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Thank you for providing an opportunity to provide input on the California Energy Commission's 2022 Pre-Rulemaking for Building Energy Efficiency Standards. These comments are specifically addressing the compressed air system monitoring proposal.

In 2019, the E2e Project, a joint research initiative of the University of California, Berkeley, the Massachusetts Institute of Technology, and the University of Chicago completed a project to determine whether industrial facilities in California would save energy and money when given access to process-level submetering and analysis. The project was selected for funding by the Energy Commission through the EPIC program. I served as the project manager on the contract and am submitting these comments to describe some of the project's findings that could be relevant to the Energy Commission's proposed standards.

Our project was motivated by the fact that most industrial customers are unaware of many low-cost energy conservation and energy efficiency opportunities. We wanted to learn whether, when given access to data and analysis, the facility would take action to save energy. The project focused on compressed air systems, although a similar approach could be taken for other industrial processes. The E2e Project partnered with Lightapp, now known as Zira, a company that has developed a software platform for collecting facility data, analyzing the data and delivering actionable recommendations to facility personnel.

The E2e Project team is made up of economists who applied their expertise in designing rigorous evaluations to design a randomized controlled trial. A randomized controlled trial is consider the "gold standard" among program evaluation methods and can provide confidence in energy savings estimates. In this project each of the 102 participating facilities received monitors at no costs. The facilities all also got access to Lightapp's software—some for free and some at a discounted price. Data was collected from each site for at least 90 days prior to the facility being given access to the analytical software. Then each facility began a 12-month treatment period during which facility personnel could access the software and received customized recommendations.

Of the facilities contacted to participate in the study, about 22% of eligible plants opted to participate. The evaluation found that, on average, facilities that participated in the project decreased the electricity used by their compressed air systems by 17%, which equates to annual cost savings of $30,000. At the end of treatment period facilities had the opportunity to pay for continued access to the Lightapp software, on a market basis. Forty-four percent of facilities chose to do so.

The Final Report for the project (EPC-14-075) is available at this link:
https://ww2.energy.ca.gov/2019publications/CEC-500-2019-060/CEC-500-2019-060.pdf
We have also attached an Addendum that was submitted to the Energy Commission in February 2020 and contains updated analysis including additional months of data from each facility.

We noted the Energy Commission asked two specific questions that address here:

Q1: are the identified monitoring points and procedures adequate to identify compressed air system issues?

I understand that the proposed standards describe monitoring minimum requirements in Section 120.6(e)3 and these requirements include the measurement of system pressure, measurement of amps or power at each compressor, measurement of airflow at each compressor, and certain logging, storage and visual trending requirements.

Our project did not look at the impact of different measurement configurations, but I can describe the equipment we used in our project. Participants could receive up to three power meters, two pressure sensors, one flow meter, plus all necessary communication devices. We installed the flow meters on the main header, not on each compressor as suggested by the standard. I would note that the flow meters are the most expensive of the meters we deployed, and could be complex to install in operating facilities. For example, in some instances a compressed air system, and, thus, the production process, needed to be idle for installation to occur. This requires careful coordination and, for some facilities, may only be possible during rare shut-downs. The Commission should confirm that measuring the airflow at each compressor is necessary.

Q2: is an 80% realization rate for compressed air monitoring adequate?

Our project estimated an average energy savings of 17% across all participating facilities. It is likely the case that some facilities saved far more than that and some less. The types of energy savings opportunities and the engagement of the facility staff varied considerably from one facility to the next. Some facilities found significant savings opportunities such as mis-programmed control systems (e.g. relying too much on less efficient compressors), leaks, and compressors idling when they could be shut off entirely. Our analysis doesn’t enable us to decompose the 17% into these sources of savings or attribute the savings to specific facilities. Such an analysis is unlikely to be statistically sound. Thus, I would recommend the Commission use an estimated average savings instead of attempting to estimate separate energy savings for different categories of facilities.

Our study looked at the average savings over a one-year period. Nearly one-half of facilities chose to continue paying for access to the software beyond the one-year project period. Some expanded the system beyond compressed air. This implies these facilities expect to find additional energy savings opportunities over time. This is not surprising given how dynamic many manufacturing environments are. New production lines are frequently added, removed and modified. These changes will put different demands on a compressed air system. We also encountered situations where the monitoring data and analysis was used by facility staff to justify investments in new, more energy efficient equipment. These upgrades will in turn save more energy. While the equipment upgrade will be generating the energy savings, the monitoring technology can be critical to justifying that decision.

