Boston Area Laboratory Energy Benchmarking Study

Year 3 Data Analysis Report: University Labs

A Report from the Higher Education Working Group
Boston Green Ribbon Commission

Prepared by kW Engineering
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About the Author

kW Engineering is a nationwide energy engineering consulting firm specializing in saving energy and reducing utility costs. kW's mission is to make all buildings sustainable by improving operation while increasing building value and delivering energy and cost savings.

Report author Alison Farmer delivers energy efficient solutions to kW's high-tech and higher-ed clients, ranging from strategic planning and energy analysis to detailed control system design and commissioning. Alison is a former research astrophysicist who now makes her impact on this planet via a deep dedication to energy efficiency in buildings. Specializing in labs, Alison has chaired I2SL's Lab Benchmarking Working Group since its inception in 2014.

About the Boston Green Ribbon Commission (GRC)

The mission of the GRC is to convene leaders from Boston's key sectors—business, education, health care, non-profit, finance, real estate, professional services, tourism and others—to support the outcomes of the City's Climate Action Plan. The GRC works on a network model and comprises a set of sector-based and initiative-based Working Groups. Together, participants focus on two key strategies: 1) Climate Ready Boston, to help the City become climate resilient and prepared for future impacts of sea level rise, more intense heat, and flooding, and 2) Carbon Free Boston, to develop policy and technology pathways that will enable Boston to reach its goal of net zero carbon by 2050.

About the GRC Higher Education Working Group

The GRC Higher Education Working Group represents the unique constituency of large research and residential campuses in Boston and neighboring cities. Lab facilities are often the source of the greatest energy use at large research institutions, disproportionate to the square footage they occupy, so they are a key area of focus for educational institutions. The Higher Education Working Group commissioned this data collection and analysis effort to better understand how Boston area lab buildings compare to each other and to lab buildings nationally.

The Higher Education Working Group is chaired by Harvard University and managed by the Harvard University Office for Sustainability.

Acknowledgment

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Boston Area Laboratory Energy Benchmarking Study
Supplemental Report: 2016 Data

Executive Summary

The third and final year of the Boston Area Laboratory Energy Benchmarking Study added 2016 energy data to the study dataset, along with 11 buildings that were not previously in the sample.

Focusing on buildings with no known data issues, use changes, or renovations during the study period, the results are stable: the typical scatter in building energy usage between 2015 and 2016 is ±5%. Differences in weather between years account for only a portion of this variation.

Taken as a whole, this innovative three-year study has made significant positive impacts both locally and nationally. Achievements include:

- Demonstrating that Boston-area academic lab building energy consumption is consistent with that of labs in the rest of the country.
- Setting a baseline for Boston lab building energy use against which progress can be measured over time.
- Providing much-needed context for lab energy consumption in the era of building energy disclosure ordinances, and showing that there is significant diversity in both functional requirements and energy performance within the lab building category.
- Developing an energy scoring system for biology and chemistry lab buildings, akin to an Energy Star score for labs, which takes varying functional requirements into account in assigning energy performance scores to buildings.
- Illustrating the ways in which benchmarking data can be used to provide actionable insights, e.g. candidate energy efficiency measures for further investigation.
- Introducing beyond-energy benchmarking for labs: sharing data on operational policies and practices is a promising new avenue for catalyzing positive change.
- Providing participating organizations with separate detailed reports on their own buildings in the context of the full sample.
- Paying close attention to the important issue of data quality in order to construct a robust dataset. Using this dataset, proving that quantitative benchmarking is feasible for lab buildings – a proof that has eluded work done using national benchmarking samples.
- Impacting national lab benchmarking efforts by publicly sharing the benefits of the study: by sharing study data with the Labs21 benchmarking database, enabling the community at large to benefit from an enhanced (anonymized) peer group for lab benchmarking; and by publishing the study reports on the Green Ribbon Commission website, allowing lessons learned to be incorporated into plans being made for future industry-wide lab benchmarking tools.

Potential future directions for this work, which could be undertaken by the Green Ribbon Commission or other industry groups, include:

- Further refining and expanding the draft energy scoring system to incorporate additional lab types and functional requirements.
- Developing beyond-energy benchmarking questions and metrics to enable greater collaboration and exchange of lessons learned between participating organizations.
- Expanding to other lab industry sectors, to include e.g. commercial biotech and pharmaceutical labs, and multi-tenant lab facilities.
- Further developing actionability tools, e.g. by combining benchmarking studies with the results of comprehensive energy audits to identify key high-level questions that might indicate promising savings potential.
- Including water-use benchmarking alongside metrics for energy and operational practices.

These future directions, along with the 2016 (Year 3) results and a comparison between all three years of study data, are discussed in detail in the body of this Supplemental Report. For detailed discussions of results from previous years, refer to the Year 1 and Year 2 reports on the Green Ribbon Commission's website.

