Understanding Building Infrastructure and Building Operation through DOE Asset Score Model: Lessons Learned from a Pilot Project

Na Wang, PhD **Supriya Goel** **Willy Gorrissen** **Atefe Makhmalbaf**

Associate Member ASHRAE *Student Member ASHRAE*

ABSTRACT

The U.S. Department of Energy (DOE) is developing a national voluntary energy Asset Score system to help building owners to evaluate the as-built physical characteristics (including the building envelope and mechanical and electrical systems) and overall building energy efficiency, independent of occupancy and operational choices. The energy Asset Score breaks down building energy use information by simulating building performance under typical operating and occupancy conditions for a given use type. A web-based modeling tool, the energy asset scoring tool facilitates the implementation of the Asset Score system. The tool consists of a simplified user interface built on a centralized simulation engine (EnergyPlus). It is intended to reduce the implementation cost for the users and increase model standardization over that of typical building energy modeling approaches.

A pilot project with forty-two buildings (consisting mostly of offices and schools) was conducted in 2012. This paper reports the findings. Participants were asked to collect building data and enter them into the scoring tool. If available, participants also provided their utility bills, existing ENERGY STAR scores, and previous energy audit/modeling results. The results from the asset scoring tool were compared with the building energy use data provided by the pilot participants. Two comparisons were performed. First, ASHRAE 90.1 prototype buildings were used as an industry standard modeling approach to test the accuracy level of the scoring tool. Second, the pilot buildings were used for comparison of the actual building energy use, either from the utility bills or via ENERGY STAR Portfolio Manager, against the modeled energy use. It was intended to examine how well the energy Asset Score represents a building's system efficiencies, and if it is correlated to a building's actual energy consumption.

The analysis showed that the asset scoring tool, which uses simplified building energy model, could provide results comparable to a more detailed energy model. The buildings' as-built efficiency can be reflected in the energy Asset Score. An analysis between the modeled energy use through the scoring tool and the actual energy use from the utility bills can further inform building owners about the effectiveness of their building's operation and maintenance. The building infrastructure analysis provided by the tool can help building owners evaluate the as-built efficiencies of the building systems, independent of operational decisions. The pilot program has helped define the path for further development of the tool as well as the evaluation methodology for the building systems and highlighted several aspects that need to be addressed to improve the applicability and reliability of the scoring tool.

INTRODUCTION

Na Wang, Supriya Goel, Will Gorrissen and Atefe Makhmalbaf are engineers in the Electricity Infrastructure and Buildings Division, Pacific Northwest National Laboratory, Richland, Washington.

The U.S. Department of Energy (DOE) is developing a national voluntary energy Asset Score system that includes an energy asset scoring tool to help building owners evaluate their buildings with respect to similar buildings. One of the goals of the energy Asset Score system is to facilitate cost-effective investment in energy efficiency improvements of commercial buildings. Asset Score will allow building owners and operators to compare their building infrastructure against similar buildings and track building upgrade progress over time. It can also help other building stakeholders (e.g. designers, tenants, financiers, and appraisers) understand the relative efficiency of different buildings in a way that is independent from their operations and occupancy.

DOE's long-term goal is to ensure that there is a linked set of compatible metrics and scoring approaches that can be used to effectively evaluate a building's as-built and in-operation efficiencies. DOE envisions these linked scores describing various aspects of building energy performance, such as the performance of building assets, performance of building operations, as well as its performance in comparison to similar buildings. The current work on the energy Asset Score system is part of this larger vision.

In 2012, DOE began initial pilot testing of the energy Asset Score. As a result of that effort, improvements to the tool, training materials, and other aspects of the project have been made. In 2013, DOE will continue to assess the energy asset scoring system through additional pilot testing as well as sensitivity analysis. The first pilot project was launched in March 2012. Information webinars, training sessions, and pilot materials were provided from March to May. Starting from the middle of June, pilot participants were given three months to enter building information into the asset scoring tool and receive their building report (Asset Score Report). Thirty-three organizations representing 62 buildings originally signed up for the pilot; complete data of 42 buildings were entered into the scoring tool within the required time period. One-year utility data of 17 buildings and existing energy models (from previous energy audits) of 13 buildings were received. Among the pilot buildings, 34 (81%) were office buildings, 7 (17%) were schools; and 1 (2%) was an unrefrigerated warehouse. The pilot buildings varied in location, size, and vintage as shown in **Figure 1**.

