A Network Manageable Advanced Gas Sensor

EPA Workshop on SF_6 Emission Reduction Strategies
Latest Advances in Leak Detection, Monitoring, and Repair
May 6–7, 2014

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Modtech Corp.

Advanced? Features and Benefits

Developed as an extension of a proven electromechanical design
→ Retain the benefits of a widely accepted density switch, easy installation, reliable operation

Accurate leak rate determination and tracking
→ Report instantaneous leak rate, time to alarm, time to lockout

Network interfaced
→ Remotely configure operation, access real time and stored data, **firmware updates**

Store years of data
→ Enable edge analytics, long term analysis, USB flash access, more

Embedded web server
→ Works with any PC, laptop, tablet, smart phone, with any web browser

Low pressure range operation (< 5 psig)
→ Know if the breaker operates under inadequate fill conditions

Advanced? Features and Benefits cont'd

|		
Simple 3-LED display	→	Operation signals status and density with 1 psi – even without gauge
Acoustic monitoring	→	Capture breaker events: operation, compressor run, other activity
Digital signal processing	→	Filter banks with each data path tuned to trend specific variables
Virial equation computation	→	Accurately account for the non-ideal behavior of the target gas
Thermal gradient estimation	→	Enhanced accuracy, detect self-heating, infer contact resistance
Extensible data acquisition platform (DAQ)	→	Add sensors, digital and analog outputs, measure and integrate CT's

Platform

The advanced sensor is based upon a proven electro-mechanical density switch.
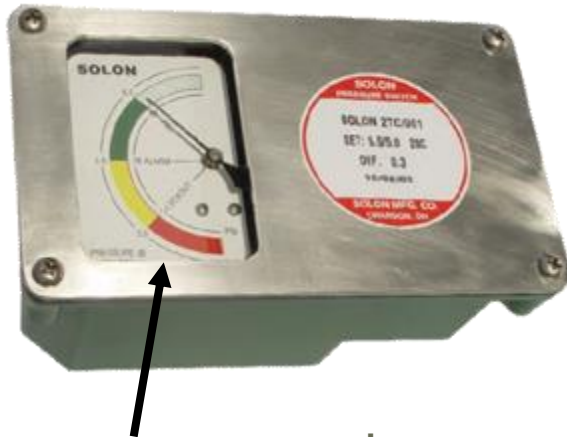
Integral density gauge

Lever actuates up to four SPDT switches adjusted for fill, alarm, and lockout density conditions

Failsafe bi-metal temperature compensation
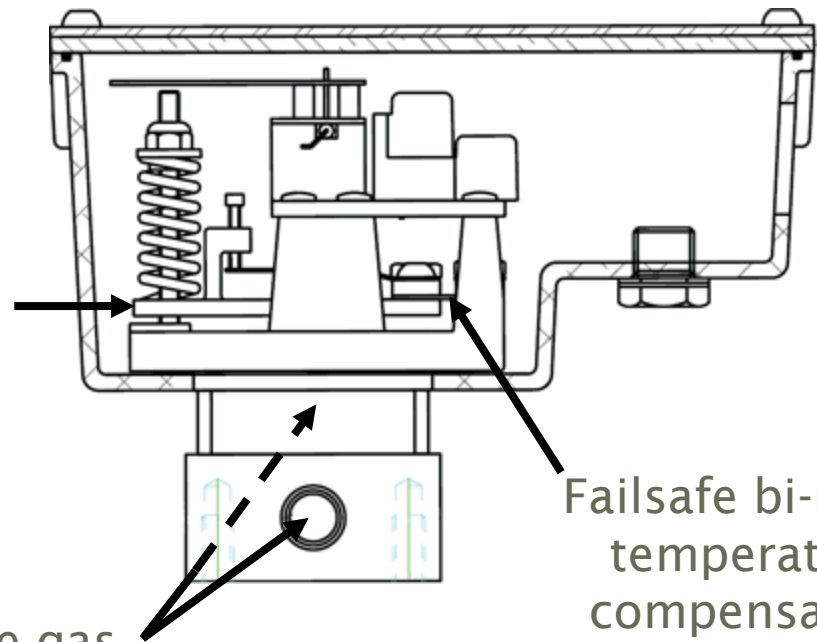
Reliable gas interface

A typical intrinsic configuration is shown.
Bulb type and other styles available.

Electronics

Integrated electronics provide high resolution leak detection and network manageability. User acceptance and familiarity are preserved.

All electromechanical features are retained including integral density gauge

Foolproof circular connector or pluggable terminal

Redundant displacement measurement

SPDT sense interface

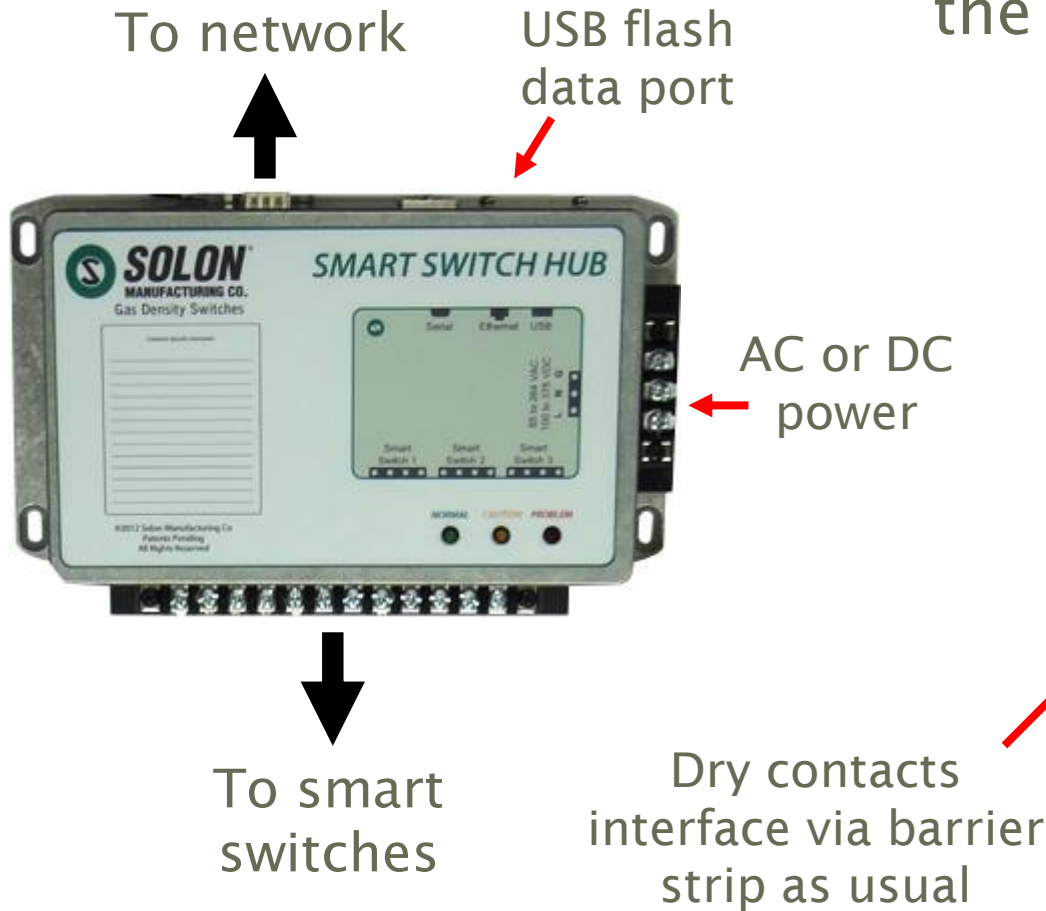Flexible communications interface

Atmospheric pressure sensor

Redundant temperature measurement

Micro-power microcontroller

Robust printed circuit assembly

Hub included

Hub (RTU) interfaces multiple advanced gas sensors and the user's SCADA network.

To network

USB flash data port

AC or DC power

To smart switches

Dry contacts interface via barrier strip as usual

Status

The advanced sensor has passed type tests, cold test, and is currently completing one-year field testing
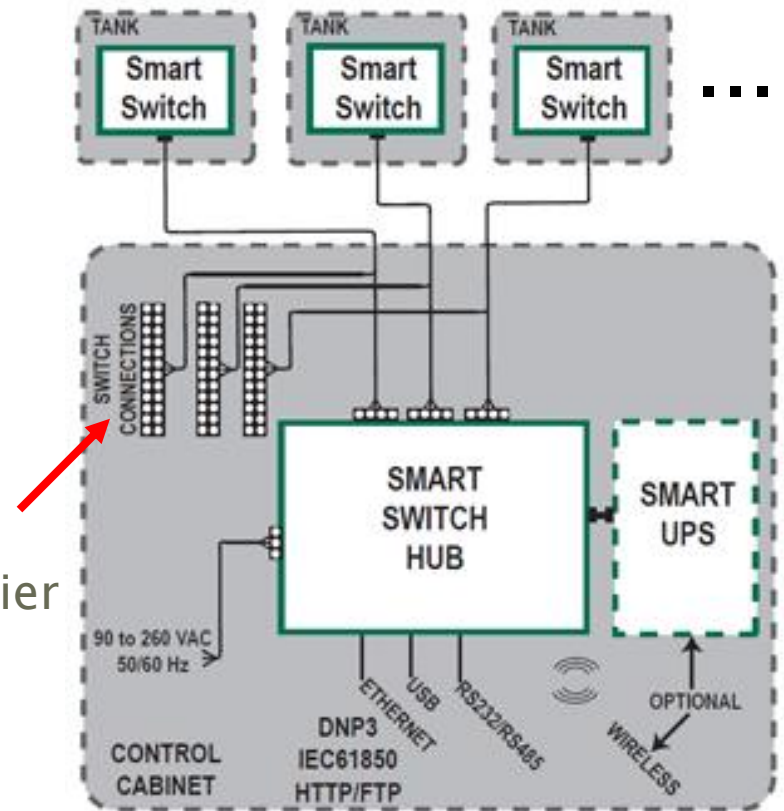
Butler, PA
38 kV, 1200 A
6.8 kg SF_6
~0.17 m^3
75 psig at 21.1 °C

Birmingham, AL
245 kV, 3000 A
53 kg SF_6
~1.4 m^3
71 psig at 20 °C

Web browser view

Web

Web

Temperature corrected pressure and alarm status

RTC	°C	°F
1	15	59
		Outside Bulb
2	17.6	63.7
		Right Tank
3	17	62.6
		Inside Bulb
4	15.2	59.3
		Middle Tank
5	14.9	58.9
		Left Tank
6	15.9	60.5
		2TC Cage

RTC	°C	°F
1	29.1	84.4
		Frame under middle tank
2	30.8	87.5
		Left Tank
3	30.1	86.2
		Middle Tank
4	30.6	87
		2TC Gas Block
5	31.1	88.1
		Bulb Inside
6	36.3	97.3
		SSH Housing

PRESSURE @
70.0°F / 21.1°C
66.7 PSI

PRESSURE @
68.0°F / 20.0°C
65.7 PSI

SW	1	2	3	4
NO/NC	01	10	10	XX

(butler) 2TC #1

SW	1	2	3	4
NO/NC	01	10	10	XX

(butler) DAQ #1

SW	1	2	3	4
NO/NC	10	10	10	XX

(birmingham) 2TC #1

SW	1	2	3	4
NO/NC	00	00	00	XX

(birmingham) DAQ #1

1

2

Web management Device Summary
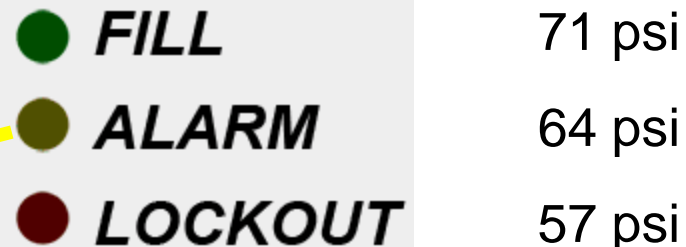
LED indication