Contents

1. Introduction

The first two years of this study involved the collection of data from 121 lab buildings from seven academic institutions in the Boston area, including building energy use data for calendar years 2014 and 2015; the Year 1 and Year 2 reports are available on the Boston Green Ribbon Commission website.[1]

In this third and final year of the study, calendar year 2016 data was added to the dataset along with data for an additional 11 buildings (from two additional organizations) not previously in the sample. This final year of analysis sought to solidify the conclusions of the previous two years: in particular, it was hoped that few new data quality issues would arise and that the parameters associated with the energy scoring system would be found to be steady between Years 2 and 3. These outcomes would lend confidence in the robustness of the dataset and in the use of the energy scoring system.

This report supplements the Year 1 and Year 2 reports; the background, conclusions, and discussions contained in those reports are not repeated here. In this report we describe the approach to 2016 data collection; the demographics of the full three years of data; data quality trends; energy use trends; weather data comparisons; an update to the energy score formulation; a summary of the outcomes and impacts of this study; and recommendations for future work by the Green Ribbon Commission or other groups.

[1] http://www.greenribboncommission.org/library/?fwp_search=benchmarking&fwp_library_types=reports

2. Approach to Data Collection

A new, customized data request spreadsheet (Figure 1) was issued to the seven institutional participants in the original study. The request was limited to annual utility usage data for calendar year 2016, plus a record of any major changes in building operations or occupancy that could significantly alter energy usage compared with the previous year.

Source energy usage was calculated from reported thermal and electrical energy data for each building in the same way as in the original study, i.e. using the standard Energy Star site-to-source conversion factors.

Follow-up questions were asked of institutions where significant differences were found between 2015 and 2016 energy usage data.

Building Name	Calendar Year 2016 Site Energy Usage					Any Important Changes to Building Between 2015 and 2016 (e.g. Changes to Schedule, Metering, Occupancy, Processes)
	Electricity	Natural Gas	Chilled Water	Steam or Hot Water	Data Type	
	kWh	Therms	Ton-hours	klbs or MMBtu		

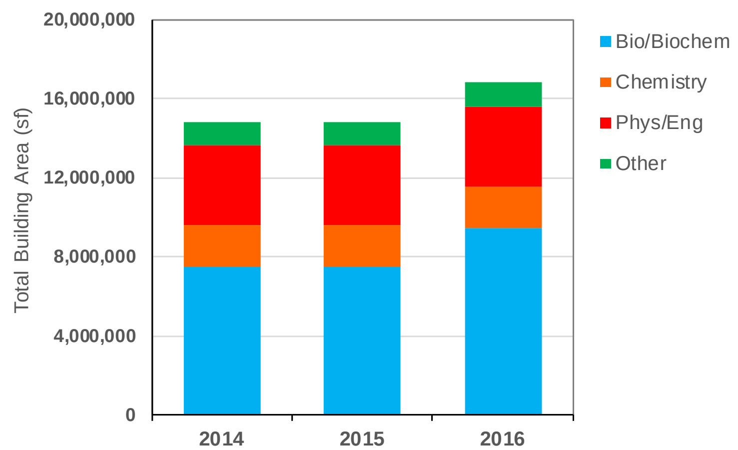
Figure 1: Data collection spreadsheet for 2016 data.

Several organizations that were not part of the original study sample expressed interest in joining the study. Data were obtained from an additional 11 research laboratory buildings from two healthcare organizations. For these buildings, the data request covered all building properties fields but energy use data were restricted to calendar year 2016.

3. Results: Demographics

The Full Sample

The total number of buildings in the dataset, and the total building square footage for each lab type, are shown in Figure 2. The expansion of the study participants for the third year of data collection has taken the sample size to 132 buildings and 16.8 million gross sf (up from 121 buildings covering 14.8 million sf). Almost all of these new additions were biology or biochemistry facilities. The total number and area of lab buildings in the greater Boston area is expected to significantly exceed the total study sample: the current sample does not include pharmaceutical or biotech facilities, or multi-tenant buildings.



Year	2014		2015		2016	
Lab Type	Bldg area (sf)	# Buildings	Bldg area (sf)	# Buildings	Bldg area (sf)	# Buildings
Bio/Biochem	7,530,685	46	7,530,685	46	9,458,573	56
Chemistry	2,050,073	16	2,050,073	16	2,050,073	16
Phys/Eng	4,057,397	50	4,057,397	50	4,109,276	51
Other	1,195,059	9	1,195,059	9	1,195,059	9
Total	**14,833,213**	**121**	**14,833,213**	**121**	**16,812,980**	**132**

