Executive Report on the Evaluation of GSA Total Estimated Cost Impact (TECI) Metrics and Building Benchmarking

ISWG Presentation October 2020

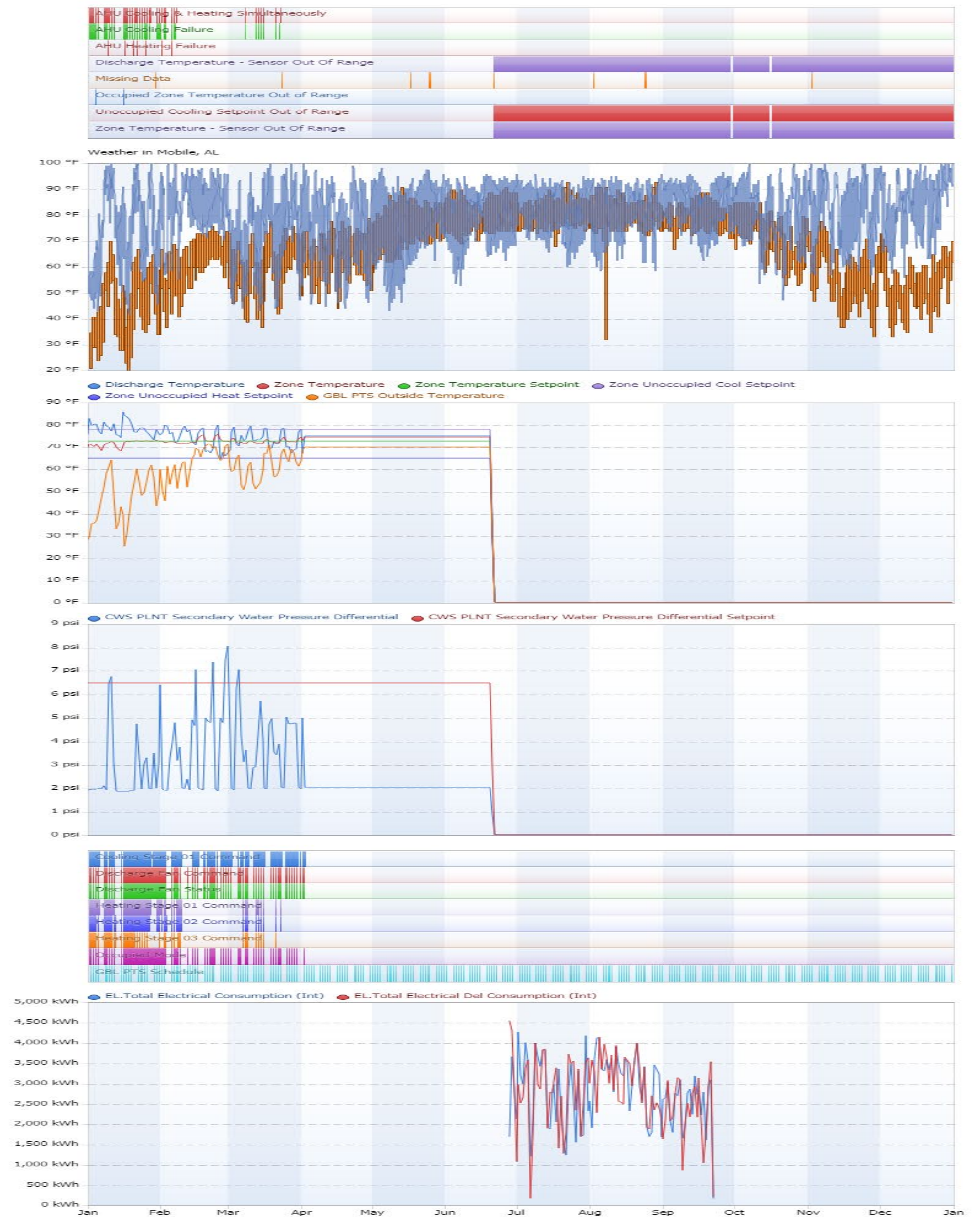
Carnegie Mellon University

Center for Building Performance & Diagnostics

Vivian Loftness, Azizan Aziz, Chenlu Zhang, Yujie Xu

Big Data! Advanced Meters and GSALink provides Building Managers, Regional Managers and the Central Office *a Dashboard with Integrated Access to*:

1. **Advanced Meter data** (Ion EEM 15 minute interval data)
2. **Building Automation data**
   (BAS sensor and controller settings for equipment and spaces)
3. **Weather** data
4. Key **GSA specifications** for facility and building equipment (age, climate, etc)
5. Equipment specific **Sparks** - to facilitate decisions for Energy and IEQ
6. **Total Estimated Cost Impacts** (energy, maintenance and social TECI) for Spark inaction
7. 'Second Eyes' **GSALink Team** with building and equipment specific expertise



AHU failures 15 min intervals, for multiple years

Setpoints vs outdoor temperature 15 min intervals, for multiple years

Zone temperatures 15 min intervals, for multiple years

Secondary water pressure 15 min intervals

Setpoints 15 min intervals, for multiple years

Total electrical 15 min intervals, for multiple years

The GSALink maintains a cumulative data base on energy, BAS and TECI's that provide portfolio wide expertise for GSA building management with over 90 buildings to date.

- Normalized, tagged, and aggregated datasets.
- Operational data in across +57 million square ft of GSA real estate. +46,000,000,000 time-series points of historical data, with 55,660,986 points added daily.
- Utilizes analytics rules to make operational recommendations, integrated closely with GSA's Computerized Maintenance Management System (CMMS).

No other multi-variable database is maintained year over year, and the BAS industry will charge per BAS point and utility meter every year.

Advances in Spark Management and TECI Prioritization Metrics

In 2013, a Total Estimated Cost Impact (TECI) was implemented by IBM and used for prioritization in Tririga, calculated using Spark duration and Static Dollar/Hour value assigned to each rule.

OA < 65 degrees then

$$Energy = \left(\left(\frac{Cooling\ BTU}{3412.14} \times\ kWh\ Rate\ x\ 0.5\right) + \left(\frac{Heating\ BTU}{3412.14} \times\ kWh\ Rate\right)\right) \times 15\%\ (Adj.\ Multiplier) \times Spark\ Duration$$

$$Maintenance = ((Area\ Served\ \times O\&M\ \$/sqft/yr)\ /\ 365\ days\ /\ 24\ hours) \times 25\%\ (Adj.\ Multiplier) \times Spark\ Duration$$

$$Social = (Area\ Served \times \frac{1\ Person}{10{,}000\ sqft}) \times Hourly\ Spend \times 10\%\ Prod\ Decrease \times 20\%\ (Adj.\ Multiplier) \times Occ\ Duration$$

$$Final\ Cost = (Energy + Maintenance + Social)$$

AHU Economizing and Cooling

$$Energy = \left(\frac{Cooling\ BTU}{3412.14} \times kWh\ Rate\right) \times 25\%\ (Adj.\ Multiplier) \times Spark\ Duration$$

$$Maintenance = ((Area\ Served\ \times O\&M\ \$/sqft/yr)\ /\ 365\ days\ /\ 24\ hours) \times 25\%\ (Adj.\ Multiplier) \times Spark\ Duration$$

$$Social = (Area\ Served \times \frac{1\ Person}{10{,}000\ sqft}) \times Hourly\ Spend \times 10\%\ Prod\ Decrease \times 25\%\ (Adj.\ Multiplier) \times Occ\ Duration$$

$$Final\ Cost = (Energy + Maintenance + Social)$$

AHU Economizing and Heating

$$Energy = \left(\frac{Heating\ BTU}{3412.14} \times kWh\ Rate\right) \times 10\%\ (Adj.\ Multiplier) \times Spark\ Duration$$

$$Maintenance = ((Area\ Served\ \times O\&M\ \$/sqft/yr)\ /\ 365\ days\ /\ 24\ hours) \times 25\%\ (Adj.\ Multiplier) \times Spark\ Duration$$

$$Social = (Area\ Served \times \frac{1\ Person}{10{,}000\ sqft}) \times Hourly\ Spend \times 10\%\ Prod\ Decrease \times 25\%\ (Adj.\ Multiplier) \times Occ\ Duration$$

$$Final\ Cost = (Energy + Maintenance + Social)$$

In June 2017 with the migration to Maximo (CMMS), a more accurate model was implemented, customizing TECI values at the equipment level for:

- **Energy Impacts (eCost)**
- **Maintenance Impacts (mCost)**
- **Social/Human Impacts (sCost)**

The CMU 2019 Study assessed the accuracy of the calculations with time series energy data.