Even without a gauge, a good indication of density can be noted by observing the LEDs on the smart switch

Four flashes of the yellow LED (3+1) indicate a temperature corrected pressure on the order of 3-4 psi below alarm level, i.e. 60 to 61 psi.
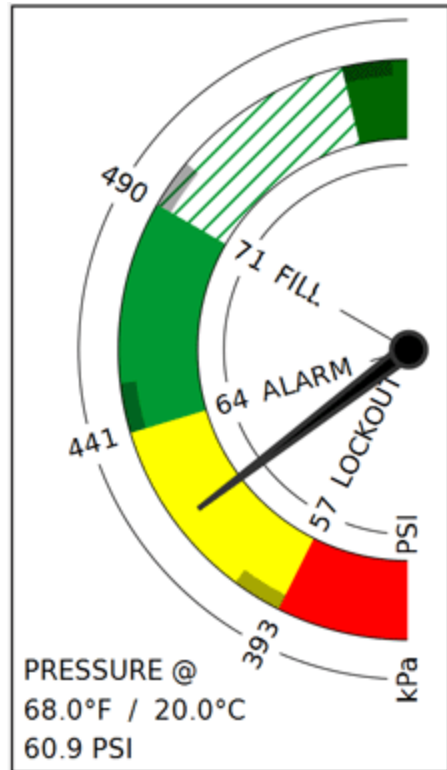
● FILL   71 psi

● ALARM   64 psi

● LOCKOUT   57 psi

A quick flash on the next lower LED indicates a leak condition has been detected.

LED indication

🟢 **FILL**	71 psi
🟡 **ALARM**	64 psi
🔴 **LOCKOUT**	57 psi

Web management   Leak Detection

Birmingham
as of April 24, 2014

RTC	°C	°F
1	29.8	85.7
	Frame under middle tank	
2	31.9	89.4
	Left Tank	
3	30.6	87.1
	Middle Tank	
4	29.5	85
	2TC Gas Block	
5	31.8	89.3
	Bulb Inside	
6	37.3	99.1
	SSH Housing	

SW	1	2	3	4
NO/NC	10	10	10	XX
2TC #1				

SW	1	2	3	4
NO/NC	00	00	00	XX
DAQ #1				

PRESSURE @
68.0°F / 20.0°C
66.2 PSI

+ Device Summary

┌─ Leak Detection ──

Current Leak Rate (g/d)	Time to alarm	Time to lockout
19	58 Days	301 Days
	Sat Jun 21 2014	Thu Feb 19 2015

1   **2**   **3**

Leak rate

RTC	°C	°F	
1	29.8	85.7	Frame under middle tank
2	31.9	89.4	Left Tank
3	30.6	87.1	Middle Tank
4	29.5	85	2TC Gas Block
5	31.8	89.3	Bulb Inside
6	37.3	99.1	SSH Housing

PRESSURE @
68.0°F / 20.0°C
66.2 PSI

SW	1	2	3	4		SW	1	2	3	4
NO/NC	10	10	10	XX		NO/NC	00	00	00	XX
2TC #1						DAQ #1				

+ Device Summary

Leak Detection

Current Leak Rate (g/d)	Time to alarm	Time to lockout
19	58 Days Sat Jun 21 2014	301 Days Thu Feb 19 2015

Time to alarm

Leak Detection

Current Leak Rate (g/d)	Time to alarm	Time to lockout
19	58 Days Sat Jun 21 2014	301 Days Thu Feb 19 2015

Time to lockout

RTC	°C	°F	
1	29.8	85.7	Frame under middle tank
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68.0°F / 20.0°C
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NO/NC	10	10	10	XX	NO/NC	00	00	00	XX
2TC #1					DAQ #1				

+ Device Summary

Leak Detection

Current Leak Rate (g/d)	Time to alarm	Time to lockout
19	58 Days Sat Jun 21 2014	301 Days Thu Feb 19 2015

Web   Application Configuration

These parameters are set by the factory to match the switch setpoints

Web

Atmospheric Pressure Sensor

SW	1	2	3	4		SW	1	2	3	4
NO/NC	10	10	10	XX		NO/NC	00	00	00	XX
2TC #1						DAQ #1				

+ Device Summary

+ Leak Detection

+ Application Configuration

+ Profile Configuration

+ Device Configuration

+ Raw Data

Pressure

ROS Gauge Inc (psi)	ROS Gauge Dec (psi)	ROS Gauge Avg (psi)	ROS Absolute (psi)	**TCor Avg (psi)**
68.6	68.2	68.6	82.8	66.3
HES Gauge Inc (psi)	HES Gauge Dec (psi)	HES Gauge Avg (psi)	HES Absolute (psi)	**Atmosphere Pres (psi)**
71.6	71.3	71.6	85.8	14.25

1

Data log

Set log rates for each switch
Export data to spreadsheet

Data is logged for each switch, for years, ASCII format, spreadsheet compatible

Data log

- Temperature
- Gas pressure (psig)
- Atmospheric pressure
- SF6 Gas density
- Alarm state
- Contact states
- Pressure (corrected)
- Leak rate
- Fill and fault events
- Contact bus voltage

Logged date includes:

Data log data   For each smart switch

	per record	per day	per month	per year
Data records	1	8.5E+04[*]	2.6E+06	3.1E+07
Samples	70	5.9E+06	1.8E+08	2.2E+09
Bytes	292	2.5E+07	7.5E+08	9.0E+09
Compressed bytes	20	1.7E+06	5.1E+07	6.2E+08

*at 1 Hz standard sampling rate (other rates can be programmed)

64 Gb memory store accommodates 100 switch-years
(e.g. 33 years of data for 3 switches, or
1.7 years of data for 64 switches).

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Data log data For each smart switch

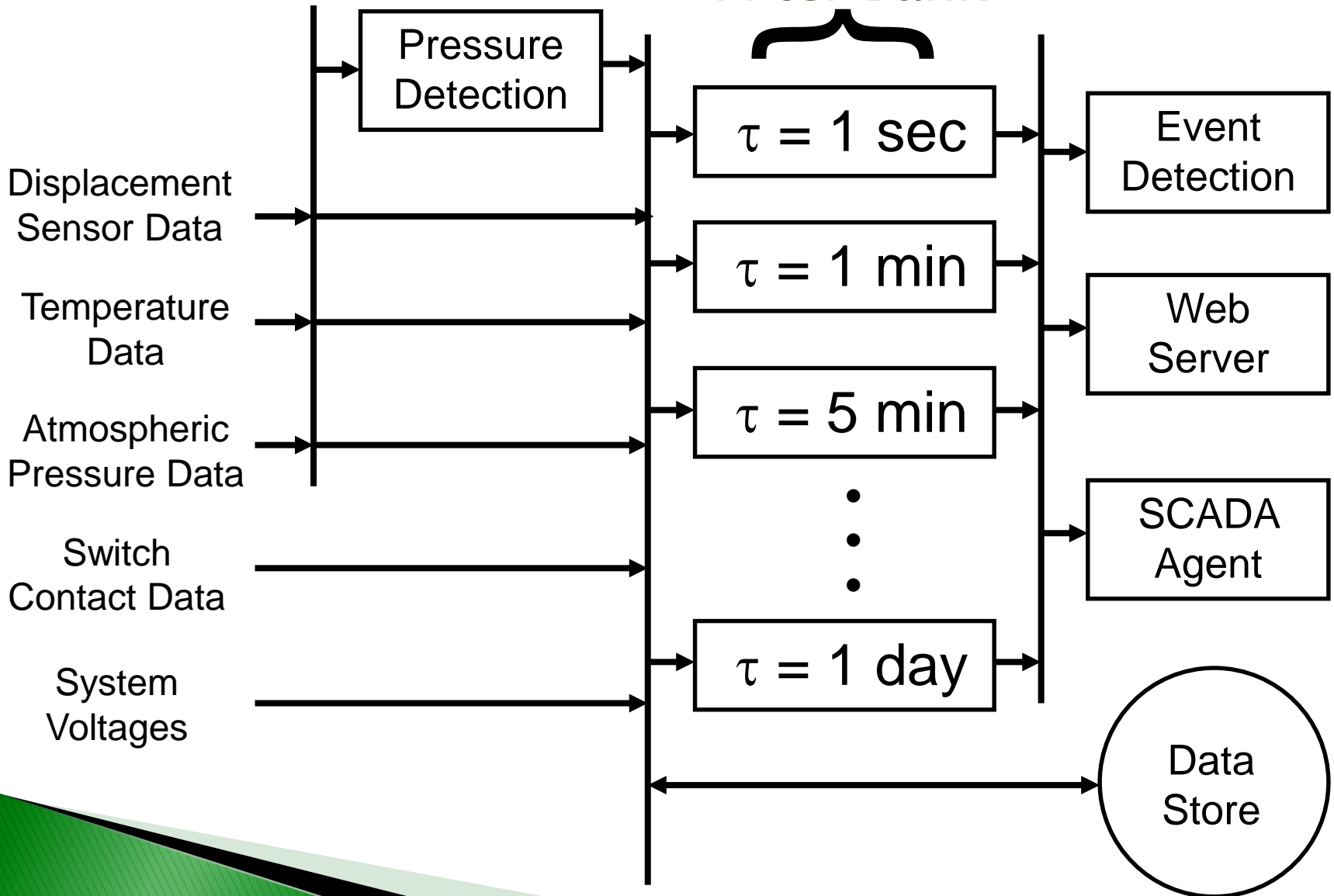|	per record	per day	per month	per year
Data records	1	8.5E+04 *	2.6E+06	3.1E+07
Samples	70	5.9E+06	1.8E+08	2.2E+09
Bytes	292	2.5E+07	7.5E+08	9.0E+09
Compressed bytes	20	1.7E+06	5.1E+07	6.2E+08