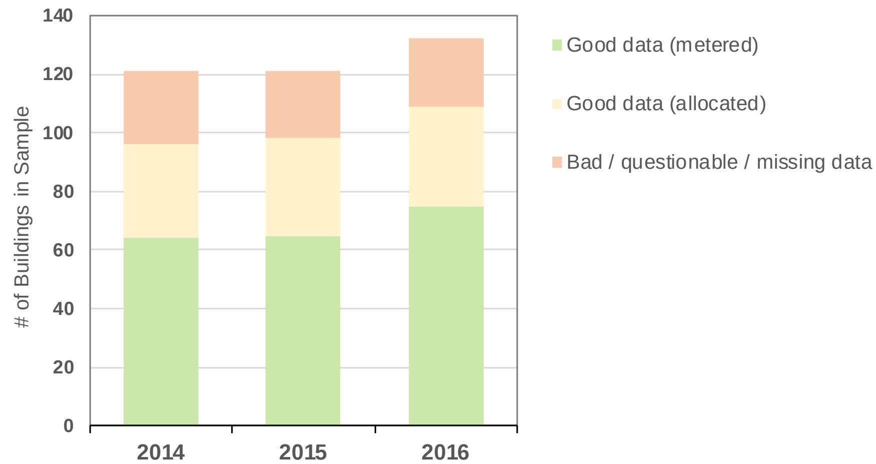
Figure 2: Demographics of the study sample, 2014-2016.

Data Quality

As in previous years, basic data quality checks were carried out on all submitted data. Again, some buildings were found to have highly varying energy usage between years; in these cases, follow-up questions were asked of the data submitters. In many cases, data reporting issues were then identified; some of these were then corrected. Data quality tags were added (or updated, if the issues were found to be present in previous years' data) accordingly. All data submissions known to be "bad" or "questionable" were flagged as such and were not used in quantitative analyses. Reasons for flagging included unavailability of data for 2016, overly approximate energy use allocations, problems discovered with data transfer between reporting systems, and problems with energy meters.

It was hoped that few new data quality issues would arise in 2016, after significant efforts in Year 2 to address issues discovered in the Year 1 dataset. The identification of new data quality issues is, however, highly valuable. The efforts of the submitters to identify problem data are crucial in preventing questionable data from being used where it should not be. By enabling the exclusion of questionable data points from quantitative analyses, these efforts significantly strengthen the conclusions of this work.

Of the 132 buildings in the final sample, 80 are marked as having consistently "good" data for all three years of the study. Of these, 48 buildings have dedicated energy meters (labeled as "metered"), rather than "allocated" energy data based on apportioning energy usage measured for a group of buildings. Data quality trends are shown in Figure 3.



Year	2014	2015	2016
Good data – metered	64	65	75
Good data – allocated	32	33	34
Bad / questionable / missing data	25	23	23
Total number of buildings	121	121	132

Figure 3: Data quality demographics, 2014-2016.

Reported Changes

In the 2016 data submissions, 15 buildings were listed as having undergone renovations or energy projects since 2015. In detailed comparisons of energy usage between years, these buildings were treated separately from those with no known changes. A further 12 buildings had no reported energy data for previous years (11 new participants, and one building at which a gut renovation project was in progress during 2014 and 2015).

Some of the "known change" classifications for the 2015 dataset (vs. 2014) were updated based on additional information received from submitters in Year 3.

4. Results: Energy Usage

Overall Energy Usage

The total source energy usage of all buildings with "good" allocated or metered data for 2016 is shown in Figure 4 below. The total 2016 energy usage of these 109 buildings is 8.1 million MMBtu, equivalent to the energy consumed by 54 million square feet of office buildings.

As before, a significant fraction of the energy use by the full sample is due to a relatively small number of large, fairly energy intensive biology/biochemistry laboratory buildings.