66 Spark Rules in the GSALink SkySpark operational support system tied to building HVAC assets

(a lot of brainpower in this list)

HVAC RULES

AHU Cooling and Heating Cycling
AHU Cooling and Heating Simultaneously
AHU Cooling Failure
AHU Cooling Valve Leaking
AHU Cooling Valve Unstable
AHU Damper Unstable
AHU Discharge Fan Failure
AHU Discharge Fan Unstable
AHU Discharge Pressure Setpoint Unreachable
AHU Discharge Pressure Unstable
AHU Discharge Temperature Setpoint Unreachable
AHU Discharge Temperature Unstable

AHU Economizing and Cooling
AHU Economizing and Heating
AHU Excessive Discharge Fan Speed

AHU Excessive Outside Air During Unoccupancy
AHU Excessive Return Fan Speed
AHU Heating Failure
AHU Heating Valve Leaking
AHU Heating Valve Unstable
AHU Outdoor Damper Stuck Closed
AHU Outdoor Damper Stuck Open
AHU Outside Airflow Too Low
AHU Outside Airflow Unstable
AHU Return Pressure Setpoint Unreachable

Boiler Cycling
Boilers Running During Warm Weather
Hot Water Pressure Unstable

Chiller Cycling
Chilled Water System Failure
Chilled Water Pressure Setpoint Unreachable
Chilled Water Pressure Unstable
Chiller Running During Unoccupied Periods
Cooling Tower Temp Setpoint Unreachable

Occupied Cooling Setpoint Out of Range
Occupied Heating Setpoint Out of Range
Occupied Zone Temperature Out of Range
Pump Cycling
Sensor Failure
Sensor Out of Range

Terminal Unit Airflow Setpoint Unreachable
Terminal Unit Airflow Unstable
Terminal Unit Heating Failure
Terminal Unit Heating Valve Leaking
Unoccupied Cooling Setpoint Out of Range
Unoccupied Heating Setpoint Out of Range

Unoccupied Zone Temperature Out of Range
Zone Cooling Damper Malfunction
Zone Heating Damper Malfunction
Zone Over Cooling
Zone Over Heating
Zone Pressure Setpoint Unreachable

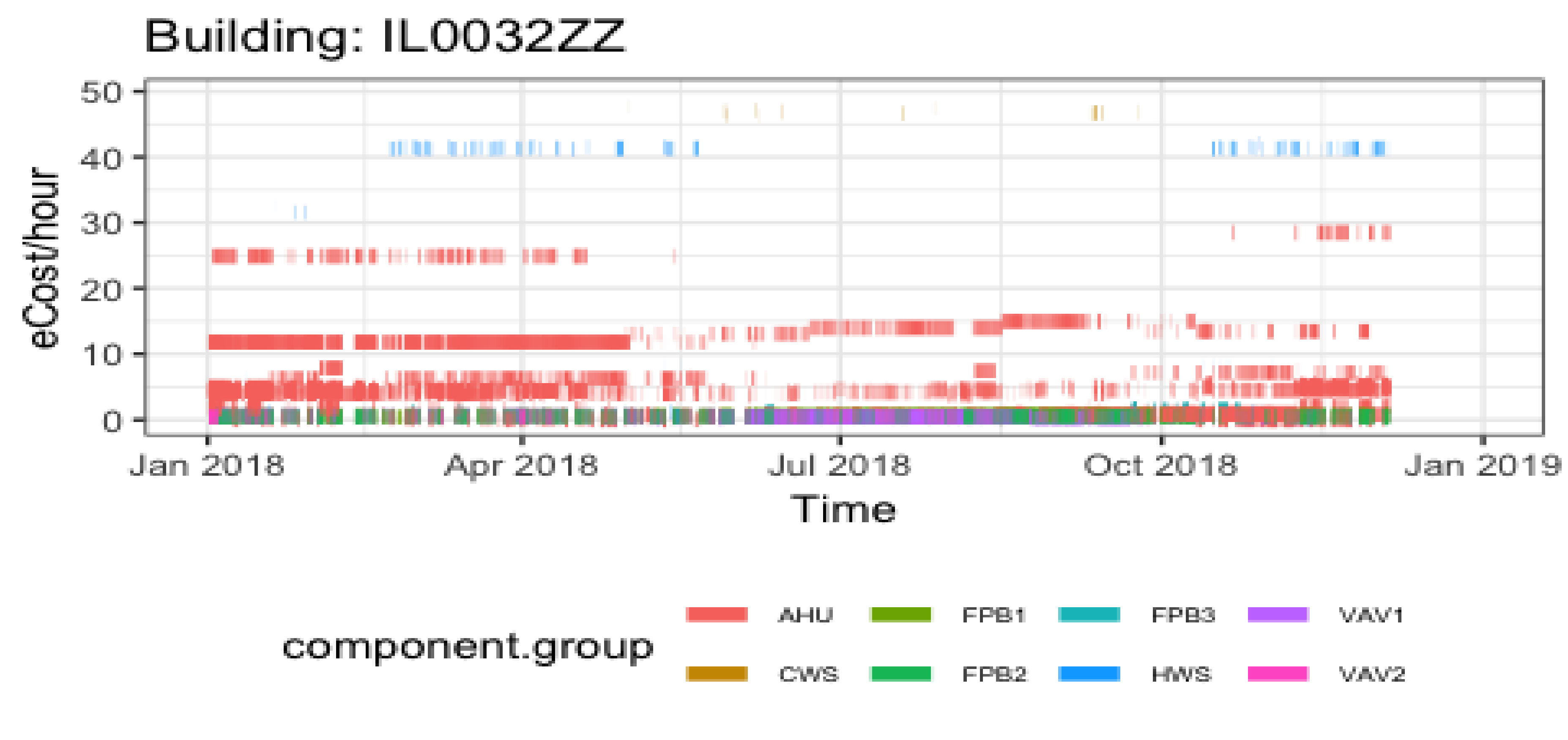
ENERGY RULES

Building Running Too Late
Building Starting Too Early
Excessive Water Usage During Unoccupancy
Maximum Peak During Unoccupancy
Short Demand Peak

DATA RULES

Bad Energy Data
Double Dipping Data
Missing Data

It is critical to understand that a wide range of Sparks occur in each GSA building for very diverse time periods, as illustrated by a year of Sparks in IL0032ZZ. Data analytics of a full year of 15-minute data for 60 buildings across the US reveals energy costs of Sparks.



Methodology: **Ridge regression analysis of actual energy use assigns weighting (impact multipliers) between a string of simultaneous Sparks.**

- Data aggregated to hourly-whole building scale
- Summing the energy, and adding up all minutes of Spark rules triggered for equipment.

$$BTU_{bt} = \beta_0 + \sum_{brt} \beta_{br} Minutes_{brt} + \gamma_b temperature_{bt} + \epsilon_{it}$$

Where *minutes_brt* is the total spark duration in minutes of rule *r* triggered in building *b* during the hour *t. temperature_bt* is the outdoor temperature of building b at hour *t*.

