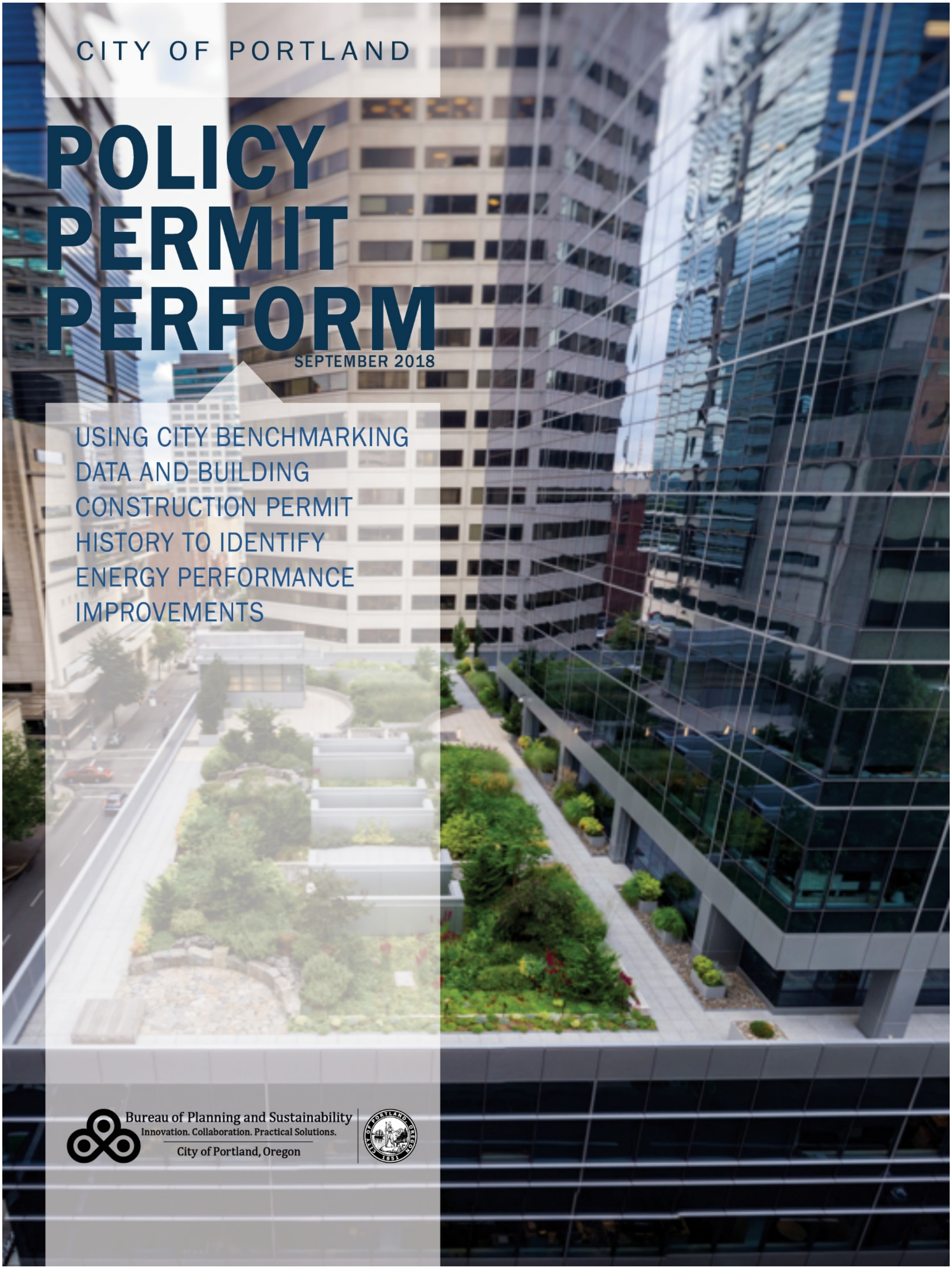

CITY OF PORTLAND

POLICY PERMIT PERFORM

SEPTEMBER 2018

USING CITY BENCHMARKING DATA AND BUILDING CONSTRUCTION PERMIT HISTORY TO IDENTIFY ENERGY PERFORMANCE IMPROVEMENTS

Bureau of Planning and Sustainability
Innovation. Collaboration. Practical Solutions.
City of Portland, Oregon

ACKNOWLEDGEMENTS

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POLICY, PERMIT, PERFORM

USING CITY BENCHMARKING DATA AND BUILDING CONSTRUCTION PERMIT HISTORY TO IDENTIFY ENERGY PERFORMANCE IMPROVEMENTS

CONTENTS

SUMMARY

The City of Portland and Multnomah County 2015 Climate Action Plan (City of Portland and Multnomah County 2015) targets a 40 percent reduction in carbon emissions below 1990 levels by 2030. To reach this goal, the plan includes a key objective to reduce the total energy use of existing buildings by 25 percent. Buildings are responsible for one-half of carbon emissions in Portland, Oregon, U.S., and improving their performance is critical to achieving the City's climate goals.

As part of its climate action planning, the City of Portland (City) passed an ordinance on April 22, 2015, requiring commercial buildings 20,000 ft^2 and larger to benchmark and disclose annual energy performance metrics through ENERGY STAR® Portfolio Manager® (ESPM), including greenhouse gas emissions, building energy use intensity (EUI) and ENERGY STAR scores. Twenty-five cities in the U.S. have adopted similar policies requiring energy benchmarking (BuildingRating 2018). These policies are generating a treasure trove of data about the drivers of building performance, but practitioners are only beginning to link benchmarking data to other datasets to produce actionable insight into improving building performance.

