Development of an Operational Emissions Score for Laboratories

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1. Overview

Environmental performance scoring provides an intuitive way for building owners and operators to normalize, understand, and improve the performance of their facilities. Laboratory buildings present unique challenges for normalized score frameworks due to their complexity and the variety of characteristic information that can impact environmental performance, uniquely positioning the Laboratory Benchmarking Tool (LBT) [1] as a strong foundation for environmental scoring mechanisms tailored to laboratory buildings. After developing LBT’s energy score in 2023, efforts began to develop a complementary score specific to operational emissions.

This memo describes the development of a novel system for assigning laboratory buildings a score that reflects their operational greenhouse gas (GHG) emissions performance relative to their peers, primarily for use in the LBT. The score was designed to rate a building’s operational emissions performance based on its location (i.e., electrical grid emissions rate), energy consumption, and fuel mix, while adjusting for some factors the building owner cannot control (i.e., functional requirements like lab use type, occupied hours, weather, etc.). This score is meant to evaluate location-based operational emissions, and is meant to be complementary to the LBT's energy score. A market-based emissions score would require additional data that is not currently available in the LBT.

This work was carried out by Lawrence Berkeley National Laboratory (LBNL) and the International Institute for Sustainable Laboratories (I2SL). We also received valuable feedback from several stakeholders and members of the I2SL Labs2Zero Operational Emissions Technical Advisory Council (TAC).

2. Data Sources

The primary source of data for this analysis was the dataset underlying the Laboratory Benchmarking Tool (LBT) [1], which is the largest known collection of energy-related information on laboratory buildings. We utilized only the subset (1004 building-year records) of the dataset that has been quality checked by LBNL after being entered by users of the LBT, but acknowledge that some data errors may not have been detected. For each record, the database contains over 100 fields describing various characteristics of the laboratory building (e.g., size, age, location, operating characteristics, installed systems, and energy consumption). See the full list of LBT data fields and their descriptions [2] for more information. We carefully inspected the data and removed any data deemed to be unreliable (e.g., physically unrealistic) or otherwise not representative of laboratories in general (e.g., abnormally high or low values relative to other buildings). For this initial version of the score, we considered only buildings located in the United States.

For each building in the LBT dataset, we computed source energy from the energy consumption of each individual fuel using conversion factors from Figure 1 of the U.S. Environmental Protection Agency's (EPA) Technical Reference on Source Energy [3].

To compute GHG emissions from energy consumption of individual fuels, we used different sources for emissions factors, depending on the fuel.

For all fuels except grid electricity and district chilled water (i.e., natural gas, fuel oil #2, district hot water, and district steam), we used the factors in Figure 1 of the EPA's Technical Reference on GHG Emissions [4]. Buildings using fuels other than those specifically listed in the LBT (i.e., fuel type entered as "Other") were excluded from the analysis.

For grid electricity, we first looked up each building's eGRID subregion from its ZIP code using the EPA's Power Profiler Emissions Tool [5]. We then computed GHG emissions due to grid electricity using Table 1 in the eGRID Summary Tables [6]. If ZIP code was not available, we used the state average emissions factor from Table 3. If neither ZIP code nor state was available, we used the national average factor from Table 3. Fewer than 1% of buildings did not have a ZIP code available in the dataset.

For district chilled water, we started with the emissions factor for an electric-driven chiller in Figure 3 of the EPA's Technical Reference [4], then scaled the factor using the ratio of each particular building's grid emissions factor to the national average factor (from Figure 5 in EPA's Technical Reference [4]).

For example, consider a building in ZIP code 60463. The Power Profiler [5] indicates eGRID subregion RFCW, and the Summary Tables [6] indicate an electricity emissions factor of 1052.5 lbCO2e/MWh = 477 kgCO2e/MWh. In the Technical Reference [4], the district chilled water factor from Figure 3 is 52.7 kgCO2e/MMBtu, and the national average electricity factor from

Figure 5 is 389 kgCO2e/MWh. Thus, the district chilled water factor for this building would be computed as 52.7 x 477 / 389 = 64.6 kgCO2e/MMBtu.

3. Computing a Score

In order quantify a building's operational emissions performance relative to its peers, we first predict the amount of energy a typical building with the same functional requirements is expected to use, then compute the GHG emissions a typical building would be expected to emit as a result of that energy use, then compare the building's actual GHG emissions to the expected emissions.