FY18 Sparks TECI and Data Analysis: CMU Results

Energy Cost Impacts
$7 million in savings
for 60 buildings in 2018

+

Maintenance Cost Impacts
$4 million in savings
for 60 buildings in 2018

+

Social Cost Impacts
$6 million in savings
for 60 buildings in 2018

GSAlink Operations annual cost per building: $33,000

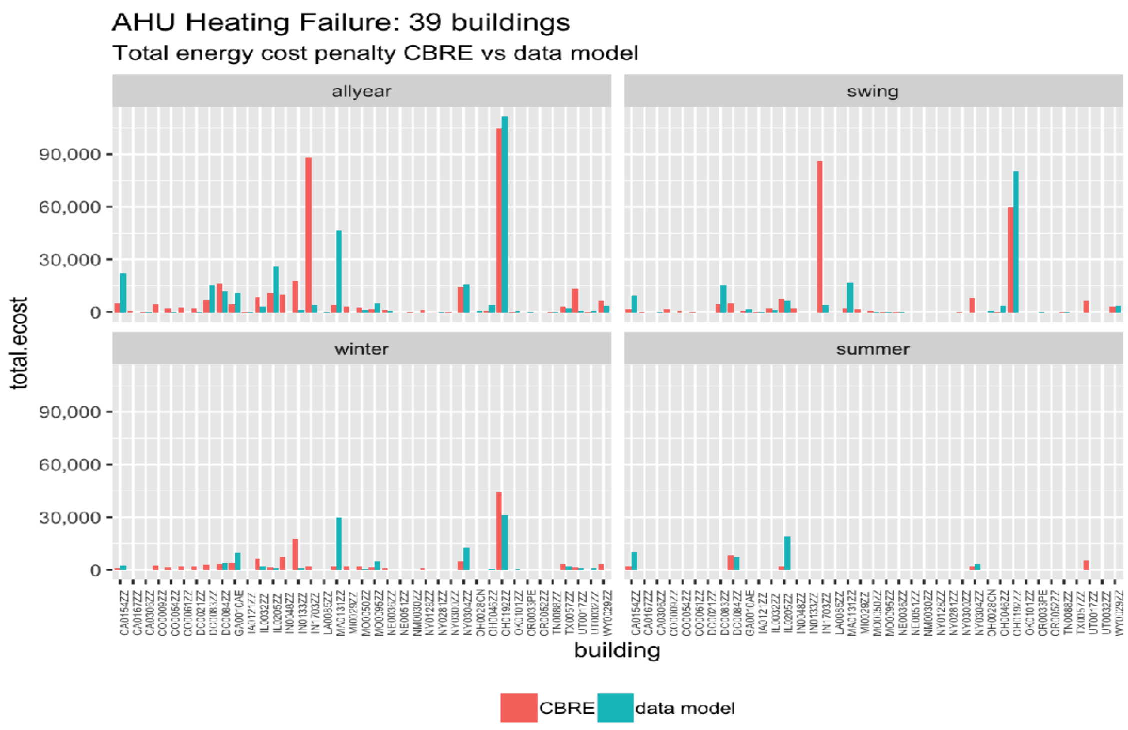
CMU identified Ave. Savings per building: $283,000

Annual Payback < 1.5 month per building

eCost

"This cost reflects the extra energy used by the asset during the Spark period or the extra energy needed by associated equipment to make up for the inefficient Sparking equipment."

Ridge Regression demonstrated the TECI eCost estimated energy savings for Spark corrections were fully evident in 2018 energy use data across buildings



total ecost$:

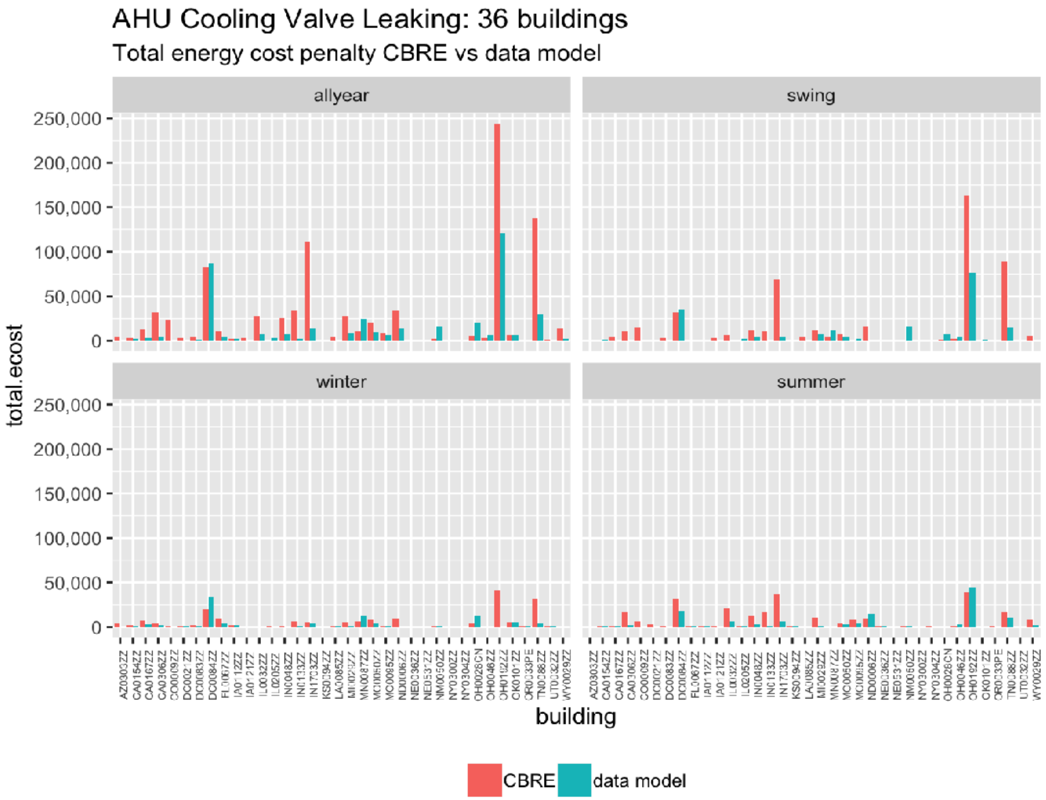
CBRE	335,468.
data model	288,970. = **86% of CBRE**

TECI eCost Summary

- 27 Spark eCosts Parallel Ridge Regression Analysis of 2018 Interval Energy Data, and estimates should be kept as is.
- 12 Spark eCosts Over-estimate Ridge Regression Analysis of 2018 Interval Energy Data, and estimates should be reduced, or studied further.
- 12 Spark eCosts Under-estimate Ridge Regression Analysis of 2018 Interval Energy Data, and estimates should be raised.
- 7 Spark eCosts where Ridge Regression Analysis was not effective, due to very small energy impacts, with a critical need for field intervention studies.