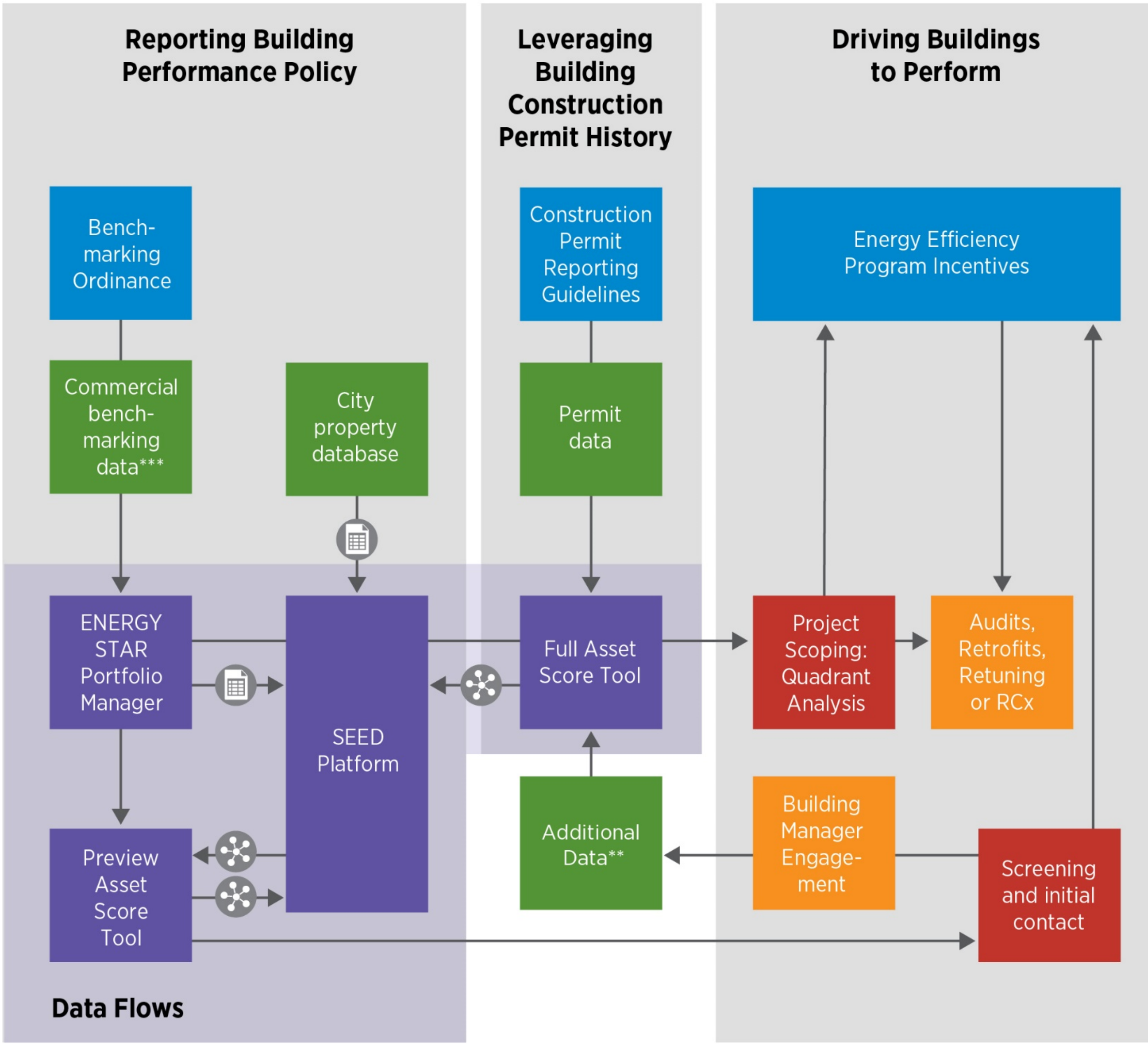
In 2016, the City received a financial assistance award from the U.S. Department of Energy (DOE) through the Cities Leading through Energy Analysis and Planning (Cities-LEAP) project (Award Number DE-0007737). Portland's project evaluated the application of the DOE Building Energy Asset Score Tool and rating system developed by Pacific Northwest National Laboratory (PNNL) to commercial buildings that report to the City.

The City used building construction permit history to develop Asset Scores for a set of office buildings that reported energy performance for 2015 – the first year the City mandated energy benchmarking and reporting for commercial buildings 50,000 ft^2 and larger.

The primary project objective was to link energy benchmarking data and commercial building permit data to analyze commercial buildings systems that present the best, specific opportunities to improve energy performance.

Integrating these datasets from two City departments, the Bureau of Development Services and the Bureau of Planning and Sustainability, could expand Portland's use of analytics to inform climate policy decisions and strategic targeting of financial incentives for building owners and managers who are best positioned to improve the performance of their buildings.

As shown in Figures 1 and 2, the project began with the commercial benchmarking data received for 340 commercial buildings that submitted calendar year 2015 energy reports.



* Application programming interface (API) is currently available only for generating Preview Asset Scores, full Asset Score API is in development.

** Additional data includes building geometry, verification of building systems such as lighting type and HVAC system performance ratio, and other information not available through the construction permit data.

*** Number of floors is also needed but not available in ENERGY STAR Portfolio Manager.

Figure 1: Project overview and the organization of different activities within this report.

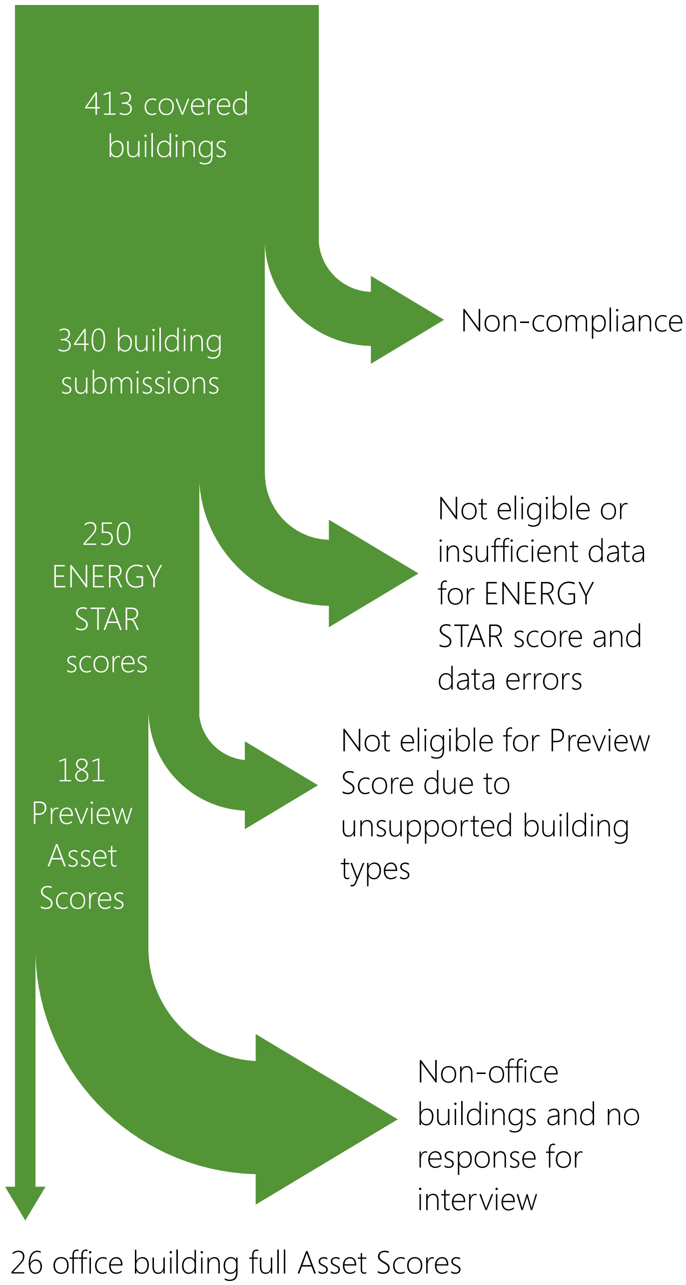


Figure 2: Commercial buildings researched.

The City retained Research Into Action and Energy 350 (RIA team) to evaluate this self-reported benchmarking data. Based on a survey of 53 building managers, the RIA team found that most respondents used the City's compliance tools, including a How-to Guide and Help Desk, and found access to utility data to be straightforward.

However, almost one-third of the respondents encountered challenges when estimating the gross floor area (GFA), and some experienced confusion regarding the input of property use types and details into ESPM. Based on the RIA team's recommendations, the City refined its How-to Guide, created online answers to frequently asked questions, and hosted office hour sessions to help building managers accurately characterize their building's physical characteristics and operations in ESPM.