In order to predict expected energy use, we use the linear regression model developed as part of the LBT Energy Score methodology (see [7] for details). This model was constructed by identifying statistically-significant relationships between source energy use intensity (EUI) and several variables deemed as functional requirements of laboratory buildings, thus reflecting typical energy use while adjusting for characteristics and operating behaviors necessary for a functioning laboratory. The model predicts source EUI (kBtu/sqft) with the following coefficients:

- Intercept (assigned to all buildings): 290.5 kBtu/sqft
- Occupied Hours: 0.4473 (kBtu/sqft) / (hours/week)
- Lab Area Ratio (net lab space as fraction of building gross area): 2.979 (kBtu/sqft) / %
- CDD65: 42.78 (kBtu/sqft) / (1000 degree-days)
- Lab Type = Manufacturing: +138.4 kBtu/sqft
- Lab Type = Teaching: -83.04 kBtu/sqft
- Lab Use = Bio/Chem: +74.50 kBtu/sqft

We used the LBT database to establish the relationship between a typical laboratory building's energy consumption and its operational GHG emissions, based on the assumption that the LBT contains a representative sample of laboratories in the United States. This assumption is difficult to test, but since the LBT is the largest known collection of laboratory energy data, we believe it to be reasonable. For each peer building in the LBT database, we computed the ratio of location-based GHG emissions intensity (GHGI) to source EUI, then computed the average of that ratio to be 0.040981 kgCO2e/kBtu. For each building, we multiply its predicted source EUI by this ratio to yield its predicted GHGI (interpreted as the GHGI of a typical laboratory building with similar functional requirements to the building in question).

To compare a building's operational emissions performance to that of its peers, we compute its GHGI ratio as its actual GHGI divided by its predicted GHGI. The resulting GHGI ratio represents the proportion of predicted GHGI that the building actually used. For example, a GHGI ratio of 0.75 means the building emitted 75% as much as predicted for a building with the same functional requirements and a typical ratio of GHGI to source EUI (i.e., a typical fuel mix and typical emissions factors).

Following the methodology used for the LBT Energy Score [7], we fit a gamma distribution to these GHGI ratios (see Figure 1), then used the fitted gamma distribution to generate a lookup table (see Table 1) that maps each range of GHGI ratios to the corresponding operational emissions score. The score represents the percentage of buildings performing worse than a given building (i.e., a score of 100 indicates highest performance and a score of 1 indicates lowest performance). For example, consider a building with a predicted GHGI of 27.01 kgCO2e/sqft, and assume that this building's actual GHGI was 17.12 kgCO2e/sqft. The GHGI ratio is computed as 17.12 / 27.01 = 0.6338. According to Table 1, this ratio corresponds to a score of 73.