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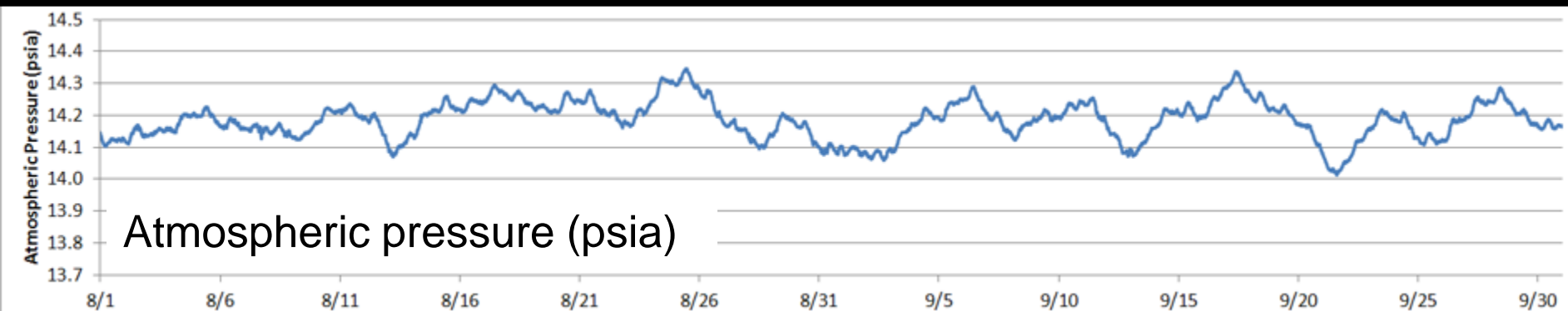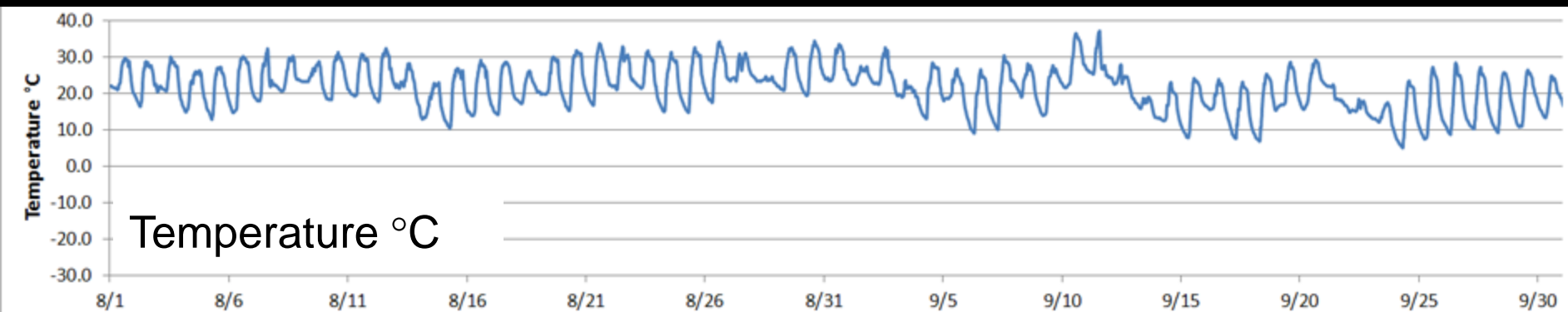(e.g. 33 years of data for 3 switches, or
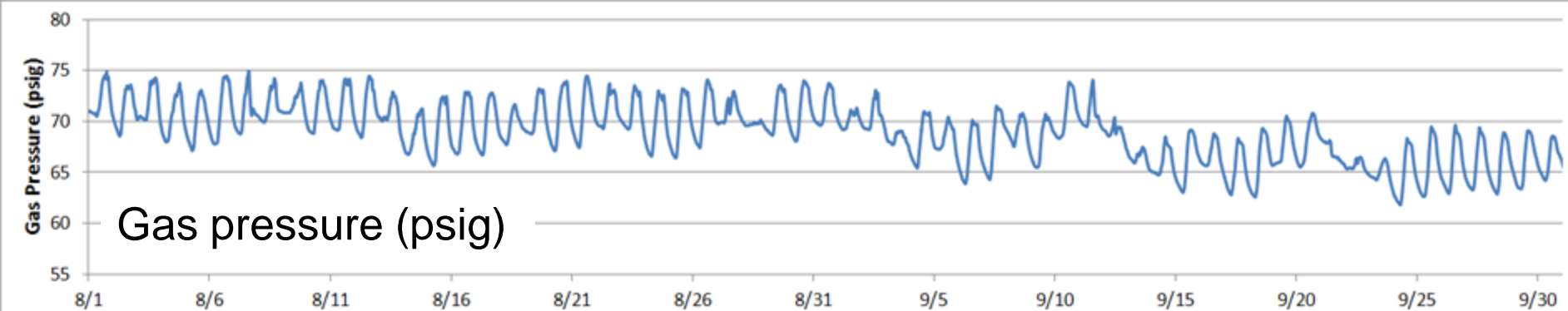1.7 years of data for 64 switches).
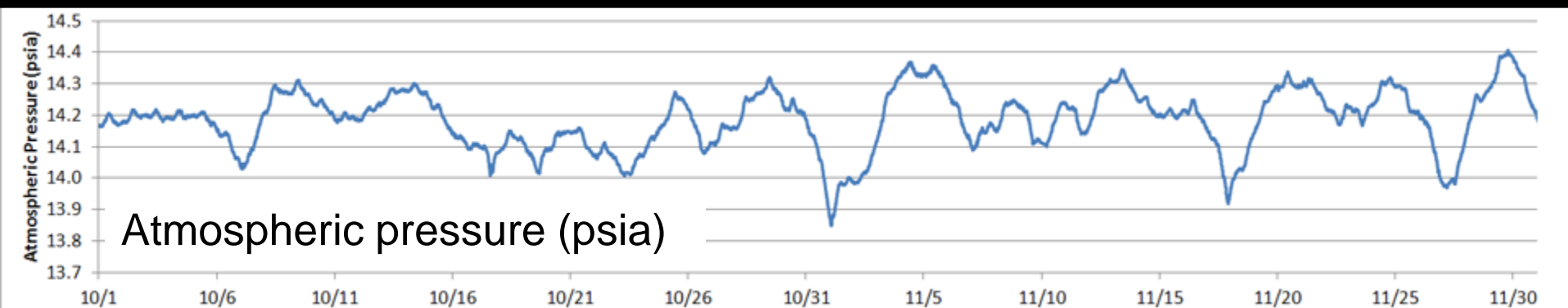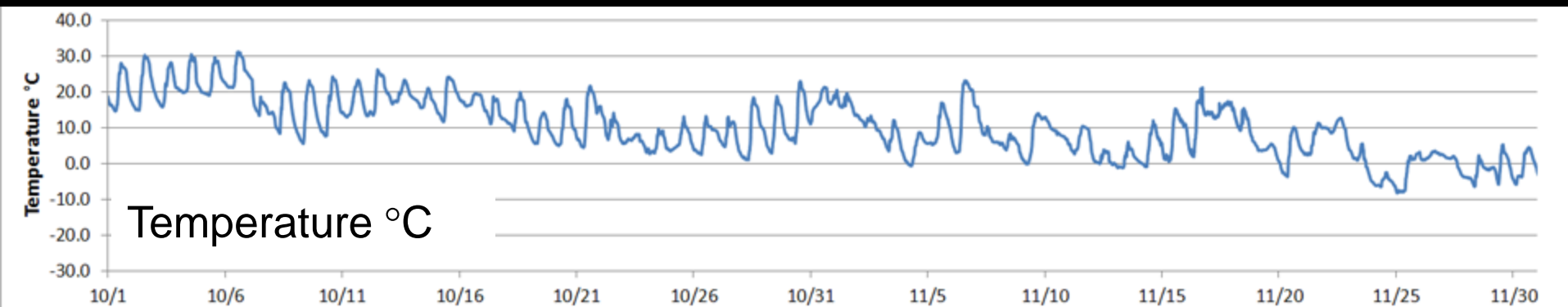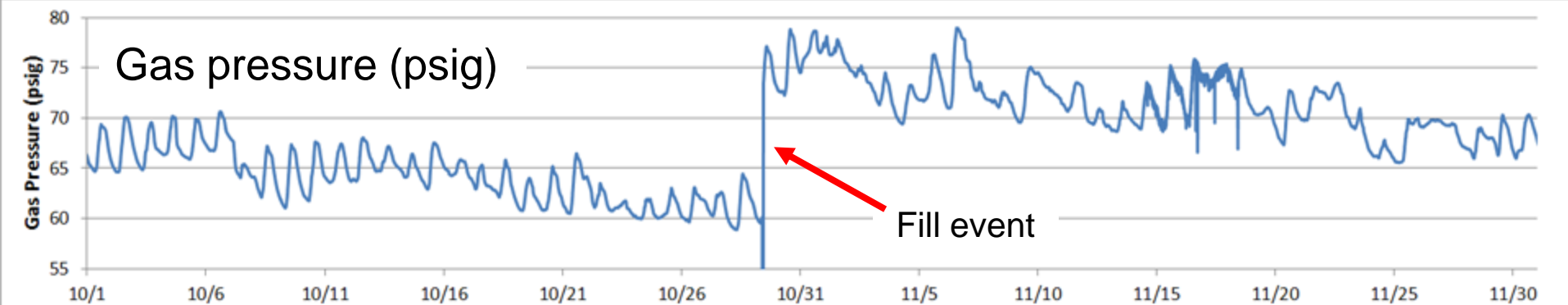
Data flow

Digital processing throughout Filter Bank

Basic data

Gas pressure (psig)

Temperature °C

Atmospheric pressure (psia)

Basic data

Gas pressure (psig)

Fill event

Temperature °C

Atmospheric pressure (psia)

Basic data

Gas pressure (psig)

Temperature °C

Atmospheric pressure (psia)
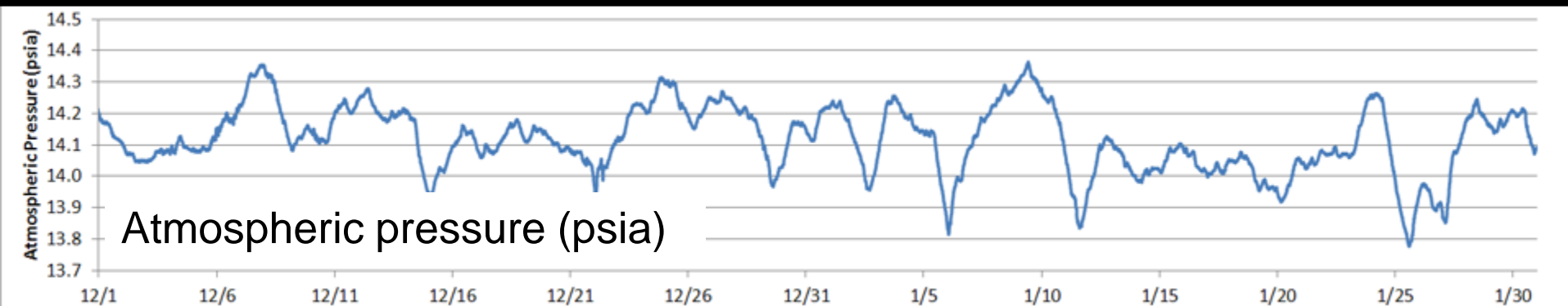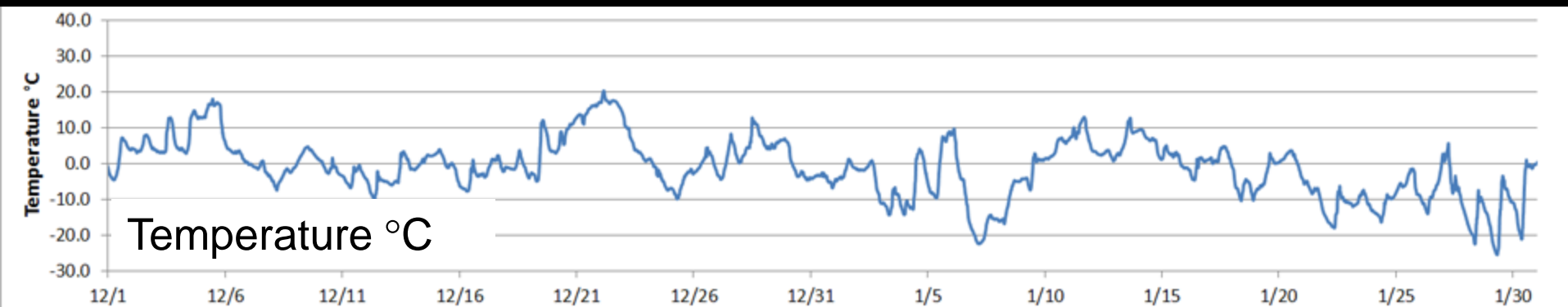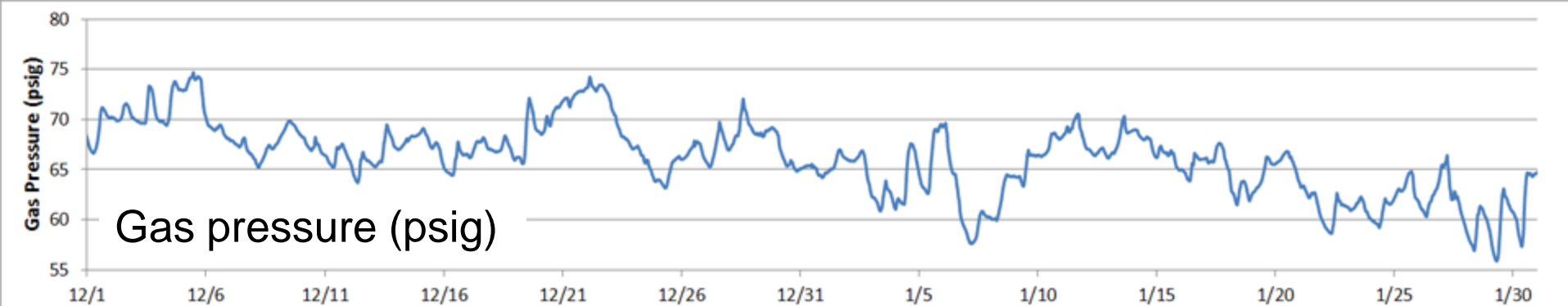
Leek estimation   Butler, PA Aug–Jan