Concurrently with the RIA team's evaluation, the City worked with PNNL to estimate DOE Asset Score Preview (Preview) scores for 181 of the 340 commercial buildings that submitted ESPM reports to the City. Asset Score Tool is a web-based tool developed by PNNL for DOE to evaluate and rate the as-built energy efficiency of a building. Asset Score Tool's full analysis capability runs a detailed energy model based on building geometry, age, envelope, lighting and mechanical systems using standard operating assumptions to give the building a score, similar to a miles per gallon rating for a car. Preview, a simplified deployment of the full Asset Score Tool, provides a preliminary score range using only seven data points, six of which are readily available in the ESPM benchmarking data. Analysis of the combined Preview scores and the operational ESPM scores identified buildings with a high potential for energy improvements through either retro-commissioning (RCx) and retuning of existing operations or capital investments into building systems.

The City contracted Whole Building Solutions (WBS) to mine building permit history and develop full Asset Scores for a subset of 26 office buildings that were eligible for both ENERGY STAR scores and Asset Scores. WBS researched permits and building plans to identify mechanical, lighting and envelope systems and other building characteristics necessary to complete Asset Scores. This historical data was recorded using the web-based Asset Score Tool, which evaluates the as-designed energy efficiency of existing buildings. Much of this City information was available online after 2010; however, WBS had to search through microfiche

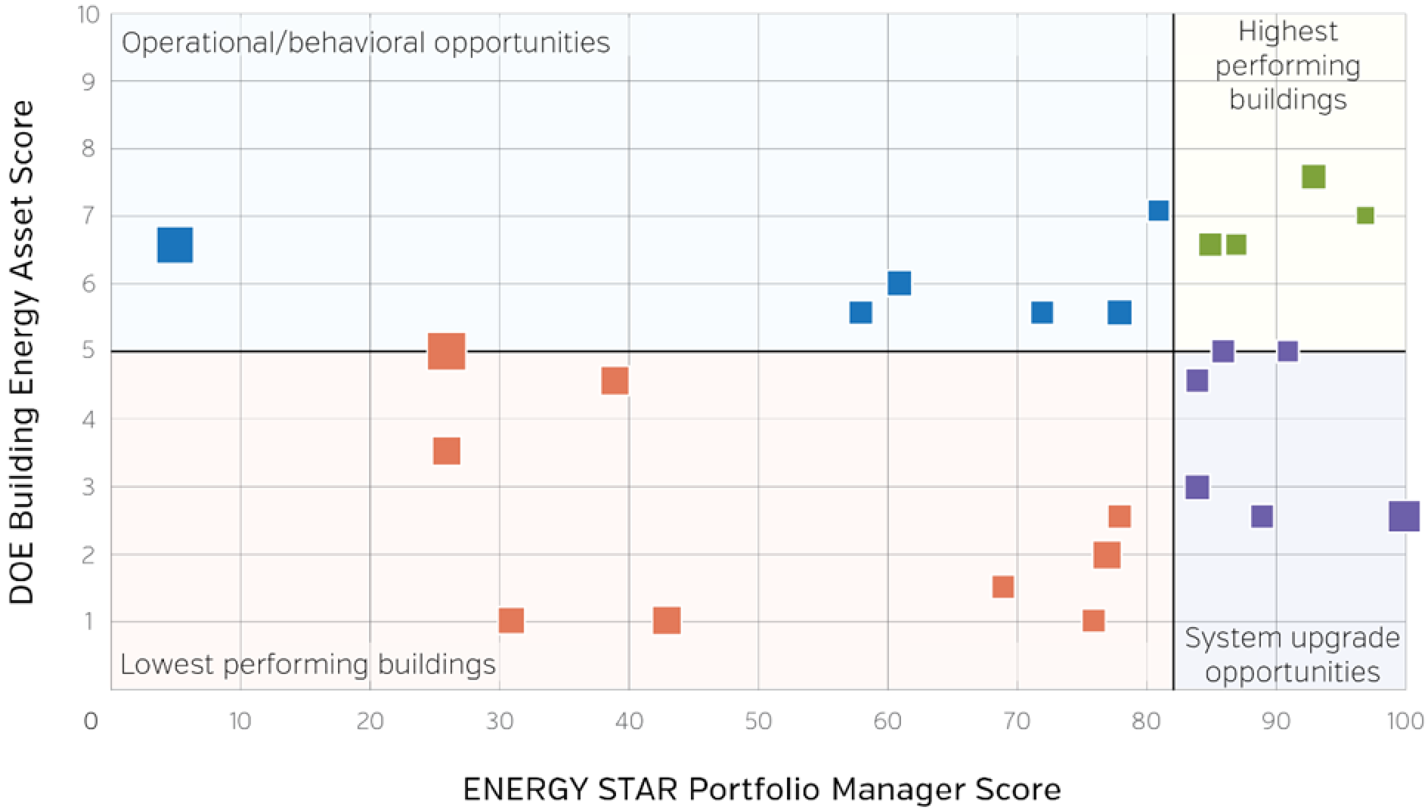


Figure 3: Quadrant view of building Energy Asset scores and Portfolio Manager Scores.

files and the City's database to obtain permit and plan history prior to 2010. Although building geometry, mechanical system type and basic envelope information was consistently identifiable, WBS found permit data gaps that prevented complete and accurate Asset Scores for most of the office buildings. If the City decides to develop Asset Scores based on building permit information in the future, WBS recommended requiring lighting plans, control diagrams and as-built drawings that reflect how the buildings are actually constructed. In addition, WBS recommended uploading plans and permits from microfiche storage into a more comprehensive, searchable database consistent with the City's current online permit information. To identify the actual lighting types, WBS and City staff conducted site visits of all 26 office buildings.

As part of managing the flow of ESPM and Asset Score data for the project, Earth Advantage, a sub-recipient of the Cities-LEAP award, created a DOE Standard Energy Efficiency Data (SEED) (USDOE 2018) instance for the City and used Asset Score's Application Programming Interface (API) (Asset Score 2018) capabilities to develop two new features in the SEED Platform™: (1) automated Asset Score Preview ranges calculated based on benchmarking data and the City's estimate of number of building floors; and (2) storage of full Asset Score information. Results are shared in Technical Appendix A, including future capability with BuildingSync XML.

Leveraging the construction permit history and site visit information for the 26 office buildings, The Cadmus Group (Cadmus) analyzed benchmarking data and Asset Score information to identify opportunities and drivers to improve performance. Correlation and regression analysis of the combined dataset was completed to determine whether building operations or specific systems – mechanical, lighting or envelope –

present the best opportunities to improve energy performance.

The central outcome of this project was Cadmus' detailed analysis of the richer dataset that was created by combining the City of Portland's commercial building permit activity and building-specific energy performance information based on metrics from ESPM and Asset Score Tool. Some of their findings collaborate with well-known facts, such as buildings with less efficient lighting systems are good targets for efficiency improvements through lighting upgrades. This analysis also helped identify that individual heating, ventilation, and air conditioning (HVAC) equipment efficiency does not necessarily correlate with building performance. However, overall HVAC system performance, as measured with the Total System Performance Ratio (TSPR) metric, is a better indicator of building performance (Goel et al. 2014). As a metric, TSPR considers whole system performance that includes equipment efficiency and system controls, such as resets for static pressure and chilled water setpoints, which can be more effective and financially feasible options for improving building performance. Given the high cost associated with envelope retrofits, opportunities to upgrade envelope insulation are likely to be limited. However, buildings with single-pane and non-thermal break windows are good candidates for window replacements, such as upgrading to double-pane windows with thermal breaks.

