Comparing Apples to Oranges: Energy Benchmarking of Supermarkets with Limited Data

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ABSTRACT

Current approaches for benchmarking building energy consumption are either too data intensive to be feasible in practice or too data agnostic to be useful. We present a limited data approach where in, instead of using minutiae required for accurate HVAC modeling, we model the heating/cooling loads, the drivers for HVAC. This allows us to see how a building's (i) weather independent consumption compares to the optimal value and (ii) weather dependent consumption compares with its expected heating/cooling loads. Based on this two dimensional metric, we benchmark 94 geographically diverse supermarket stores and present our findings.

Keywords

Building energy management, supermarkets, Benchmarking, Energy modeling

1. ENERGY BENCHMARKING

Given the end user activities, occupancy patterns, age of a building, and the constraints imposed by the building's design and ambient conditions, benchmarking attempts to determine how far is the building's actual energy consumption from the optimal value. Determining this is non-trivial owing to the huge parameter space involved. Nevertheless, benchmarking energy consumption of buildings is required to identify: (i) the outliers in terms of better/worse performance and (ii) possibilities of improvement.

Existing approaches & Limitations. Buildings are typically benchmarked using energy use intensity (EUI). EUI is obtained by normalizing the overall energy usage with respect to parameters such as total floor space, number of occupants, and working hours. However, such benchmarking may not be accurate due to the possible non-linear influence of factors such as occupancy, area, operational schedules, and weather on energy consumption. Two alternatives to EUI based benchmarking exist.

In *data-driven benchmarking*, parameters such as building type, floor area, location, occupancy and energy use are collected from an *ensemble* of buildings. A regression model for energy consumption as a function of these parameters is then derived from this data. Individual buildings are compared with respect to the average performance and appropriately ranked [4]. Standard ranking methods such as EnergyStar, Cal-Arch, and BEE, follow this strategy. However, this approach can only indicate how well a building is doing compared to its peer group. The entire peer group may be inefficient, which could cause an inefficient building to be rated as being efficient.

In *model based benchmarking*, an energy model for each *individual* building is defined. The model parameters are calibrated for an ideal energy behavior adjusted for the building's age. The model's ideal energy consumption is then estimated through simulations. The building's actual energy consumption is benchmarked against this estimated value and opportunities for improvement are identified by a sensitivity study on the model parameters [2]. As the model can be customized for each building, the benchmarking is done against absolute values thereby mitigating the drawbacks of data-driven relative benchmarking.

The efficacy of model-driven benchmarking is limited by its exacting requirements on data availability. For instance, to create an accurate energy model of a building, one would require the age adjusted efficiency and performance curves of each of the HVAC and/or refrigeration system components. Further, researchers have also shown that simulation tools can introduce uncertainty (as much as 22%) in estimating the energy consumed by HVAC systems [3].

2. PROPOSED APPROACH

There is a need for an absolute benchmarking methodology that neither requires data on HVAC systems nor estimates the energy consumed by HVAC systems. We propose such an approach where in, instead of using a model to estimate the *energy* consumed by a building's HVAC system, we use the model to estimate the building's *ideal heating and cooling demands that drive the HVAC operations*. The heating/cooling demands are more innate to a building's structure, lay-out and operations. The ideal heating and cooling demands are independent of the building's HVAC systems. Hence such a modeling does not require any data on the HVAC systems.

We categorize the energy consumed by a building into two components: weather independent and weather dependent. We estimate the ideal energy consumption of weather independent component and compare it with the component's actual consumption in the building; for the weather dependent component, we estimate the building's ideal heating and cooling loads rather than the energy consumed to service these loads. We then compare this ideal load with the building's actual weather dependent energy consumption.

Limitations. While we can identify that the HVAC system in a building as a whole is inefficient, the inefficiencies cannot be drilled down to individual components such as a chiller or blower. The