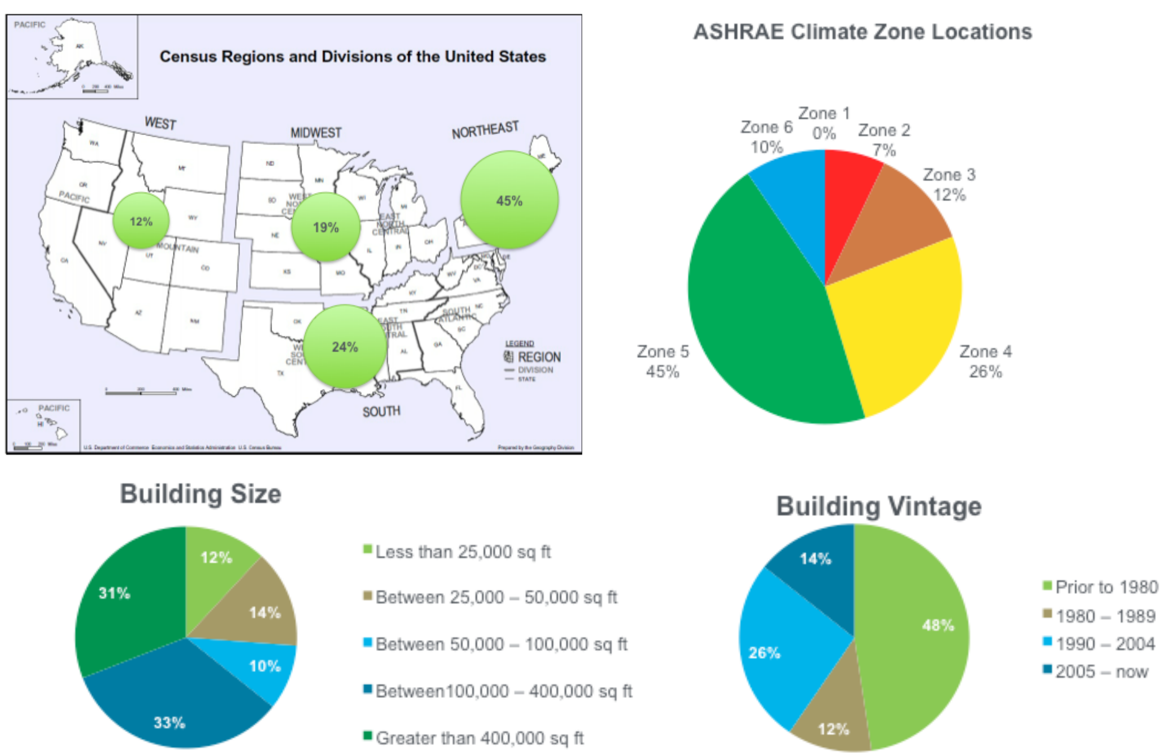

Figure 1 Regional locations, climate locations, sizes, and vintages of pilot buildings.

PILOT TEST METHODOLOGIES

The pilot project was intended to test the Asset Score system and tool on three aspects: ease of data collection, accuracy of energy model, and usefulness of Asset Score. The research questions are:

1. How easy or difficult is it to collect reliable building data for an Asset Score?
2. How accurately can the Asset Score model simulate a building's energy performance based on the limited inputs from the users?
3. Can the Asset Score reflect a building's as-built efficiency and help building owners understand their building's infrastructure and operation?

The first aspect of data collection was assessed using self-reported data collection experience. Participants were required to return their data collection forms and indicate the difficulty level and the confidence level for each data input. Questionnaires distributed before and after participants collected their building data aimed at assessing the average time for data procurement. Pilot participants were first asked to estimate and then report the actual data collection time. Both questionnaires indicated an average data collection time of 6 – 8 hours. Data input time was reported to be less than 3 hours.