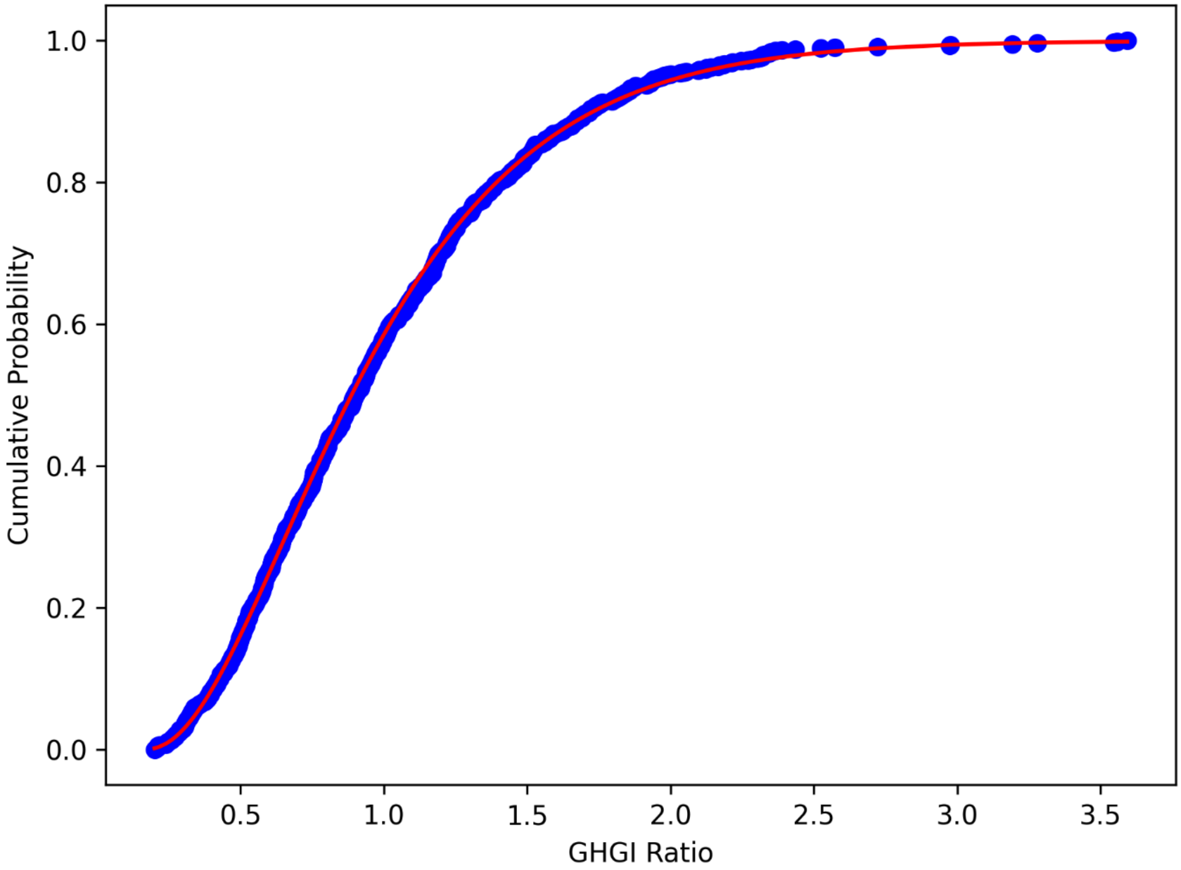

Figure 1: Cumulative distribution function for GHGI ratio. The blue circles represent the ratios computed from the dataset. The red line represents the gamma distribution fitted to the computed ratios.

Score	GHGI Ratio Min	GHGI Ratio Max
100	0	0.2477
99	0.2477	0.2797

98	0.2797	0.3045
97	0.3045	0.3256
96	0.3256	0.3445
95	0.3445	0.3618
94	0.3618	0.3780
93	0.3780	0.3933
92	0.3933	0.4079
91	0.4079	0.4219
90	0.4219	0.4355
89	0.4355	0.4486
88	0.4486	0.4614
87	0.4614	0.4740
86	0.4740	0.4863
85	0.4863	0.4983
84	0.4983	0.5102
83	0.5102	0.5220
82	0.5220	0.5336
81	0.5336	0.5451
80	0.5451	0.5565
79	0.5565	0.5678
78	0.5678	0.5790
77	0.5790	0.5902
76	0.5902	0.6013
75	0.6013	0.6124
74	0.6124	0.6234
73	0.6234	0.6345
72	0.6345	0.6455
71	0.6455	0.6565
70	0.6565	0.6675
69	0.6675	0.6786
68	0.6786	0.6897
67	0.6897	0.7007
66	0.7007	0.7119
65	0.7119	0.7230
64	0.7230	0.7342
63	0.7342	0.7455
62	0.7455	0.7568
61	0.7568	0.7682
60	0.7682	0.7797
59	0.7797	0.7912
58	0.7912	0.8029
57	0.8029	0.8146

56	0.8146	0.8264
55	0.8264	0.8383
54	0.8383	0.8504
53	0.8504	0.8625
52	0.8625	0.8748
51	0.8748	0.8873
50	0.8873	0.8998
49	0.8998	0.9126
48	0.9126	0.9255
47	0.9255	0.9385
46	0.9385	0.9518
45	0.9518	0.9652
44	0.9652	0.9789
43	0.9789	0.9927
42	0.9927	1.0068
41	1.0068	1.0212
40	1.0212	1.0358
39	1.0358	1.0506
38	1.0506	1.0658
37	1.0658	1.0813
36	1.0813	1.0970
35	1.0970	1.1132
34	1.1132	1.1297
33	1.1297	1.1466
32	1.1466	1.1639
31	1.1639	1.1817
30	1.1817	1.1999
29	1.1999	1.2187
28	1.2187	1.2380
27	1.2380	1.2579
26	1.2579	1.2785
25	1.2785	1.2997
24	1.2997	1.3217
23	1.3217	1.3446
22	1.3446	1.3683
21	1.3683	1.3931
20	1.3931	1.4189
19	1.4189	1.4460
18	1.4460	1.4744
17	1.4744	1.5043
16	1.5043	1.5359
15	1.5359	1.5695