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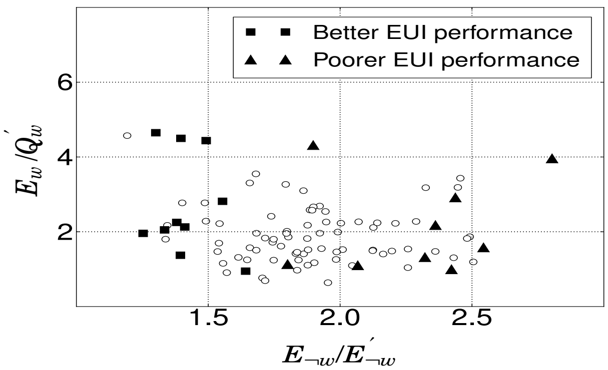
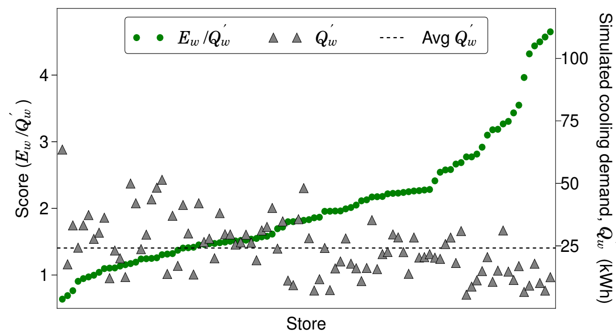


(a) Performance of case study stores under the proposed benchmarking and EUI (kWh/m^2) based standard.



(b) Stores with poor weather dependent performance have possibly over-sized HVAC systems.

Figure 1: Results of our two dimensional benchmarking on a real world supermarket chain of 94 stores.

inefficiencies in individual HVAC components of buildings with poor HVAC performance can be identified through a subsequent deeper study.

Challenges. In conventional EUI based benchmarking and data driven benchmarking, a building can be ranked using just the aggregate energy consumption value. This value is easier to obtain since it could be obtained directly from the utility bills. However, in the proposed two dimensional scheme, a building's energy consumption has to be specified in terms of two orthogonal components – viz. weather independent consumption and weather dependent consumption. As with the EUI based schemes, we assume that only the aggregate consumption of a building is made available (i.e, we do not expect a building to have any sub-metering to monitor the consumption of individual activities/equipment). Given this, a suitable methodology for dis-aggregating the overall energy consumption value into the two orthogonal components is required.

While this may sound challenging, by exploiting the following key observations, it is possible to design a dis-aggregation technique that performs satisfactorily in practice: (i) In certain industry verticals (such as retail outlets, supermarkets, restaurants, and hotels) the individual facilities under a single enterprise are homogeneous in terms of business activities, operations, and even building layout with similar thermal zoning. This uniformity implies that the individual building designs and operations can be reasonably 'templatized' for each enterprise. (ii) During winter, when the facilities have insignificant cooling demand (with the heating being done by gas), their electricity consumption will roughly equal their weather independent consumption.

3. REAL WORLD CASE STUDY

Using the proposed methodology, we benchmark a set of geographically diverse 94 stores from a supermarket using only those data that can be easily gathered. Our model leverages the studies done by organizations such as US National Renewable Energy Laboratory (NREL) to create suitable model templates for the benchmarking exercise [1].

The performance of the various stores along the two orthogonal dimensions is shown in Figure 1(a). The X axis gives the ratio of the actual weather independent energy consumption $E_{\neg w}$ over the expected weather independent energy consumption $E'_{\neg w}$. The Y axis represents the ratio of the actual weather dependent energy consumption $E_{\neg w}$ over the expected weather dependent cooling demand $Q'_{\neg w}$. Lower values along each of these dimensions indicate a better energy performance. The graph shows that the store population has a significant spread along both the axes. More importantly, *we find that stores that do well in one dimension need not necessarily do well in the other dimension.*

A naive benchmark EUI (kWh/m^2) reference figure for supermarkets has been prescribed by the standard authorities for the case study geography. We ranked the case study stores as per this benchmark value too. The plot in Figure 1(a) also identifies the top 10% of the performers and the worst 10% of the performers as per this EUI metric on our benchmarking axes. The top and worst stores as per the naive benchmarking align towards the left and right respectively in the plot. This suggests that the EUI benchmarking value seems to be heavily influenced by the weather independent consumption.

Our benchmarking, in conjunction with our energy dis-aggregation approach, gives insights on possible causes for poor energy performance of stores. For instance, we notice from Figure 1(b) that stores that have lesser cooling loads seem to perform poorly in weather dependent energy consumption. A possible reason could be that the stores have an oversized HVAC system that has been sized for the average enterprise cooling load.

To conclude, we believe that the proposed two dimensional benchmarking methodology, together with the dis-aggregation approach, is well suited for objectively benchmarking a large set of homogeneous buildings from any vertical especially when data availability is limited.

4. REFERENCES

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