This research project determined that developing Asset Scores based on site visits is preferable to mining City building permit data. In addition, the use of benchmarking data to develop Asset Score Preview Scores is recommended as a first step in engaging building managers to develop full Asset Scores. Asset Score Tool outputs can help building managers quickly identify opportunities for improvement and then work with the utility incentive administrator and energy service providers to develop their retrofit plan. Where full Asset Scores are available, analysis using a quadrant matrix with ENERGY STAR scores is recommended to identify buildings that present the best opportunities for operational-behavioral improvements versus ones with opportunities for upgrades to physical building systems. Figure 3 demonstrates the quadrant view for the 26 office buildings in this study. This workflow and the tools will help cities, utility incentive administrators, building portfolio managers and energy service providers develop energy programs and strategies for screening and analysis of buildings with the greatest energy savings potential.

This report describes the project approach and research results to inform future coordination of ESPM and Asset Score data, including the use of benchmarking data to generate Preview scores. Given better awareness of energy performance, building managers can make more informed decisions to reduce energy consumption and carbon emissions. With cities, states and jurisdictions adopting benchmarking and auditing ordinances, there are substantial amounts of data submitted to cities that could be used to inform investments in energy efficiency.

KEY PERFORMANCE METRICS DEFINED

ENERGY STAR Portfolio Manager score (ESPM score) is a measure of how well a building performs relative to similar U.S. buildings on a scale of 1 (least efficient) to 100 (most efficient) based on historical utility bills. ESPM scores are normalized for climate, weather, electricity source fuel mix, property type and use details, such as operating hours and number of computers.

Building Energy Asset Score (Asset Score) is an as-built rating that identifies the energy efficiency of a building using standard operation parameters. Buildings are scored on a scale of 1 to 10, where 1 represents an extremely low-efficiency building and 10 represents a building of the maximum efficiency using current building technologies. Asset Scores are normalized for climate, weather and standard building operations.

Preview is a preliminary Asset Score range for as-built building efficiency. It uses robust regression analyses and default values to assess the range of building performance and potential for improvement on the same scale as the Asset Score.

Site Energy Use Intensity (EUI) is a building's total annual energy consumption onsite divided by its floor area. Site EUI indicates the overall building energy performance and is measured in $kBtu/ft^2$ (one thousand British thermal units per square foot). A low EUI signifies good energy performance, but certain property types will always use more energy than others.

Source EUI is a Site EUI that accounts for energy losses that take place during generation, transmission and distribution of the energy. Source energy use is the total amount of raw fuel that is consumed by a building and incorporates upstream efficiency impacts of energy delivery systems for different fuel sources to give a more complete assessment of the energy consumption resulting from building operations.

Total System Performance Ratio (TSPR) is a metric to evaluate the overall efficiency of an HVAC system. It is a ratio of annual building loads to annual heating and cooling energy. The denominator includes energy consumption of all system components, including reheat systems, pumps and heat recovery, among others.

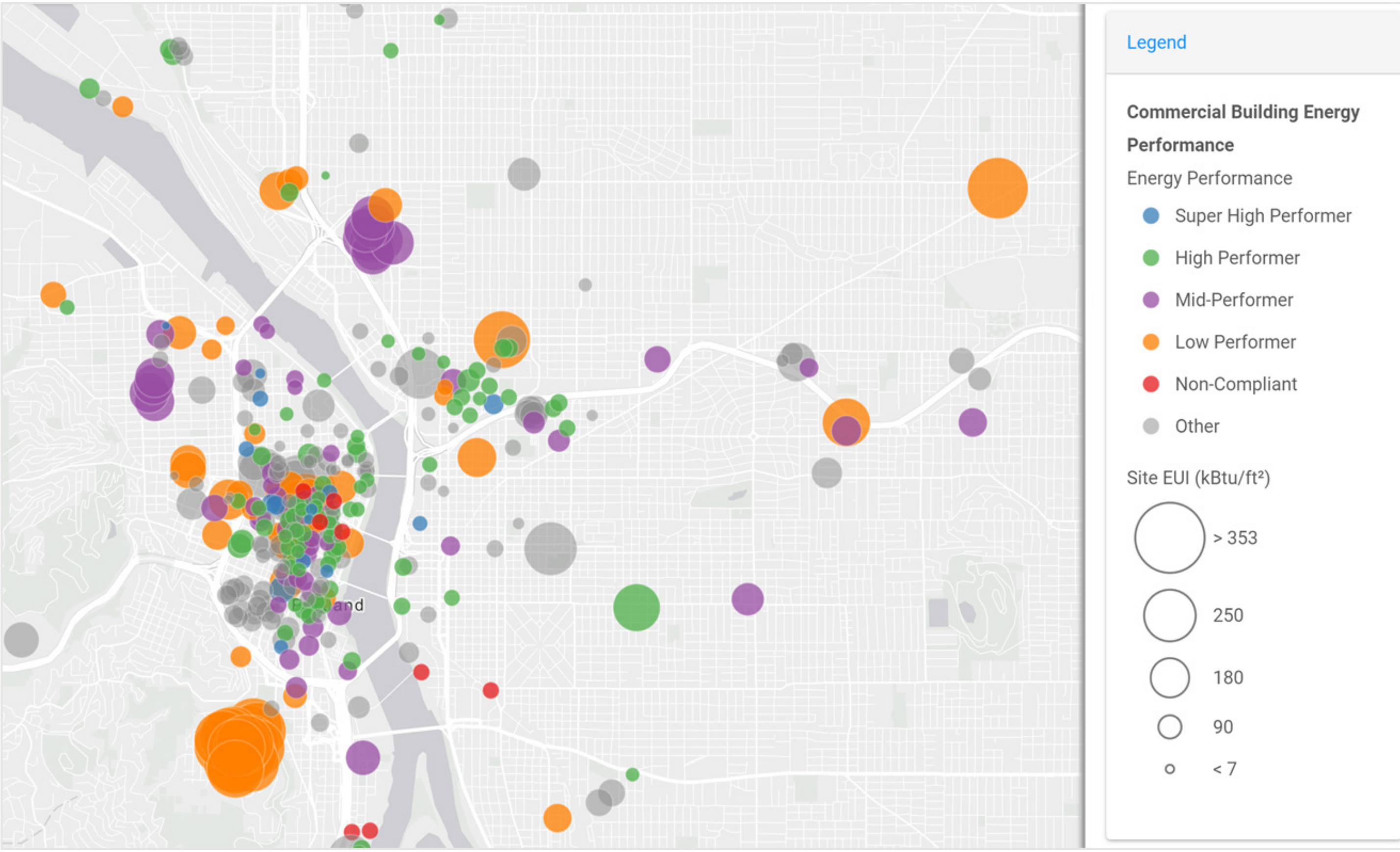


Figure 4: City of Portland commercial building energy performance map.

On Earth Day, April 22, 2015, the Portland City Council adopted the Commercial Building Energy Performance Reporting Ordinance (City of Portland 2015) to benchmark, measure and advance progress toward the City's climate goals for existing buildings. The ordinance requires Portland's largest commercial buildings to use the ESPM benchmarking tool for tracking energy performance metrics and reporting this information annually to the City, starting with calendar year 2015.

