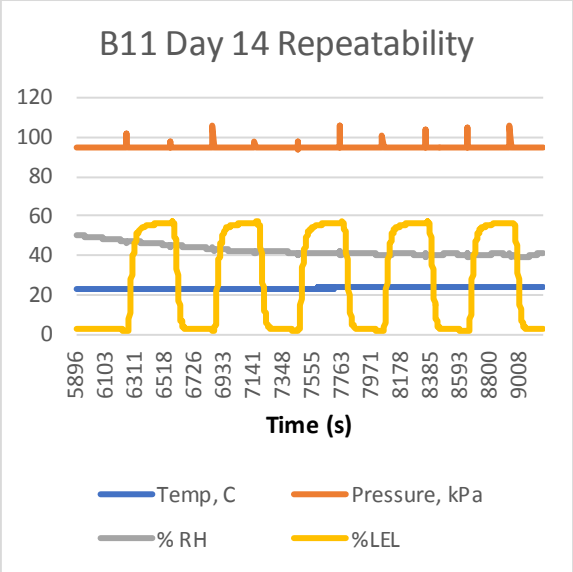


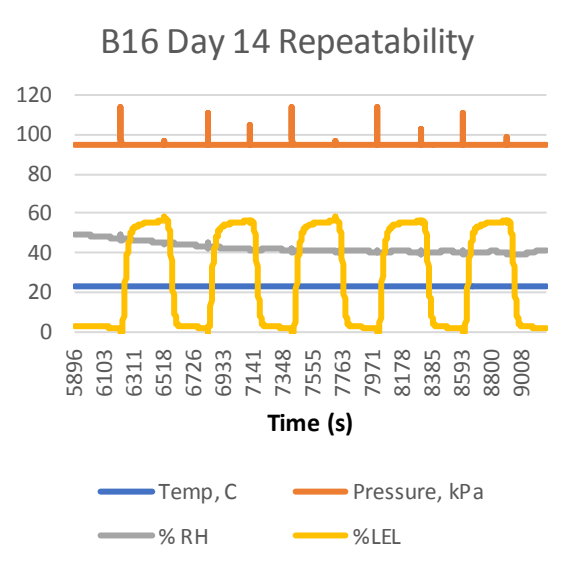
Observations:

- SGX & Micropel sensors continued to exhibit an offset from zero.

Repeatability Results; MPS Sensors, Day 14:



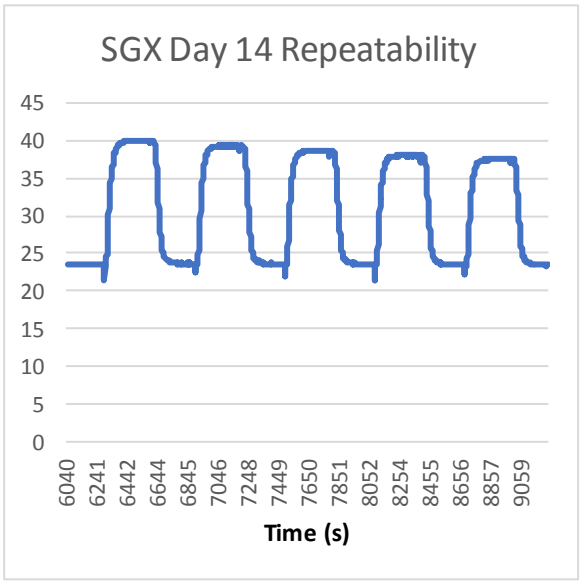


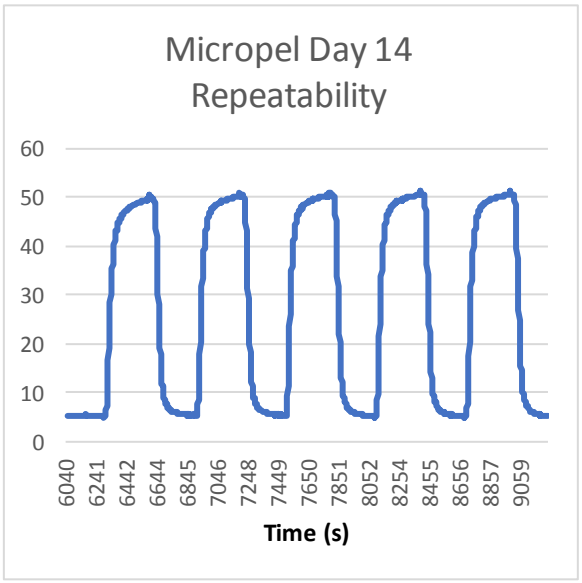


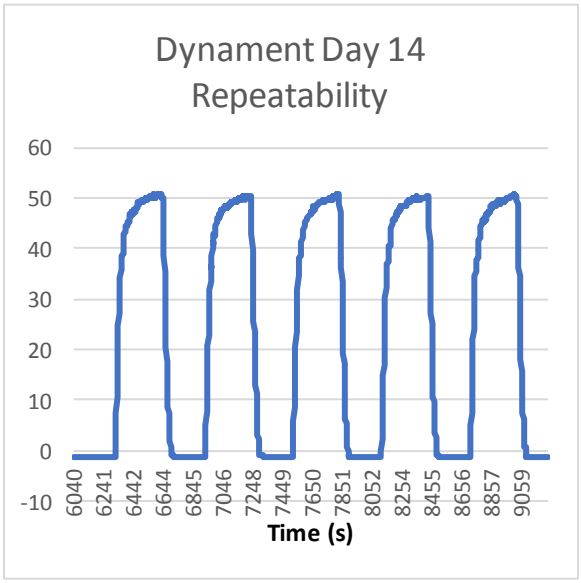
Observations:

- MPS sensors continue to provide repeatable and the most accurate and consistent results at Day 14

Repeatability Results; Competitor Sensors, Day 14:



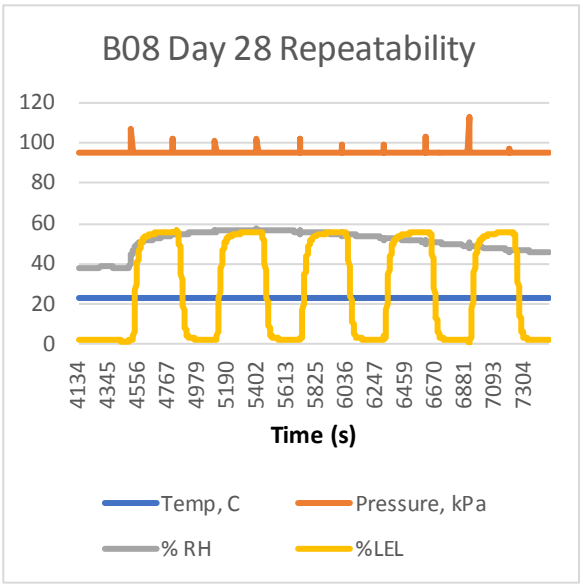


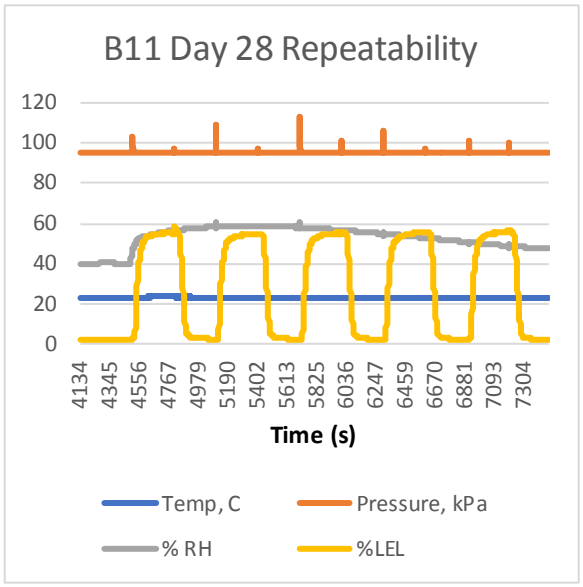


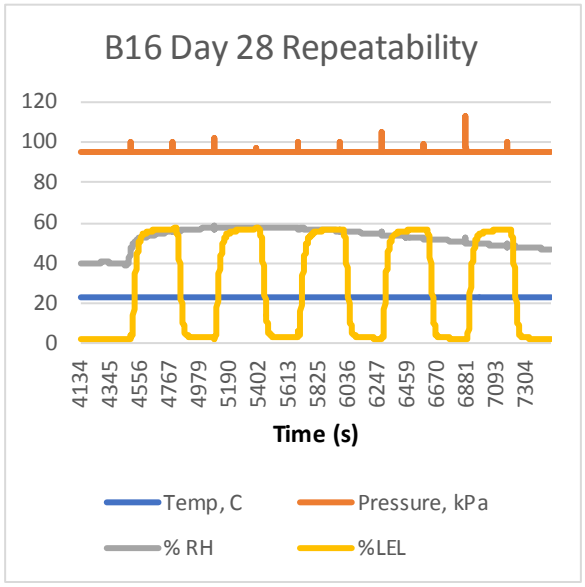
Observations:

- SGX & Micropel sensors continues to exhibit an offset from zero with the SGX sensor providing results that are not consistently repeatable.

Repeatability Results; MPS Sensors, Day 28:



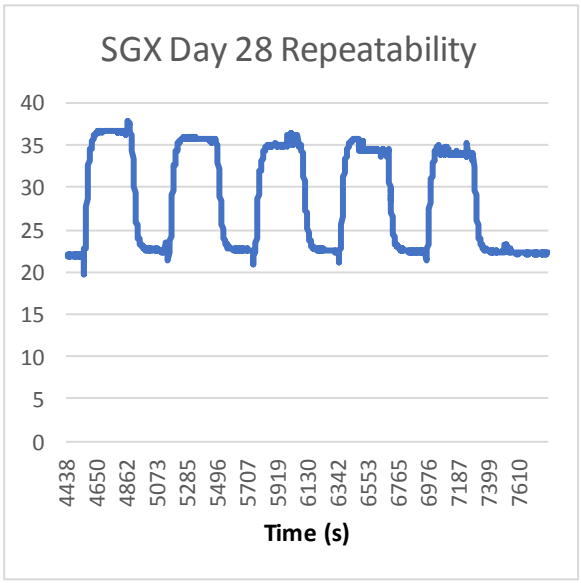


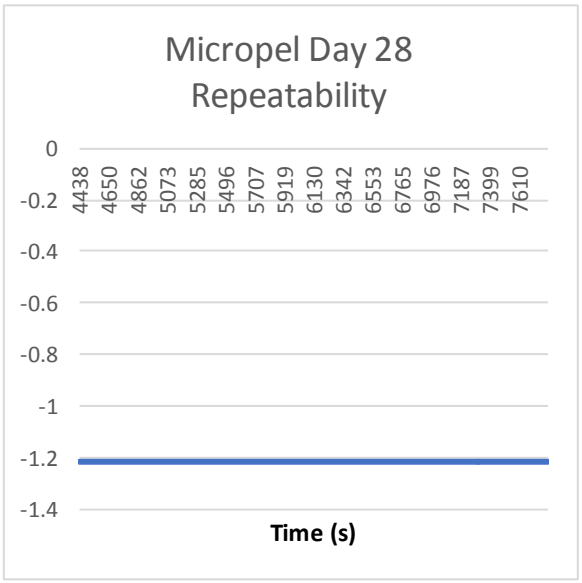


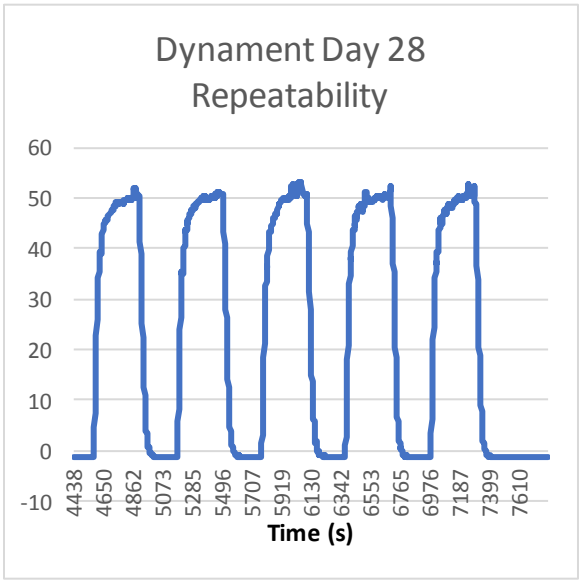
Observations:

- MPS sensors continue to provide repeatable measurements at Day 28

Repeatability Results; Competitor Sensors, Day 28:



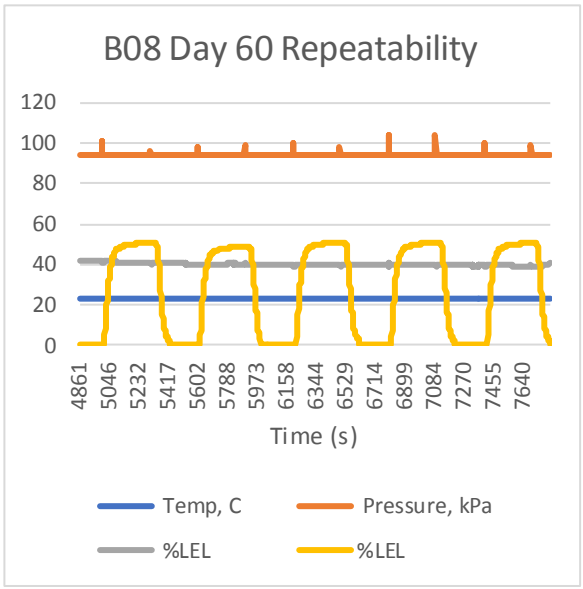


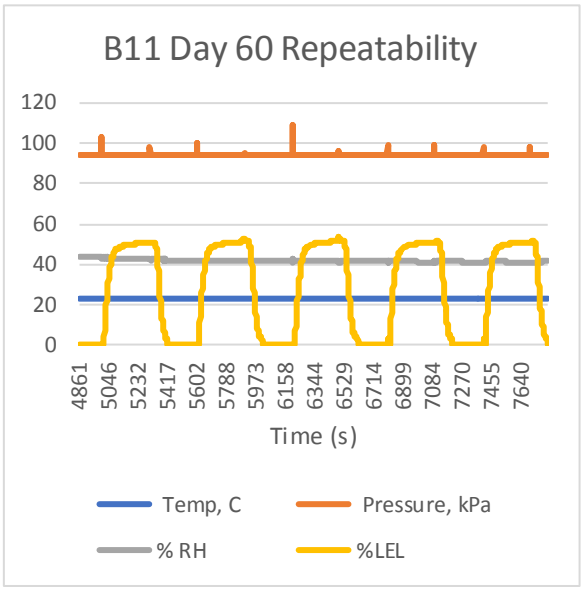


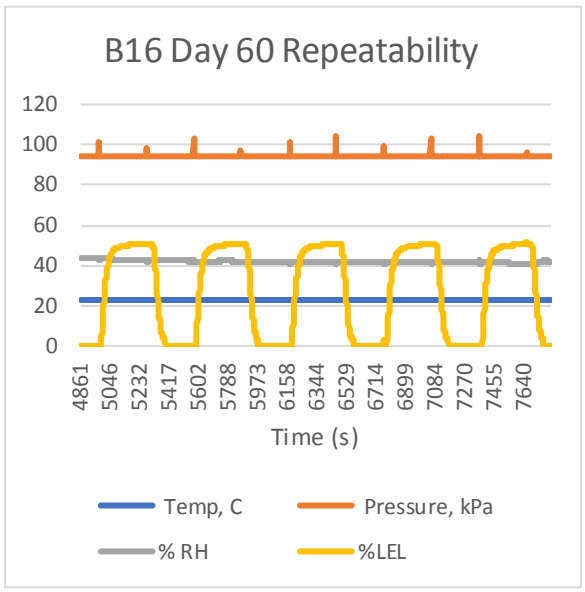
Observations:

- SGX sensor continues to provide an offset from zero and inconsistent results
- Micropel sensor becomes totally unresponsive either due to poor connection to the microcontroller or possible sensor degradation

Repeatability Results; MPS Sensors, Day 60:



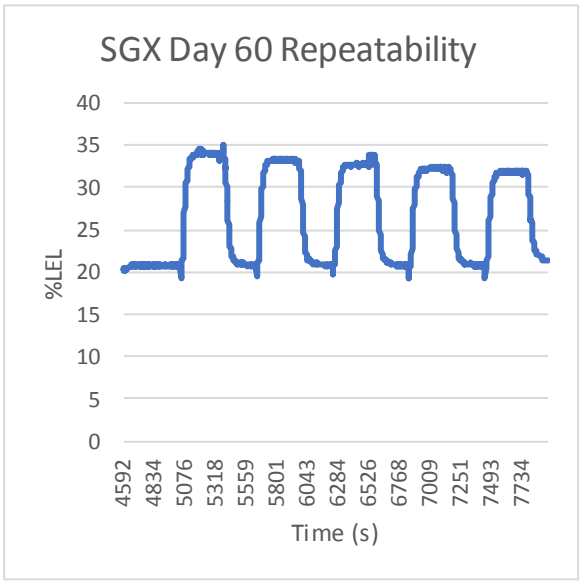


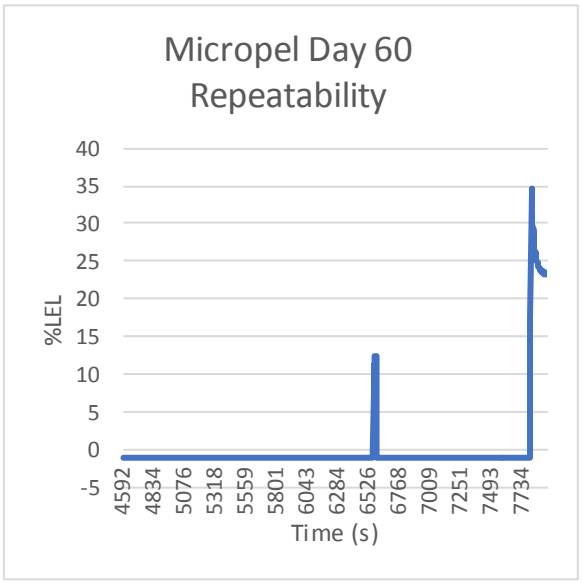


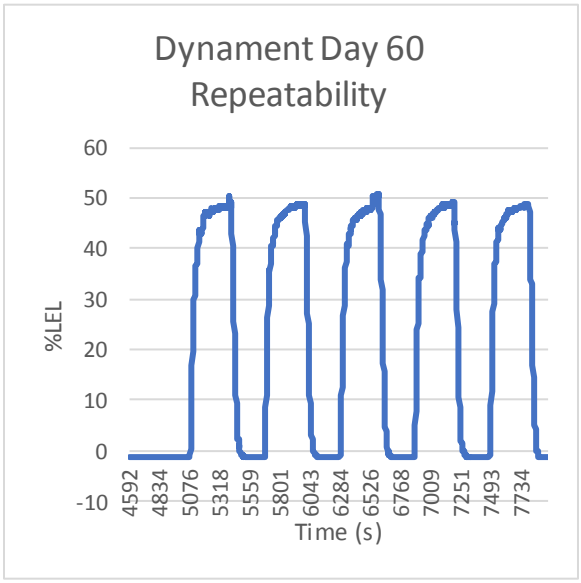
Observations:

- MPS sensors continue to provide repeatable measurements at Day 60

Repeatability Results; Competitor Sensors, Day 60:







Observations:

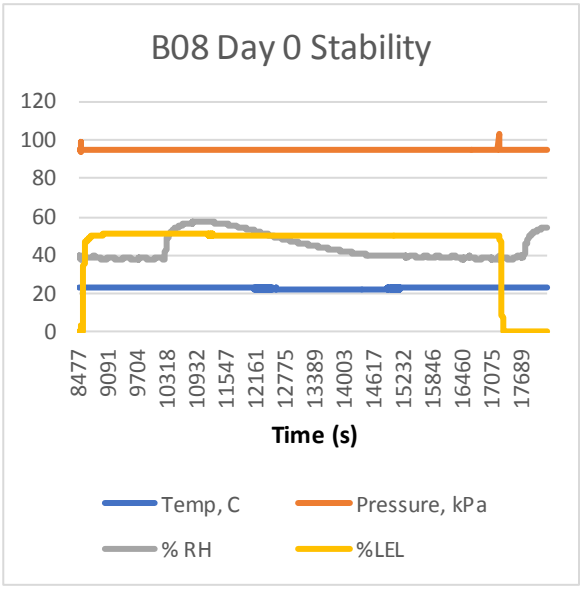
- SGX sensor continues to provide an offset from zero and inconsistent results
- Micropel sensor remains totally unresponsive with intermittent erratic measurements either due to poor connection to the microcomputer or possible sensor degradation

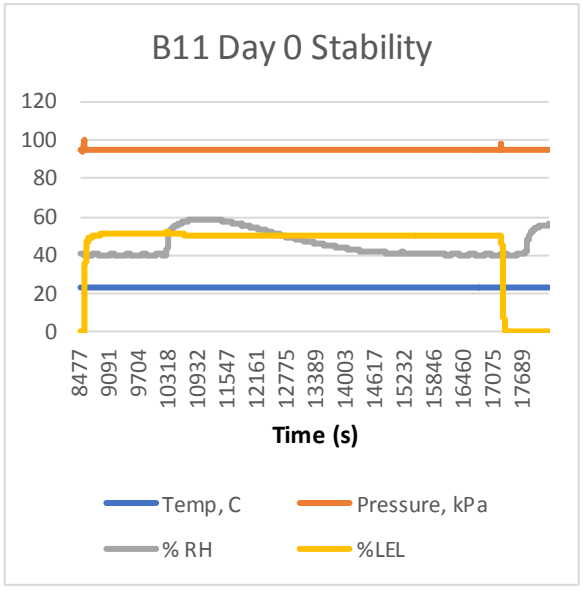
Stability Test Procedure

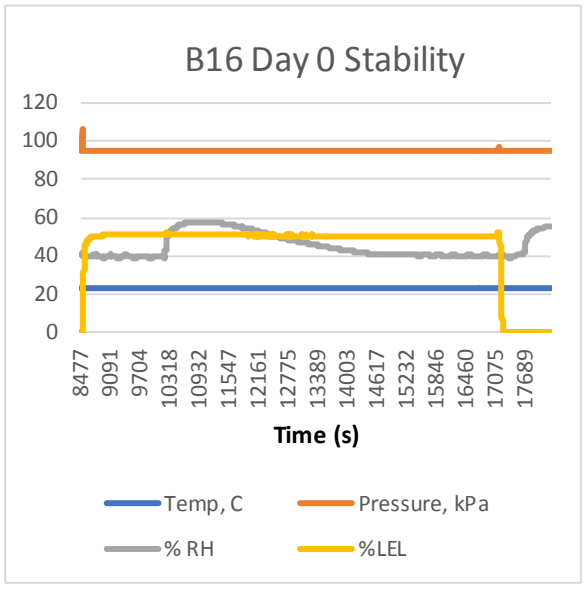
Protocol Number	Gases Required	Chamber Settings	Timing
3	50 % LEL Methane Zero Air Purge Gas	20C 50% RH	Gas flow for up to 2 hours 2 hours 10 minutes total time

Gas Flows: Zero Air 5 minutes, 50% Methane 120 minutes, Zero Air 5 minutes, end.

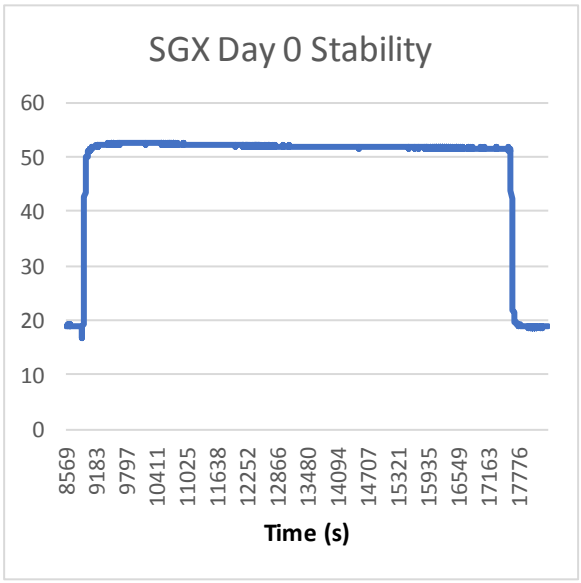
Stability Results; MPS Sensors, Day 0:

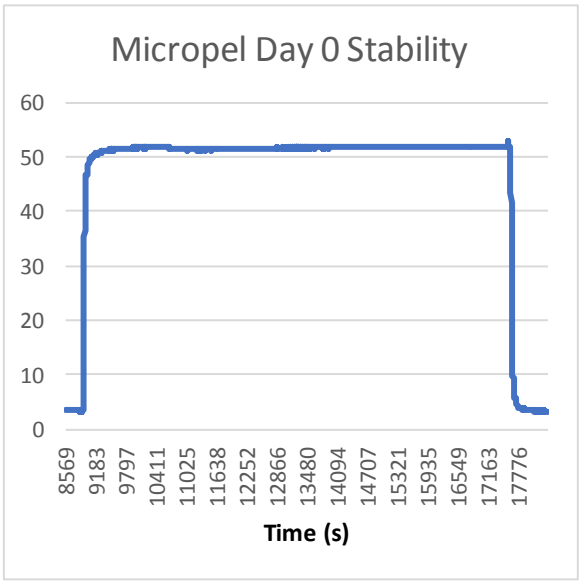


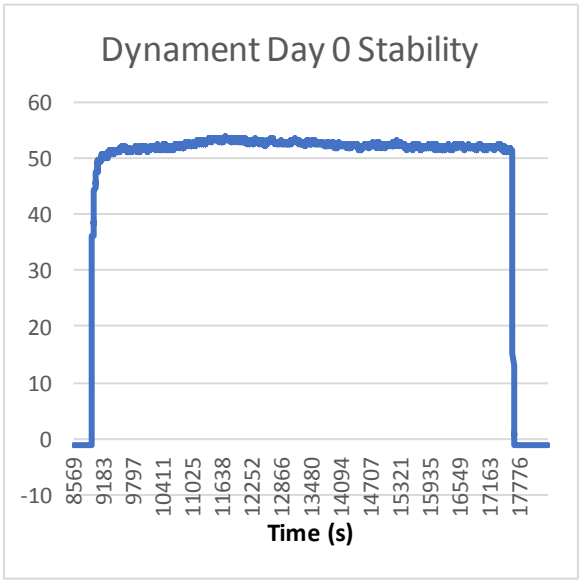




Stability Results; Competitor Sensors, Day 0:



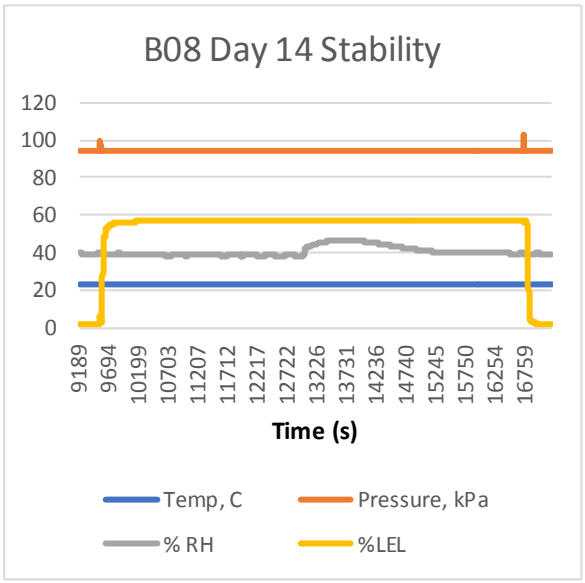


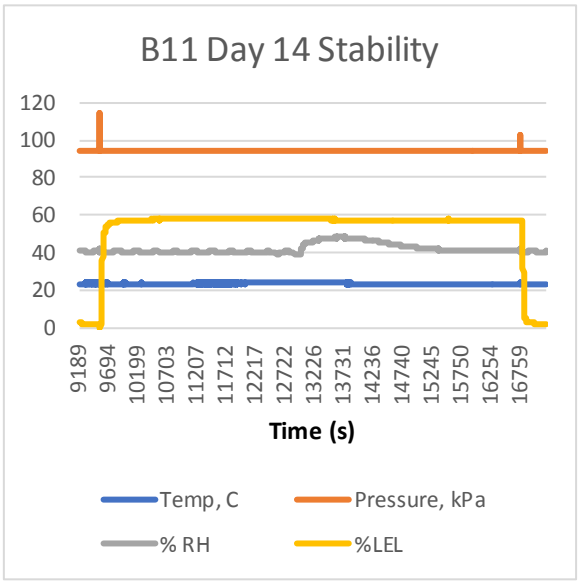


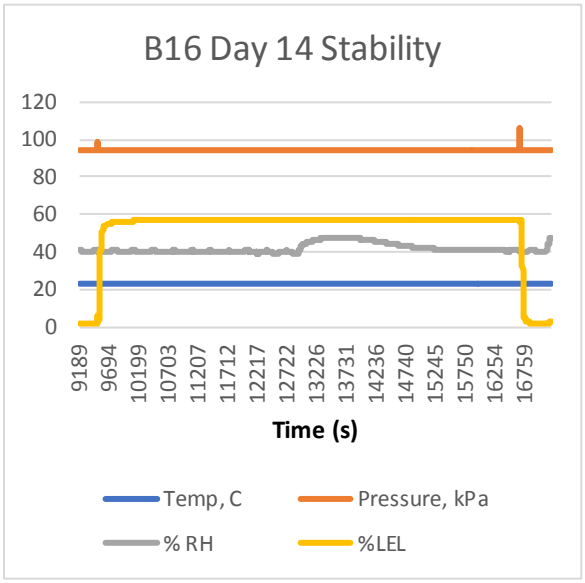
Observations:

- All sensors provide relatively stable measurements however, SGX and Micropel sensors continue to have an offset from zero

Stability Results; MPS Sensors, Day 14:



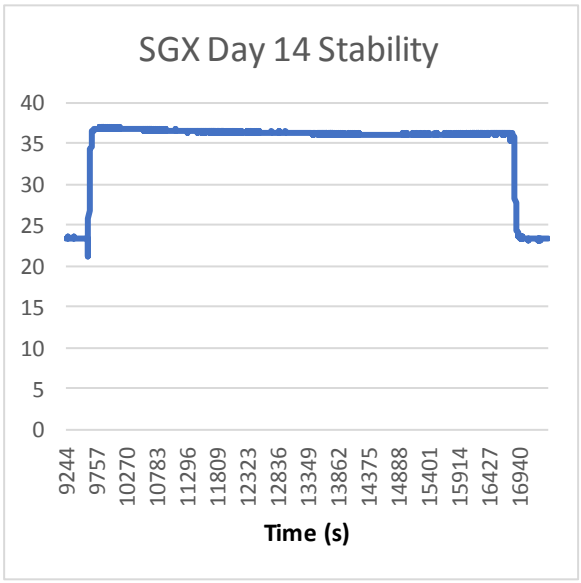


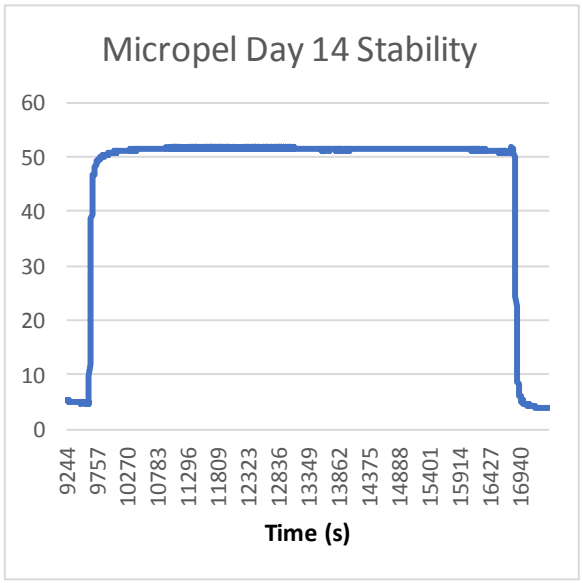


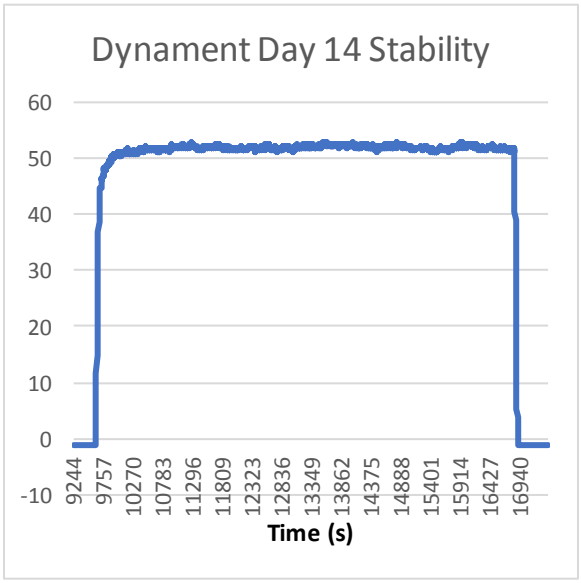
Observations:

- MPS sensors maintain stable results at Day 14

Stability Results; Competitor Sensors, Day 14:



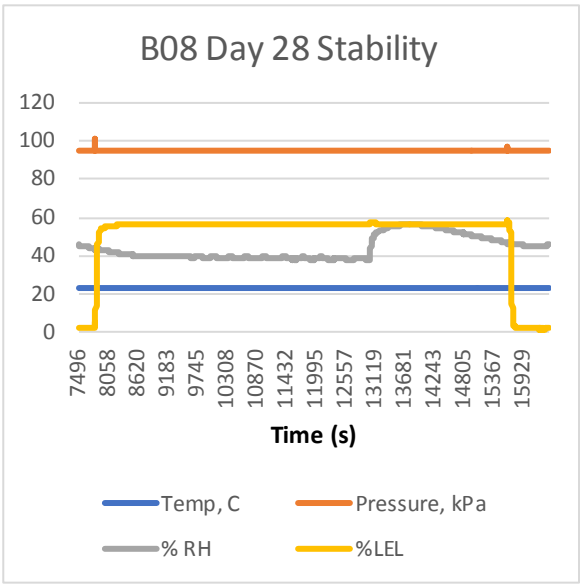


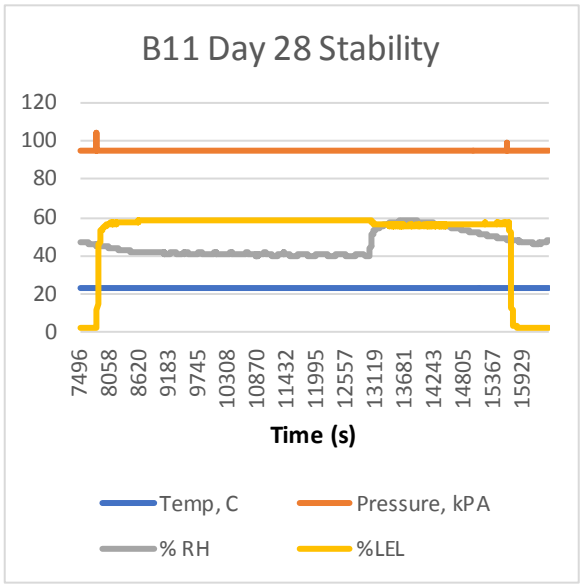


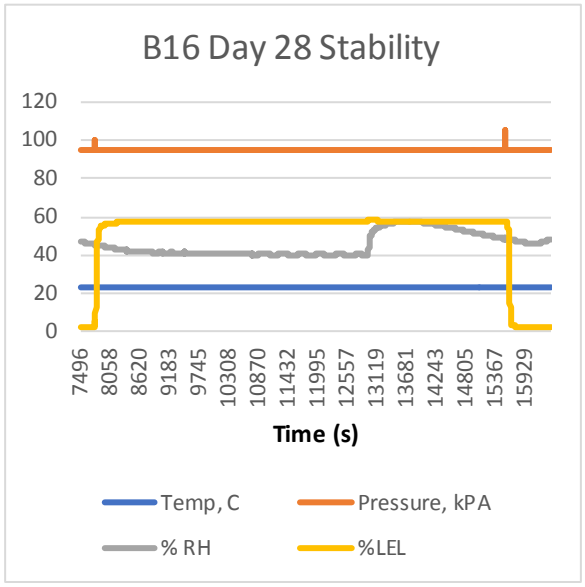
Observations:

- All sensors provide relatively stable measurements however, SGX and Micropel sensors continue to have an offset from zero

Stability Results; MPS Sensors, Day 28:



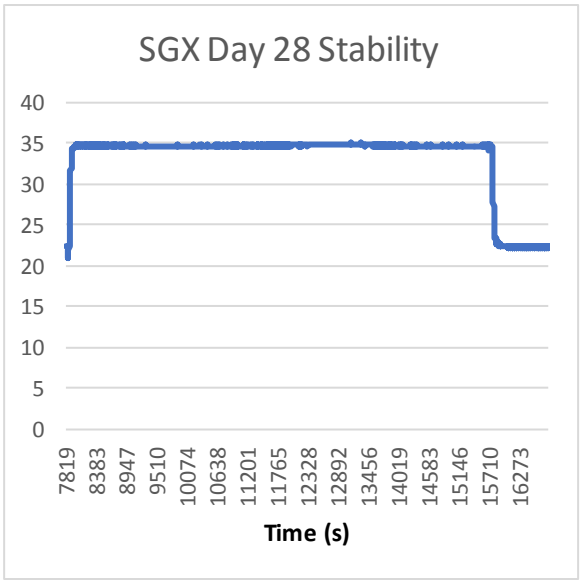


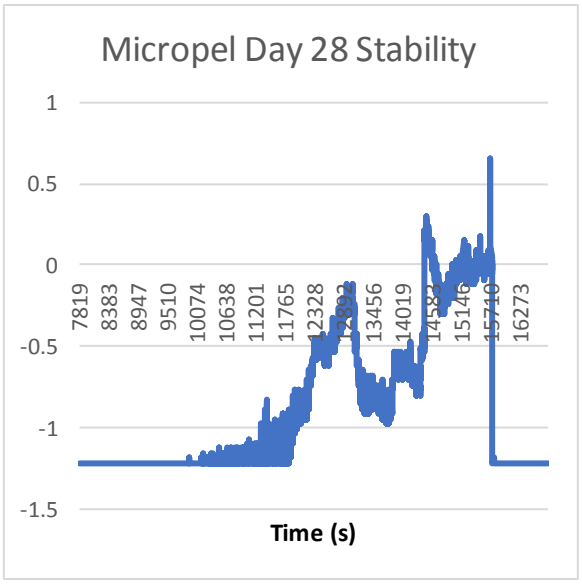


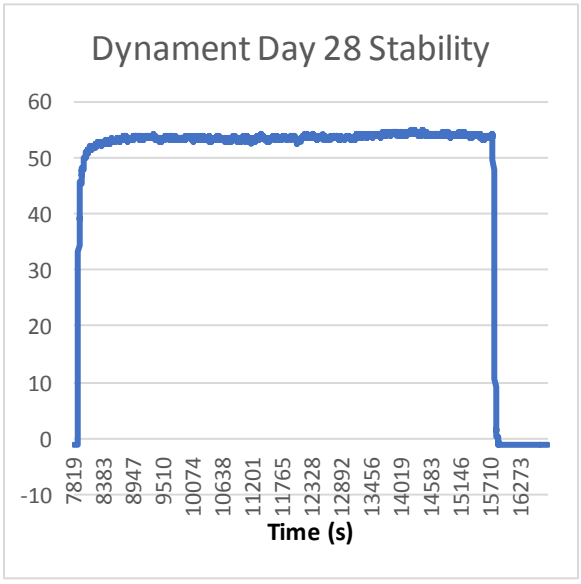
Observations:

- MPS sensors maintained stable results at Day 28

Stability Results; Competitor Sensors, Day 28:



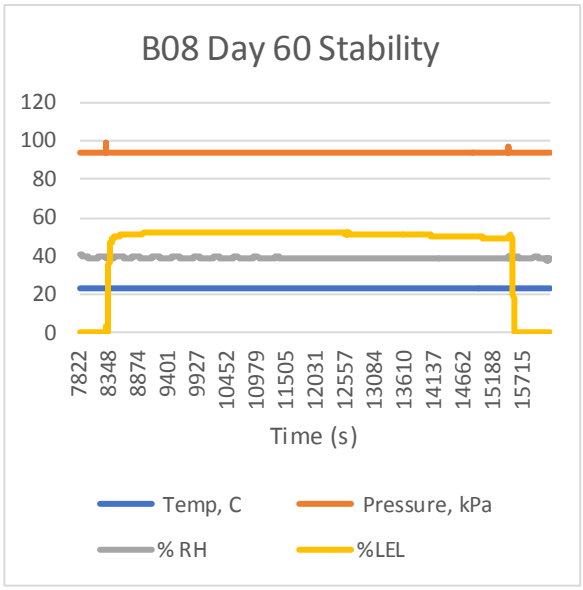


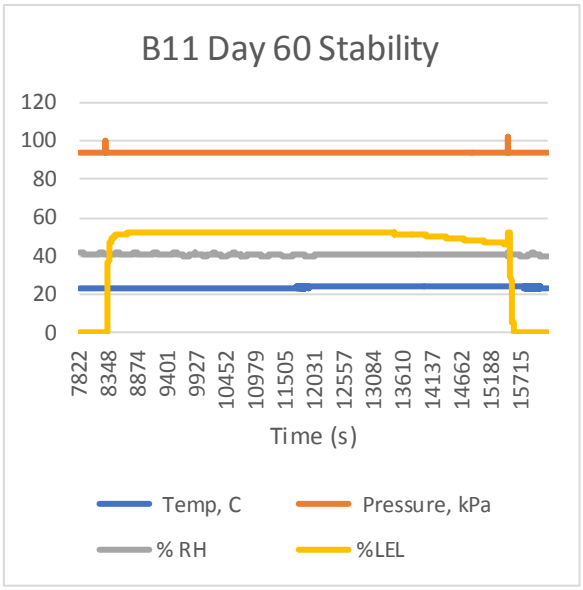


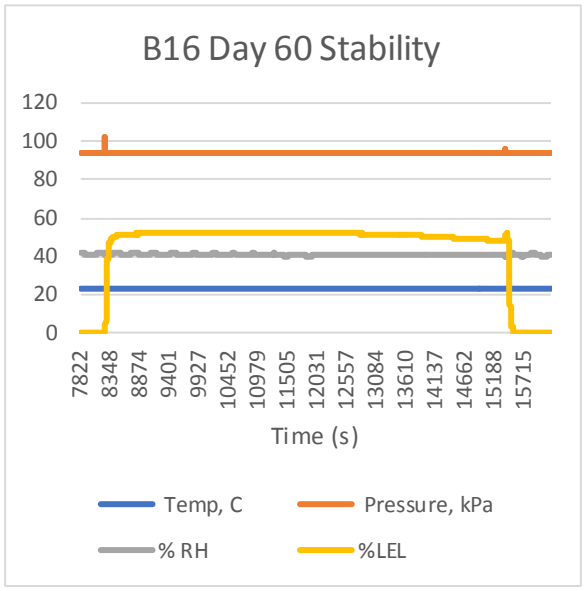
Observations:

- SGX sensor maintained an offset from zero yet showed stable measurements
- Micropel sensor showed erratic behavior at Day 28 due to a possible poor connection to microcontroller or sensor degradation

Stability Results; MPS Sensors, Day 60:



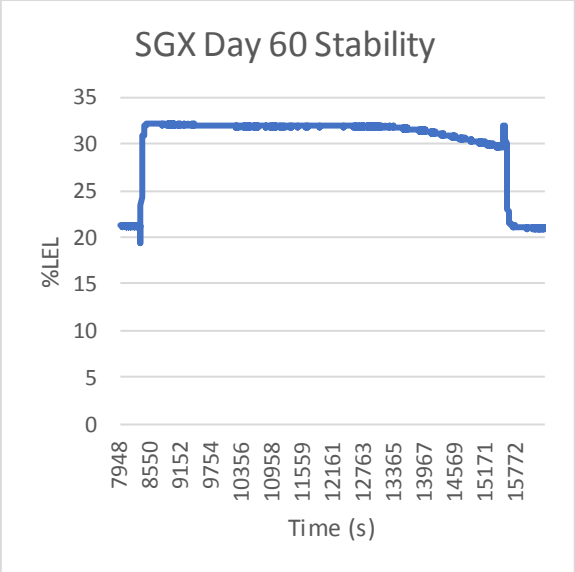


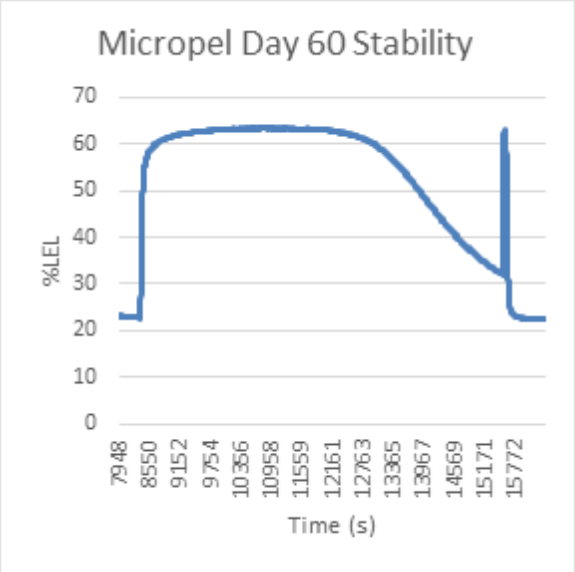


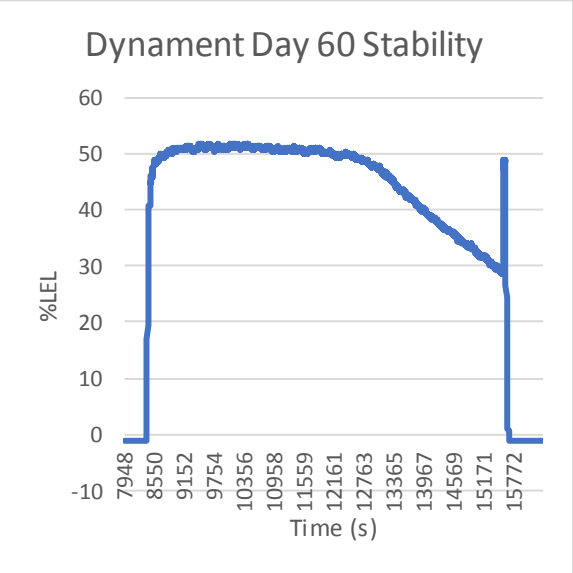
Observations:

- MPS sensors maintained stable results at Day 60

Stability Results; Competitor Sensors, Day 60:







Observations:

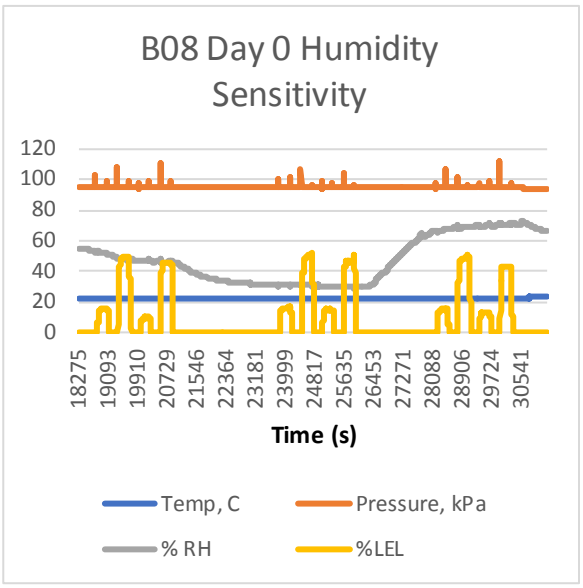
- All sensors showing unstable measurements with SGX and Micropel still exhibiting an offset from zero.

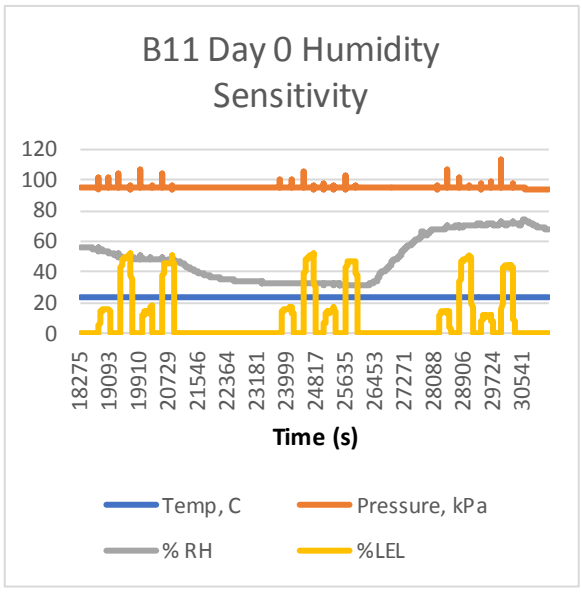
Humidity Sensitivity Test Procedure

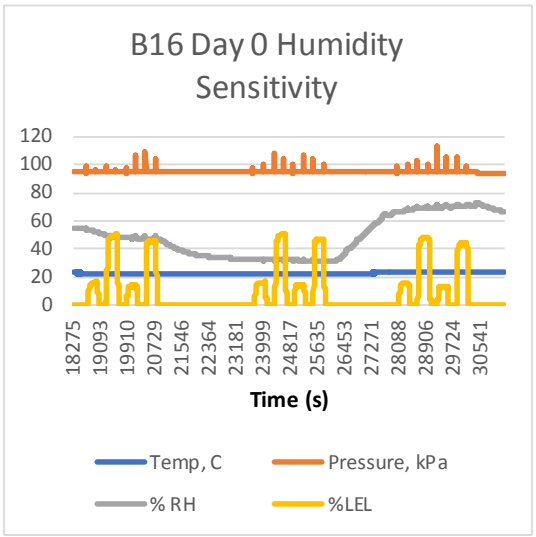
Protocol Number	Gases Required	Chamber Settings	Timing
4	15% LEL Methane 50 % LEL Methane 15% LEL Propane 50% LEL Propane Zero Air Purge Gas	20C 25% RH 60% RH 90% RH	Sequential flow of test gases for 5 minutes each with zero air purge between once humidity stabilized at target set point. 3 hours 50 minutes total time

Gas Flows: Zero Air 20 minutes, 15% Methane 5 minutes, Zero Air 5 minutes, 50% Methane 5 minutes, Zero Air 5 minutes, 15% Propane 5 minutes, Zero Air 5 minutes, 50% Propane 5 minutes, Zero Air 10 minutes; performed at 60% RH, 25% RH, and 90% RH.

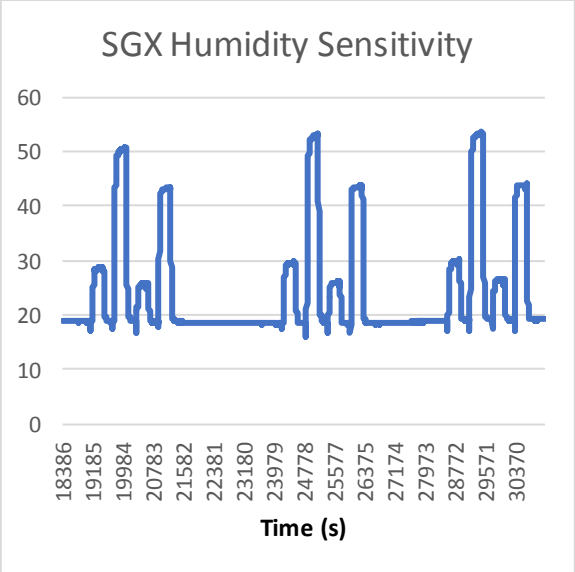
Humidity Sensitivity Results; MPS Sensors, Day 0:

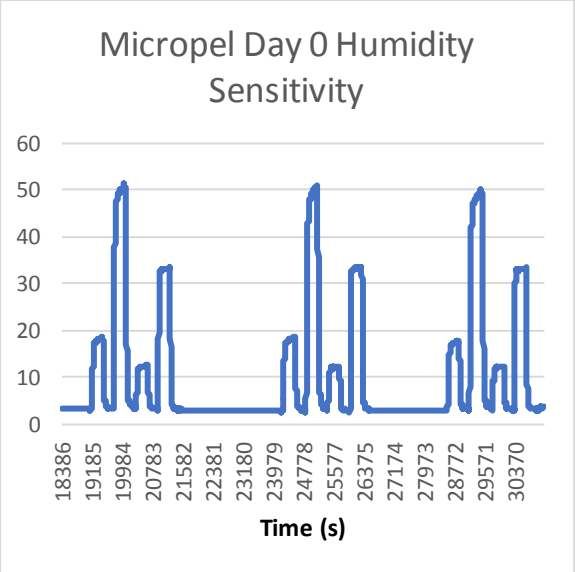


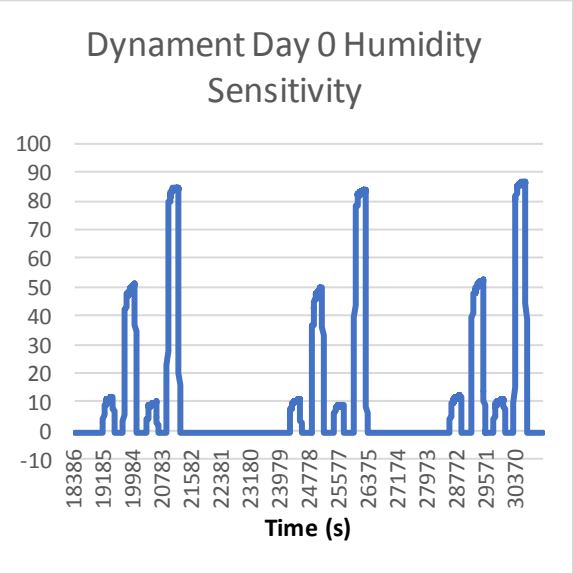




Humidity Sensitivity Results; Competitor Sensors, Day 0:



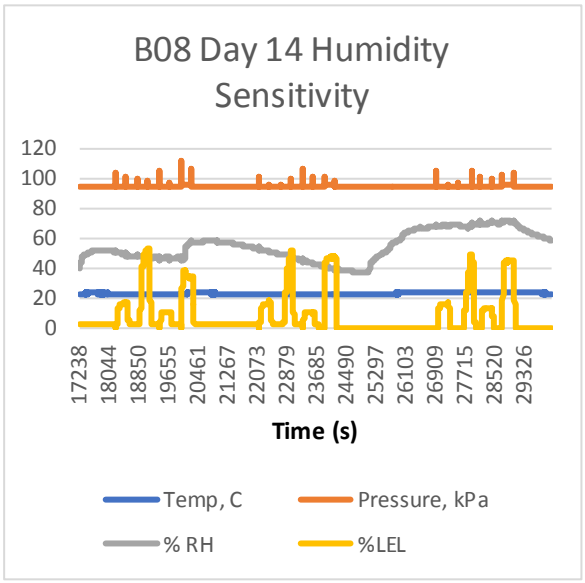


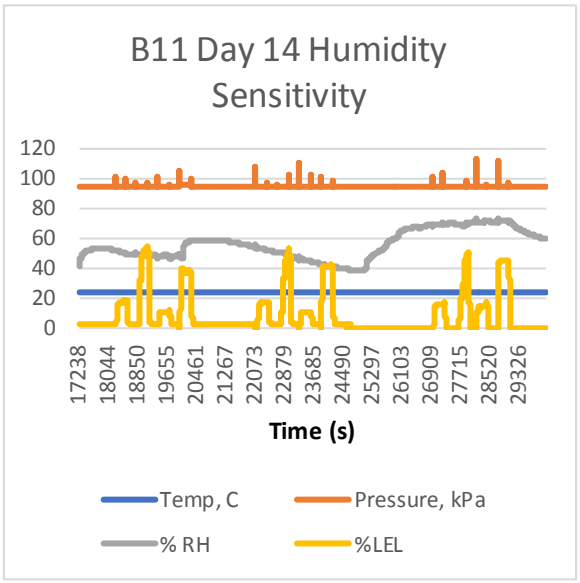


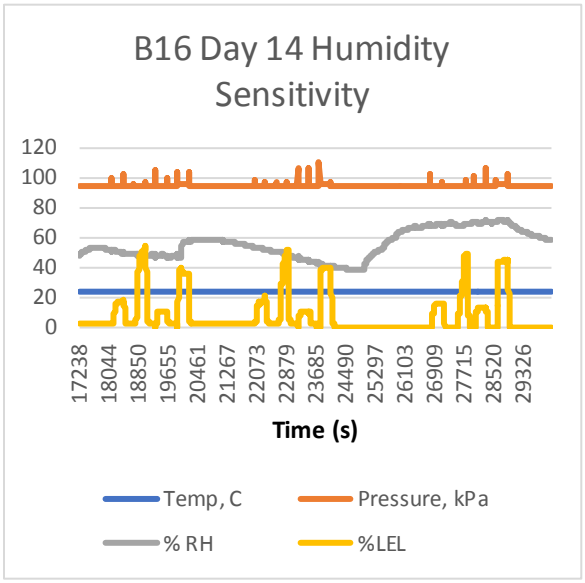
Observations:

- SGX and Micropel sensors exhibiting an offset from zero

Humidity Sensitivity Results; MPS Sensors, Day 14:



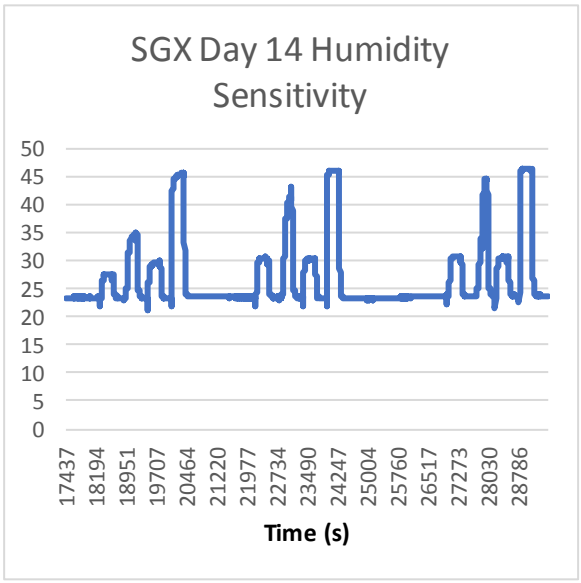


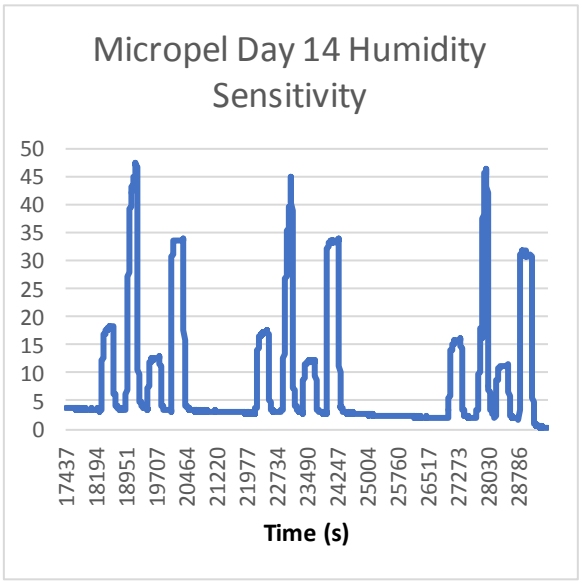


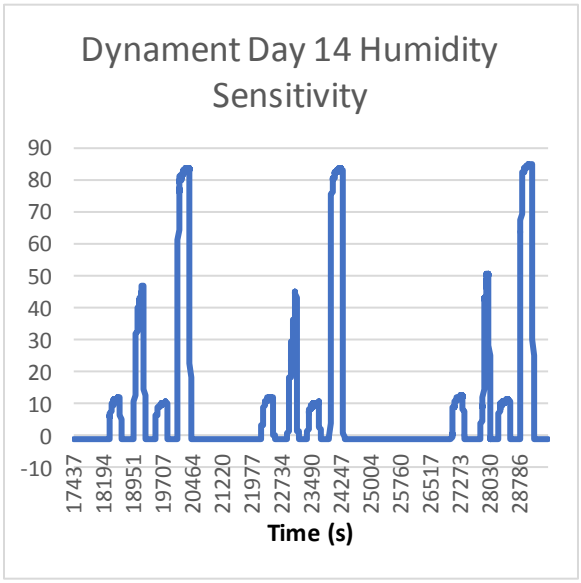
Observations:

- MPS sensors exhibiting the most accurate and consistent results despite dynamic humidity conditions at Day 14

Humidity Sensitivity Results; Competitor Sensors, Day 14:



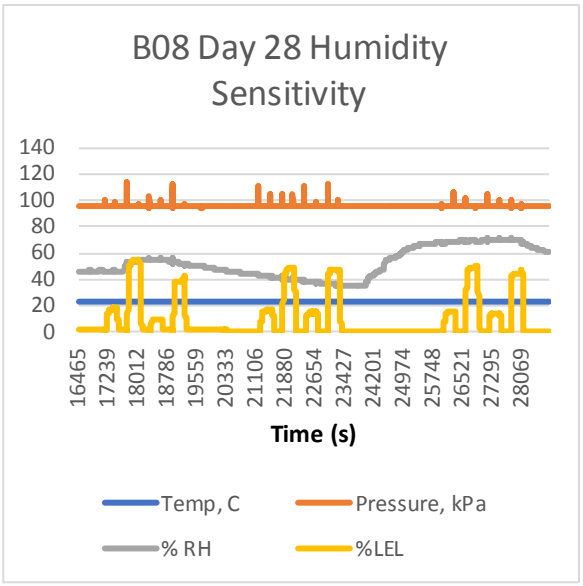


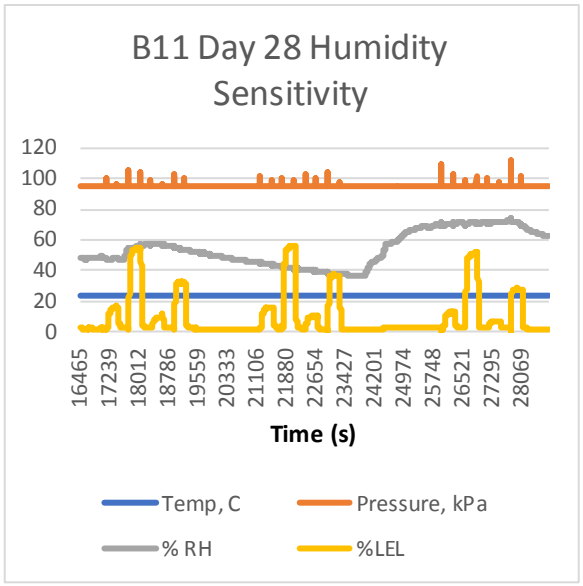


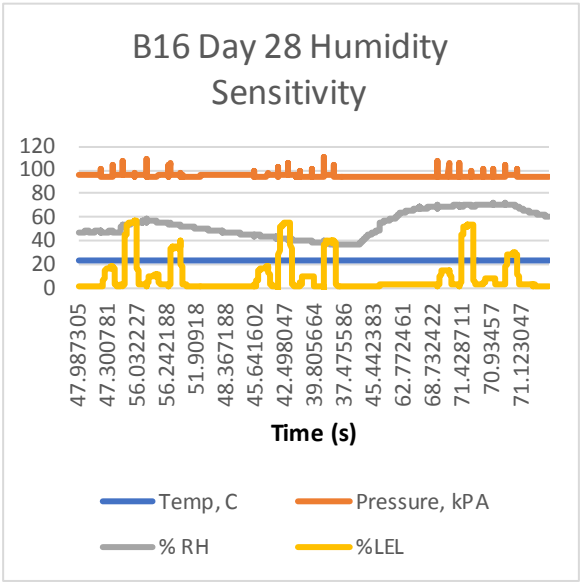
Observations:

- SGX and Micropel exhibiting an offset from zero

Humidity Sensitivity Results; MPS Sensors, Day 28:



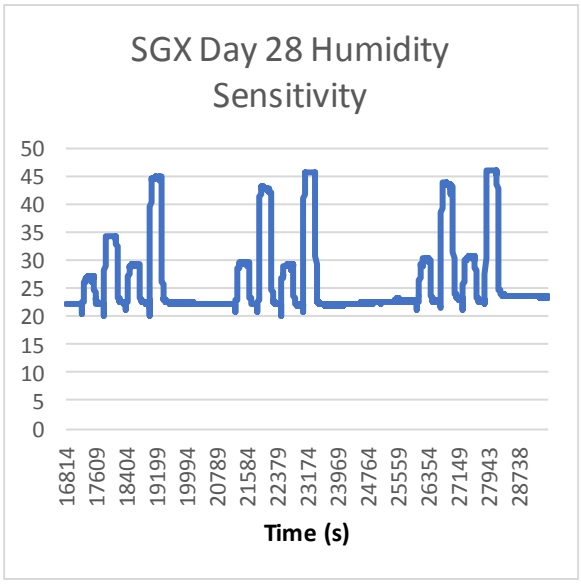


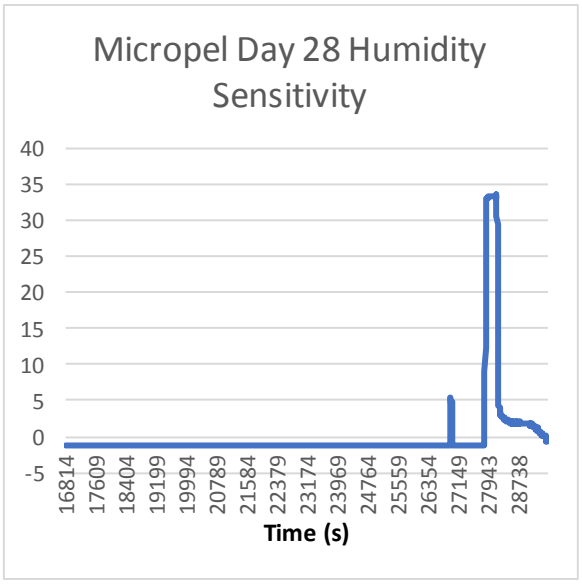


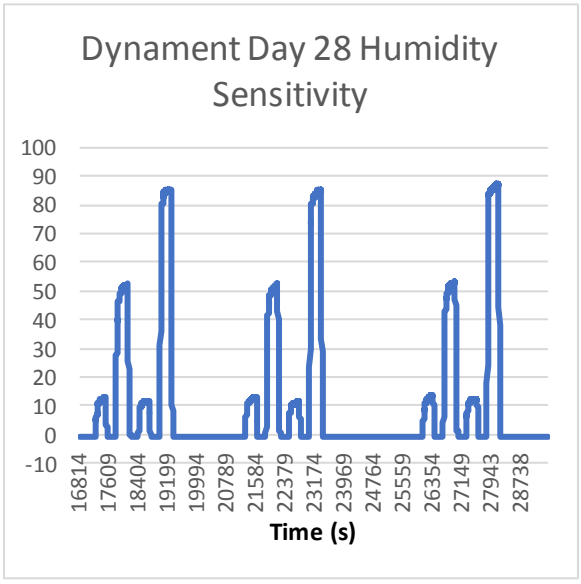
Observations:

- MPS sensors exhibiting the most accurate and consistent results despite dynamic humidity conditions at Day 28

Humidity Sensitivity Results; Competitor Sensors, Day 28:



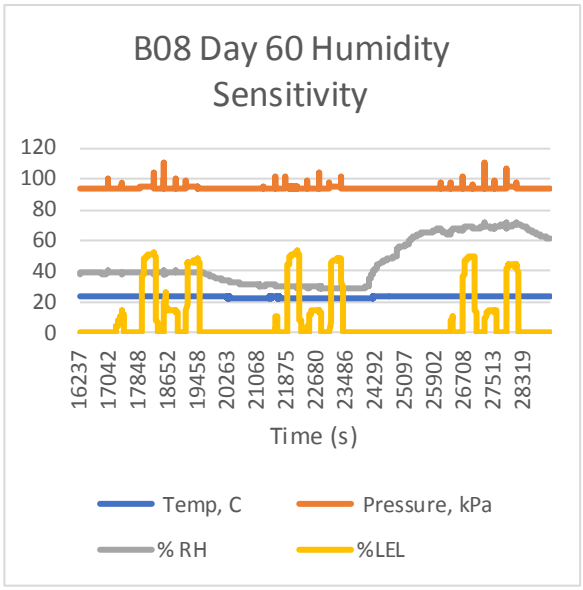


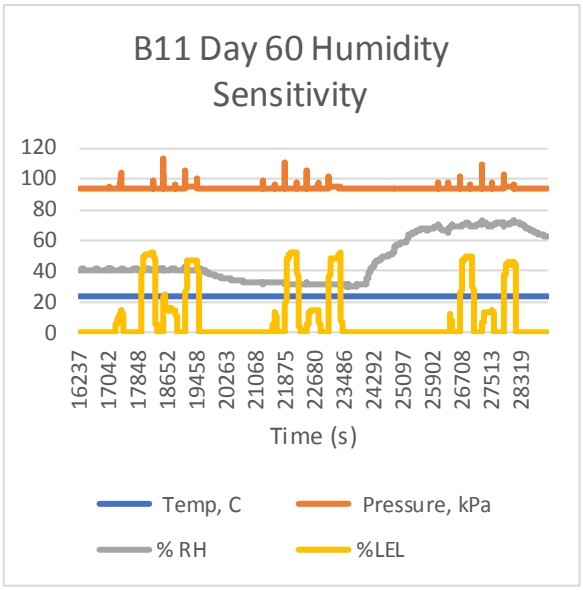


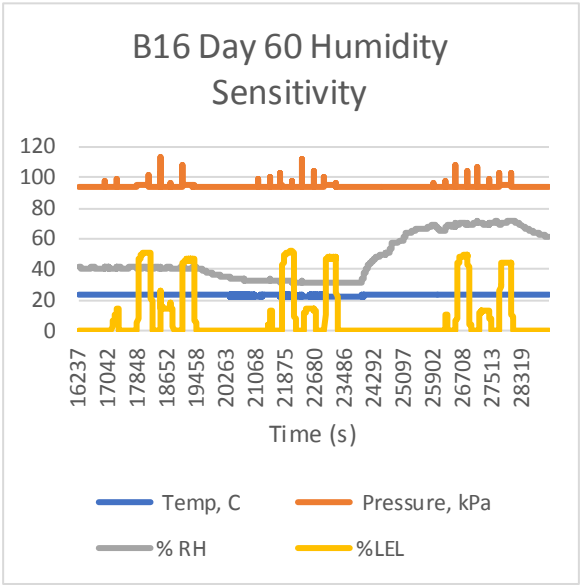
Observations:

- SGX sensor showing offset from zero
- Micropel sensor remains irresponsive and erratic throughout Day 28 testing.