The tool accuracy was evaluated through comparisons between the energy Asset Score model and ASHRAE 90.1 Prototype building models. The Prototype buildings (Thornton et al, 2012) represent 80% of the commercial building floor area in the United States for new construction, including both commercial buildings and mid- to high-rise residential buildings. These include the 16 building types in 17 climate locations for three editions of ASHRAE Standard 90.1 (90.1-2004, 90.1-2007 and 90.1-2010). They were selected to provide consistency and transparency and to provide an industry accepted baseline for the evaluation of the accuracy of energy models created through the asset scoring tool. The purpose of this analysis is to identify the degree of variation in results between the simplified Asset Score energy model as compared to the detailed EnergyPlus model. It evaluates variation of results due to a limited set of inputs required by the Asset Score model as against a detailed set of inputs, simplification of thermal zoning layout and building geometry, and the mechanical system configurations based on assumptions and inferences used by the tool (McCabe & Wang, 2012). For the purpose of testing, the operating conditions of the Prototype models were modified for consistency with COMNET assumptions (Architectural Energy Corporation, 2010) used for Asset Score models, to eliminate possibility of variation in results due to building operational assumptions. A comparison was carried out for annual energy end use data, building assembly configuration, internal gain, and HVAC system configuration for the Asset Score model against the Prototype energy model. Findings through this analysis are discussed in the following section.

Ability of the tool to predict actual energy use of buildings has been evaluated for the pilot projects through a comparison between the Asset Score model and utility bills. The purpose of this analysis is to identify a correlation, if any, between the energy use results predicated through the Asset Score model and the actual energy consumption of a building. Asset Scores of the pilot buildings were also compared with their ENERGY STAR scores (Environment Protection Agency, 2012) to drawing correlations or distinctions between the two scoring programs. This paper discusses the findings from these comparisons and identifies lessons learned, which have helped define the path for further development of the tool.

The third research question the pilot project aimed to answer is whether the asset scoring tool can help building owners understand their building's infrastructure and pinpoint to the problematic areas. An Asset Score report comprises of four main sections: score, structure and systems, opportunities, and building assets. The 'structure and systems' section includes site and source energy use intensities (EUIs) by system, as well as evaluations of building envelope, lighting, heating, cooling, and water heating systems. The 'opportunity' section identifies opportunities for energy savings based on a life cycle cost analysis and estimates energy savings and payback periods for each listed opportunity. Analysis of pilot buildings tested the methodology used for building system evaluations and suggested improvements and modifications.

FINDINGS

Tool accuracy was tested using the ASHRAE Prototype buildings. Pilot buildings were used to investigate the correlation between the predicted annual energy use through the Asset Score models and the actual annual energy use provided through utility bills. Asset Scores were also compared against ENERGY STAR scores, when available. The results are discussed in this section.

ASHRAE Prototype Buildings

During the first pilot project, the Asset Score models utilized COMNET standards for schedules of operation and internal loads, which are different from the assumptions used in the Prototype buildings. The Prototype building models were therefore modified using COMNET standards for a fair comparison. Two sets of models also use consistent internal loads, building envelope configuration, and mechanical system equipment efficiencies. Energy use intensities (EUI) from the two sets of models were compared. A variation of 10-15% in both whole building EUI and EUI by end use was observed. This is considered acceptable given the level of simplification of Asset Score models. A comparison using Large Office Prototype, compliant with ASHRAE 90.1 2004 standard for Climate Zone 5A, is shown in Table 1 as an example.

Table 1: EUI (kBtu/sq.ft) Comparison for Large Office Prototype Building Located in Chicago

	Asset Score Energy Model	90.1 2004 Prototype
	EUI (kBtu/sq.ft)*	
Whole Building	78.04	83.76
Heating	15.23	12.31
Cooling	10.22	10.33
Interior Lighting	11.73	9.77
Exterior Lighting	0 (Not included in the current asset scoring tool)	1.87
Interior Equipment	39.01	39.55
Fans	1.43	2.12
Pumps	0.42	1.5
Heat Rejection	0	1.13
Humidification	0	0.06
SWH	0 (Not included in the asset scoring tool during this test)	1.09

* For SI Units, multiple kBTU/sf value by 11.36 for MJ/sq.m

As indicative through the table above, a simplified energy model using limited user-inputs for building geometry, thermal zoning, building construction assembly, and mechanical systems results in a less than 10% variation of whole building energy use compared with a detailed model. Further analysis is being carried out to investigate the discrepancies for each system component. During the first pilot test, the asset scoring tool did not include certain building components such as exterior lighting and service hot water, and did not support some HVAC systems such as ground source heat pumps and district heating and cooling. These will be added for the second pilot.