In April 2016, commercial buildings in Portland 50,000 ft^2 and larger began reporting individual building energy performance metrics to the City using ESPM, including greenhouse gas emissions, building EUI and ENERGY STAR scores based on monthly utility bills, building floor area, property use type and operational details. The following year, the building size threshold dropped to 20,000 ft^2 to cover approximately 80 percent of the conditioned commercial floor area in Portland. In calendar year 2016, the City began publishing an annual summary of results (City of Portland 2016 and 2017) and a map of individual energy performance metrics, as shown in Figure 4 (City of Portland 2018).

For calendar year 2015, 413 commercial buildings were expected to report performance. The City received submittals for 340 of those buildings, for a compliance rate of 82 percent. To help building owners and managers comply with the new requirements, the City worked with Energy Trust of Oregon and the Northwest Energy Efficiency Alliance to provide free ESPM workshops, a step-by-step *Energy Reporting*

How-To Guide (City of Portland 2018) and an Energy Reporting Help Desk for customized assistance. Additionally, Portland's three energy utilities – NW Natural, Pacific Power, and Portland General Electric – enhanced their customer services, enabling building owners and managers to easily obtain whole-building energy use data for the entire 2015 calendar year.

To start the Cities-LEAP project, the RIA team reached out to a list of contacts for 250 buildings that reported 2015 ENERGY STAR scores to the City. The RIA team conducted telephone surveys of 53 building managers about their approaches to estimating their ESPM inputs, the challenges they encountered, and their use of the City's tools (Research Into Action 2017). In addition to enabling the RIA team to assess the validity of the ESPM data, the surveys helped identify ways the City may be able to better support future years of benchmarking and thereby improve accuracy. Based on the RIA team's recommendations, the City refined its How-to Guide, created online answers to frequently asked questions, and hosted office hour sessions to help building managers accurately characterize their building's physical characteristics and operations in ESPM.

Of the 250 ENERGY STAR score-eligible buildings that reported 2015 energy performance to the City, 181 were also eligible for analysis using Asset Score Tool developed by PNNL for DOE. Since Asset Score does

The RIA team's key findings (Research into Action 2017):

- Fifty-three respondents appreciated and used all three of the City's support tools. Almost all respondents (87 percent) consulted the *Energy Reporting How-To Guide* at least once, 55% contacted the Help Desk, and 49% attended a workshop. Respondents gave positive feedback on the support they received from the City.
- Almost one-third of the respondents encountered challenges when estimating the GFA. These challenges related to use-type definitions, particularly uncertainty about whether a building qualifies as mixed-use property, and about when to count covered walkways and attached parking garages in the GFA. Owners of buildings with tenants had a more challenging time estimating GFA than did building owners without tenants. Building owners commonly used the total square footage of their properties from architectural drawings to estimate GFA.
- Most respondents entered their electric and natural gas usage data (58% and 61%, respectively) manually by reviewing their utility bills. Most respondents found it relatively straightforward to obtain energy data from their utilities and entering energy usage data into Portfolio Manager. Four respondents with separately-metered tenants had difficulty obtaining and/or completing the waivers that the utilities required to release the tenants' usage data to them.
- In almost all cases, building owners included separately-metered tenants' energy usage data in their reporting.
- Respondents had little difficulty estimating weekly operating hours, the number of workers on the main shift, and the number of computers at the building. The respondents accounted for businesses' hours of operation and the type of business when estimating these inputs. Some used information from their buildings' human resources, security, or information technology departments.
- Several respondents expressed concern about the demands placed on them by the City's ordinance. Some respondents found the process time-consuming and/or confusing. In a few cases, respondents said they needed to hire a third party to ensure their submissions were done correctly.

not support some use types, like data centers and mixed-use buildings, not all 250 buildings could be analyzed.

Asset Score is a web-based tool that provides a simplified workflow for a user to specify the characteristics of a building, including its geometric configuration, envelope, mechanical and lighting systems (Wang et al. 2015). Using this information, Asset Score Tool develops a whole building energy model using EnergyPlus (EnergyPlus 2018) and OpenStudio (OpenStudio 2018) and scores a building based on its modeled EUI (Wang et al. 2016). Asset Score Tool also evaluates individual building systems to identify cost effective retrofit opportunities and a potential Asset Score for the building. The tool generates a PDF report that includes a building's current score, potential score, cost-effective upgrade opportunities and estimated energy savings by end use. Figure 5 shows the score scale for the full Asset Score capability. This capability also rates the performance of individual building systems as 'Fair', 'Good' or 'Superior', which can be helpful for identifying inefficient building systems that could potentially benefit from retrofits.

Preview (Goel et al. 2018) is another analysis capability of Asset Score Tool that can be used for buildings with minimal available information. A preliminary analysis with Preview can identify buildings with the highest potential for energy savings and candidates for detailed analysis using Asset Score Tool. Preview uses minimal information about the building to infer typical building characteristics based on DOE's Commercial Building Energy Consumption data (EIA 2017) and the PNNL prototype buildings (Thornton et al. 2011).

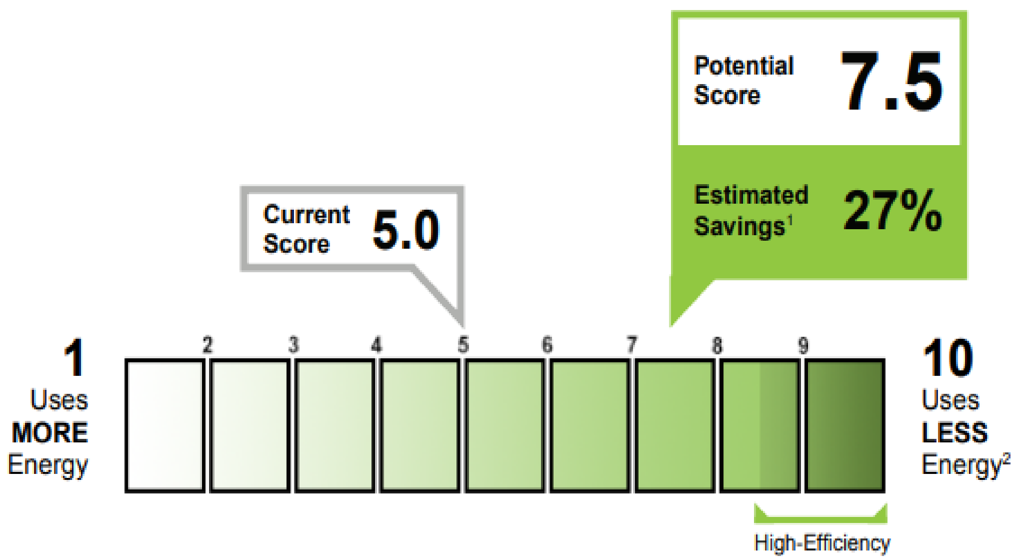


Figure 5: Example of the scores generated through full Asset Score analysis.

Preview uses robust regression analysis based on the uncertainty associated with the default parameters to generate a score range on a scale of 1 to 10. Figure 6 is an example of the Preview score range generated for a building. Preview can provide a corresponding source EUI range as well. Preview requires the following seven data points to generate a score range:

1. Building location
2. Gross floor area
3. Number of floors
4. Orientation
5. Principal use type
6. Year of construction
7. Year of major retrofits (if applicable)

With the exception of number of floors, the data required for Preview is readily available in the ESPM benchmarking data reported to the City.