14	1.5695	1.6053
13	1.6053	1.6437
12	1.6437	1.6851
11	1.6851	1.7301
10	1.7301	1.7795
9	1.7795	1.8343
8	1.8343	1.8958
7	1.8958	1.9661
6	1.9661	2.0485
5	2.0485	2.1483
4	2.1483	2.2753
3	2.2753	2.4517
2	2.4517	2.7475
1	2.7475	inf

Table 1: Lookup table mapping each range of GHGI ratios to the corresponding operational emissions score.

4. Next Steps

We computed emissions scores for each of the buildings in the LBT dataset (including several test buildings entered into the LBT solely for the purpose of testing the emissions score), and confirmed the desired behavior of the score. For example:

- An all-electric building with a typical site EUI located in a region with a very dirty electric grid received a very low emissions score.
- An all-electric building with a typical site EUI located in a region with a very clean electric grid received a very high emissions score.
- A building with a typical site EUI and fuel mix, but located in a region with a very clean grid received a moderately high emissions score.
- A building with a typical site EUI and fuel mix, but located in a region with a very dirty grid received a moderately low emissions score.
- A building with a typical site EUI, relatively little electric use, and located in a region with a dirty grid received a higher emissions score than a similar building with a typical fuel mix.

In addition, we performed several checks for biases within the scoring system. We looked at buildings with very high scores and confirmed that the scores are warranted (e.g., an all-electric building in a very clean grid region), and likewise for very low scores. We also looked for relationships between emissions scores and laboratory characteristics (e.g., lab type, climate, grid region, electric to site ratio) and found no strong correlations beyond the expected relationships (e.g., as expected, scores were generally lower for buildings in grid regions with higher carbon intensity). We also looked at buildings with abnormal combinations of energy scores (see [7]) and emissions scores, and confirmed that both scores are as expected (e.g., a building with a high energy score but a low emissions score has a low overall source EUI, but uses a lot of electricity and is located in a region with a dirty electric grid).

We are confident in the utility of this scoring system, but acknowledge that further scrutiny and refinement may be needed to achieve stakeholder buy-in and widespread adoption and use of the score. We will continue to check for indications that the score is treating any particular types of buildings unfairly (e.g., whether buildings of particular types or in particular locations tend to score abnormally higher or lower than their peers). If we identify any such biases, we will consider adjustments to the scoring methodology (potentially advised by additional data collection).

We also plan to collect data from a handful of pilot laboratory buildings that have additional data available than what is available in the LBT database. We will compute scores for those pilot labs then compare the score to the expected level of performance of that laboratory based on the more detailed data (i.e., we will check our computed scores for some pilot sites known to be high- or low-performing and make sure the score is consistent).

Lastly, as the LBT database grows and more information about the relationship between laboratory energy use and GHG emissions is available, we will consider updating the regression model used to predict expected source EUI, the factor used to convert predicted source EUI to GHGI, and the scoring methodology itself. As electrical grids change (e.g., as more renewables come online), we will also monitor updated emissions factors from the EPA and update our methodology when appropriate.

5. References

[1] International Institute for Sustainable Laboratories. "Laboratory Benchmarking Tool". 2023. https://lbt.i2sl.org/.

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[3] U.S. Environmental Protection Agency (EPA). "ENERGY STAR Portfolio Manager Technical Reference: Source Energy". August 2023. https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf.

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[6] U.S. Environmental Protection Agency (EPA). "eGRID Summary Tables". 2023. https://www.epa.gov/system/files/documents/2023-01/eGRID2021_summary_tables.xlsx

[7] T. Walter, J. Kace, and A. Farmer. "Development of an Energy Score for Laboratories". August 2023. https://lbt.i2sl.org/files/Development%20of%20an%20Energy%20Score%20for%20Laboratories.docx.pdf.