Pilot Buildings: Utility Bills

This analysis is aimed at examining whether the predicted building energy use is correlated to its actual energy consumption. Figure 2 depicts the variation between the modeled building site EUI and actual building energy use. The variation ranges from 5% to 80% between EUIs predicted through the Asset Score model and calculated from utility bills. A case-by-case analysis indicated that several reasons contributed to the high level of variations: unregulated loads (as in the case of Building No. 1), thermostat set points and occupancy schedules (as in the case of Building No. 7), and errors in user's data entry (as in the case of Building No. 8). In some cases, discrepancies occurred because of a temporary workaround when the scoring tool did not support certain HVAC system types, such as ground source heat pumps in the case of Building No. 5.

Buildings with a higher correlation between the Asset Score results and utility data were found to be those more accurately represented in the scoring tool in case of their geometry, mechanical systems, and operational conditions. Hence, with the integral assumptions underlying the simulation structure of the asset scoring tool, it is difficult to draw direct comparisons. The asset scoring tool is intended to evaluate building infrastructure independent of building operation choices. A correlation between EUIs from asset model and from utility bills (or calibrated energy models) is not an appropriate metric to evaluate the tool accuracy. On the other hand, replacing the standard operational parameters of the energy asset model with the actual operational parameters should demonstrate a certain level of EUI correlation when a large sample of asset models is available.

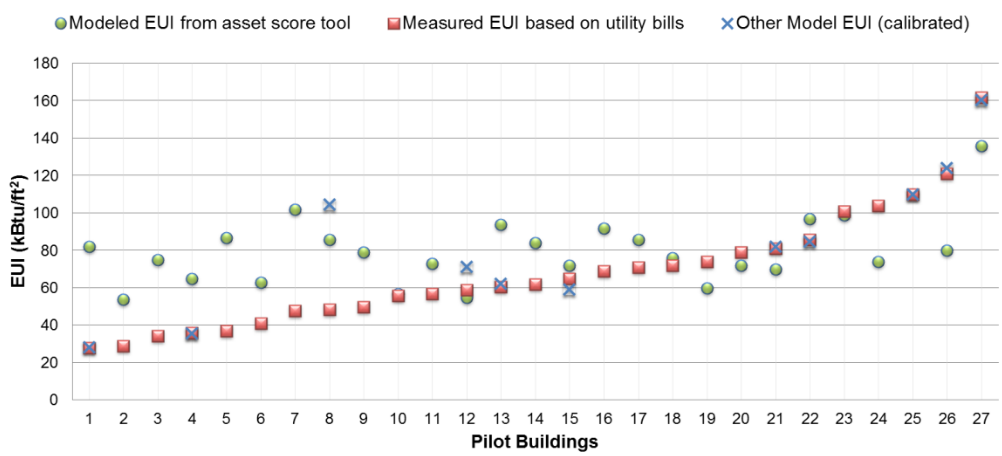

Figure 2 Whole building site EUI (kBtu/sq.ft): Asset Score compared to utility bills and calibrated energy models

Pilot Buildings: Asset Score Compared to ENERGY STAR Score

As a part of the pre-pilot questionnaire, participants were asked about their expectation for Asset Score. In general, participants with a high ENERGY STAR score expected to receive a high Asset Score. However, the Asset Score is not correlated to ENERGY STAR score due to their different definitions, purposes, and calculation methods. ENERGY STAR score is based on a statistical analysis on Commercial Building Energy Consumption Survey (CBECS) data (Energy Information Administration, 2006). It rates a building on a scale of 1-100 and benchmarks it against the performance of existing building stock represented in CBECS. Asset Score also uses a scale of 1-100; however it is a linear technical scale with a score of 100 depicting a net-zero energy building. Based on feedback collected from the pilot project, DOE is still investigating the most appropriate scoring method.

Regardless of the scoring methodology, further examination of pilot building characteristics shows that buildings with a lower asset score have less efficient building systems. For example, a building with an ENERGY STAR score of 95 has an envelope U-value of 0.231 and a cooling equipment coefficient of performance (COP) of 2.79; while another building with an ENERGY STAR score of 42 has an envelope U-value of 0.093 and a cooling COP of 3.2. The former has a lower asset score than the latter. As a complementary assessment tool to Portfolio Manager, Asset Score helps building owners and operators gain insight into their building "DNA."