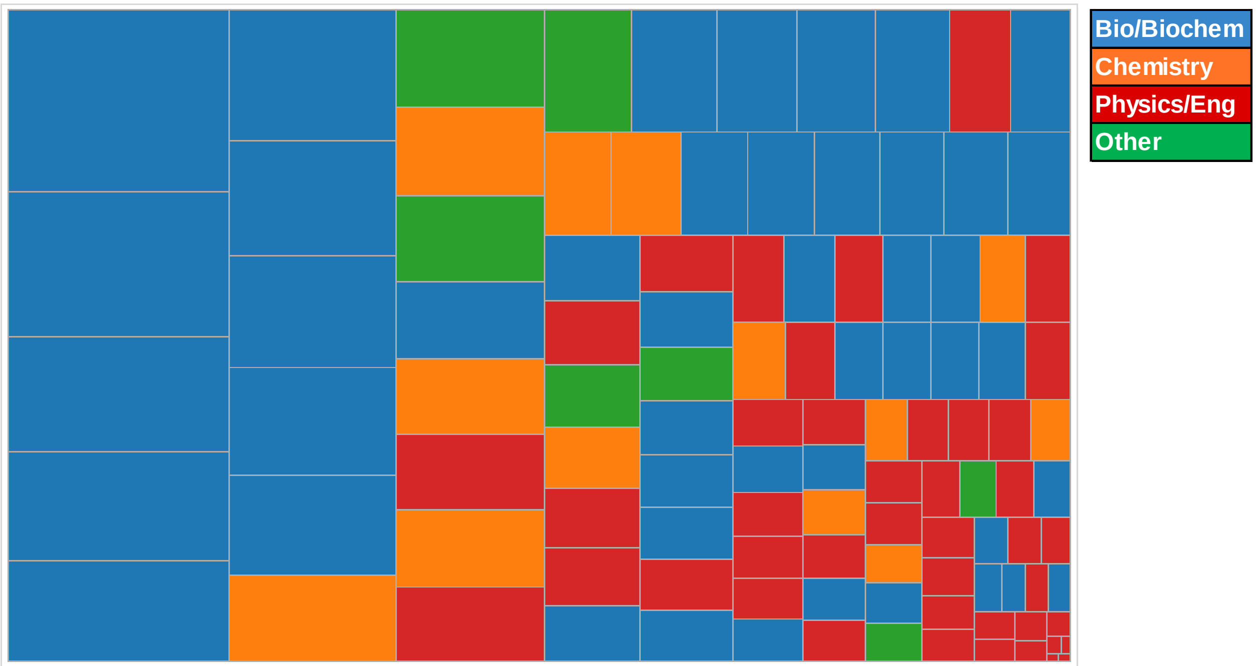


Figure 4: Tree diagram for the 109 buildings with "good" energy data for 2016. The area of each rectangle is proportional to the total source energy consumption of one building.

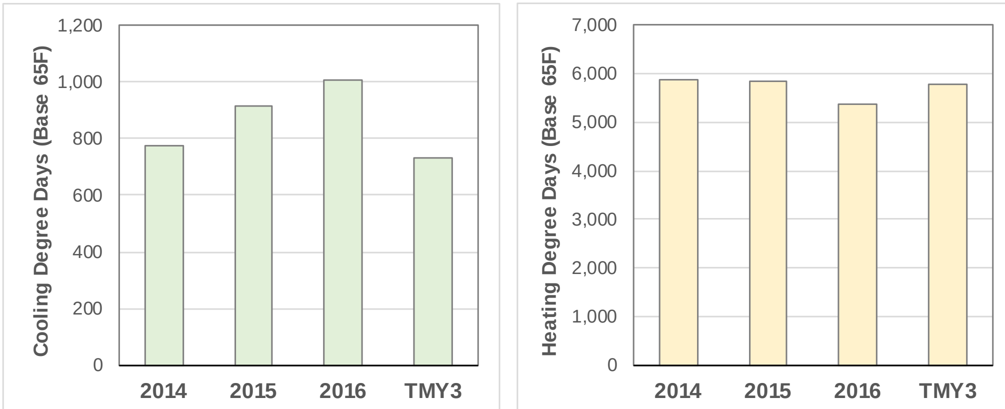
The average and median energy use intensity (EUI) for each category of buildings in the 2016 sample are displayed in Table 1. Note that, because of differences between years in the population of buildings with "good" data, this table is not directly comparable with summary tables from previous reports. Comparisons between years are provided later in this section.

Table 1: Energy intensity summary for the 2016 dataset, including all "good" data, both fully metered and allocated. All EUIs are expressed in kBtu/sf/yr.

	# Buildings	Average Source EUI	Median Source EUI	Stdev of Source EUI	Average Site EUI
Bio/Biochem	46	547	548	160	292
Chemistry	13	633	605	211	355
Physics/Eng	43	432	386	229	244
Other	7	542	552	98	286
All Types	109	512	507	204	280

Weather Comparison

A comparison of Boston weather between the three study years and a typical meteorological year (TMY3) is shown in Figure 5.



Year	Cooling Degree Days, Base 65F (CDD65)	CDD65 / (2014 CDD65)	Heating Degree Days, Base 65F (HDD65)	HDD65 / (2014 HDD65)
2014	773	1.00	5,881	1.00
2015	914	1.18	5,826	0.99
2016	1,005	1.30	5,370	0.91
TMY3	734	0.95	5,793	0.99

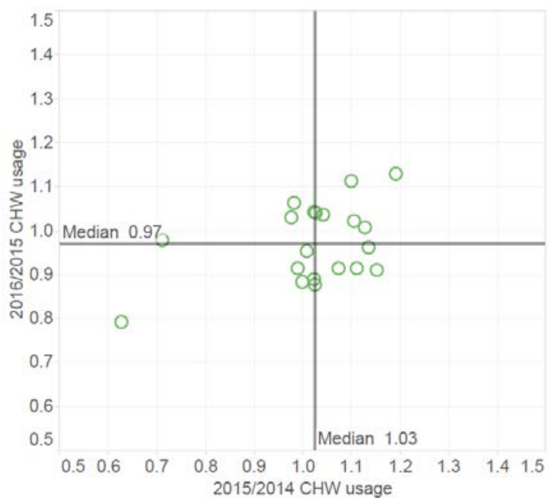
Figure 5: Annual cooling and heating degree day summary, 2014-2016 and TMY3.