Humidity Sensitivity Results; MPS Sensors, Day 60:



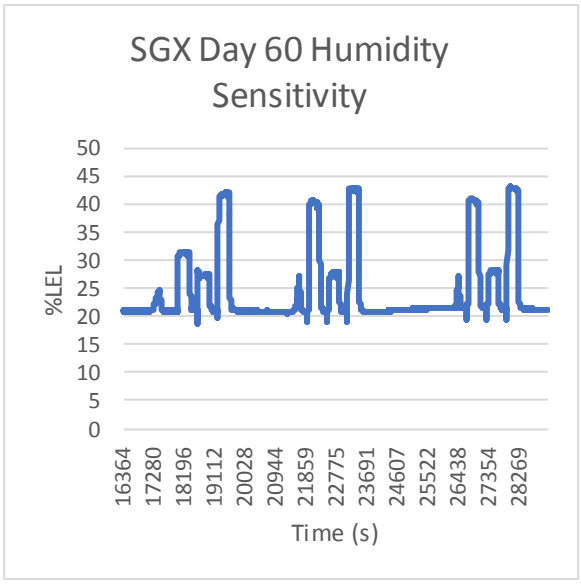


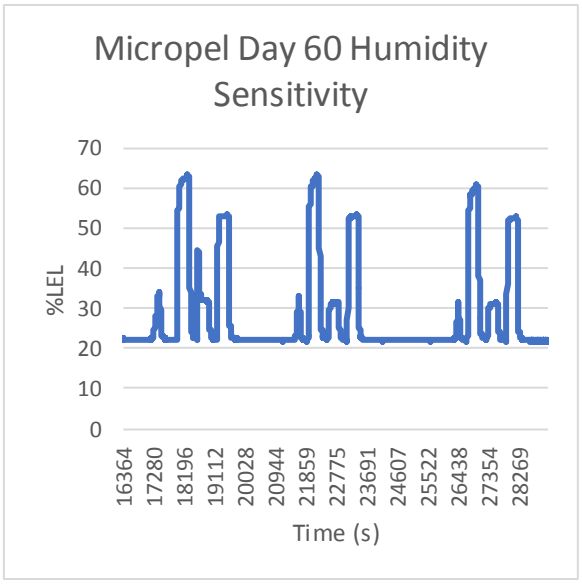


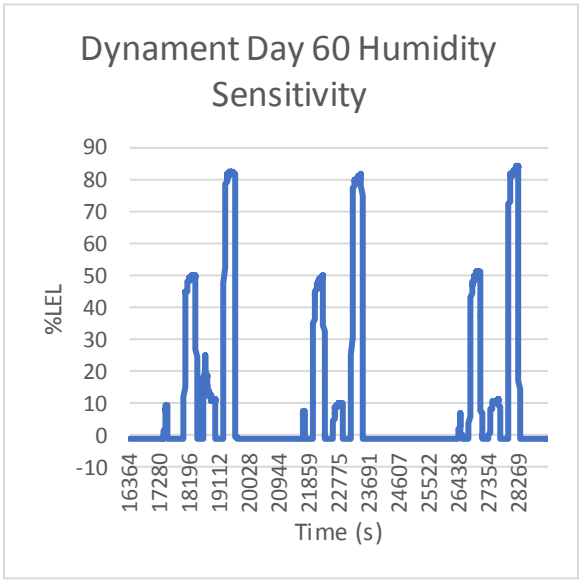
Observations:

- MPS sensors continued giving reliable results despite varying humidity at Day 60
- 15 %LEL Methane calibration gas was near empty during the middle of Day 60 testing explaining the sharp peak at the beginning of the test graphs.

Humidity Sensitivity Results; Competitor Sensors, Day 60:







Observations:

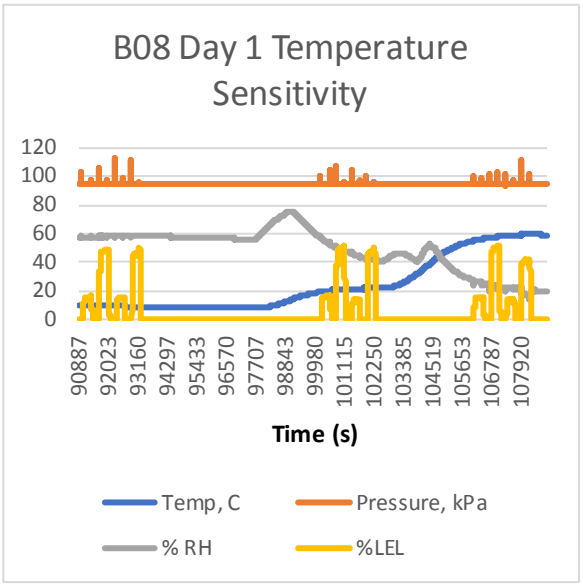
- SGX and Micropel sensors continued to have an offset from zero at Day 60 Testing.
- 15 %LEL Methane calibration gas was near empty during the middle of Day 60 testing explaining the sharp peak at the beginning of the test graphs.

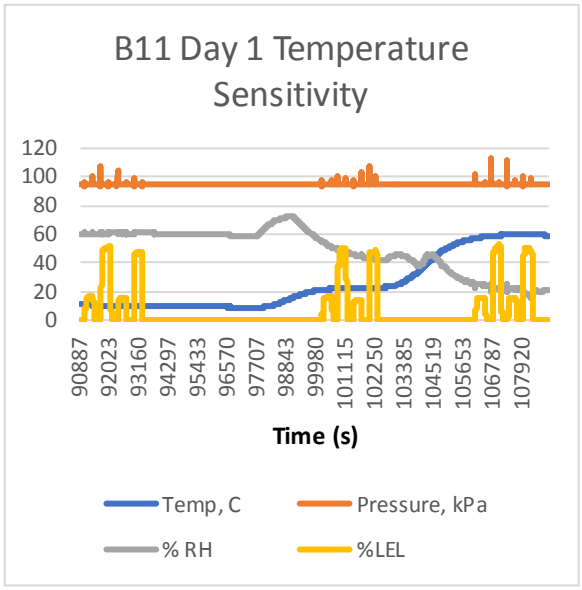
Temperature Sensitivity Test Procedure

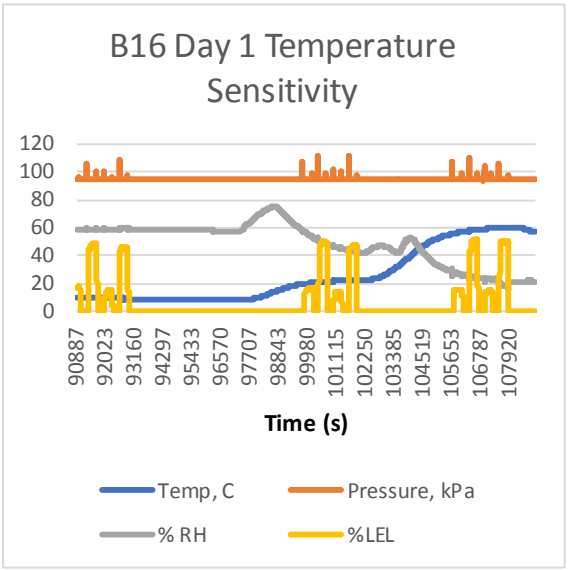
Protocol Number	Gases Required	Chamber Settings	Timing
5	15% LEL Methane 50 % LEL Methane 15% LEL Propane 50% LEL Propane Zero Air Purge Gas	-40C 20C 60C Humidity: 25-30RH	Sequential flow of test gases for 5 minutes each with zero air purge between once temperature stabilized at target set point. 7 hours 15 minutes total

Gas Flows: Zero Air 110 minutes, 15% Methane 5 minutes, Zero Air 5 minutes, 50% Methane 5 minutes, Zero Air 5 minutes, 15% Propane 5 minutes, Zero Air 5 minutes, 50% Propane 5 minutes, Zero Air 5 minutes; performed at -40C, 20 C, and 60 C, following temperature ramps.

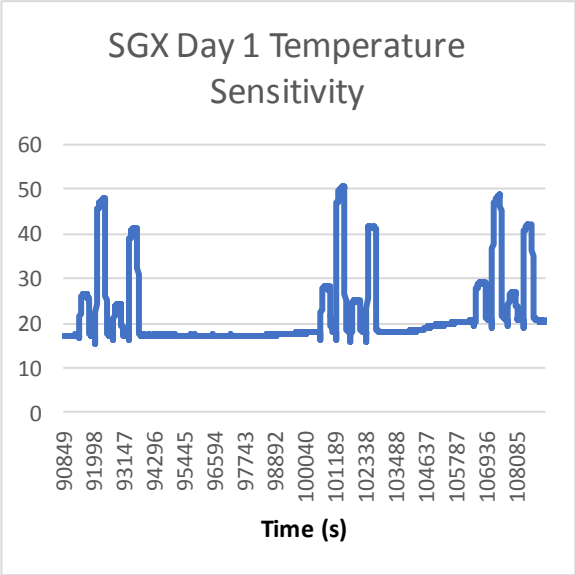
Temperature Sensitivity Results; MPS Sensors, Day 1:

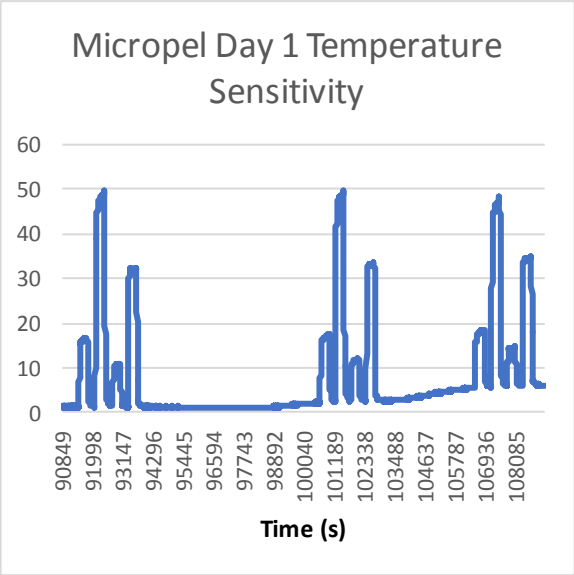


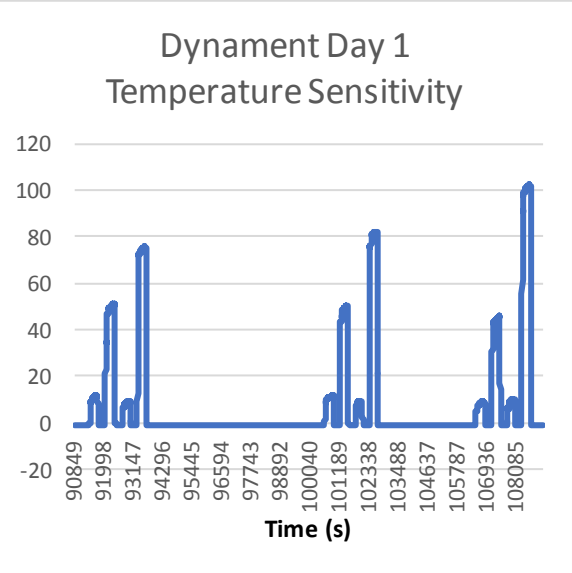




Temperature Sensitivity Results; Competitor Sensors, Day 1:



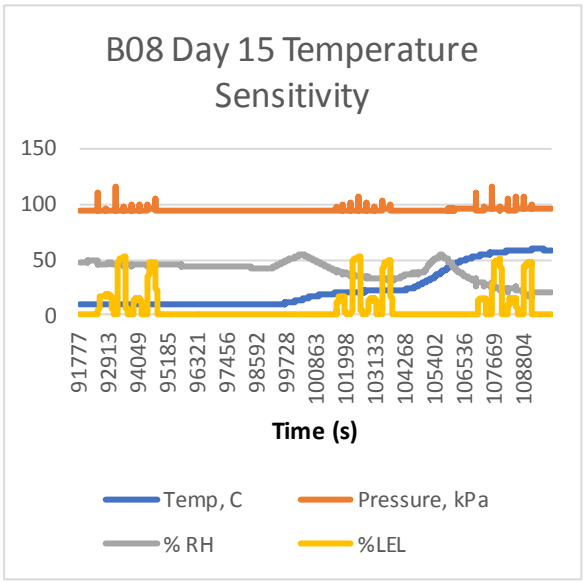


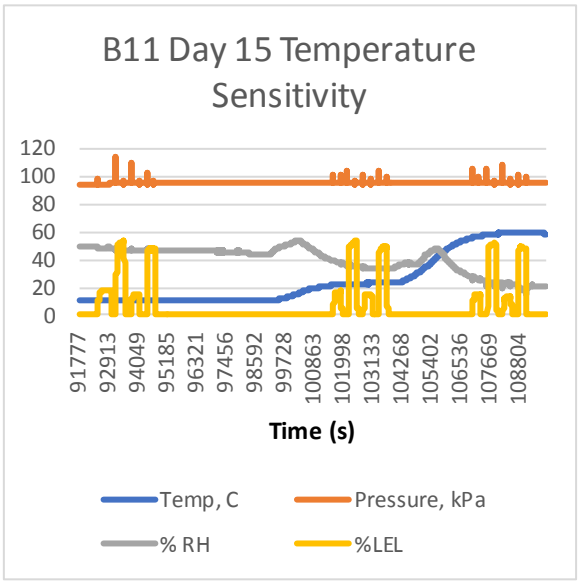


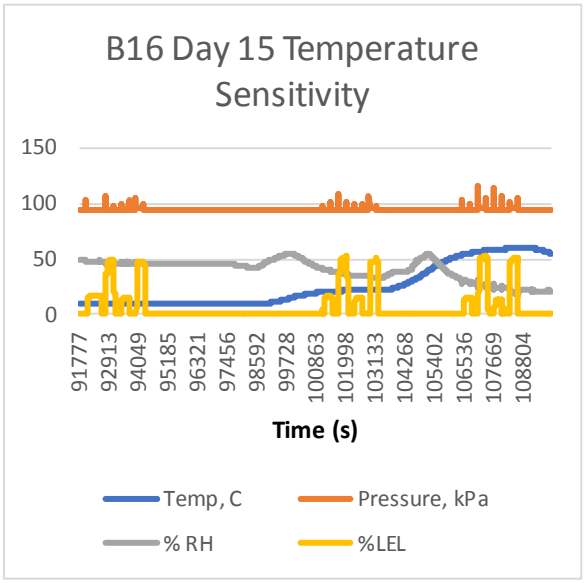
Observations:

- SGX and Micropel sensors continued to have an offset from zero at Day 1 Testing. These sensors also showed a shift in results as temperature varied which can be seen in the slight upward shift in the SGX and Micropel graphs above.