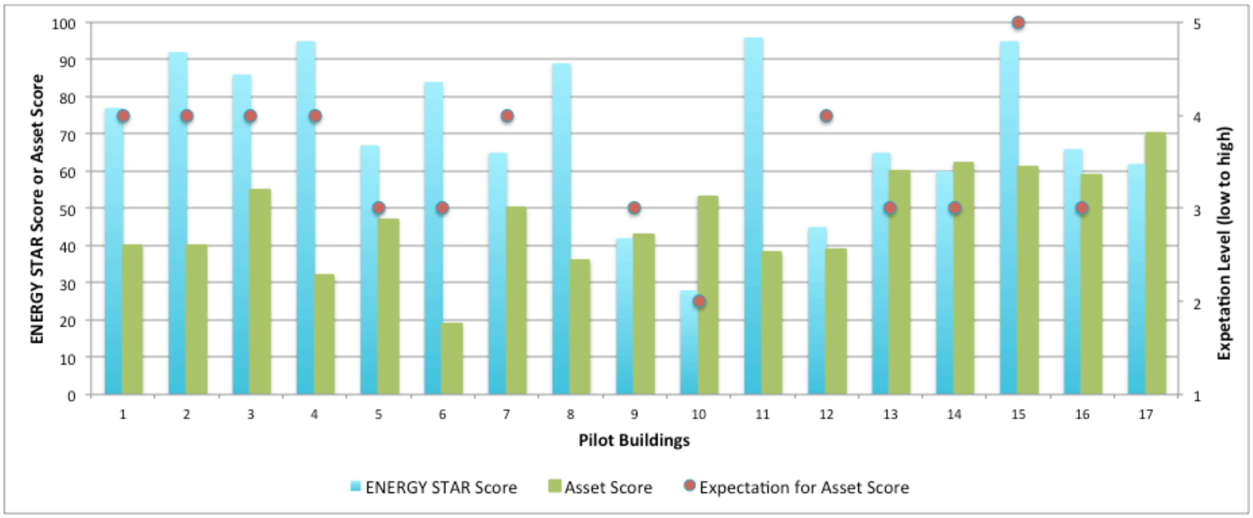

Figure 3 Achieved Asset Score compared to expected score and Energy Star score

Pilot Buildings: Buildings Infrastructure Analysis

Building system components interactively affect a building's energy use and its performance outcome measured in the utility bills. Asset Score segregates factors related to a building's physical infrastructure. It allows building owners and operators to compare their building infrastructure against similar buildings and track building upgrade progress over time. In addition to a whole building score, system evaluation is an important feature of Asset Score.

A prescriptive approach, which compares envelope U-factors, lighting power density, and the equipment COP against the code requirements, is often used to evaluate building systems. The pilot test revealed that a prescriptive approach using rated equipment efficiency is inadequate because of the interacting effects of the building envelope, internal gains, and system efficiency. **Figure 4** below shows the Asset Score, cooling EUI, and cooling COP of the pilot buildings. As indicative through the data, cooling EUI is not directly correlated to the rated cooling equipment COP. This suggests a need for a different system evaluation methodology that can take into account the interacting effects of building envelope, internal gains, and system efficiencies. A more comprehensive metric should be developed to address integrated system performance.

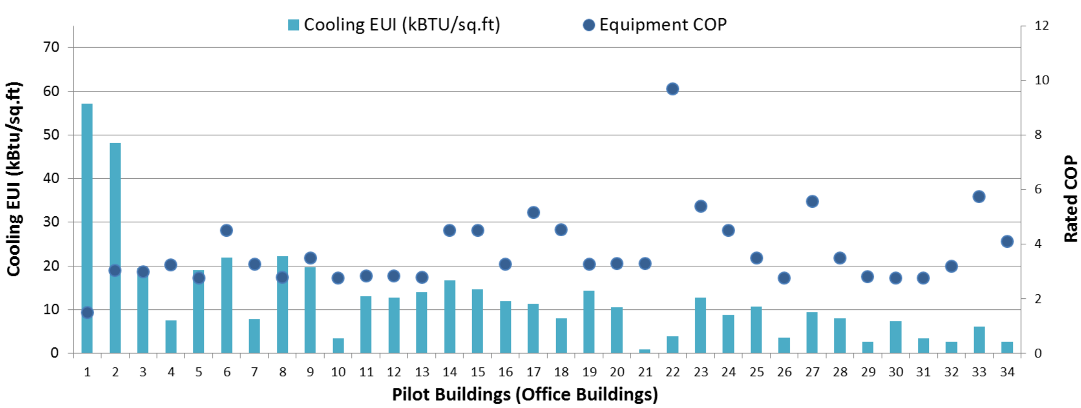

Figure 4 (a) Cooling EUI (kBtu/sq.ft) vs Asset Score (b) Cooling EUI (kBtu/sq.ft) vs rated equipment COP (Note that the COP value for building No. 22 is incorrect because of user's data entry error. An EER value was likely entered as COP.)