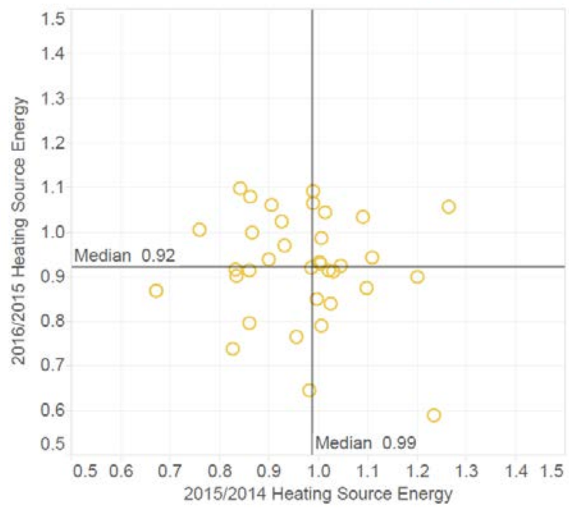
2016 was generally hotter than 2015, which was hotter than 2014. 2014 was closest to a "typical" year in terms of heating and cooling degree days.

Many of the buildings in the sample are served by campus central plant systems. For buildings with chilled water or heating energy usage data spanning all three years (metered, good data with no known changes), annual energy use comparisons are shown in Figure 6. For heating energy, the median usage ratio between years is close to the expected value; this is not the case for the chilled water usage data.

In both cases, significant scatter (at the ±10% level) exists between years. It is reasonable to conclude that the variations in energy usage due to unreported minor process, occupancy, or operational changes (or perhaps metering problems) are at least as large as the weather-driven variations.

More detailed conclusions around weather-related variations could be made with a sample containing more years of data, spanning a larger geographical area, or including monthly energy usage data.





	Weather: CDD65 Ratio	CHW Energy Usage	
		Median ratio	Standard dev.
2015 vs. 2014	1.18	1.03	0.14
2016 vs. 2015	1.10	0.97	0.09

Using only the 20 buildings with chilled water usage, consistently good metered data, and no known renovations.

	Weather: HDD65 Ratio	Heating Source Energy Usage	
		Median ratio	Standard dev.
2015 vs. 2014	0.99	0.99	0.13
2016 vs. 2015	0.92	0.92	0.12

Using only the 36 buildings with heating energy usage, consistently good metered data, and no known renovations.

Figure 6: Annual variations in cooling (left) and heating (right) energy consumption.

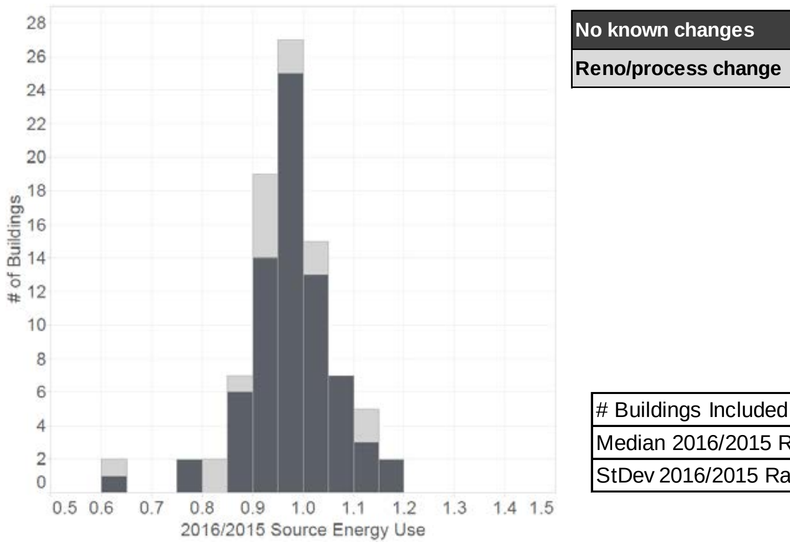
Source Energy Usage Comparison

For the sample of 38 buildings with consistently good metered data between years and no reported changes over the full study period, the average and median source energy use intensities are shown in Table 1. There has been no significant change in these quantities over the study period.

Table 2: Summary of sample source energy use intensities, 2014-2016.

Data Type	Year	Source Energy Use Intensity (kBtu/sf/yr)					
		2014		2015		2016	
	# bldgs	Avg	Median	Avg	Median	Avg	Median
Metered, no known changes, no bad data	38	544	563	539	569	529	535

The distribution in the ratio of 2016 to 2015 total energy usage is shown in Figure 7. For buildings with no known changes between years, the median ratio is 0.97 and the standard deviation is 0.05 (smaller than for either chilled water or heating energy alone). The ratio distribution is tighter than initially found for the Year 2 vs. Year 1 data; this is likely to be due to improvements in data quality and data reporting in Years 2 and 3 of the study.



	No Known Changes 2015-2016		All Buildings (with good data)
	Metered	Allocated	
# Buildings Included	46	27	88
Median 2016/2015 Ratio	0.97	0.97	0.97
StDev 2016/2015 Ratio	0.05	0.13	0.09

Figure 7: 2015-2016 source energy usage comparison.

As before, the spread in energy use between years is greater for buildings with allocated energy usage data than for those with dedicated building energy meters. This is expected because where energy usage is allocated, changes in <u>any</u> of the buildings served by the meters in question can affect the allocated energy usage for the lab building in the sample; such changes would not be reported as part of the data requests for this study.