For this analysis, the number of floors was estimated based on a combination of City LIDAR data, field estimates and online research.

The batch analysis capability in Preview was used to analyze 181 buildings through a simple spreadsheet upload. The batch analysis capability provides a useful resource for analyzing a large number of buildings through a spreadsheet upload of the data and a spreadsheet download that provides the Preview results. Preview provides a source EUI range and a corresponding Asset Score range (Goel et al. 2018).

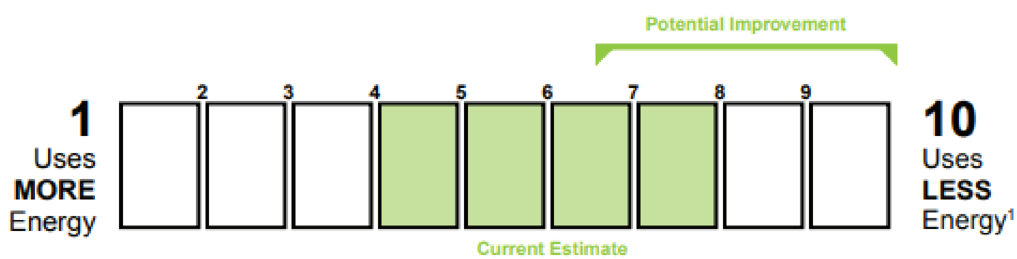


Figure 6: Example of the score range generated through Asset Score Preview.

Preview score ranges and source EUI can be helpful in categorizing buildings with low, medium or high potential for energy savings. For the 181 buildings included in the batch analysis, the estimated median Preview source EUI was compared to the ESPM source EUI to understand the actual, operational ESPM building performance when compared to the Preview-predicted performance based on assets. As shown in Figure 7, three distinct bins were observed by plotting Preview source EUI versus ESPM source EUI. These bins could potentially guide energy improvement strategies based on the highest potential for retro-commissioning or retuning of existing operations or capital investments into building system retrofits.

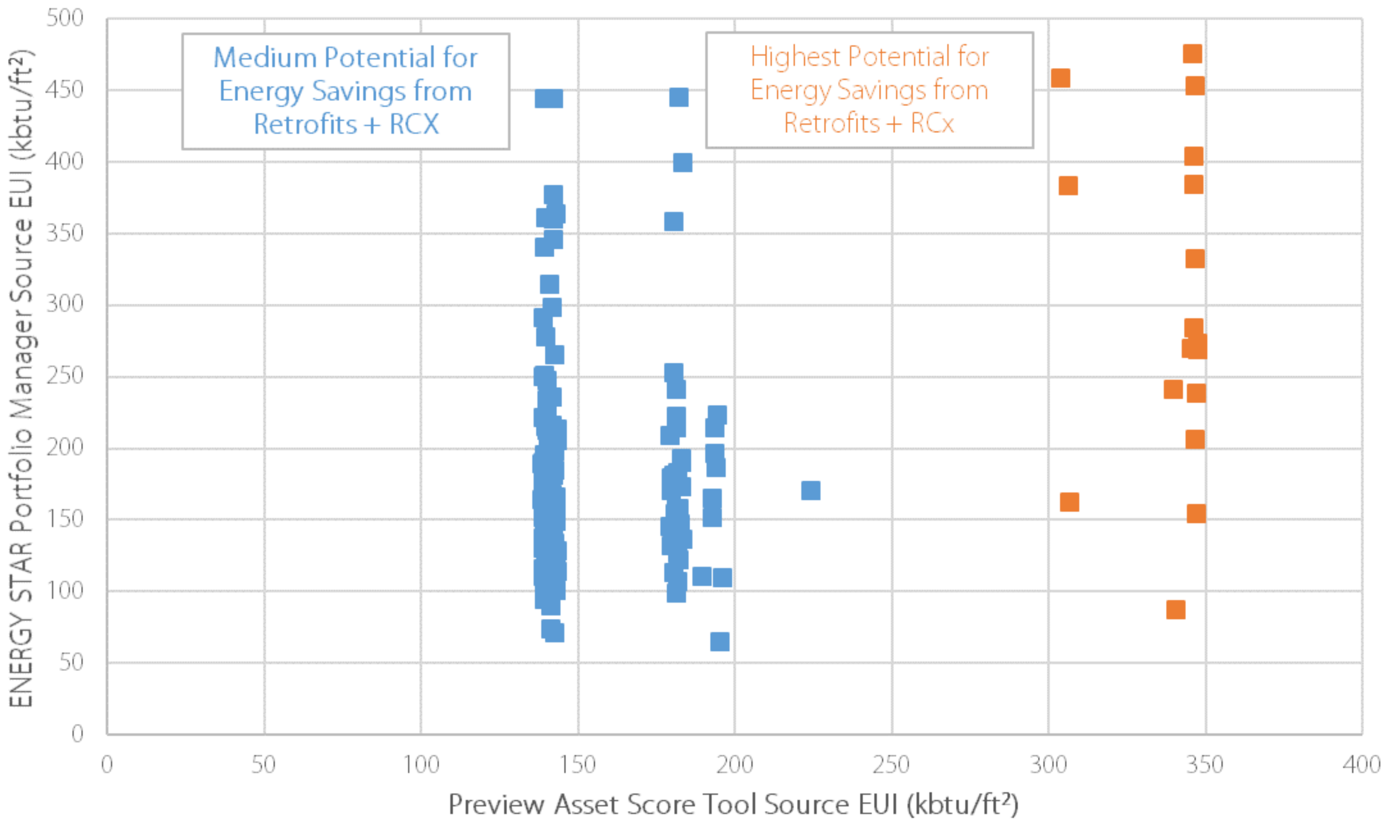


Figure 7: Comparison of Preview mean source EUI against source EUI from Portfolio Manager.

LEVERAGING BUILDING CONSTRUCTION PERMIT HISTORY

Building construction permit history data is potentially a valuable source of building system information that cities could leverage for energy analysis inputs. Permit data is accessible to local governments and does not require direct contact with building owners and managers. However, storage of this data in archives and databases can pose a significant challenge. To determine the extent of this effort, the City contracted WBS to mine building permits for 26 comparable office buildings that were eligible for both ENERGY STAR scores and Asset Scores.

WBS researched existing permit records and building plans to identify mechanical, lighting and envelope systems and other building characteristics necessary to complete Asset Scores. The minimum data required by Asset Score Tool is shown in the Asset Score Data Collection Form provided in Technical Appendix B. WBS recorded the permit data on a web-based version of this form to develop full Asset Scores.

Much of the City information collected by WBS was available online after 2010. However, WBS had to search through microfiche files and the City's database to obtain permit and plan history prior to 2010. Although building geometry, mechanical system type and basic envelope information was consistently identifiable, WBS found the following key data gaps that prevented complete and accurate Asset Scores for all of the office buildings:

- Lighting type, mounting type, watts per lamp, lamps per fixture, total number of fixtures, and occupancy controls
- Wall, floor and roof thermal properties
- The presence of cool roofs
- Window and skylight glass type, gas fill type, U-value and solar heat gain coefficient
- Mechanical system efficiency, controls and year of manufacture

If the City decides to develop Asset Scores based on building permit information in the future, WBS recommended the following information be collected in the permitting process to accurately reflect the actual, installed mechanical and lighting details:

- Lighting plans
- HVAC system controls
- As-built drawings to verify how the building was actually constructed

WBS concluded that permit data was a useful source for some information, like building dimensions, envelope properties and general HVAC system type, but deciphering some other inputs like lighting fixtures or mechanical system details was either not possible or too cumbersome to carry out by reviewing permit data.