27 Sparks with Comparable TECI eCost and Energy Regression

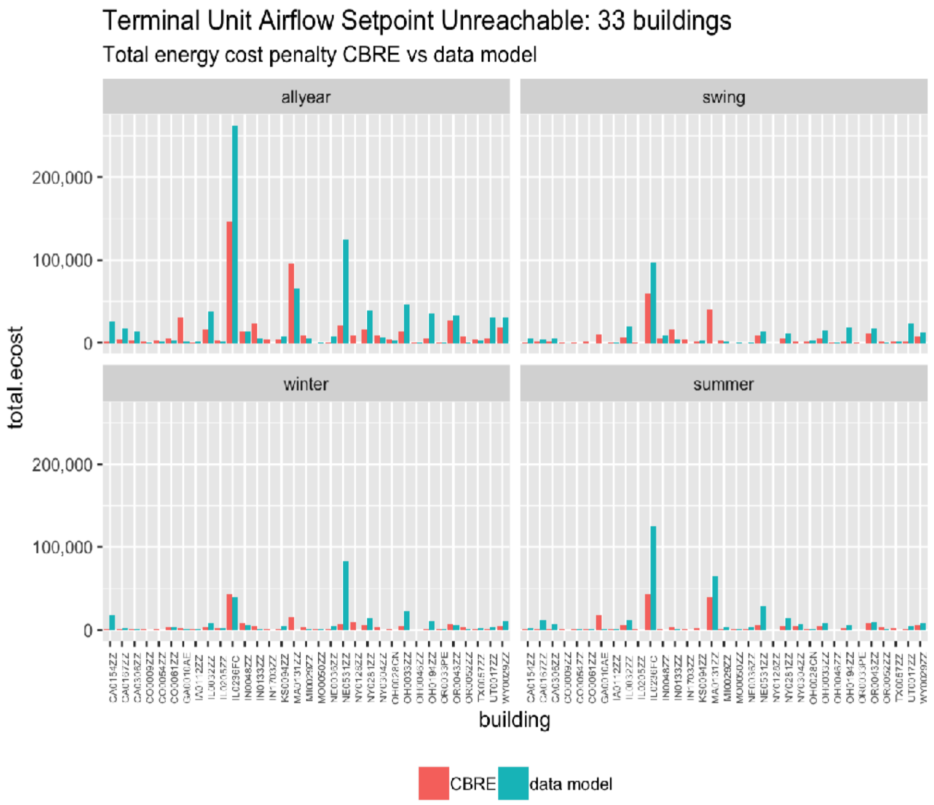
SPARK RULE	# of 60 buildings in data set	# of hours of Spark in these bldgs 2018	CBRE_raw	energy data model_raw	% delta
AGREE WITH ESTIMATION					
AHU Cooling Valve Leaking	38	46,234	900,920	407,265	45%
AHU Heating Valve Leaking	38	41,787	693,827	267,056	38%
AHU Discharge Temperature Setpoint Unreachable	49	93,193	642,654	537,465	84%
Terminal Unit Airflow Setpoint Unreachable	33	301,670	507,277	832,255	164%
AHU Heating Failure	40	43,757	335,468	288,970	86%
AHU Outside Damper Stuck Closed	39	38,740	291,558	255,198	88%
AHU Cooling Failure	42	50,097	256,407	219,170	85%
AHU Damper Unstable	48	23,693	253,288	482,089	190%
AHU Cooling & Heating Simultaneously	19	8,634	238,873	131,791	55%
AHU Cooling Valve Unstable	51	35,433	227,392	142,644	63%
AHU Outside Damper Stuck Open	34	18,247	196,009	127,468	65%
AHU Economizing & Heating Simultaneously	24	17,563	131,299	67,913	52%
AHU Heating Valve Unstable	43	17,926	103,980	57,404	55%
AHU Economizing & Cooling Simultaneously	29	13,756	102,208	115,236	113%
AHU Discharge Fan Failure	40	76,557	95,103	147,067	155%



total ecost$:

CBRE 900,920.

data model 407,265. = **45% of CBRE**



total ecost$:

CBRE	507,277.	
data model	832,254.	= **164% of CBRE**

12 Sparks where TECI eCost << Energy Regression

UNDERESTIMATED					
AHU Excessive Outside Air During Unoccupancy	38	40,350	209,503	576,421	275%
AHU Discharge Pressure Setpoint Unreachable	44	125,469	139,046	315,055	227%
AHU Excessive Discharge Fan Speed	45	99,024	89,118	1,185,475	1330%
AHU Excessive Return Fan Speed	21	21,543	22,852	625,382	2737%
Chilled Water Pressure Setpoint Unreachable	17	8,770	10,791	129,414	1199%
AHU Outside Airflow Too Low	3	3,169	7,959	24,949	313%
Terminal Unit Heating Failure	11	12,153	4,205	27,324	650%
AHU Cooling & Heating Cycling	25	266	2,767	15,279	552%
AHU Discharge Fan Unstable	35	2,565	1,655	11,460	692%
AHU Discharge Pressure Unstable	18	1,322	1,265	17,385	1374%
Terminal Unit Airflow Unstable	27	2,354	853	27,492	3223%
Pump Cycling	44	4,150	325	13,982	4302%
			490,339	**2,969,618**	

Several Sparks need Field "Intervention" Studies to Definitively Quantify Energy Cost-Benefits

(confounding Datasets in Regression Data Analysis)

- Unoccupied Cooling Setpoint Out of Range
- Occupied Cooling Setpoint Out of Range

- Chiller Running During Unoccupied Periods
- AHU Excessive Outside Air During Unoccupied Periods

- AHU Outside Damper Stuck Closed
- AHU Outside Damper Stuck Open
- AHU Cooling & Heating Simultaneously

GSALink is the largest repository of equipment performance across a portfolio of buildings in the US.

There is significant opportunity to use higher level analytics (AI) to identify and address portfolio wide failures, such as leaking AHU heating and cooling valves in 60% of the portfolio.

SPARK RULE	# of 60 buildings in data set	# of hours of Spark in these bldgs 2018	CBRE_raw	energy data model_raw	% delta		possible outlier buildings by number	CBRE_remove outlier	data model_remove outlier	% delta
AGREE WITH ESTIMATION										
AHU Cooling Valve Leaking	38	46,234	900,920	407,265	45%					
AHU Heating Valve Leaking	38	41,787	693,827	267,056	38%		DC0083ZZ	559,684	247,376	44%
AHU Discharge Temperature Setpoint Unreachable	49	93,193	642,654	537,465	84%					
Terminal Unit Airflow Setpoint Unreachable	33	301,670	507,277	832,255	164%					
AHU Heating Failure	40	43,757	335,468	288,970	86%					
Boiler Cycling	24	8,104	297,746	69,733	23%		CA0154ZZ TN0088ZZ	136,742	69,733	51%
AHU Outside Damper Stuck Closed	39	38,740	291,558	255,198	88%					
AHU Cooling Failure	42	50,097	256,407	219,170	85%					
AHU Damper Unstable	48	23,693	253,288	482,089	190%					
AHU Cooling & Heating Simultaneously	19	8,634	238,873	131,791	55%					
AHU Cooling Valve Unstable	51	35,433	227,392	142,644	63%					
AHU Outside Damper Stuck Open	34	18,247	196,009	127,468	65%					
AHU Economizing & Heating Simultaneously	24	17,563	131,299	67,913	52%					
AHU Heating Valve Unstable	43	17,926	103,980	57,404	55%					
AHU Economizing & Cooling Simultaneously	29	13,756	102,208	115,236	113%					
AHU Discharge Fan Failure	40	76,557	95,103	147,067	155%					
AHU Discharge Temperature Unstable	42	17,536	92,455	78,773	85%					
Occupied Zone Temperature Out of Range	32	116,675	76,623	166,802	218%					
Zone Pressure Setpoint Unreachable	1	3,378	65,655	39,353	60%					
AHU Return Pressure Setpoint Unreachable	7	10,718	44,565	103,555	232%					
Terminal Unit Heating Valve Leaking	11	13,172	21,590	59,796	277%					
Heat Exchanger Temp Unstable	4	835	10,314	7,004	68%					
Cooling Tower Temperature Setpoint Unreachable	5	543	4,712	2,691	57%					
Hot Water Pressure Setpoint Unreachable	15	2,562	3,053	2,929	96%					
Zone Over Cooling	2	1,386	1,084	539	50%					
Hot Water Pressure Unstable	4	77	236	349	148%					
Chilled Water Pressure Unstable	10	262	215	1,822	847%					
AHU Outside Airflow Unstable	3	14	46	154	335%					
Hot Water Circ Pump Running	2	210	13	1,373	10562%					
Boilers Running During Warm Weather	2	125	0	7						
			5,594,570	**4,613,871**	ave. 84% agreement					
POTENTIALLY OVERESTIMATED										
Heat Exchanger Temp Setpoint Unreachable	10	5,587	268,345	5,393	2%					
Chiller Cycling	36	6,763	247,159	4,450	2%		OH0033ZZ	15,838	4,450	28%
Chilled Water System Failure	11	4,655	246,479	20,801	8%		GA0010AE	8,264	4,010	49%
Maximum Demand During Unoccupancy	49	3,792	110,588	39,958	36%					
Building Running Too Late	28	2,302	72,296	8,891	12%		DC0084ZZ	23,948	8,814	37%
Building Starting Too Early	25	1,461	65,560	7,942	12%		DC0084ZZ	31,310	7,942	25%
Hot Water System Failure	14	1,062	22,024	2,696	12%		IN1703ZZ	12,573	2,470	20%
Zone Over Heating	1	5,565	4,008	-						
			1,036,459	**90,131**						
UNDERESTIMATED										
AHU Excessive Outside Air During Unoccupancy	38	40,350	209,503	576,421	275%					
AHU Discharge Pressure Setpoint Unreachable	44	125,469	139,046	315,055	227%					
AHU Excessive Discharge Fan Speed	45	99,024	89,118	1,185,475	1330%					
AHU Excessive Return Fan Speed	21	21,543	22,852	625,382	2737%					
Chilled Water Pressure Setpoint Unreachable	17	8,770	10,791	129,414	1199%					
AHU Outside Airflow Too Low	3	3,169	7,959	24,949	313%					
Terminal Unit Heating Failure	11	12,153	4,205	27,324	650%					
AHU Cooling & Heating Cycling	25	266	2,767	15,279	552%					
AHU Discharge Fan Unstable	35	2,565	1,655	11,460	692%					
AHU Discharge Pressure Unstable	18	1,322	1,265	17,385	1374%					
Terminal Unit Airflow Unstable	27	2,354	853	27,492	3223%					
Pump Cycling	44	4,150	325	13,982	4302%					
			490,339	**2,969,618**						