Comparing the total source energy usage data for all three years in Figure 8 below shows that there continue to be some significant outliers with large energy use changes between years, even for buildings with dedicated meters and no reported process changes or renovations.

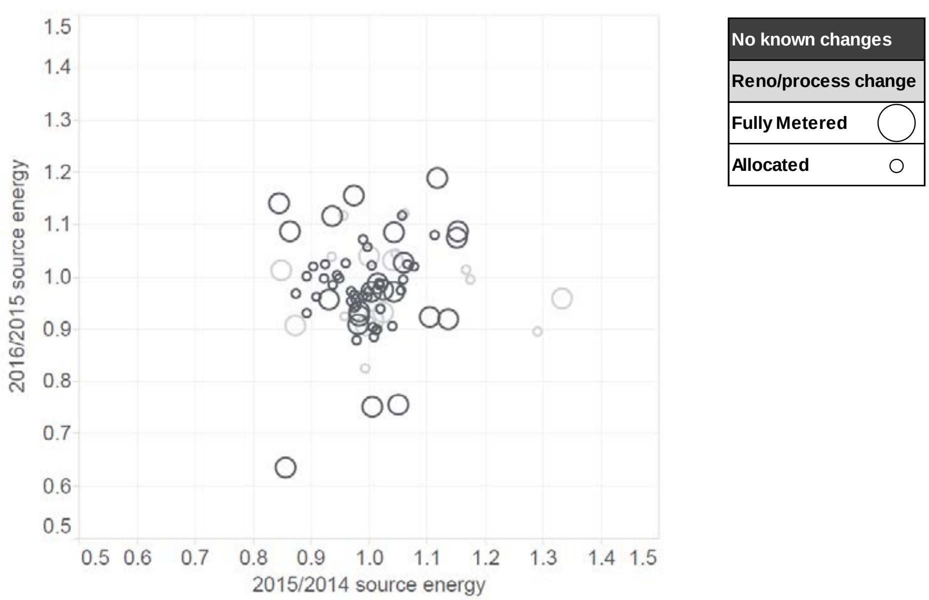


Figure 8: 2014/15/16 source energy usage comparison, distinguishing buildings by metering type and whether any known changes occurred between years.

5. Energy Score Update

Updating the Analysis

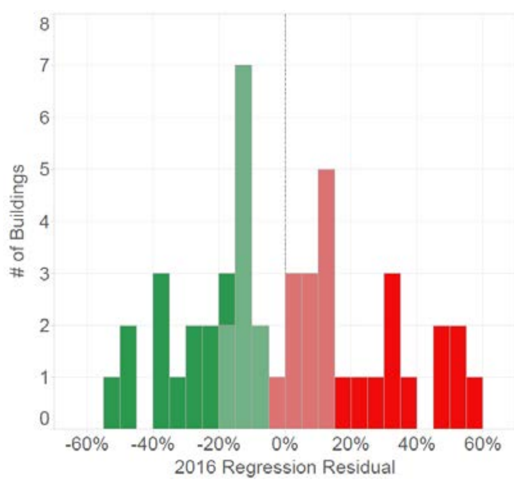
With improved data quality each year, it is worthwhile to use the latest data to recalculate the parameters associated with the draft lab building energy scoring system. For a detailed discussion of the energy scoring system and the methods used to develop it, refer to the Year 1 report. Using just the 2016 data for fully metered bio/biochem and chemistry buildings (47 buildings total) yields the regression results shown in Table 2. For comparison, the 2015 results are also provided.

Table 3: Energy score regression analysis results for 2015 (from Year 2 report) and 2016 (new).

	2016			2015 (from Year 2 report)		
	Coefficient	**Stdev**	**Significant?**	**Coefficient**	**Stdev**	**Significant?**
% lab area (bio)	385	144	Yes	397	136	Yes
% lab area (chem)	513	173	Yes	551	168	Yes
Weekly operating hours	0.8	1.3	No	0.5	1.3	No
Fume hoods/lab sf	71,750	53,338	Borderline	21,166	41,763	No
Constant	245	147	Yes	305	139	Yes
R^2 (EUI)	**30%**			**27%**		
R^2 (source energy)	**79%**			**82%**		

The new results are not significantly different from those derived in Year 2, and the amount of variation in EUI explained by the regression (i.e. R^2) continues to be similar to that seen for typical Energy Star scores for buildings. While the scoring system still only incorporates a few of the myriad functional requirements of lab buildings, most of the included factors are significant. This, and the observed stability, lends confidence in the use of this scoring system for identifying both high-performing lab buildings and those that would benefit from further attention.

The distribution of regression residuals for the 47 buildings used to derive the scoring system is shown below (Figure 9), with color coding indicating the assigned scores (based on quartile rankings, as in previous years).



Quartile (score)	Quartile upper bound on residual	# bldgs in quartile (in regression dataset)
1	-19%	12
2	-1%	11
3	16%	12
4	-	12

Figure 9: 2016 energy scores (and quartile score thresholds) for the 47 buildings used to develop the energy scoring system.