I would be happy to discuss our project further with the Commission if this would help with the development of the compressed air monitoring standards.

Respectfully Submitted,

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ADDENDUM A: Savings Analysis Results and Detailed Benefits to Ratepayers

As of January 31st, all participants have completed at least nine months of Treatment, and 78 participants have completed the full 12 month Treatment Period (breakdown shown in Table 1). The analyses in this report are done using the data from all 96 project sites. The results could change once complete treatment data from all 96 sites is analyzed.

Table 1. Treatment Status

Treatment Status	Sites
Complete	78
At least nine months of Treatment	18
Total	**96**

Savings Analysis Results

In order to estimate the energy efficiency impacts of the Lightapp EMS, the research team focused on the change in electricity used (kWh). If the Lightapp EMS improved energy efficiency, this would be demonstrated by a negative change in electricity usage (kWh).

Five regression models were run, each using different control variables. Four regressions used the 5-minute data and take different time-based variables into account. One regression used the weekly aggregated data. The breakdown of these results and their statistical significance can be found in Appendix B. For the results in this report, the research team used the average of the statistically significant outcomes as the resulting impact of the Lightapp EMS, showing the results for both last value carried forward and linear interpolation for the imputed data.

When using the recorded data only, on average, facilities with access to the Lightapp EMS observed an estimated 16.5% decrease in compressed air electricity usage, corresponding to an estimated annual reduction in electricity bills of $29,378 per facility, using the California average electricity rate for industrial customers in 2019 of $0.15/kWh[1]. When using the imputed data calculated by taking the last value forward as well as the reported data, facilities with access to the Lightapp EMS observed an estimated 16.8% decrease in compressed air electricity usage, corresponding to an estimated annual reduction in electricity bills of $29,989 per facility. When using the imputed data calculated by linear interpolation as well as the recorded data, facilities with access to the Lightapp EMS observed a 17.6% decrease in compressed air electricity usage, corresponding to an estimated annual reduction in electricity bills of $31,440 per facility. The breakdown of this change is detailed below in Table 2.

[1] U.S. Energy Information Administration. "Electric Power Monthly" November 2019

Table 2. Annual Compressed Air Electricity Usage and Cost Breakdown Per Site

	% Change	Electricity Usage Reduction (kWh)	Electricity Cost Reduction ($)
Recorded Data	-16.5%	194,168	$ (24,717.60)
Recorded + Imputed Data (Last Value)	-16.8%	198,206	$ (25,231.66)
Recorded + Imputed Data (Linear Interpolation)	-17.6%	207,797	$ (26,452.54)

When the results of all methods of analysis are averaged together, participant sites saw an overall average decrease of 17% and annual savings of $30,269 per facility. As 96 participant sites were used for this analysis, the resulting total yearly energy savings is estimated at $2.9 million.

Updated Benefits to Ratepayers

From the beginning, the E2e Engage project focused on the benefits to California Investor-Owned Utilities (IOUs) electricity ratepayers, specifically by enabling industrial and manufacturing facilities to lower their electricity costs. In the short term, this could lead to lower prices for the final goods and materials produced by the participating facilities. In the long run, this project identified industries in which Lightapp's optimization technology was adopted more readily and led to larger electricity cost savings. In addition, the project points toward opportunities to support this technology through IOU-funded energy efficiency programs.

The high level of participation in the project by industrial facilities (22% of all eligible plants opted to participate) could help inform future policies, projects, and funding for industrial energy efficiency projects. The majority of public energy efficiency funding goes towards residential and commercial programs, and this project demonstrated that significant opportunities remain for industrial programs. The Lightapp technology could also expand beyond compressed air systems, and the methodology followed in this project could be used in the design and execution of similar industrial project focusing on new aspects of manufacturing systems, such as production equipment or chillers.

Due to the ongoing nature of this research project, all estimates related to specific energy savings based on these results should be viewed as preliminary. Future publications may show different results based on additional data collected since the time of this report.