84% agreement

mCost

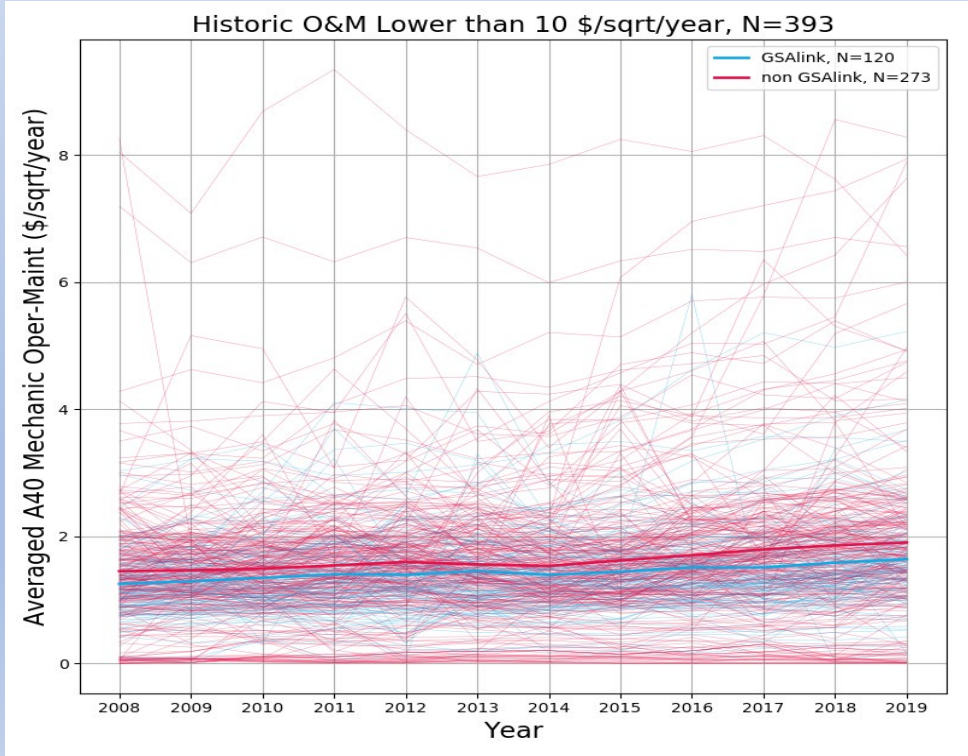
"the expenses that add up when maintenance is either not performed or is not performed on a timely basis to ensure overall performance and lifecycle of equipment".

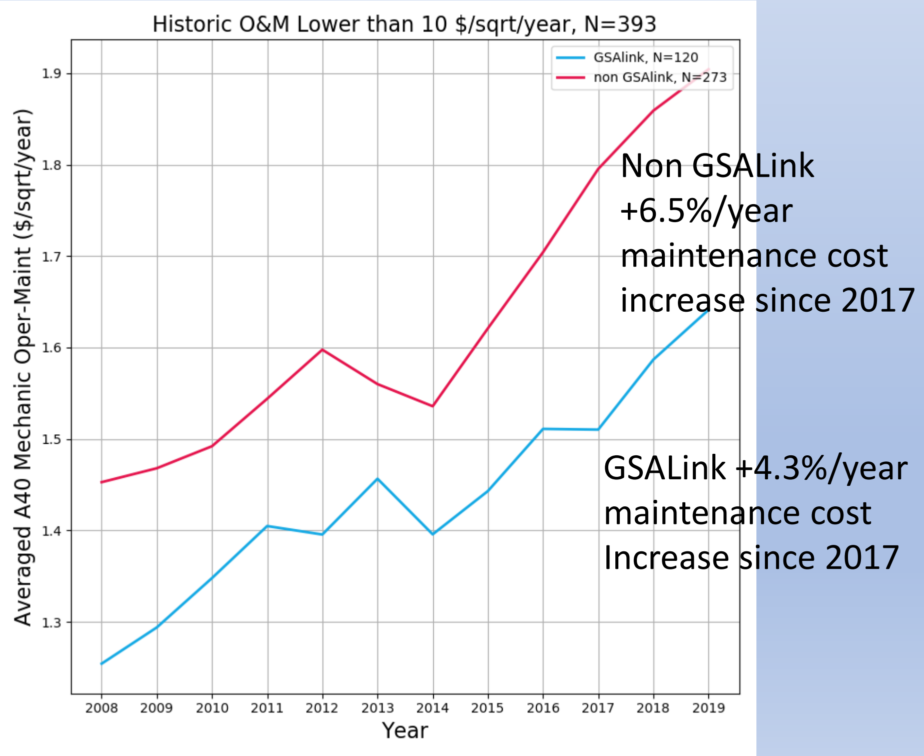
GSALink provides 9 of 15 Services in LBNL documented US Commercial Building Commissioning Scope

mCost Comparisons

- Presently, **mCosts are estimated at only 3% of the TECI costs** in the SkySpark system
- Costs from Pegasys Financial Accounting provide a reality check for quantifying the overall maintenance benefits of ongoing feedback from GSALink. **Recorded maintenance costs per square foot for the GSA portfolio suggests that the commissioning and feedback provided in GSALink buildings has benefits for reducing maintenance costs**. Correcting for starting conditions in 2013, the delta of **$0.15/sqft maintenance savings in 2018 would equal $6.3 Million for the 60 buildings in the study set.**