Changes in Scores

The majority of the variation in scores between 2015 (using the scoring system coefficients from the Year 2 report) and 2016 (using the new coefficients shown above) is due to changes in the energy usage of individual buildings, rather than changes in the regression parameters: Figure 10 below demonstrates that the change in regression residual between 2015 and 2016 is strongly correlated (R^2 of 75%) with the change in EUI.

The second largest reason for score variations is the change in the regression coefficient associated with fume hood density; this change was due to a difference in the population of buildings included in the high-quality data sample for 2016. Buildings with high fume hood density – large circles in the plot below – typically experienced a reduction in regression residual.

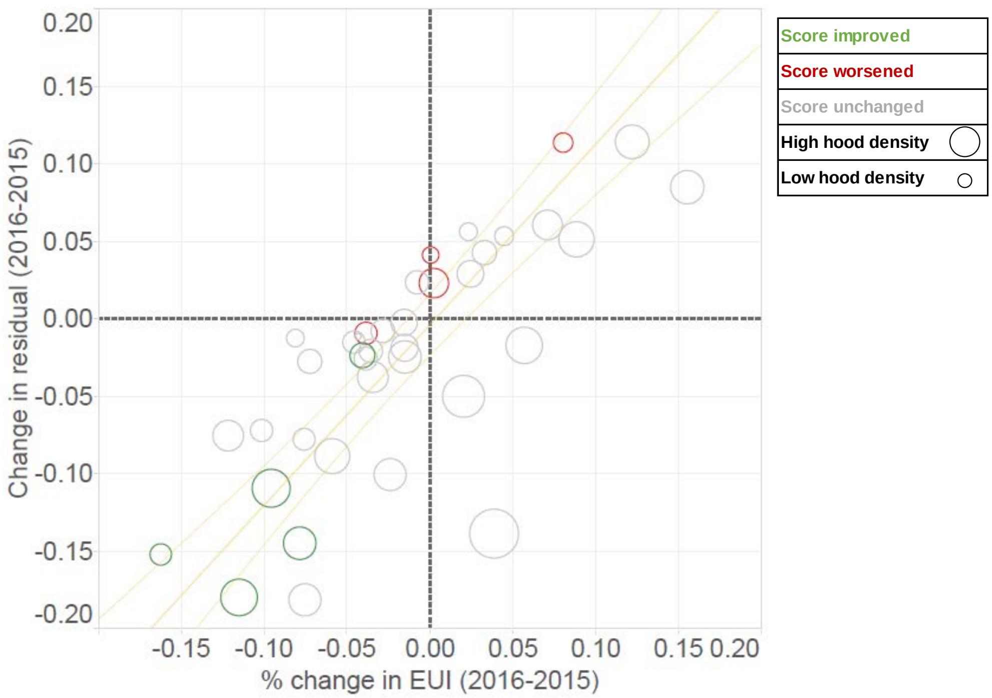


Figure 10: Change in regression residual between 2015 and 2016 vs change in building EUI between the same years. The majority of the difference in scores is due to changes in building energy consumption, not changes in the scoring system.

Potential future work to refine the energy scoring system is discussed in Section 6 below.

6. Summary and Next Steps

With this three-year study, the Boston Green Ribbon Commission has achieved an objective that has thus far eluded national lab benchmarking efforts: the study participants have assembled a set of lab building data that is of sufficient uniformity and integrity to allow quantitative assessment of building performance and the identification of both high-achieving buildings and those facilities that could most benefit from follow-up attention.

This valuable dataset should be used to inform energy policies in the Boston area (and beyond), including energy disclosure ordinances and utility company efficiency programs.

No significant change in average building energy consumption was detected over the course of the study. Further, the energy scoring system appears to have largely stabilized between Years 2 and 3.

While the 3-year study has now concluded, the work of the participants towards improved lab building energy efficiency will continue far into the future: many of the participating organizations are committed to ambitious greenhouse gas emissions reduction goals. The study results provide a snapshot of the state of Boston area (academic) lab energy usage and building properties that can be used as a valuable point of comparison as these initiatives progress.

National Impact

By submitting the study data to the Labs21 benchmarking database, the study participants shared some of the benefits of this work with the entire lab industry. By making the study reports publicly available and presenting the work at conferences and via webinars, the Green Ribbon Commission also elevated the national discussion on lab benchmarking. Lessons learned from this study have been incorporated into I^2SL's long-term plans for national lab benchmarking tools. As mentioned above, the GRC study has been invaluable in demonstrating that with a high-quality dataset, quantitative benchmarking for lab buildings is as feasible as it is for other types of building. This conclusion could not have been drawn from any of the previously existing lab benchmarking datasets.

Possible Future Projects

Future projects should consider addressing the following promising areas:

1. **Further development of energy scores**

   The draft energy score for biology and chemistry buildings appears largely to have stabilized between Years 2 and 3 of this study. The score could continue to be refined to cover additional lab types and to account for more of the functional requirements of lab buildings.