Quantitative and Qualitative Estimates of Benefits

The results of this project show that Lightapp's technology reduced the electricity used by compressed air systems by 17%

The total impact of all 102 project sites (including pilot sites) over the course of one year would be:

- 20,406,000 kWh/year in reduced consumption
- $3.1 million/year in lower bills
- 5,775 tons/year in GHG emissions

Applying the 17% savings rate to the electricity used by all industrial compressed air systems in PG&E and SCE service territories, electricity ratepayers would see savings of:

- 247,020,000 kWh/year in reduced consumption
- $37.4 million/year in lower bills
- 58,600 tons/year in GHG emissions

In addition, while this study focused solely on compressed air, the methodologies used and the underlying technology can be applied to entire industrial systems, not only compressed air systems. Based on the results of the Willingness to Pay study, 64% of the project sites that ultimately purchased Lightapp showed interest in expanding beyond compressed air after being given the opportunity to experience the technology firsthand. Extending the 17% savings to general industrial energy use could save significantly more:

- 4,940,400,000 kWh/year in reduced consumption
- $747.5 million/year in lower bills
- 1,173,000 tons/year of GHG emissions

This calculation is based on the following assumptions:

- The 2017 industrial customer total electricity usage in the territories of PG&E and SCE.[2]
- Considering compressed air systems alone, it was assumed that 50% of customers had compressed air systems[3]
- Compressed air systems consume 10% of total electricity use[3].
- The electricity savings on industrial compressed air systems are calculated by:
    - 0.50 * number of customers * MWh/customer/year * Percent Customers in IOU territories* Savings Percentage * 0.10
    - Electricity savings are converted into emissions at the rate of 0.000237 tons/kWh and cost savings at $0.1513/kWh[1].
- For reducing the energy intensity of industrial systems, it was assumed that 50% of all customers have manufacturing systems (compressed air and otherwise) large enough to benefit from the Lightapp technology. The calculation is:
    - Total Industrial GWh Usage[3] * 0.50* Percent Customers in IOU territories * Savings Percentage, which is converted into emissions and cost savings at the above rates.

The energy savings and operation efficiency that California industrial facilities gained through this project may encourage some facilities to remain in the state, preventing further reductions in the customer base for California investor owned utilities.

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[2] U.S. Energy Information Administration. "Electric power sales, revenue, and energy efficiency Form EIA-861." 2017

[3] Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory. Prepared by Xenergy, Inc. "Assessment of the Market for Compressed Air Efficiency Services." June 2001.
In other countries, such as Australia, compressed air systems also consume 10% of total industrial energy use. Sustainability Victoria. "Energy Efficiency Best Practice Guide: Compressed Air Systems." 2009.

Willingness-to-Pay Updated Results

As of January 31st, 75 of the project sites have completed the Willingness-to-Pay (WTP) phase, and these results reflect updates of those reported in the Final Report.

Participant Take-up

During the Recruitment phase, the take-up rate for all eligible industrial facilities with no previous experience using Lightapp or any other EMS was 22% (26% for the Gold sites and 15% for the Blue sites). The hypothesis tested by the first part of the WTP phase was that facilities that have experienced Lightapp (i.e., the project participants) would exhibit a higher take-up rate than facilities with no experience. For the purposes of this report, the take-up rate seen in the Recruitment phase was used as the Baseline for the latter group, although not enough data were available for a statistical comparison. Future analyses may include take-up information from new industrial facilities not contacted as part of Recruitment, but these data were not available.

Of the 75 project participants that have completed the WTP phase, 33 facilities (44%) have decided to continue using Lightapp for a fee, almost double the rate seen for eligible facilities during Recruitment. The take-up rates were virtually the same for sites that received Lightapp for free during the Treatment period (Gold sites) and those that paid a discounted rate (Blue sites). Of the 61 Gold sites, 27 participants (44%) opted to pay for the Lightapp services. Of the 14 Blue sites, 6 participants (43%) opted to pay for the Lightapp services. Summary numbers can be seen in Table 3 below.

Table 3. WTP Take-up Results

	Purchased Lightapp	Declined	Total	Percent Purchased
Gold Sites	27	34	61	44%
Blue Sites	6	8	14	43%
All Sites	33	42	75	44%