Gas density (kg/m³)

FILL

ALARM

LOCKOUT

Fill event
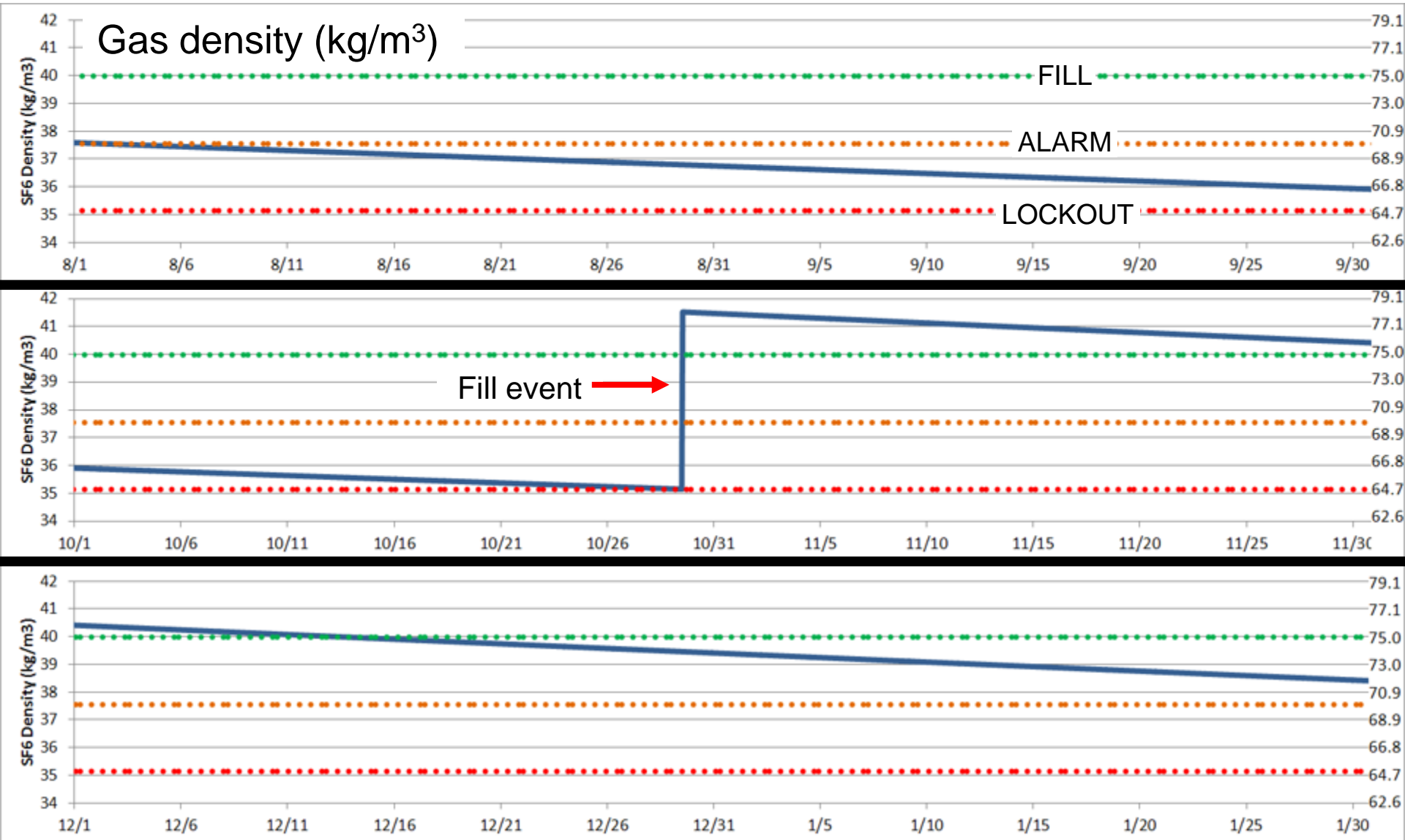
Alarm prediction   Butler

From January data, the smart switch predicts alarm threshold
will be reached late February to early March

Good match! Butler, 2/27 to 3/2/2014

Gas density (kg/m³)

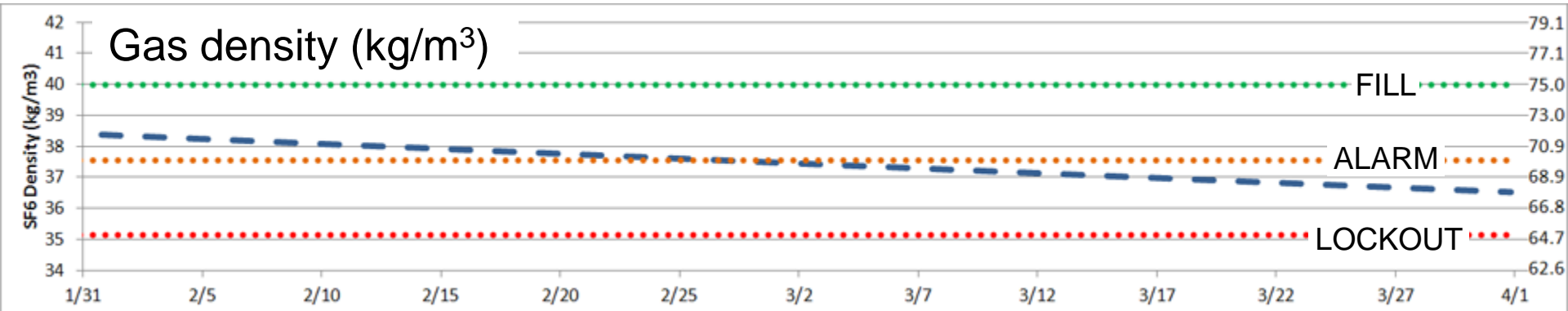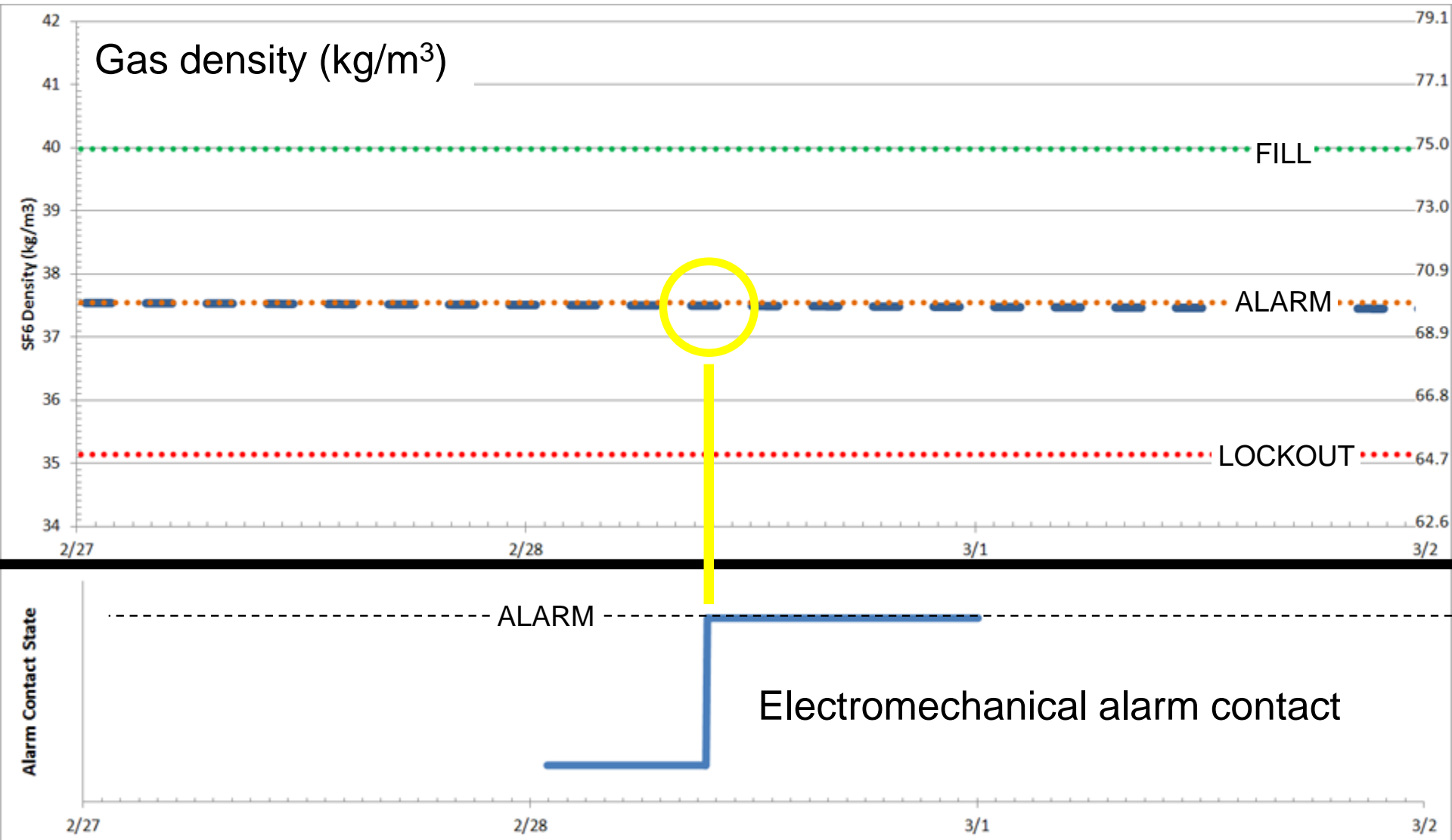FILL

ALARM

LOCKOUT

ALARM

Electromechanical alarm contact

Hi-res data   Butler, Sunday, 4/13/14

Gas pressure (psig)