For >100,000 sqft buildings and <$10/sqft maintenance, Data GSA OCFO

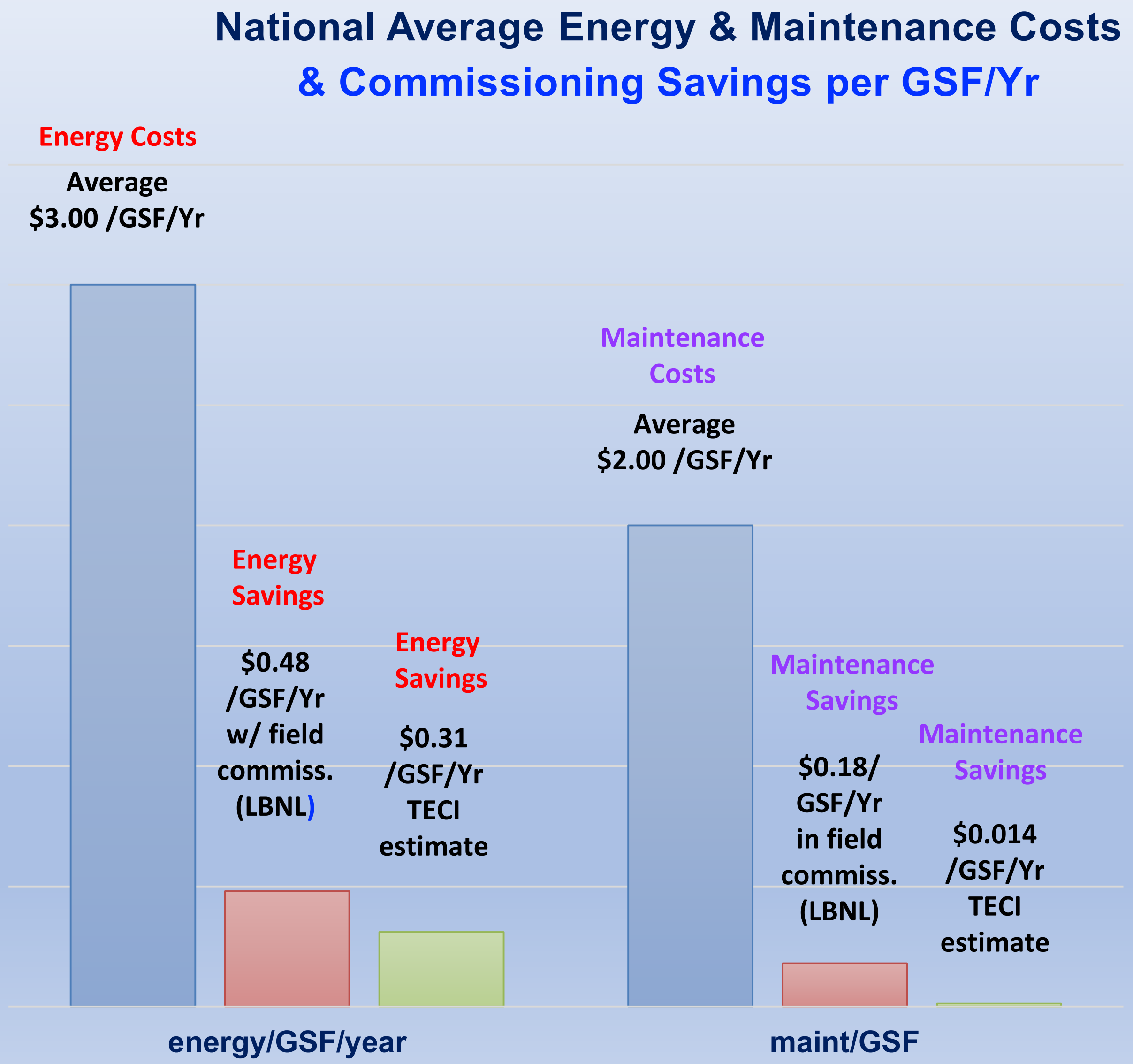




mCosts should be increased by a factor of ten!

- **GSALink provides 9 of 15 Services outlined in the LBNL US Commercial Building Commissioning Scope.**
- **2018 LBNL report identifies median non-energy benefits of existing building commissioning (EBCx) as $0.18/sq ft-yr**
- **Current T.E.C.I. mCost savings estimates $0.014/GSF/year, off by a factor of ten.**

	Energy per GSF year	Maintenance per GSF year	Social per GSF year
National average costs	3	2	130
lit savings	0.48	0.18	1.3
CBRE savings	0.31	0.014	0.2



sCost

“The effect thermal discomfort, poor air quality, and mechanical noise has on an employee’s productivity.”

TECI sCosts assessment
based on Research Linking IEQ to Occupant Performance

1. **Inadequate Fresh Air** 17% productivity degradation if CO2 > 1000 ppm (11 Sparks)
2. **Too Cold in Winter (<68F) +/-2F off setpoint.** 3% productivity impact (13 Sparks)
3. **Too Hot in Summer (>78F)** 4% productivity impact (8 Sparks)
4. **Too Cold in Summer (<71F)** 2% productivity impact (2 Sparks)
5. **Too Hot in Winter (CFR doc. 76F)** (no Sparks assigned)
6. **Too Noisy** 7.5% productivity impact of Noisy HVAC (6 Sparks)
7. **Too Dry or Too Humid** (3 Sparks, no costs assigned)