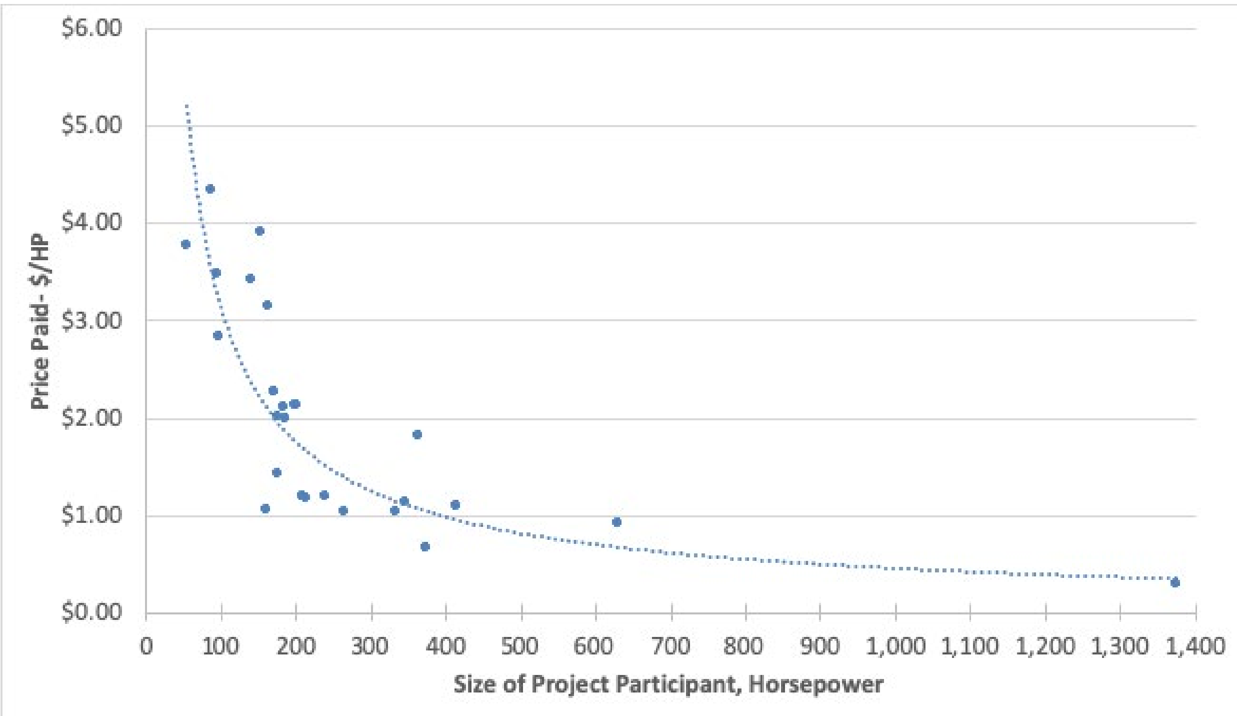
Lightapp Pricing

Lightapp changed their pricing model during the WTP Phase of the project, moving from pricing based on the size of the compressed air systems (i.e., horsepower), to charging instead based on the numbers of users and data streams required by each site. In this new model, larger sites incur higher costs due to the increased number of data streams and more site personnel using the system. Although Lightapp changed their pricing model to integrate multiple factors, the size of the participating facility was still the single largest factor affecting the cost of the Lightapp services per horsepower of compressor capacity. In order to compare across facilities of different size, all prices are represented in terms of dollars per active horsepower ($/HP) managed. At the beginning of this project and during the Recruitment phase, Lightapp defined their starting price as $3/HP, and Blue sites paid 75% of this fee ($2.25/HP) during the Treatment phase. Gold sites received all Lightapp services free of cost.

On average, participants that signed on to continue with Lightapp services paid $4,463 per month for compressed air systems, or $1.98/HP, a 34% decrease from the Lightapp starting price. There was considerable variation in the price paid, however, ranging from $4.34/HP to $0.30/HP.

No difference was seen in the price paid by Gold and Blue sites. When plotting the price paid against the size of the facilities (represented by the active HP), the trend indicates that larger facilities typically paid lower prices per HP and smaller facilities paid higher (Figure 1). The trend line included in Figure 1 is not significant due to the lack of sufficient data points, but is shown to indicate a general trend, which follows a power equation. Through discussions with project participants, the Lightapp team found that the deadlines imposed by the project, rather than cost, led to some facilities not signing on to continue and expand.

Figure 1. WTP Price for Project Participants Compared to Facility Size in Horsepower



Expansion of Lightapp Services

As facilities entered the WTP phase, one of the options available to them was to expand to equipment outside of the compressed air system. Previously, during the Treatment period, individual sites were allowed to expand if the site personnel requested it, but Lightapp was restricted from proactively marketing expansions in order to keep all of the participants as uniform as possible. Of the 33 sites that opted to purchase Lightapp, 21 sites (64%) also requested to expand into new systems, such as chillers and production equipment. In order to keep the WTP as accurate as possible, pricing for the expansion was negotiated independently of the compressed air system pricing for this study, although this was not the normal business practice for Lightapp.