Gas density = 35.98 kg/m^3

Temperature °C

Atmospheric pressure (psia)
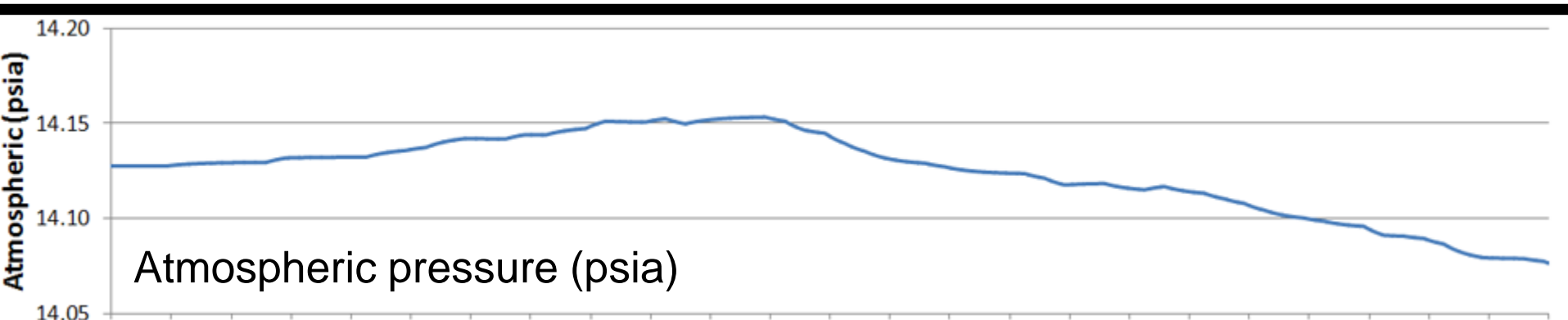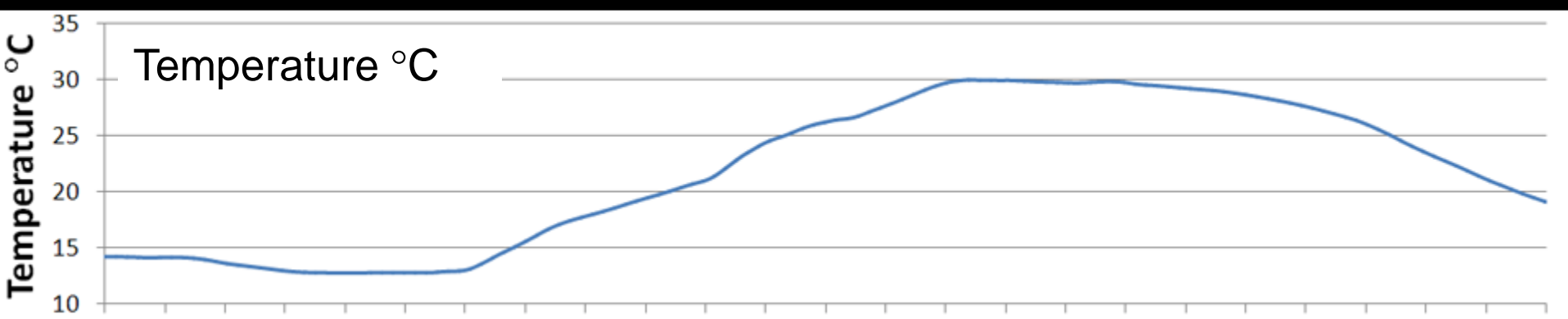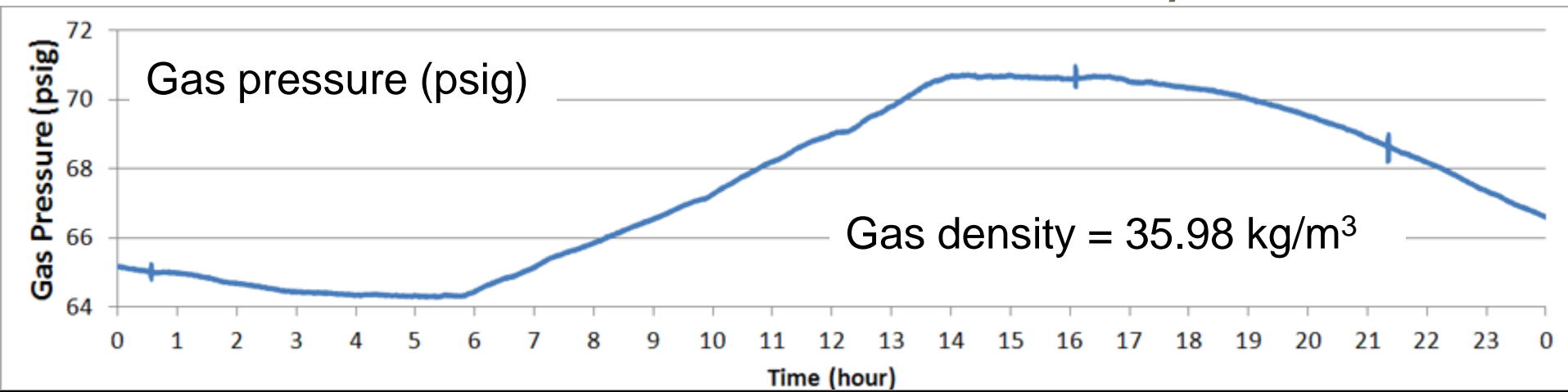
Event capture   Butler, PA 4−13−2014
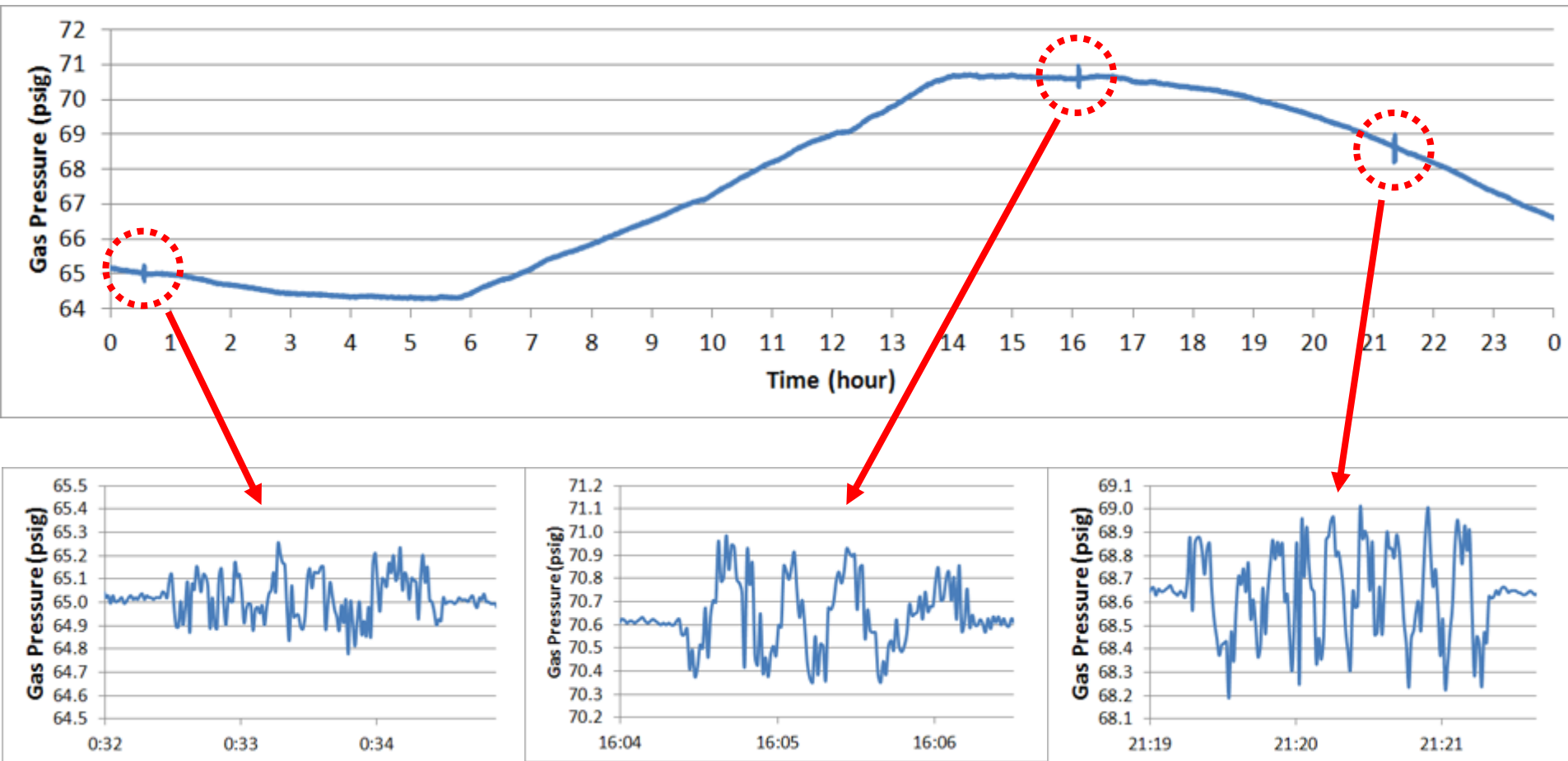
Air compressor operation: 2-minute runtime,
0.4 to 0.8 psi peak-to-peak vibration amplitude, operating
period varies from 5 to 15 hours

Data matches theory?

Butler, PA 4-13-2014

Gas density = 35.98 kg/m³

$$P = R \bullet T \bullet \left(\frac{n}{V} + B(T) \bullet \frac{n^2}{V^2} \right)$$

P

T
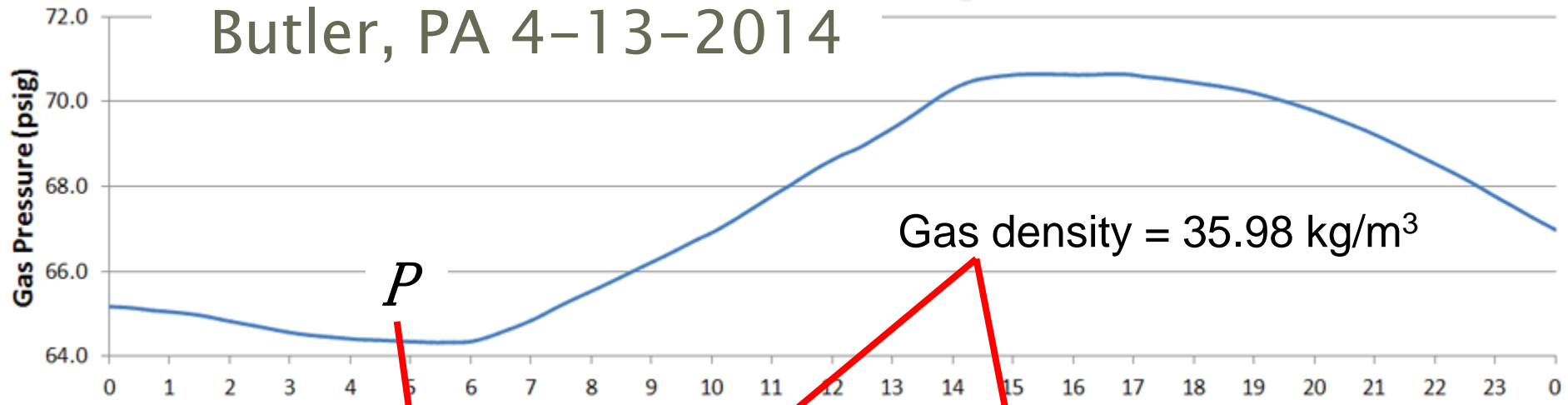
Density inferred temperature:

Butler, PA 4-13-2014

Gas density = 35.98 kg/m³
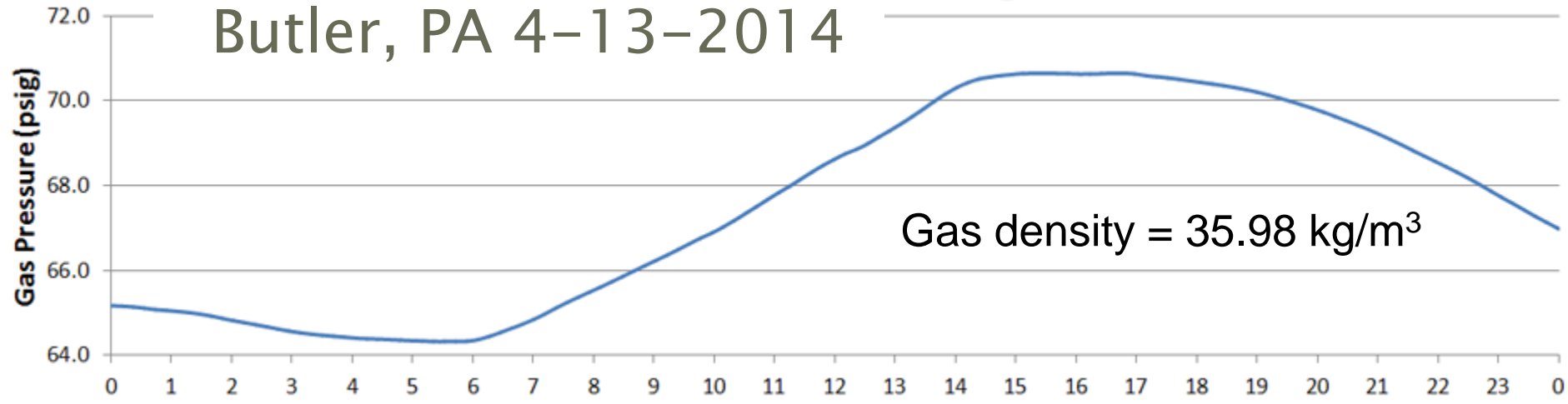
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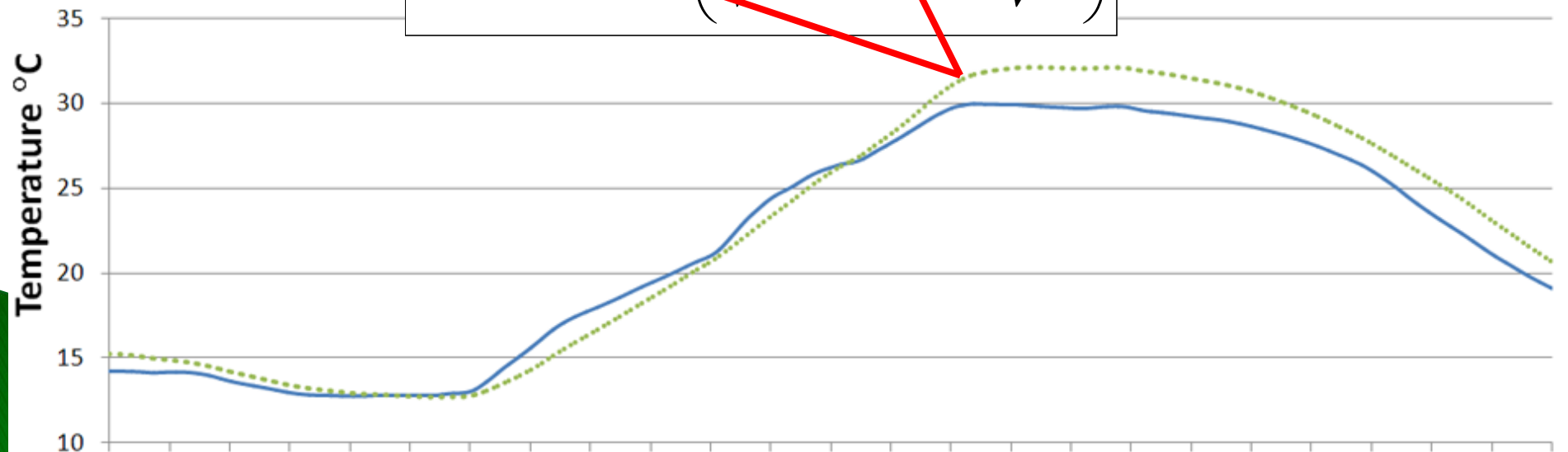
Configuration

N-NE
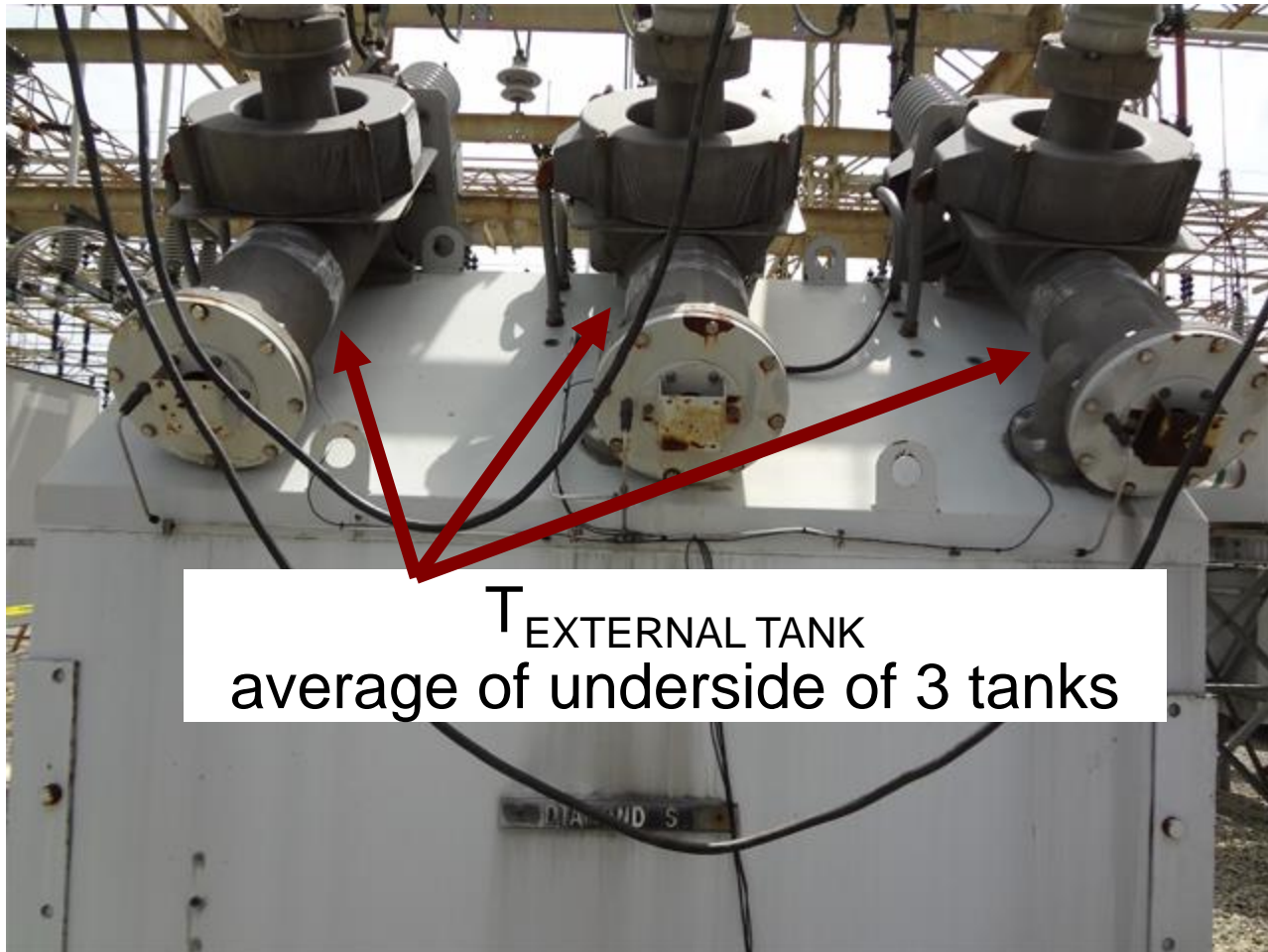
$T_{EXTERNAL TANK}$
average of underside of 3 tanks

T_{SENSOR}
under cabinet

Double check
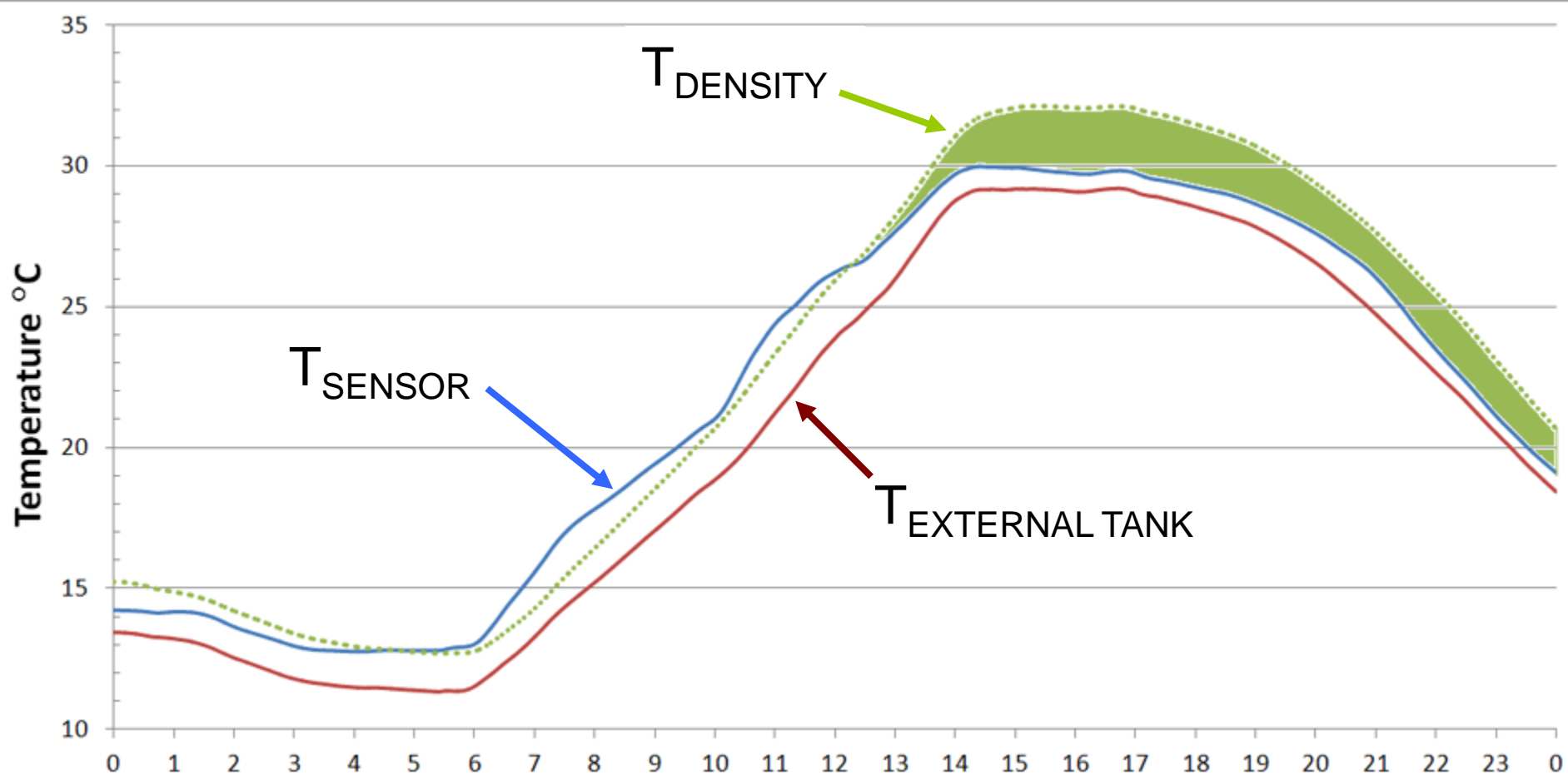
Temperature difference is not explained simply by tank vs. sensor differences