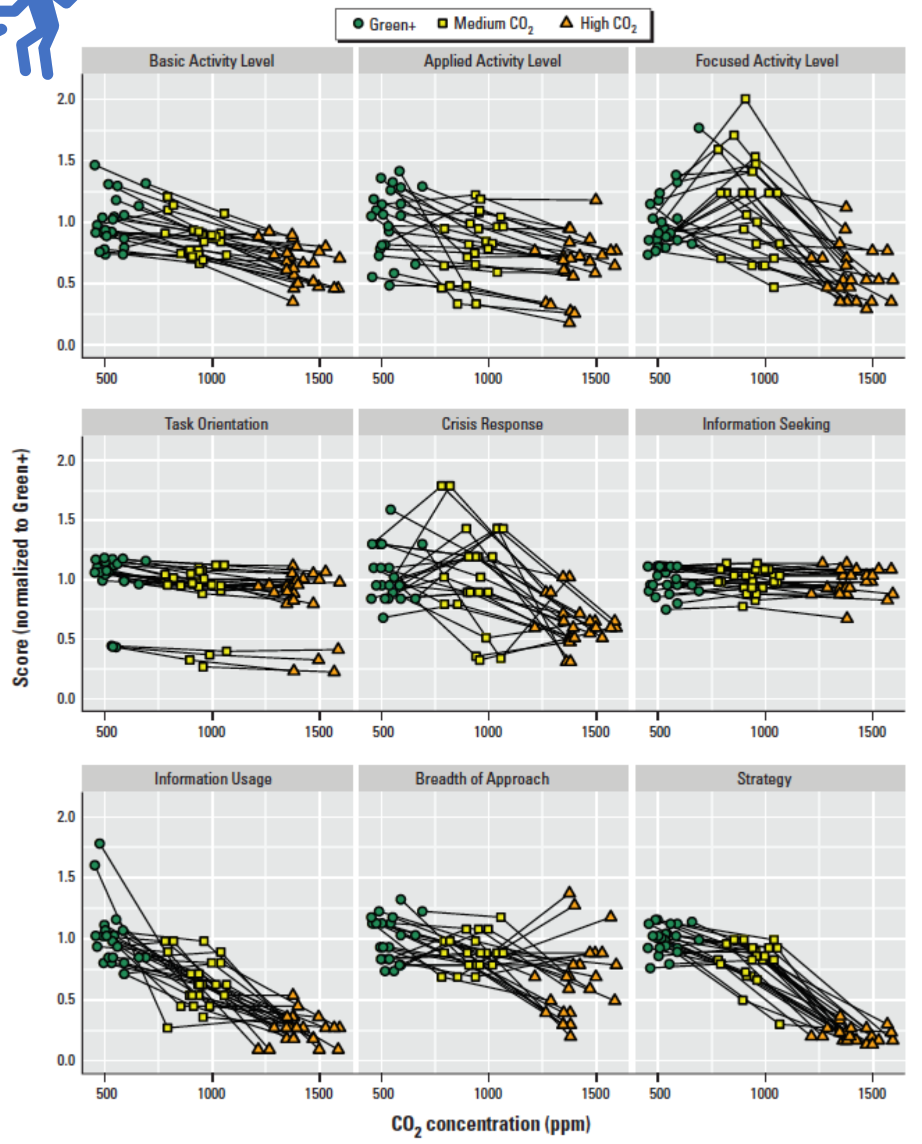


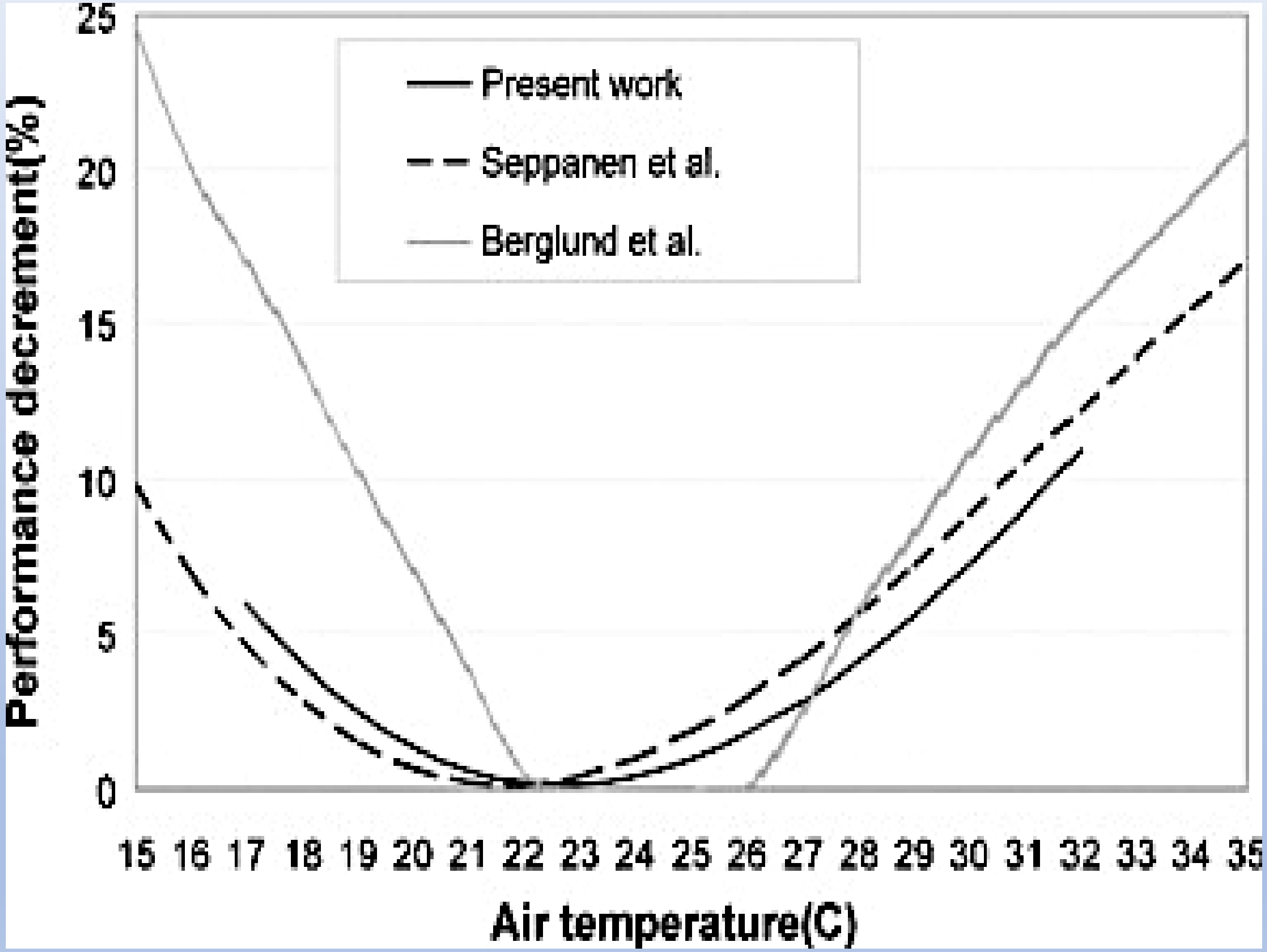
Figure 2. Cognitive function scores by domain and participant and the corresponding carbon dioxide concentration in their cubicles. Each line represents the change in an individual's CO_2 exposure and cognitive scores from one condition to the next, normalized to the average CO_2 exposure across all participants during the Green+ conditions.

The Inadequate Fresh Air research says:

"On average, a 400-ppm increase in CO2 was associated with a 21% decrease in a typical participant's cognitive scores across all domains after adjusting for participant (data not shown), a 20-cfm increase in outdoor air per person was associated with an 18% increase in these scores, and a 500-µg/m3 increase in TVOCs was associated with a 13% decrease in these scores." (Allen et al 2016).

CBRE sCost totals appear to be an effective representation of the productivity cost for these 11 Sparks combined.

However, the equations should be modified to 500 gSF/person, 17% productivity, an x/11 adjustment factor (relative weight between the 11), without changing the end result.



The Thermal Discomfort research says:

The Productivity sCosts of:

Working in Too Cold Spaces in Winter

Working in Too Hot Spaces in Summer
Working in Too Cold Spaces in Summer

(Working in Too Hot Spaces in Winter)

Sparks need to be divided by season and by whether the excursion out of comfort is too hot or too cold.

6 Sparks Related to Mechanical Noise

1. AHU Excessive Discharge Fan Speed (10% x 40% adj)
2. AHU Cooling & Heating Cycling (10% x 30% adj)
3. Discharge Fan Cycling (10% x 10% adj)
4. Heating Cycling (10% x 30% adj)
5. Cooling Cycling (10% x 30% adj)
6. Heat Pump Cooling and Heating Cycling (10% x 50% adj) (eqmt in space?)

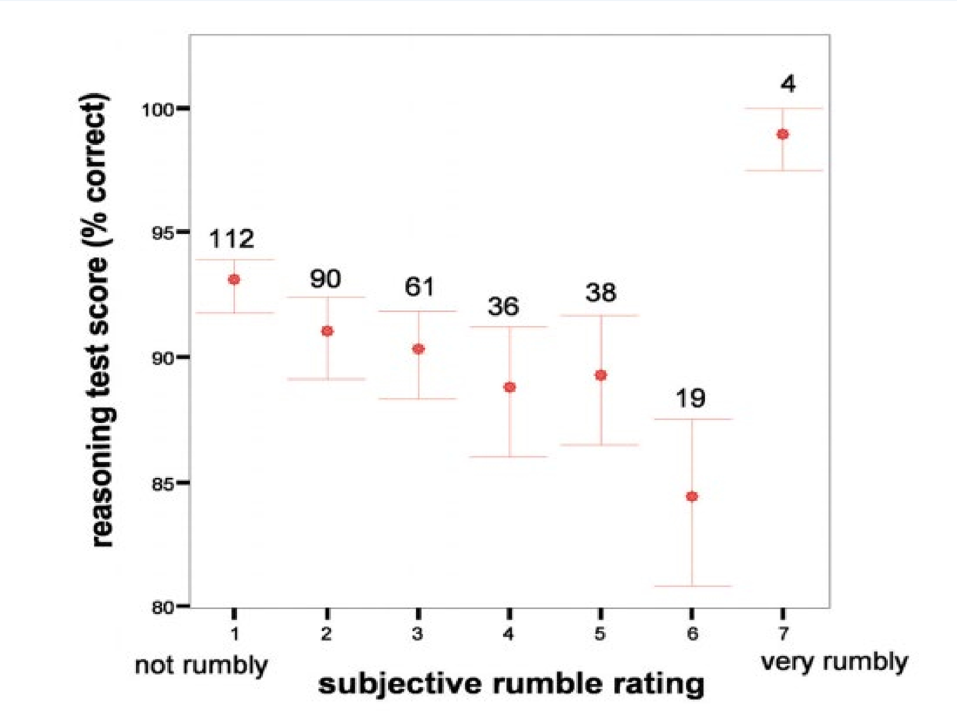


Table 3. Correlations Between the Subjective Perception Dependent Variables

	Loudness	Rumble	Roar	Hiss	Tones	Changes in Time	Annoyance	Distraction
Loudness	-	0.54**	0.57**	0.40**	0.51**	0.27**	0.77**	0.71**
Rumble		-	0.41**	0.41**	0.42**	0.24**	0.48**	0.44**
Roar			-	0.09	0.37**	0.26**	0.54**	0.44**
Hiss				-	0.37**	0.26**	0.40**	0.44**
Tones					-	0.55**	0.50**	0.47**
Changes in Time						-	0.32**	0.29**
Annoyance							-	0.86**

** indicates significance at $p < 0.01$ level

Ryherd and Wang identify a 5% drop in reasoning tests for occupants listening to mechanical rumble, and an approximate 10% drop in typing speed but not accuracy as complaints of HVAC distraction rise

If the relative impact of each of these Sparks was evenly distributed, the productivity impact should be doubled.

CMU Task 1 Conclusions

Energy Cost Savings - $7 million in savings for 60 buildings in 2018

- CMU Ridge Regression analysis of advanced metered FY18 data for 60 buildings.
- **Recommendation: Strong correspondence between TECI eCosts and the data-estimated energy cost-saving**

Maintenance Cost Savings - $4 million in savings for 60 buildings in 2018.

- Based on published field studies; LBNL demonstrates an average maintenance savings of $0.18/GSF for retro-commissioning (EBCx).
- GSAlink provides key retro-commissioning tasks (EBCx)
- GSAlink mCosts estimates $0.014/GSF
- **Recommendation: Increase TECI maintenance costs by a factor of ten**

Social cost savings - $6 million in savings for 60 buildings in 2018.