Conclusions and Lessons Learned

The WTP findings are consistent with the hypotheses that sites able to experience the Lightapp EMS directly were more likely to purchase the system compared to sites unable to experience it.

Through developing the full WTP methodology and engaging with the project participants, Lightapp and the research team have learned several critical lessons in regards to development of pricing and sales tactics for a software-based EMS. The lessons learned below reflect new conclusions reached since the submission of the Final Report.

- The sales process is more successful when the value of the product and the data are emphasized as opposed to focusing only on monetary savings
    - When clients learned of all the benefits of the data visualization, they were more likely to both purchase the product and expand beyond compressed air
    - Pitching to multiple people within one company, such as including corporate leadership in the process, was more effective than focusing only on facility personnel
- Staff turnover continued to be a critical issue
    - Keeping facility personnel involved throughout the Treatment process made the WTP process much simpler for the Lightapp team
    - The manufacturing industry will likely continue to see high employee turnover, so keeping track of the point people at each facility remained important for the Lightapp team
- As the Lightapp team gained more experience selling their product, they became better and achieved higher acceptance rates
    - By dividing the sites into four quarters, the increasing effectiveness of the sales team is easily visible
        - First Quarter: 35% success
        - Second Quarter: 40% success
        - Third Quarter: 47% success
        - Fourth Quarter: 53% success

UPDATED APPENDIX B: Statistical Models

Regression Model

$$E_{it} = \beta_0 + \beta_1(EMS)_{it} + \beta_2(Output)_{it} + \sum_{j=1}^{4}\beta_{2+j}((Temp)_{it} \times \tau_j) + \sum_{j=1}^{4}\beta_{6+j}((Press)_{it} \times \tau_j) + \sum_{j=1}^{4}\beta_{10+j}((Hum)_{it} \times \tau_j) + \phi_p + \lambda_i + \gamma_t + \varepsilon_{it}$$

$$C_{im} = \beta_0 + \beta_1(EMS)_{im} + \beta_2(Output)_{im} + \sum_{j=1}^{4}\beta_{2+j}((Temp)_{im} \times \tau_j) + \sum_{j=1}^{4}\beta_{6+j}((Press)_{im} \times \tau_j) + \sum_{j=1}^{4}\beta_{10+j}((Hum)_{im} \times \tau_j) + \phi_p + \lambda_i + \gamma_m + \varepsilon_{im}$$

E_{it} = Total compressor electricity usage of facility *i* during week *t*

C_{im} = Compressor-related portion of facility i's electricity costs in month *m*

EMS = indicator for access to Lightapp

Output = normalized facility production

Temp = air temperature

Press = air pressure

Hum = humidity

τ = time of day and time of week

λ_i = facility effects

γ_t = effects by week

γ_m = effects by month

ϕ_p = effects by utility service territory and rate

ε_{im} = additional heterogeneous effects

Effect of Engagement

$$E_{it} = \beta_0 + \beta_1(LI)_{it} + \beta_2(Output)_{it} + \sum_{j=1}^{4}\beta_{2+j}((Temp)_{it} \times \tau_j) + \sum_{j=1}^{4}\beta_{6+j}((Press)_{it} \times \tau_j)$$
$$+ \sum_{j=1}^{4}\beta_{10+j}((Hum)_{it} \times \tau_j) + \phi_p + \lambda_i + \gamma_t + \varepsilon_{it}$$

We will estimate $(\text{LI})_{it}$ using the following first-stage regression:

$$(\text{Logins})_{it} = \gamma_0 + \gamma_1(EMS)_{it} + \omega_{it}$$

E_{it} = Total compressor electricity usage of facility i during week t
LI_{it} = number of times facility personnel at facility i logged into Lightapp during week t
τ = time of day and time of week
λ_i = facility effects
γ_t = effects by week
γ_m = effects by month
ϕ_p = effects by utility service territory and rate
ε_{im} = additional heterogeneous effects

Results

The analysis used five different specifications for estimating treatment effects from Lightapp. In all specifications the dependent variable is converted to logs and so coefficient estimates represent the percentage change in outcomes due to Lightapp.