Temperature Sensitivity Results; MPS Sensors, Day 15:



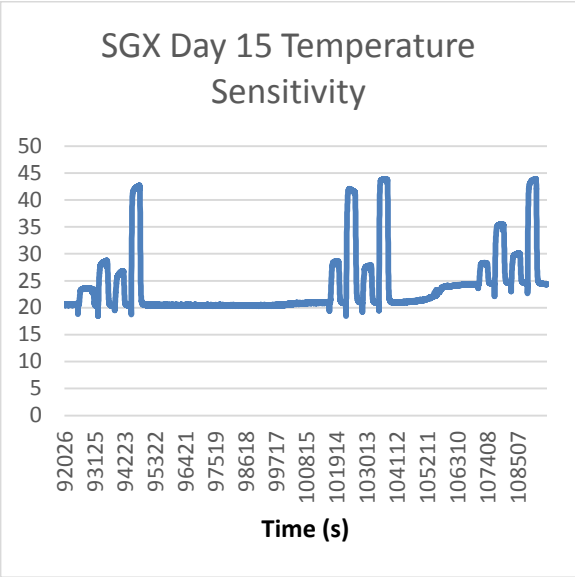


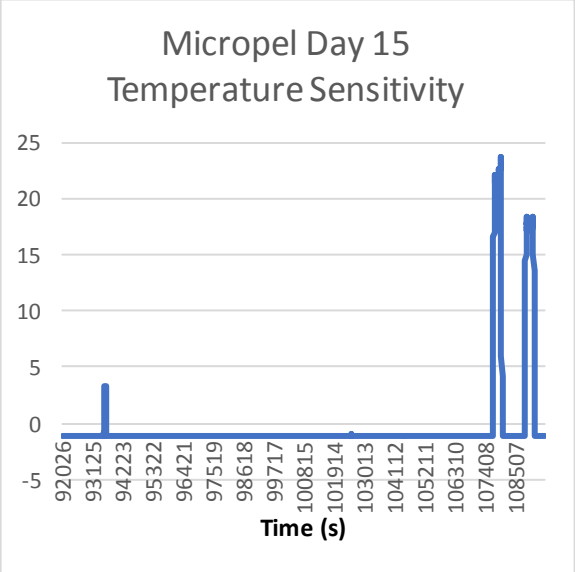


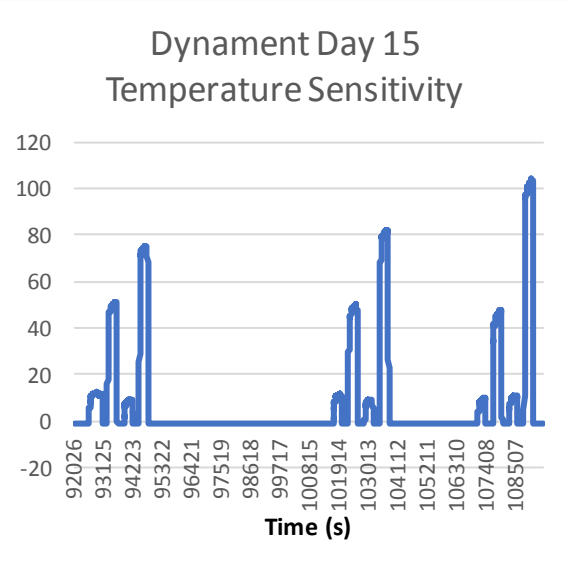
Observations:

- MPS sensors continued giving reliable results despite varying temperature at Day 15

Temperature Sensitivity Results; Competitor Sensors, Day 15:



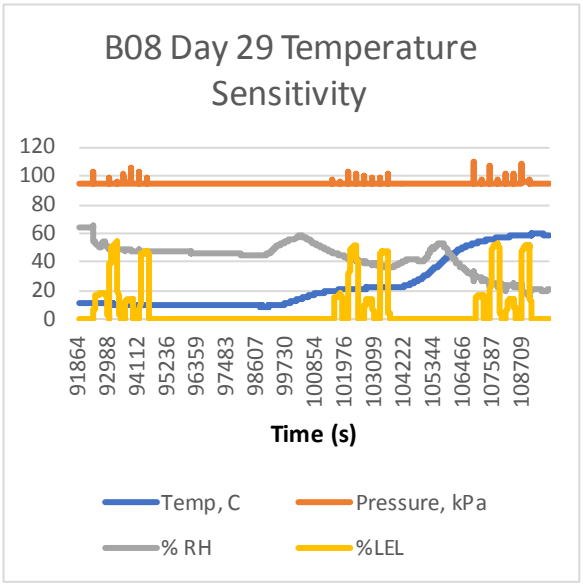


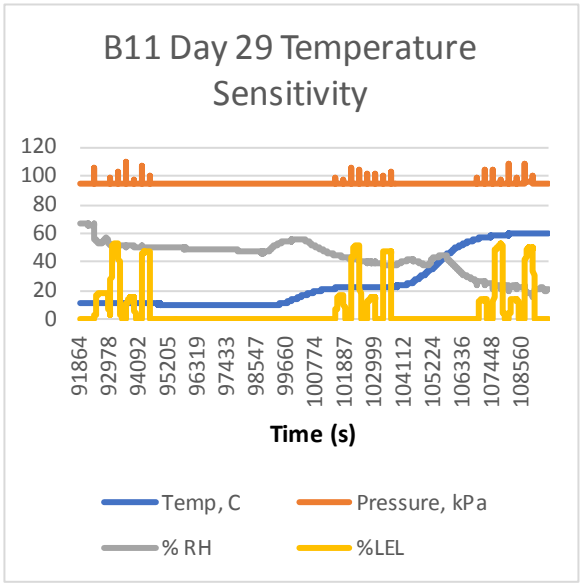


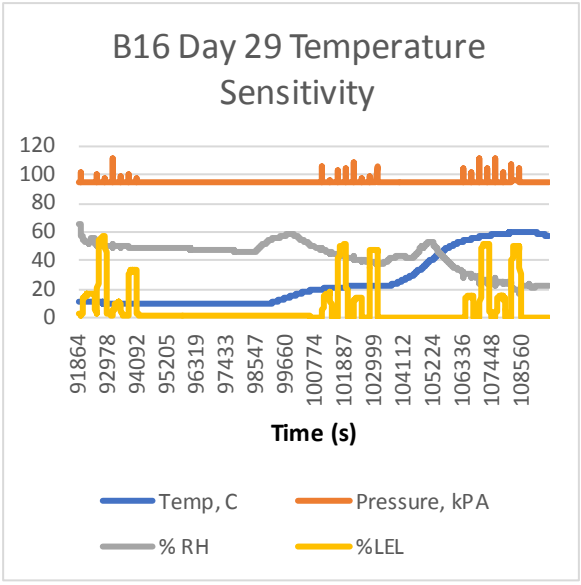
Observations:

- SGX sensor continued to have an offset from zero at Day 15 Testing. This sensor also showed a shift in results as temperature varied which can be seen in the slight upward shift in the SGX graph above.
- Micropel sensor continued erratic and unresponsive throughout Days 14 and 15 due to either poor connection to the microcontroller or sensor degradation.

Temperature Sensitivity Results; MPS Sensors, Day 29:



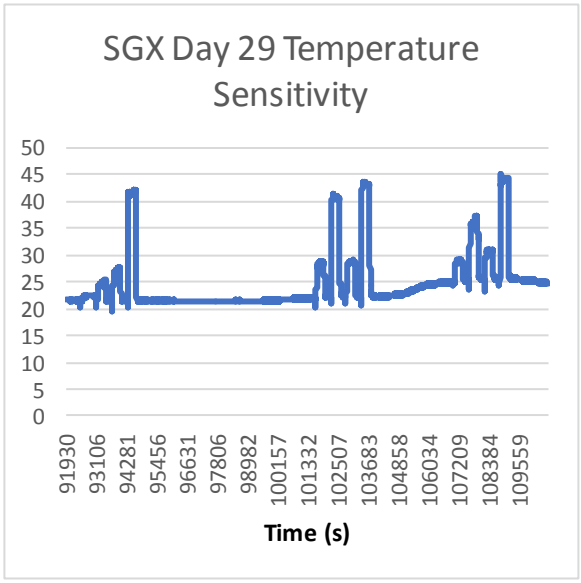


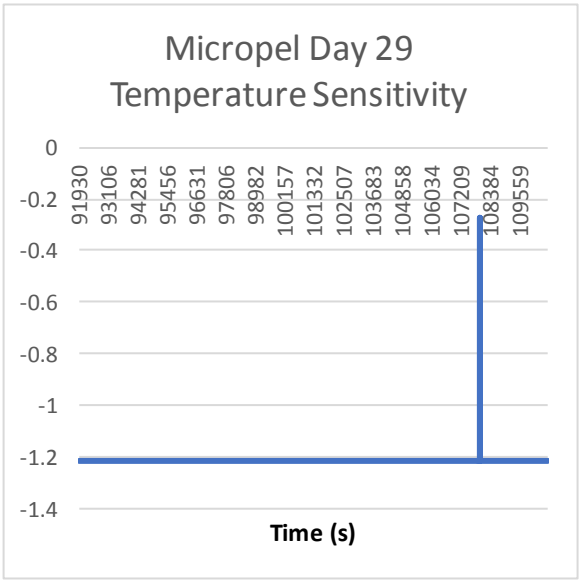


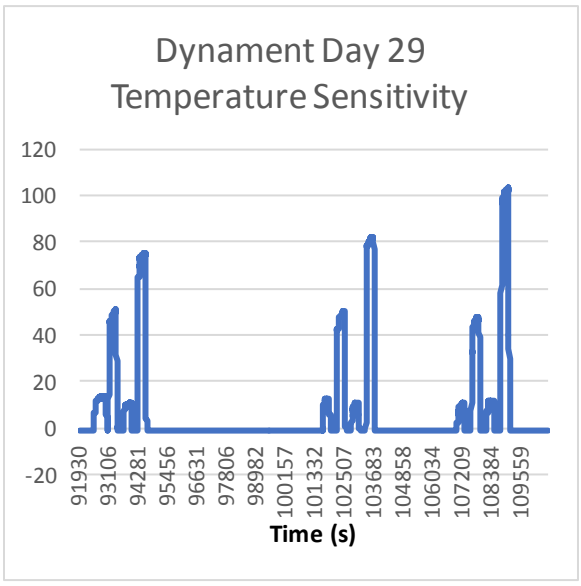
Observations:

- MPS sensors continued giving reliable results despite varying temperature at Day 29

Temperature Sensitivity Results; Competitor Sensors, Day 29:



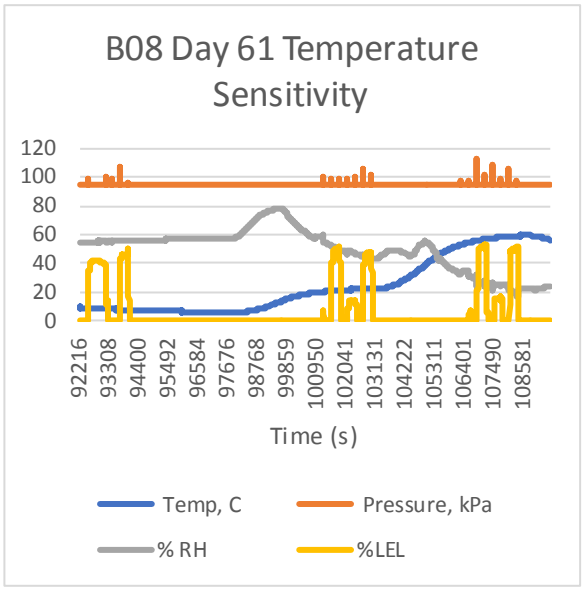


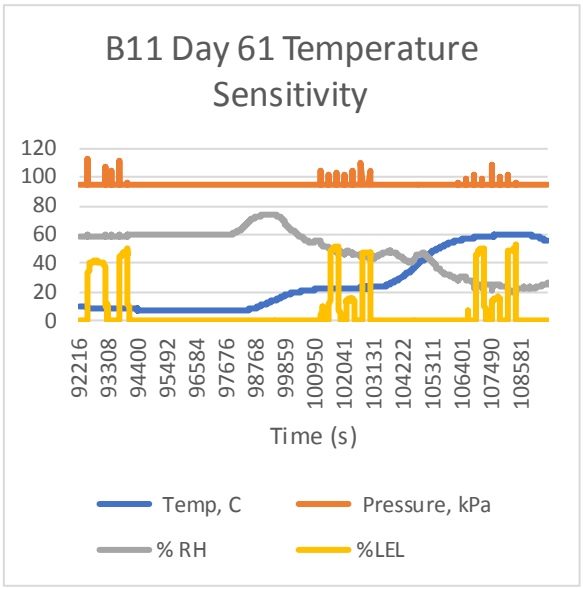


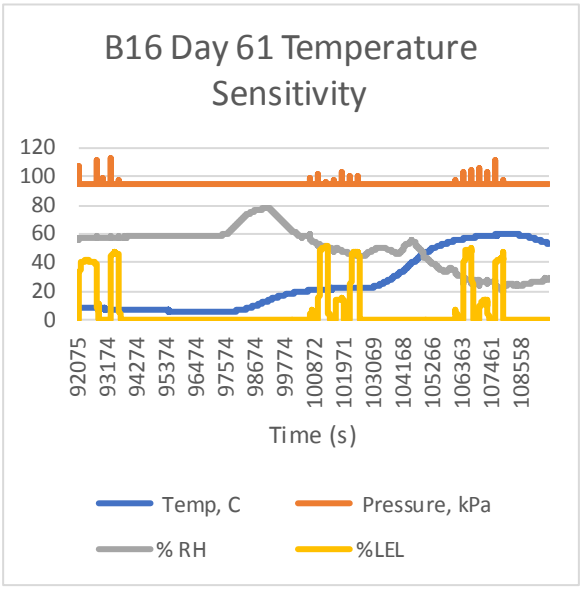
Observations:

- SGX sensor continued to have an offset from zero at Day 15 Testing. This sensor also showed a shift in results as temperature varied which can be seen in the slight upward shift in the SGX graph above.
- Micropel sensor continued erratic and unresponsive throughout Days 28 and 29 due to either poor connection to the microcontroller or sensor degradation.

Temperature Sensitivity Results; MPS Sensors, Day 61:



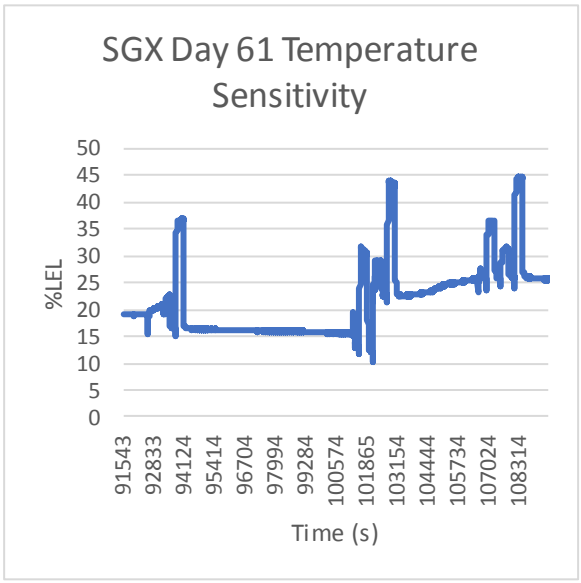


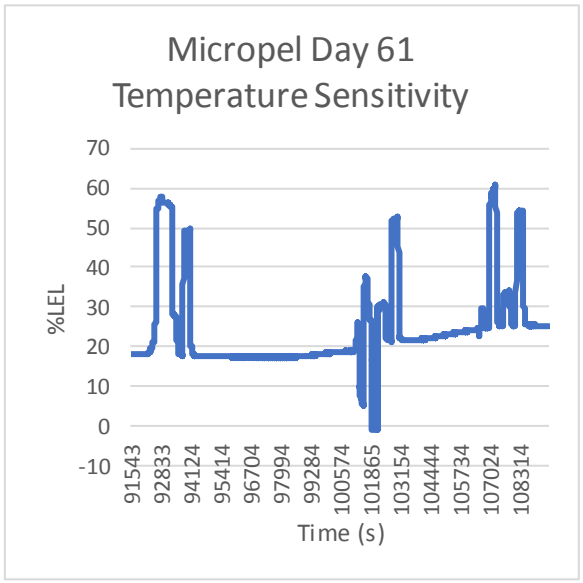


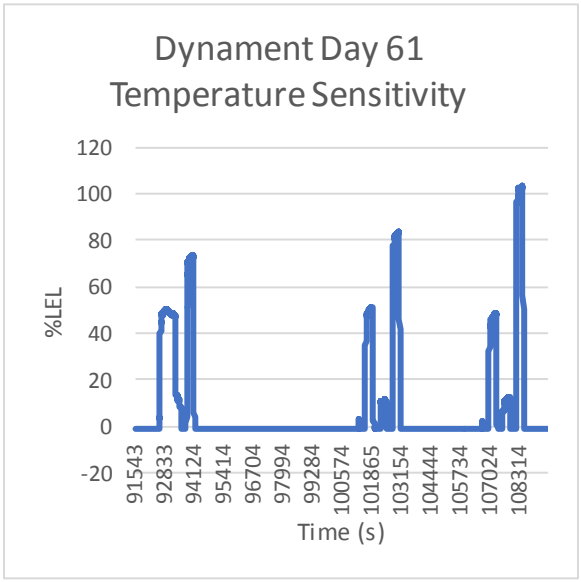
Observations:

- MPS sensors display consistent and unshifted results despite varying temperature at Day 61. The 15 %LEL Methane gas was empty during this testing which explains the absent peak for this gas in the above graphs.

Temperature Sensitivity Results; Competitor Sensors, Day 61:





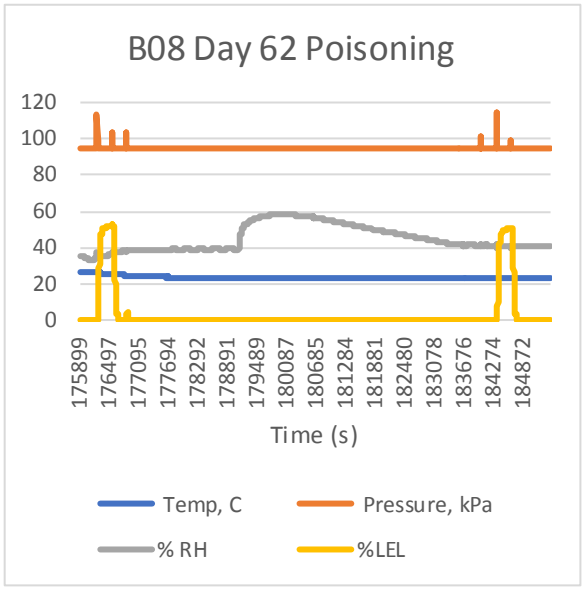


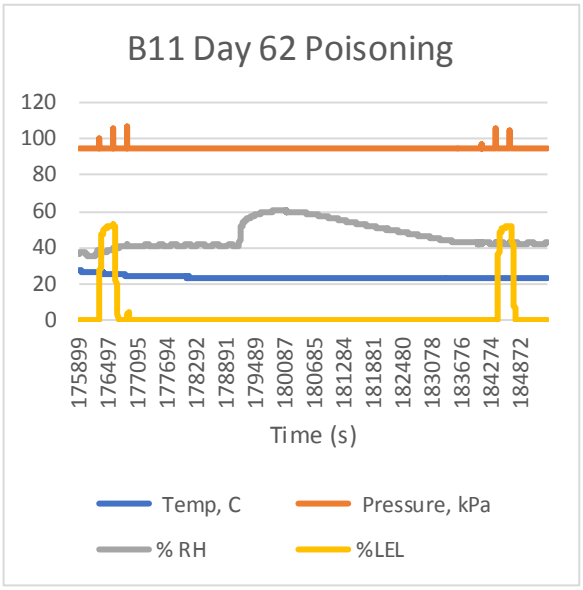
Observations:

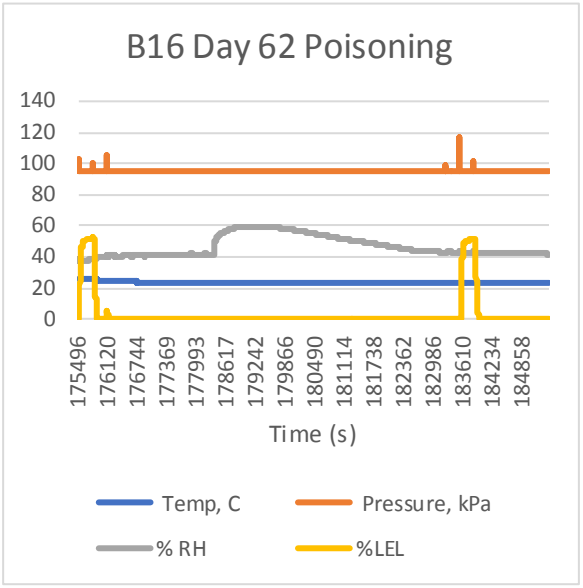
- SGX & Micropel sensors continued to have an offset from zero at Day 61 Testing. This sensor also showed a shift in results as temperature varied which can be seen in the slight upward shift in the SGX & Micropel graphs above.
- The 15 %LEL Methane gas was empty during this testing which explains the absent peak for this gas in the above graphs.

Sensor Poison Resistance Test Procedure

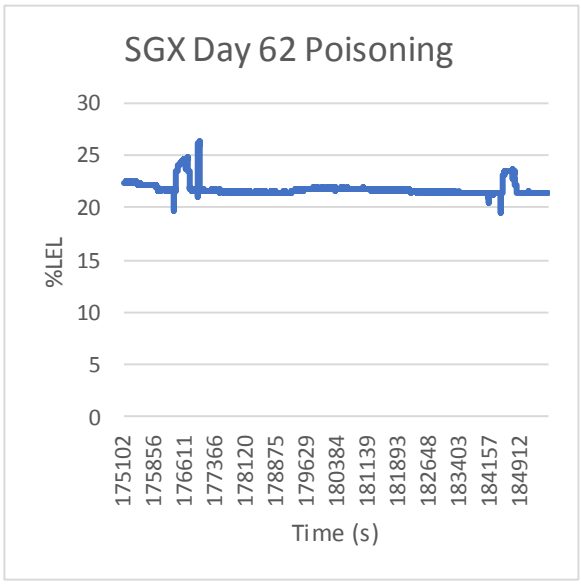
Protocol Number	Gases Required	Chamber Settings	Timing
6	50 % LEL Methane 100ppm H_2S balance Zero Air Purge Gas	20C 50% RH	a) Five (5) minutes for 50% LEL Methane; b) Five (5) minutes of Zero Air; c) Two (2) hours of 100ppm H_2S d) Five (5) minutes of Zero Air; e) Five (5) minutes of 50% LEL Methane 2 hours 15 minutes total

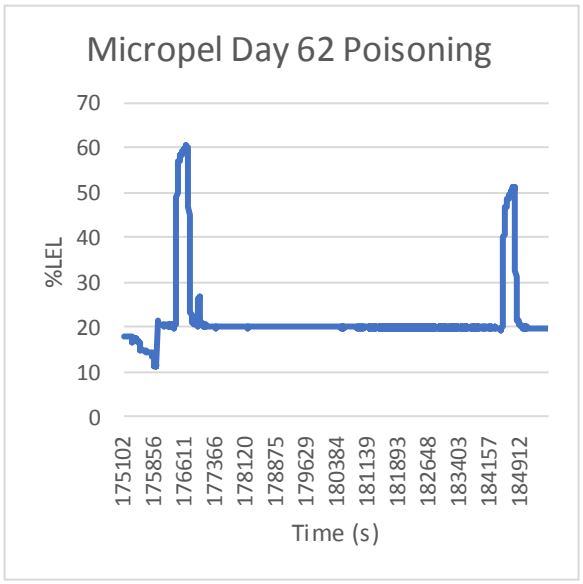


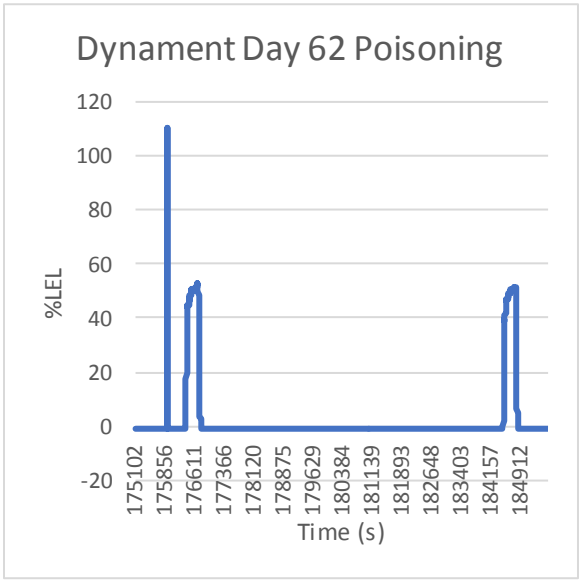




Sensor Poison Resistance Results, Competitor Sensors, Day 62:







Observations:

- All MPS sensors as well as the Micropel and Dynament sensors were able to sense the presence of 50 % LEL Methane after the poisoning exposure at Day 62. However SGX and Micropel still exhibited an offset from zero.

Conclusions:

In the opinion and experience of this Laboratory, the competitors' sensors displayed less accurate, less stable and less repeatable results when compared to the MPS sensors.

The SGX and Micropel sensors also lost the ability to calibrate prior to each testing cycle as early as Day 28.

When performing the 50 %LEL Methane manual calibration on the SGX and Micropel sensors the maximum obtainable reading was 29 %LEL despite having 50 %LEL Methane passing over the sensors.

The SGX and Micropel sensors exhibited an offset from zero starting at Day 0 and continued to be an issue through Day 62.

The MPS sensors did not require manual calibration prior to exposure and still provided more accurate, repeatable, and stable results despite varying temperature and humidity parameters.