- Based on published human performance studies related to seven environmental variables
- **Recommendation: TECI social cost estimates are predominantly accurate (if somewhat underestimated) but do need restructuring for the equations to more clearly reflect research multipliers.**

CMU Overall Conclusions

1. **GSALink with Advanced Metering & BAS records** provides a critical percent of continuous commissioning, with demonstrated energy impact of $7 million in 60 buildings for 2018. **This eTECI benefit should be expanded to all large GSA properties.**

2. If advanced metering and GSALink was installed in the 390 GSA buildings over 100,000 GSF, the energy savings triggered by Spark reporting would be estimated at 39 million dollars.

CMU Overall Conclusions continued

3. The additional maintenance benefits (mCost) and human performance benefits (sCost) of the Spark resolution, combined with the energy benefit (eCost), **yield an average $280,000 savings per building**, far exceeding the annual costs of GSALink, with a **payback of 1 month each year**.

4. GSALink TECIs identify **priorities for building subsystem maintenance and replacement for nationwide action, in a long term integrated data repository.**

5. GSALink TECIs are a critical vehicle for prompting action, which could be further enhanced by dashboards customized to different stakeholders.

TASK 1 KEY VALIDATIONS

Figure 1

FY18 Spark TECI analysis – $17 million identified across 60 buildings

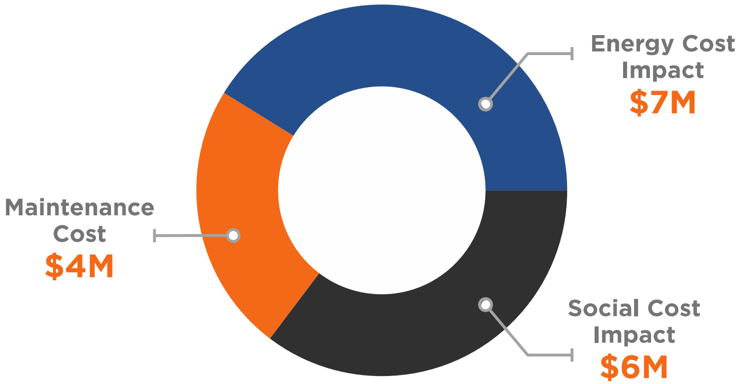


Figure 2

Annual payback (less than 2 months)

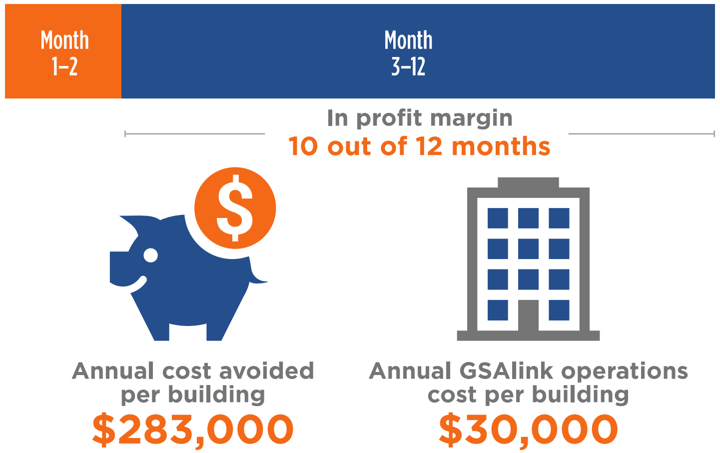


Figure 3

FY18 Spark TECI Analysis – 18% difference

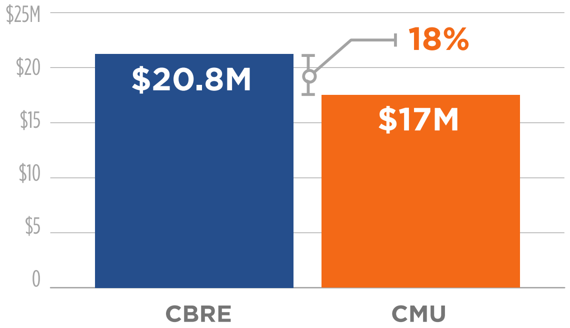
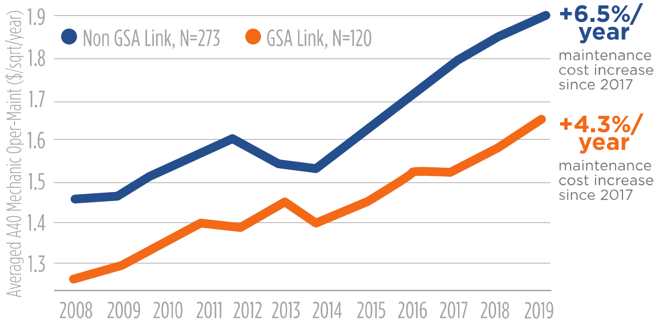


Figure 4

Averaged O&M cost data – 2.2 % difference



There are 11 Sparks related to Inadequate Fresh Air, Compromised Fresh Air

AHU Discharge pressure unreachable (compromised filters or duct path) =
poor fresh air & thermal discomfort (980k across 89 buildings)
(10% prod. x 50% adj for most)
AHU discharge fan failure = no air delivery, poor thermal comfort (810k)
(10% prod. x 50% adj)
Terminal Unit Airflow Setpoint Unreachable = poor air delivery (337k)
(10% prod. x 75% adj)
AHU OA air damper stuck closed = no fresh air delivery (305k)
(10% prod. x 40% adj). NOT used in summer?! Should be.
AHU Excessive Return Fan Speed = negative pressure and pollution intake? (154k)
(10% prod. x 40% adj)
AHU Damper Unstable = poor air delivery, poor thermal comfort (97k)
(10% prod. x 20% adj)
AHU Zone Pressure Setpoint Unreachable (24k)
(10% prod. x 10% adj)
AHU Discharge Pressure Unstable = poor air delivery, poor thermal comfort (8k)
(10% prod. x 50% adj)
AHU Outside Airflow Too Low = poor air delivery (7k)
(10% prod. x 10% adj) NOT used in summer?! Should be.
AHU Discharge Fan Unstable = poor air delivery, poor thermal comfort (6k)
(10% prod. x 40% adj)
AHU Outside Airflow Unstable = poor air ?k)
(10% prod. x 10% adj) NOT used in summer?! Should be.

Total sCost across 89 buildings = $2,728,000 or $30,000/building if evenly distributed

There are 13 Sparks related to Too Cold in Winter

1. AHU Discharge Temperature Unreachable (10% x 20% adj) OA<65 only. (427k)
2. AHU Heating Valve Leaking (10% product. x 75% adj) (392k)
3. AHU Heating Failure (10% prod. x 25% adj.) (216k)
4. Heat Exchanger Temperature Setpoint Unreachable (10% prod.x 40% adj) (161k)
5. AHU Discharge Temperature Unstable (10% prod. x 20% adj) OA<65 only. (69k)
6. AHU Heating Valve Unstable (10% prod.x 25%) (57k)
7. Hot Water Pressure Setpoint Unreachable (10% prod.x 10%adj) (51k)
8. Hot Water System Failure (10% prod.x 15% adj) (35k)
9. Terminal Unit Heating Failure (10% prod.x 75% adj) (15k)
10. Terminal Unit Heating Valve Leaking (10% prod.x 50% adj) (12k)
11. Occupied Heating Setpoint Out of Range (10% prod. x 10% adj) (8k)
12. Hot Water Pressure Unstable (10% prod.x 10%adj) (6k)
13. Zone Damper Heating Malfunction (10% prod.x 50% adj) (2k)

The CBRE sCost totals appear to be an effective representation of the productivity cost for these 13 Sparks.

However, the equations should be modified to 500 GSF/person, 3% productivity, an x/13 adjustment factor, without changing the end result.

Research average 3% productivity impact x time duration of that Spark (hrs) x % of space affected by that spark x total sq.ft. for building/500 sq.ft. per person (conservative GSF) x average salary GSA ($75/hour) x adjustment factor related to # of Sparks affecting too cold in winter and weighting between them.