All specifications pool data from each facility, *i*. Specifications (1) through (4) then use the raw data (*t = 5min).* Specification (5) uses weekly totals of the raw data (*t = week*). For kWh the weekly values are the sum of the kWh in each 5-minute period of that week. Missing values are treated as zero. Please note that for the weekly regressions it is not reasonable to only use weeks containing 100% complete 5-minute data (there are very few such weeks). For these results then, only weeks where more than 75% of the underlying 5-minute data was complete were used. The estimating equations are of the form shown below, where γ is a set of fixed effects as described in the table.

$$log(kWh_{it}) = \alpha + \beta Treat_{it} + \gamma + \epsilon_{it}$$

Addition results were also estimated after imputing missing data. A range of imputing strategies are shown here. When using imputed data an additional $Miss_{it}$ variable was included in the regressions. This is a dummy variable indicating whether an observation was imputed. Please note that for the weekly regressions it is not straightforward how to include the $Miss_{it}$ variable and so this is omitted.

Table A1: Regression Results for kWh Savings

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
No Imputed	-0.151***	-0.161***	-0.154***	-0.161***	-0.189***	-0.192***	-0.146***
	(0.024)	(0.015)	(0.024)	(0.015)	(0.022)	(0.014)	(0.022)
Imputed (Facility Mean)	-0.099***	-0.109***	-0.103***	-0.110***	-0.132***	-0.137***	-0.123***
	(0.023)	(0.014)	(0.023)	(0.014)	(0.020)	(0.014)	(0.021)
Imputed (Facility x DOW x HOD Mean)	-0.119***	-0.125***	-0.122***	-0.118***	-0.142***	-0.146***	-0.120***
	(0.023)	(0.014)	(0.023)	(0.014)	(0.021)	(0.013)	(0.022)
Imputed (Last Carried Forward)	-0.159***	-0.168***	-0.162***	-0.168***	-0.180***	-0.184***	-0.157***
	(0.024)	(0.016)	(0.024)	(0.016)	(0.022)	(0.014)	(0.024)
Imputed (Linear Interpolation)	-0.159***	-0.171***	-0.167***	-0.173***	-0.195***	-0.199***	-0.171***
	(0.025)	(0.015)	(0.024)	(0.015)	(0.021)	(0.014)	(0.023)
Observations - No Imputed	10558896	10558896	10558896	10558895	39637	39637	5945
Observations - Imputed	11457620	11457620	11457620	11457620	41789	41789	6150
No. of Facilities	91	91	91	91	91	91	91
Time Interval	5-minute	5-minute	5-minute	5-minute	Day	Day	Week
Cluster variable	date	date	date	date	date	date	week
R squared - No Imputed	0.284	0.474	0.314	0.552	0.310	0.544	0.584
R squared - Imputed	0.284	0.461	0.312	0.530	0.303	0.506	0.529
Weather Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Of-Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Facility f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Facility x Day-Of-Week f.e.	No	Yes	No	Yes	No	Yes	-
Facility x Hour-Of-Day f.e.	No	No	Yes	Yes	-	-	-
Facility x Day-Of-Week x Hour-Of-Day f.e.	No	No	No	Yes	-	-	-

Regression Analysis - kWh Savings

The results in Table A1 show a reduction in electricity consumption due to treatment of roughly 16-17%. This result is fairly stable across specifications and imputation strategies. For specifications (1) to (4) that use the 5-minute data including increasingly flexible fixed effects does not significantly alter the estimated treatment effect. A similar effect is also found when conducting the analysis with daily and weekly data, as in specifications (5) to (7).

One notable exception to the broad agreement across specifications is the differences between imputation strategies - primarily between those that impute a facility mean (rows 2 and 3) and those that conduct some form of interpolation between adjacent observations (rows 4 and 5). The lower effect estimated when imputing a facility mean is almost certainly due to the dampening effect of imputing with a mean calculated using both baseline and treatment observations. As such the results using interpolation (rows 4 and 5) are likely the most robust and that correspond closely with the results that don't use any imputation (row 1).

Whilst these results are consistent with Lightapp having the desired impact it should be noted that these do not control for changes in output at each facility. As such we cannot distinguish whether these reductions in energy usage are due to improvements from the treatment or simply due to reductions in plant output. We had originally hoped to be able to use some measure of plant-level output as a control for this, but thus far have not received this data from the study participants. One alternative approach may be to use monthly electricity billing data as a proxy for overall facility level output.