Interpretation
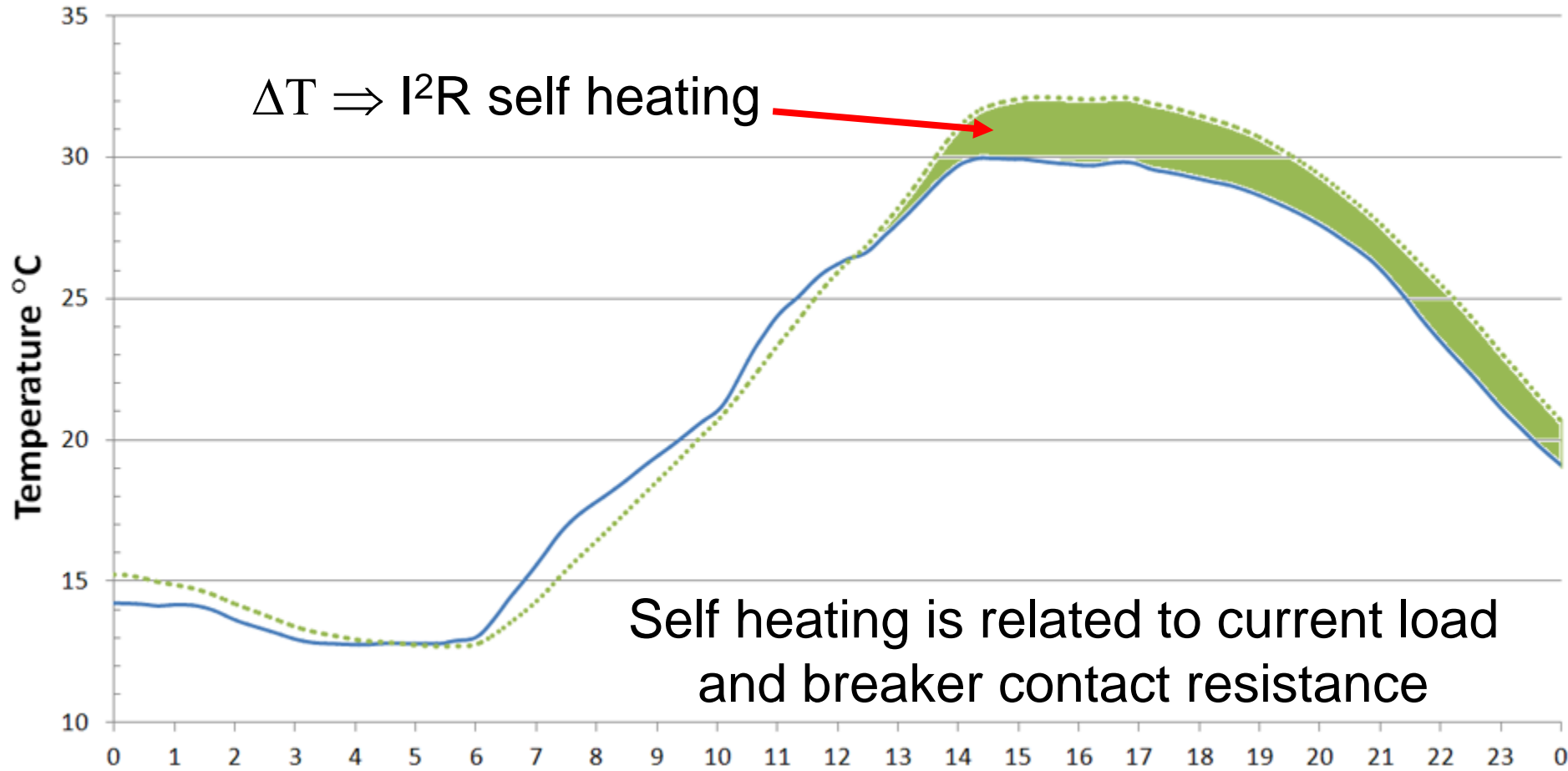
$\Delta T \Rightarrow I^2R$ self heating

Self heating is related to current load and breaker contact resistance

Trending changes in breaker contact resistance is valuable information

Event capture Butler, Tuesday, 10/29/13

Gas pressure (psig)

Gas density = 35.15 kg/m^3

Gas density = 41.52 kg/m^3

Gas line disconnected
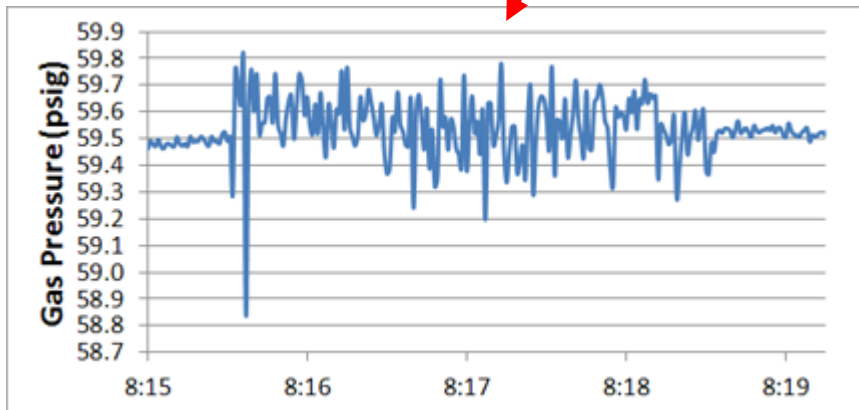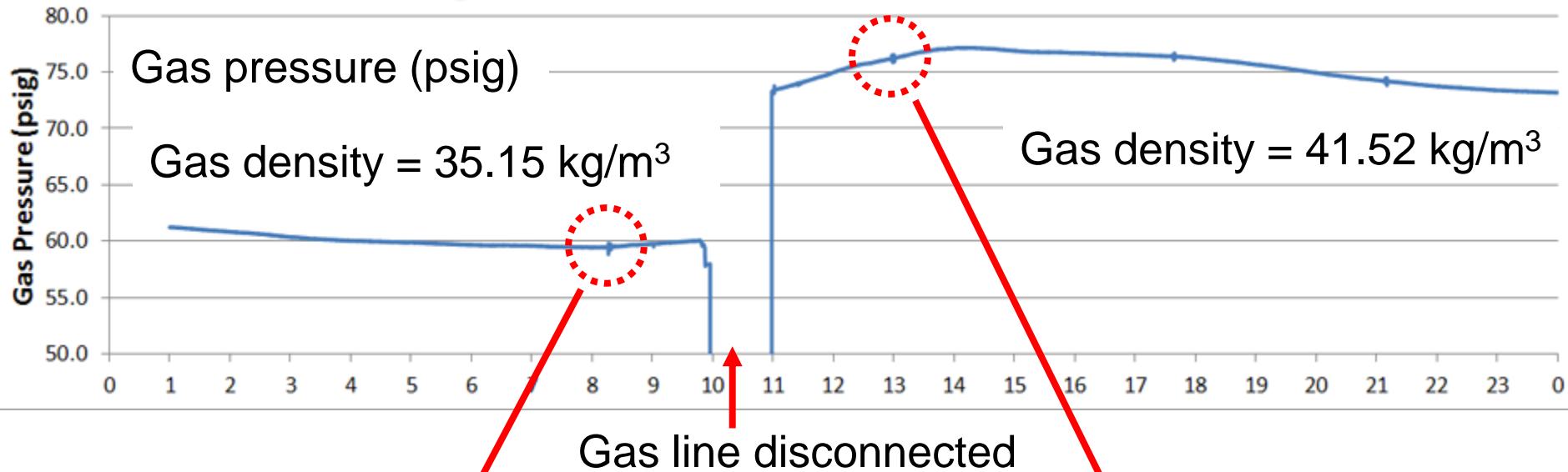
Breaker operates at 8:15
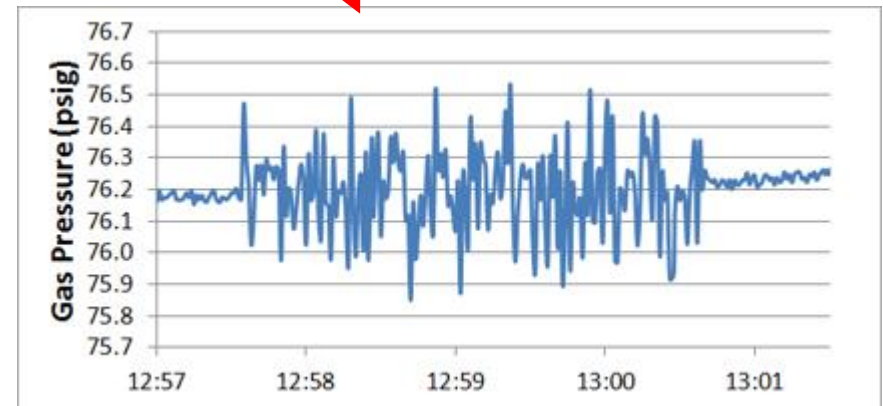
Restart at 12:58