Several factors, such as building envelope performance, internal loads, mechanical ventilation, cumulatively affect building loads. Along with the equipment efficiency, these factors define the system energy use. For a comprehensive analysis of building infrastructure, a system evaluation methodology for Asset Score will use a ratio between load and energy use as the metric **(Table 2)**. This metric takes into account all interacting parameters that affect system performance and energy use within a building. A series of performance ratio ranges will be developed using the ASHRAE 90.1 2004, 2007 and 2010 versions of the Prototype buildings. A building system will be ranked by comparing against the defined performance ranges.

Table 2. System Evaluation Methodology: Metrics for Building Infrastructure Analysis

Building Systems	Performance Indicators	Calculation Methods	Evaluations
Lighting System	kBtu/ft^2	Lighting energy use / total floor area	Metric takes into account energy use due to energy efficient lighting sources as well as lighting controls. Higher value indicates more lighting EUI, and therefore represents low-efficiency lighting system
Heating System	Annual heating system efficiency (no unit)	Annual heating load / annual heating system energy use	Metric takes into account building envelope performance, internal gains, and mechanical ventilation as well as system components like reheat coils, fans etc. Lower value indicates more heating energy use to meet the load, and therefore represents low-efficiency heating system
Cooling System	Annual cooling system efficiency (no unit)	Annual cooling load / annual cooling system energy use	Lower value indicates more cooling energy use to meet the load, and therefore represents low-efficiency cooling system
Overall HVAC System	Annual HVAC system efficiency (no unit)	Annual heating and cooling load / heating and cooling energy use	Lower value indicates more heating and cooling energy use to meet the load, and therefore represents low-efficiency HVAC system
Service Water heating System	Annual water heating system efficiency (no unit)	Water heating energy load / water heating equipment energy use	Metric takes into account system performance along with distribution system efficiency. Lower value indicates more water heating energy use to meet the load, and therefore represents low-efficiency water heating system

Note: Source energy is used in the above calculations.

CONCLUSION

The first pilot project provided invaluable lessons for the data collection process along with asset model development and tool testing. It highlighted the applicability and usefulness of the scoring tool in evaluating building systems in addition to whole building energy analysis. Direct feedback from the participants and additional information from the utility bills and ENERGY STAR scores helped understand the potentials and limitations of the scoring tool. Evaluation of output results identified parameters for which a high level of uncertainty would result in inaccurate results. Future work will include a sensitivity analysis to investigate the impact of key variables on Asset Score. Based on the sensitivity analysis, the data requirements for Asset Score will be refined. Additional features such as exterior lighting, water heating systems, and more HVAC system types will be added for the second pilot to reduce discrepancy in output results due to limitations associated with tool capabilities.

The scoring method will be re-evaluated as the current net zero energy goal (to achieve a 100 point) may make it difficult for buildings move forward along the current scale. The methodology for building infrastructure analysis was another key lesson learned as a result of the pilot test. The pilot analysis suggested that a prescriptive approach is an ineffective way for evaluating building systems. A performance-based approach takes into consideration of all interacting parameters that affect overall system performance.

The second pilot, aimed for summer 2013, will incorporate lessons learned through the first pilot and add additional building types and capabilities to the scoring tool for a more accurate analysis and comprehensive evaluation of building assets. The first pilot has helped in defining the additional capabilities that need to be added to the tool to improve its accuracy and applicability. A more comprehensive system evaluation methodology will be implemented for an accurate assessment of the building infrastructure. An early market research (McCabe & Wang 2012) as well as feedback from pilot participants have indicated value and a need for an asset scoring tool as a means to help building owners evaluate the as-built physical characteristics and overall building energy efficiency, independent of occupancy and operational choices.

ACKNOWLEDGMENTS

This work is funded by the US DOE under the Energy Efficiency and Renewable Energy program. Pacific Northwest National Laboratory is developing the Asset Score system and tool.

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