WBS also recommended uploading plans and permits from microfiche storage into a more comprehensive, searchable database. Depending on the building age and extent of permit history, WBS required 4 to 8 hours of online database and microfiche research for each building to identify building floor area, and the envelope and mechanical system inputs necessary to complete Asset Scores. This is approximately double the time that would be needed to obtain the same information from a building representative and does not include reliable lighting information, which was absent from City records.

To characterize the actual lighting systems, WBS and City staff conducted site walk-throughs of all 26 office buildings. For 12 of the offices, the research team conducted formal site visits with building managers for up to half an hour to help identify additional gaps in the permit data and verify building mechanical systems. The biggest gaps were related to building controls, which were not as easily decipherable through the mechanical drawings but were easily identified through a conversation with the building manager. Similarly, other details, such as equipment nameplate information, were more accurately identified through these site visits, which revealed the limitations of using building permits to create Asset Scores. In the future, the development of Asset Scores is recommended based on 1- to 2-hour site visits rather than researching the City's building permit data, unless significant changes are made to the permit data management.

Where available, building plans can be useful for determining some building characteristics, such as geometry, window-to-wall ratio, internal atrium dimensions and GFA. However, significant discrepancies in self-reported GFA from ESPM benchmarking reports and the GFA estimated from building plans were routinely found by the research team. Google satellite imagery was used, as needed, to supplement the GFA estimate for the Asset Scores. In some cases, this online research revealed additional corrections to envelope and mechanical systems information.

Technical Appendix C provides a table summarizing all of the key building characteristics that were collected by the research team to complete full Asset Scores based on permit review, site visits and online research.

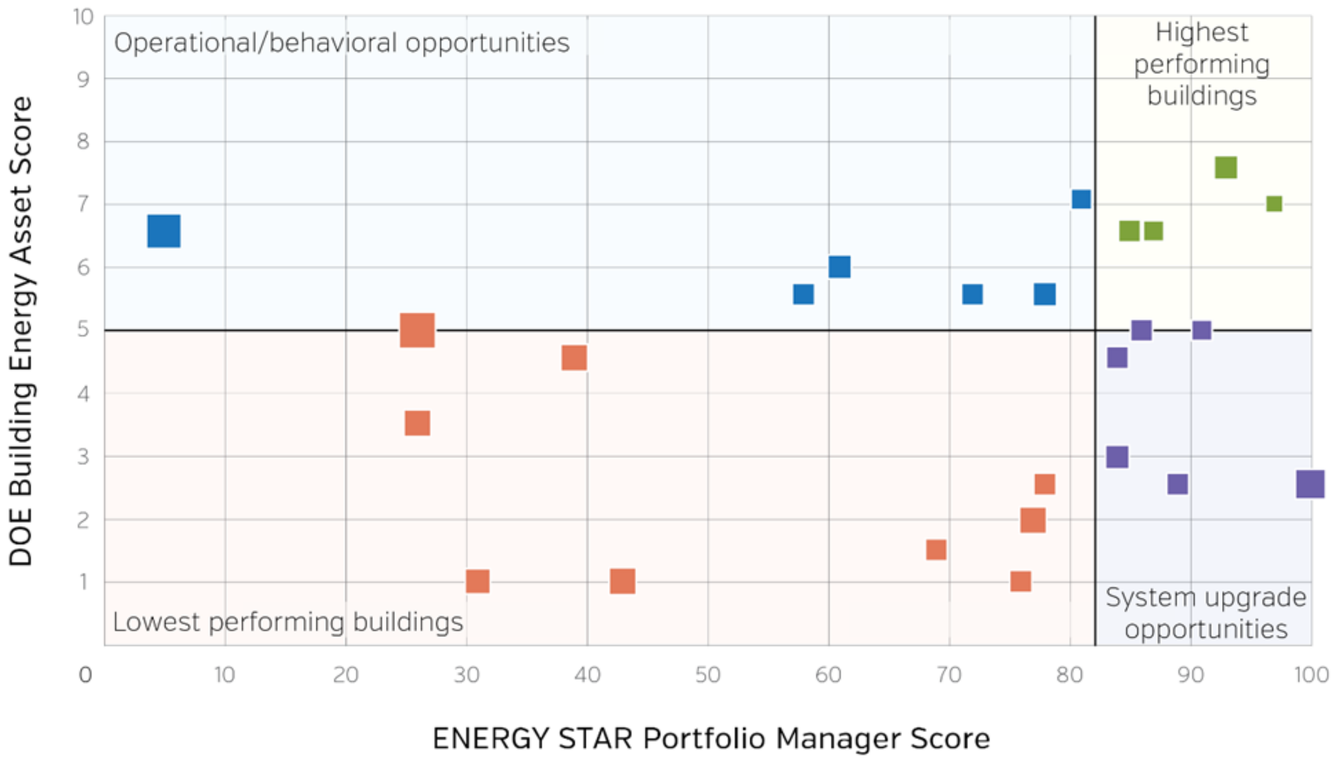


Figure 8: Quadrant view of building energy Asset Scores and Portfolio Manager scores.

ENERGY STAR scores provide a comprehensive assessment of a building's performance based on the building's physical assets, operation and occupant behavior. Asset Scores, on the contrary, use standard operation and assess the building's physical assets irrespective of operation or occupant behavior. A comprehensive analysis of both ENERGY STAR score and Asset Score of a building can inform a user on its as-designed efficiency as well as operational efficiency. For instance, a building with a high Asset Score but a low ENERGY STAR score indicates efficient physical assets but issues with operation that drive up the building's utility bills and result in a lower ENERGY STAR score.

Using the data collected through Commercial Building Energy Performance Reporting and building construction permit history, the City contracted Cadmus to (1) identify key building characteristics predictive of building energy performance and (2) analyze the degree of correlation between building characteristics and measured building energy performance. To demonstrate this, Cadmus used two datasets containing detailed information on 26 office buildings (Stevens et al. 2018):

- ENERGY STAR Portfolio Manager dataset including measured building energy performance, (building EUI and ENERGY STAR score), annual energy consumption data, GFA, year of construction, use types, operational characteristics and fuel types available on site.
- DOE Asset Score dataset including energy use predictions, building physical characteristics (including GFA, year of construction, use types, fuel types available on site), and operational characteristics.