Similar events captured to < 5 psig

Density inferred temperature

Butler, Tuesday, 10/29/13

$T_{DENSITY}$

T_{SENSOR}
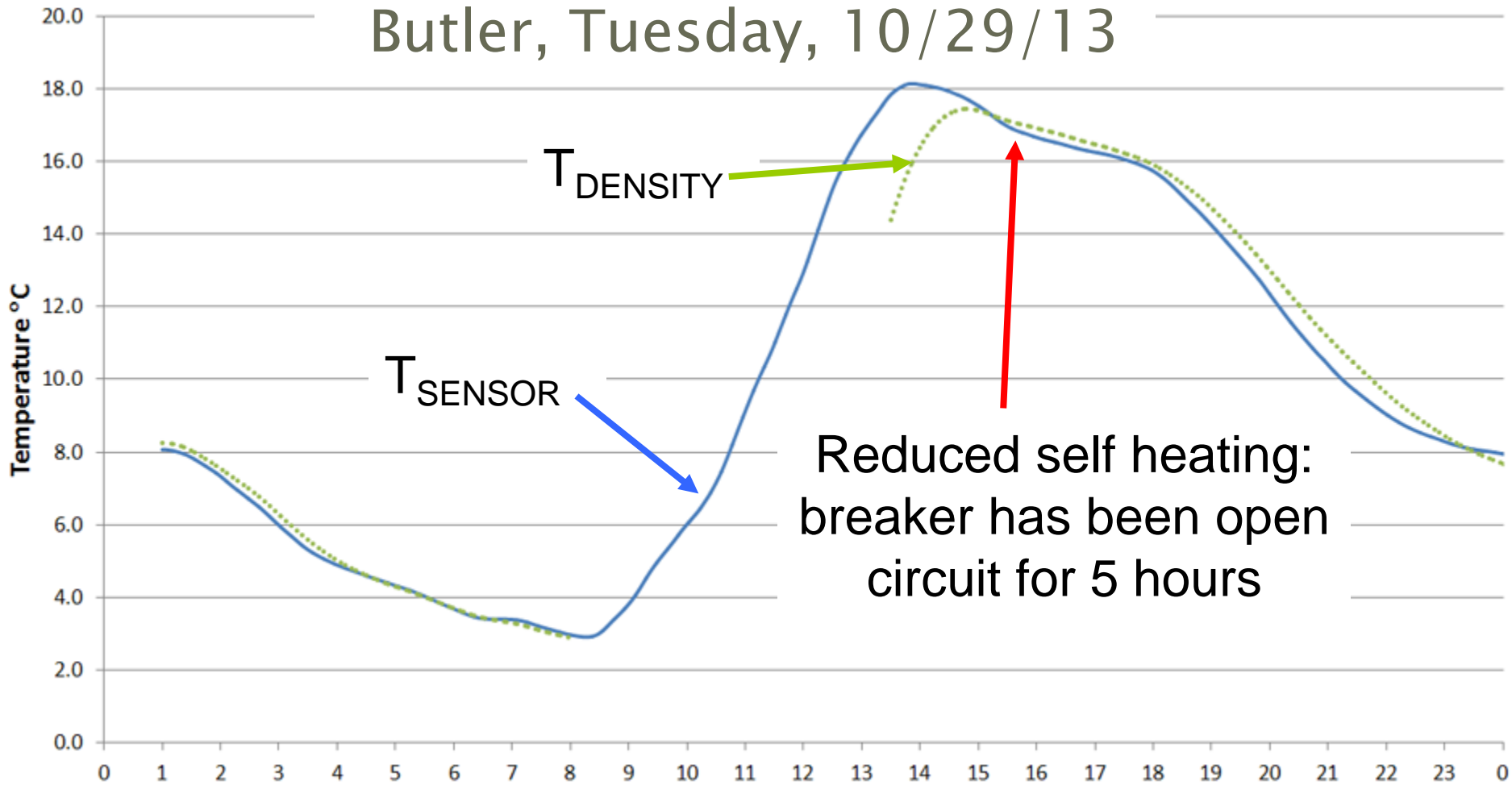
Reduced self heating: breaker has been open circuit for 5 hours

Density inferred temperature
Butler, Wednesday, 4/23/14

$\Delta T \Rightarrow I^2R$ self heating
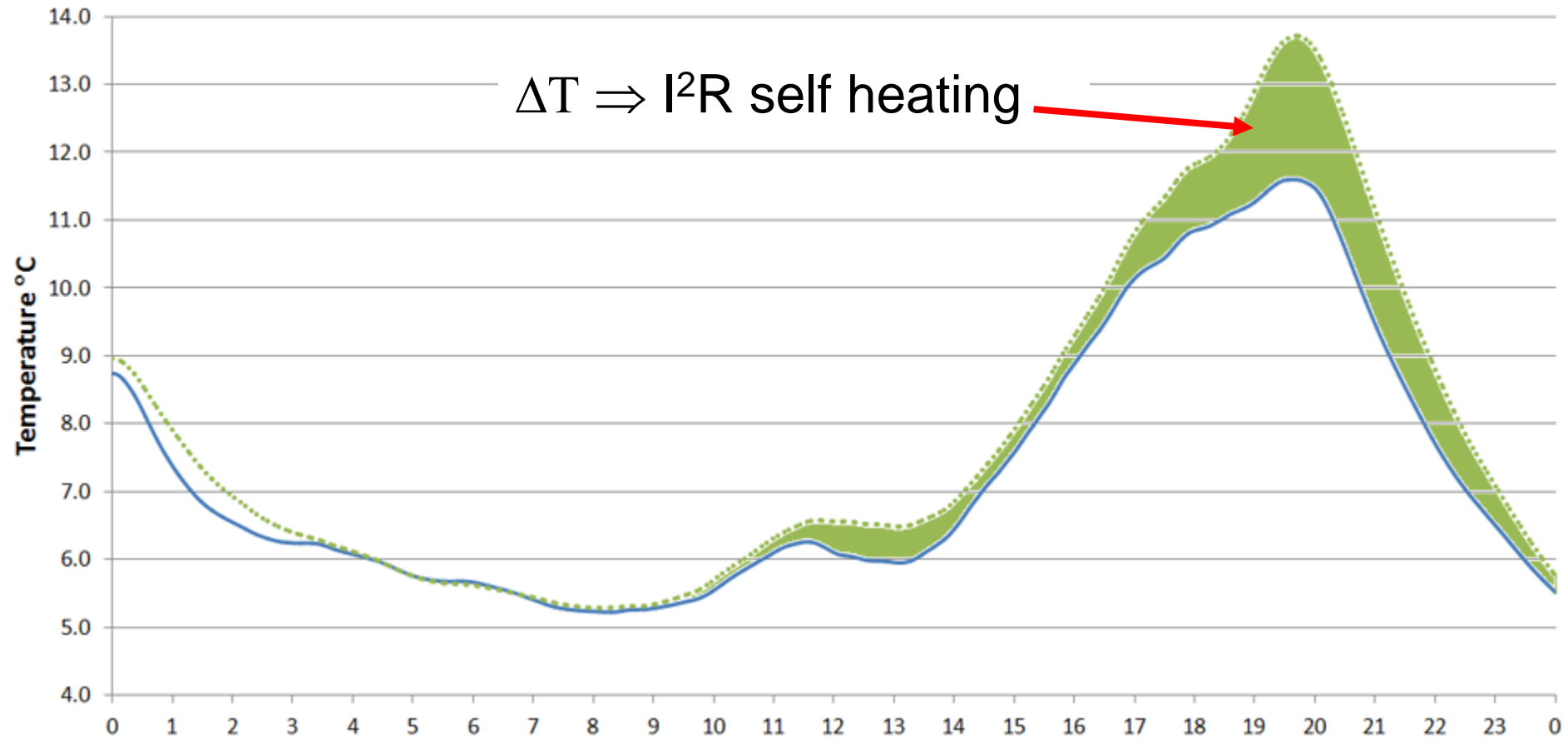
Bulb failure

If this fails ...

The electronic adaptation is similar.

... electronics instantly detect and report lever over-deflection

The preceding examples have been intrinsic type devices. Bulb type and other styles are available. The electronic adaptation to all types is similarly effective.

Extensible

Data acquisition extension with temperature and switch tallies

Extensible

To Smart Switch

To 6 x External Temperature Probes

SPDT Contact Tallies

DAQ Type 1 interfaces to any hub switch port

Networked

Data acquisition extension with temperature and switch tallies

RTC	°C	°F
1	15	59
		Outside Bulb
2	17.6	63.7
		Right Tank
3	17	62.6
		Inside Bulb
4	15.2	59.3
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PRESSURE @
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(butler) 2TC #1

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(butler) DAQ #1

RTC	°C	°F
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PRESSURE @
68.0°F / 20.0°C
65.7 PSI

SW	1	2	3	4
NO/NC	10	10	10	XX

(birmingham) 2TC #1

SW	1	2	3	4
NO/NC	00	00	00	XX

(birmingham) DAQ #1

1

2

Extensible

Standard and custom DAQ modules

Smart Switch

Multi-channel Temperature

4-20 ma Interface

Current Transformer I/F

Digital IO Module

Analog IO Module
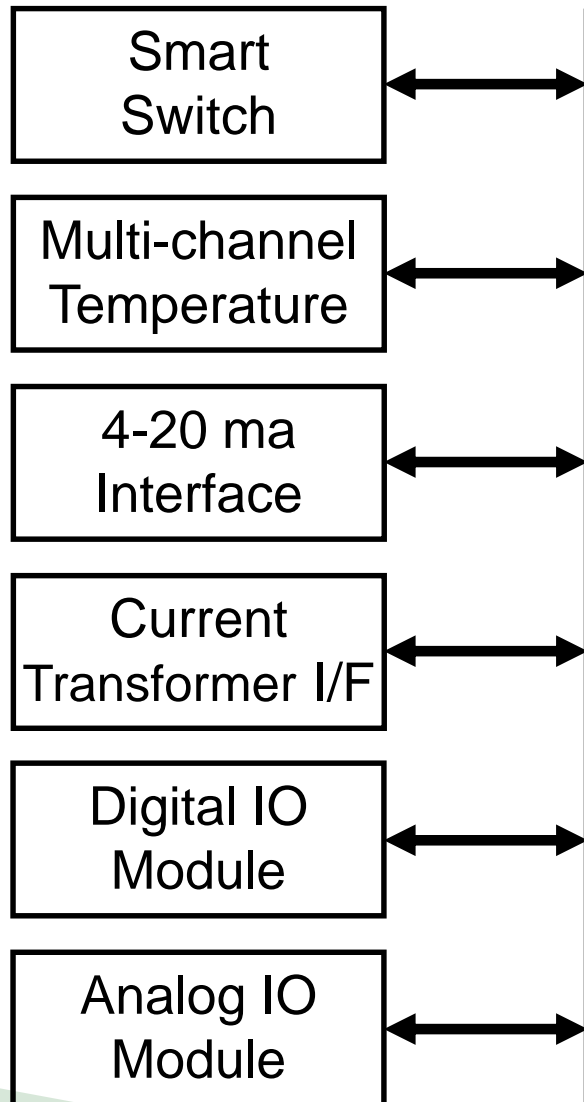
To network

USB flash data port

Alarm prediction
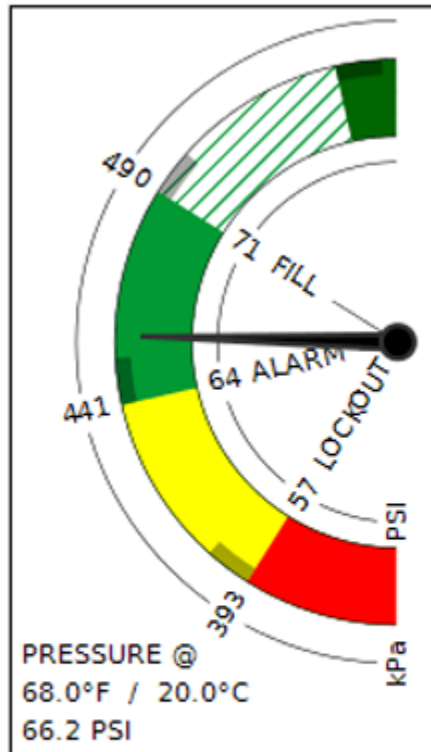
Leak Detection

Current Leak Rate (g/d)

19

Time to alarm

58 Days
Sat Jun 21 2014

Time to lockout

301 Days
Thu Feb 19 2015

Current density   35.65 kg/m^3

Current mass   49.32 kg

Summary

- Electromechanical density switch with up to four setpoints continues to operate independently (but electronics also serve to validate this operation)

- Advanced features bring many benefits including leak detection, time to alarm or lockout estimation, breaker event capture, valuable diagnostics, and more...

- Extensible data acquisition supports many maintenance and troubleshooting applications

- Flexible network interface, configuration, and data retrieval options allow data to be put to practical use, as well as remote firmware and algorithm updates

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Belleville Springs and Pressure Switches

MODTECH CORP.

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Advanced SF6 Gas
Monitoring Systems

Thank you!

Solon Manufacturing Co.
Pressure Switch Division