   It is worthwhile to revisit the motivation for and power of an energy scoring system. A regression-based energy scoring system like the one developed in this study:

   - Allows easy tracking and communication of building performance via a single, simple number, and thereby also offers an easy way to celebrate success or set performance targets.

- o Provides automatic correction for building functional requirements, and does not require the user to make detailed iterative comparisons with a peer group dataset (a challenging task for inexperienced or busy users of any benchmarking system).
- o Effectively offers comparison with all buildings in the sample rather than just a few near neighbors, and can thus be used even in sparsely populated areas of parameter space (i.e. for buildings with few close peers).
- o Can assist with prioritization of attention within a sample of buildings. By way of illustration, buildings that are represented by red points in Figure 11 (poor energy score) and are located close to the top right of the plot (high energy use and high EUI) are excellent candidates for follow-up energy audits.

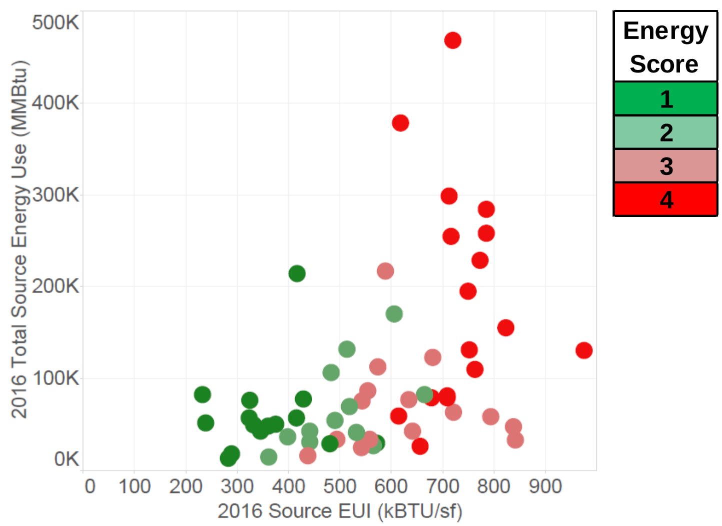


Figure 11: Example selection of candidates for follow-up energy studies. Buildings towards the top right of the plot (high energy usage and high energy use intensity) and red markers (poor energy scores) may be good potential sources of energy savings and should be prioritized in efficiency efforts.

Energy scores are not a replacement for an energy audit, and ranking exercises of this kind should be constructive rather than punitive; the development of useful energy scores is one of the many ways shared data can be used to effect positive change.

The current draft scoring system could be enhanced via the incorporation of:

- o Lab area breakdown within each building (to allow multiple lab types per building rather than considering only the predominant lab type for each building).
- o Additional lab subtypes (particularly important for physics and engineering lab categories).
- o Monthly energy usage data, or data from a wider geographic region, to allow the derivation of correction factors for weather variations.

While the scope of the GRC study could not include any of the above enhancements, some of these aspects may be incorporated in changes being made by I^2SL and LBNL to the national lab benchmarking database.

2. **Operational practices benchmarking**

   No further development in this area was carried out using the 2016 data, but this remains a high-interest area with potentially high yields for participants and industry bodies alike. Potential topics on which data could usefully be collected and shared include:

   - Health and safety policies such as fume hood face velocities, minimum lab ventilation rates, and the use of lab ventilation management plans
   - Operations and maintenance practices and staffing levels
   - Building design features
   - Implemented energy projects
   - Purchasing policies for lab equipment such as -80°C freezers
   - Building control system types and features
   - Space conditions provided in specific types of labs.

   This type of benchmarking allows sharing of lessons learned and methods for overcoming the types of obstacles that can prevent beneficial projects from being implemented in lab facilities. It can also highlight the potential for implementing operational, safety, or efficiency measures that have been successfully enacted elsewhere.

3. **Expanding to other lab industry sectors:** Combining this dataset with data on pharma, biotech, and multi-tenant lab buildings from the area would allow development of a more complete picture of Boston-area lab buildings.

4. **Water use benchmarking:** With increasing dialog on water consumption across all industries, and initial indications that lab buildings are responsible for greater levels of consumption than other building types, the inclusion of water usage data will be important in future studies. The results of these studies may well provide actionable insights; note that known water-saving measures exist for many lab-specific water end-uses, e.g. autoclaves.

5. **Improving actionability:** Combining the results of this study with those of detailed energy audits of the same buildings may help to make the benchmarking results more actionable. By correlating audit and benchmarking results, it may be possible to develop a list of key questions that can be used to quickly identify potential high-yield energy projects.

As a final note, lab facilities do not benefit from being *hors catégorie* for benchmarking or energy efficiency programs. Properly conceived energy projects in lab buildings typically deliver operational, safety, and comfort improvements as well as energy savings. This work by the Green Ribbon Commission is an excellent example of the power of sharing data, lessons learned, and expertise between organizations to catalyze progress on our shared goal of improved sustainability for lab facilities in Boston and beyond.