For further research of this concept, a quadrant matrix was developed by plotting the ENERGY STAR scores and Asset Scores for each building in the data, as shown in Figure 8. The intent of the quadrant analysis was to categorize buildings based on both their ENERGY STAR scores and Asset Scores and identify buildings that had high potential for capital retrofits versus the buildings with potential for savings through retro-commissioning or operational improvements. The score matrix quadrants were based on the Portland median ENERGY STAR score of 82 (the median of the distribution of all Portland office buildings that reported in 2015) and the midpoint Asset Score of 5. The size pf each square in the matrix is relative to the Portfolio Manager Site EUI; the sites with larger squares have a higher EUI. The quadrants are defined below:

- Highest performing: ENERGY STAR score > 82; Asset Score > 5
- Lowest performing: ENERGY STAR score ≤ 82; Asset Score ≤ 5
- Operational improvement opportunities: ENERGY STAR score ≤ 82; Asset Score > 5
- System upgrade opportunities: ENERGY STAR score > 82; Asset Score ≤ 5

The "operational/behavioral opportunities" quadrant is categorized based on the argument that the building's design and systems suggest that it should perform well, but its ENERGY STAR score indicates below median energy performance. The "system upgrade opportunities" quadrant is defined as such because the building's ENERGY STAR score indicates it is performing better than the median even though its design and systems has room for improvement. The relationships that scores and energy consumption have with variables, such as building characteristics and specific systems, are examined in the Cadmus report titled Cities-LEAP Building Energy Data Analysis (Cadmus report; Stevens et al. 2018). The results from these analyses enable detailed recommendations for the buildings in each score matrix quadrant.

Using a variety of quantitative analysis methods, the distributions of scores, source EUI and site EUI as a function of the other variables were examined. The analysis methods included correlation analysis to identify which variables are most correlated with scores and EUIs (without controlling for other variables and regression analysis to identify variables with significant relationships with scores and EUIs while controlling for known drivers of energy consumption, e.g., floor area).

The buildings in each of the four quadrants were examined to identify the degree of correlation between building variables and measured building energy. Each variable was categorized as a building characteristic (e.g., floor area) or a specific system, such as lighting (e.g., lighting power density [LPD]), HVAC (e.g., System Performance Ratio) or an envelope measure (e.g., insulation). Correlation and regression analyses were then performed by measure-specific sections.

The buildings that fell into each quadrant were examined to identify the degree of correlation between building variables and measured building energy performance to identify key building characteristics and systems that impact building performance. After reviewing factors with the highest correlation with energy performance, it was observed that the highest performing buildings had a high HVAC TSPR, which is calculated as the sum of the annual heating and cooling loads divided by the HVAC system energy use, including all components of an HVAC system, such as pumps, fans, heat recovery and heat rejection. Lower values of the TSPR indicate more energy use to meet the load and thus represent low-efficiency systems (Goel et al. 2014).

In addition, many of the highest performing buildings had an efficient building envelope based on the Wall-Window Weighted (WWW) U-Factor. The WWW U-Factor is calculated as the ratio of the sum of wall U-factor multiplied by the net wall area and the window U-factor multiplied by the total window area, divided by the sum of the net wall area and the total window area. This ratio accounts for both wall and window thermal performance as well as the window-to-wall ratio. Lower values of the WWW U-Factor indicate more efficient windows and walls and thus a more efficient envelope. Alternatively, the lowest performing buildings usually had both low-performing windows and inefficient HVAC systems as identified through the TSPR. Most of the buildings identified in the System Upgrade Opportunities quadrant have inefficient HVAC systems and thus are good candidates for HVAC systems and controls retrofit.

The details of the analysis are available in the 2018 Cadmus report (Stevens 2018). Based on their correlation and regression analysis results, the following variables were included in the correlation analyses:

- Portfolio Manager site EUI: number of floors, year built and total energy use (kBtu)
- ENERGY STAR score: source EUI and the natural log of floor area
- Asset Score site EUI: number of floors, kBtu and the natural log of floor area
- Asset Score: number of floors and source EUI

The effect of the building characteristics on scores and EUIs must be accounted for to accurately observe the effects of additional predictors.

LPD is correlated with EUI and is a significant predictor of EUI in the regression analysis. Because score is a function of EUI, a sensitivity analysis was conducted to illustrate the potential effect that decreasing LPD could have on scores. Based on the results of the regression analysis and sensitivity results, we expect a decrease in LPD of 20 percent to increase Asset Scores by an average of 1.5 points and ENERGY STAR scores by an average of 15 points. These results suggest that buildings with less efficient lighting systems could be good targets for efficiency improvements through lighting upgrades. Reducing the LPD through replacement of existing lighting with efficient LED technologies offers a first step in making efficiency improvements. Although there was not sufficient data to explore other options associated with lighting, even efficient lighting equipment could benefit from control upgrades or improved schedule management that would significantly influence EUI.

Envelope characteristics were among the most significant predictors of scores and EUIs with relationships consistent with expectations. Given the construction of commercial buildings, however, opportunities to upgrade envelope insulation are likely to be limited. Windows, on the other hand, can be replaced with more efficient units, and the buildings in this sample had a large proportion of single-pane glazing and non-thermal break windows frames that could be replaced with more efficient systems. The simple linear regression provides evidence of significant relationships between WWW U-Factor and all responses when not accounting for any other predictors. When using Window Framing Type as the only predictor for each response, this has a significant relationship with ENERGY STAR Score, Asset Score and Asset Site EUI.

As shown in Table 1, the observed relationship between the HVAC system performance ratio with site EUI, source EUI and scores matches our expectations. The observed relationships between HVAC year of manufacture, heating efficiency value and cooling efficiency value have unexpected relationships with EUIs and scores. Heating and cooling efficiency values and year of manufacture were expected to have negative correlations with EUI. The unexpected observed relationships are likely due to the small sample size and lack of variation in the data, so these variables were removed from the remaining analyses. Due to the observed correlations, regression analysis was used to quantify the effects of HVAC measures on scores and EUIs.

Table 1: HVAC correlation results.

Variable	Sample Size	Site EUI	Source EUI	Score	Expected Relationship		Behaving as Expected	
					EUI	Score	EUI	Score
Portfolio Manager Variables								
HVAC Year of Manufacture	21	0.10	0.05	(0.14)	+	-	No	No
Heating Efficiency Value	19	0.08	0.23	(0.08)	-	+	No	No
Cooling Efficiency Value	19	0.07	0.17	0.04	-	+	No	Yes
HVAC System Performance Ratio	21	(0.24)	(0.30)	0.34	-	+	Yes	Yes
Asset Score Variables								
HVAC Year of Manufacture	21	0.29	0.24	(0.20)	+	-	No	No
Heating Efficiency Value	19	0.12	0.29	(0.31)	-	+	No	No
Cooling Efficiency Value	19	0.14	0.25	(0.19)	-	+	No	No
HVAC System Performance Ratio	21	(0.57)	(0.56)	0.54	-	+	Yes	Yes

FUTURE APPLICATIONS

Twenty-five U.S. cities currently implement building energy benchmarking and disclosure policies similar to the City's ordinance (BuildingRating 2018). Mandatory audit and RCx ordinances have also been passed by several of these cities, requiring buildings to complete energy audits within a certain time frame. Since audit ordinances can be challenging and costly to implement, cities, like Portland, could benefit from a simpler process that engages building managers to take action to improve energy performance without mandating audits or RCx.

After this project, the City plans to continue exploring the potential for generating Preview scores and analyzing this data with ESPM benchmarking data. As shown in Figure 9, this type of simple analysis could identify buildings that have the highest potential for energy savings through either RCx/retuning or retrofits, and the City could strategically connect building managers to the local energy incentive administrator's programs. Managers of buildings identified as having a high potential for retrofits could develop full Asset Scores to guide an initial energy retrofit. This approach

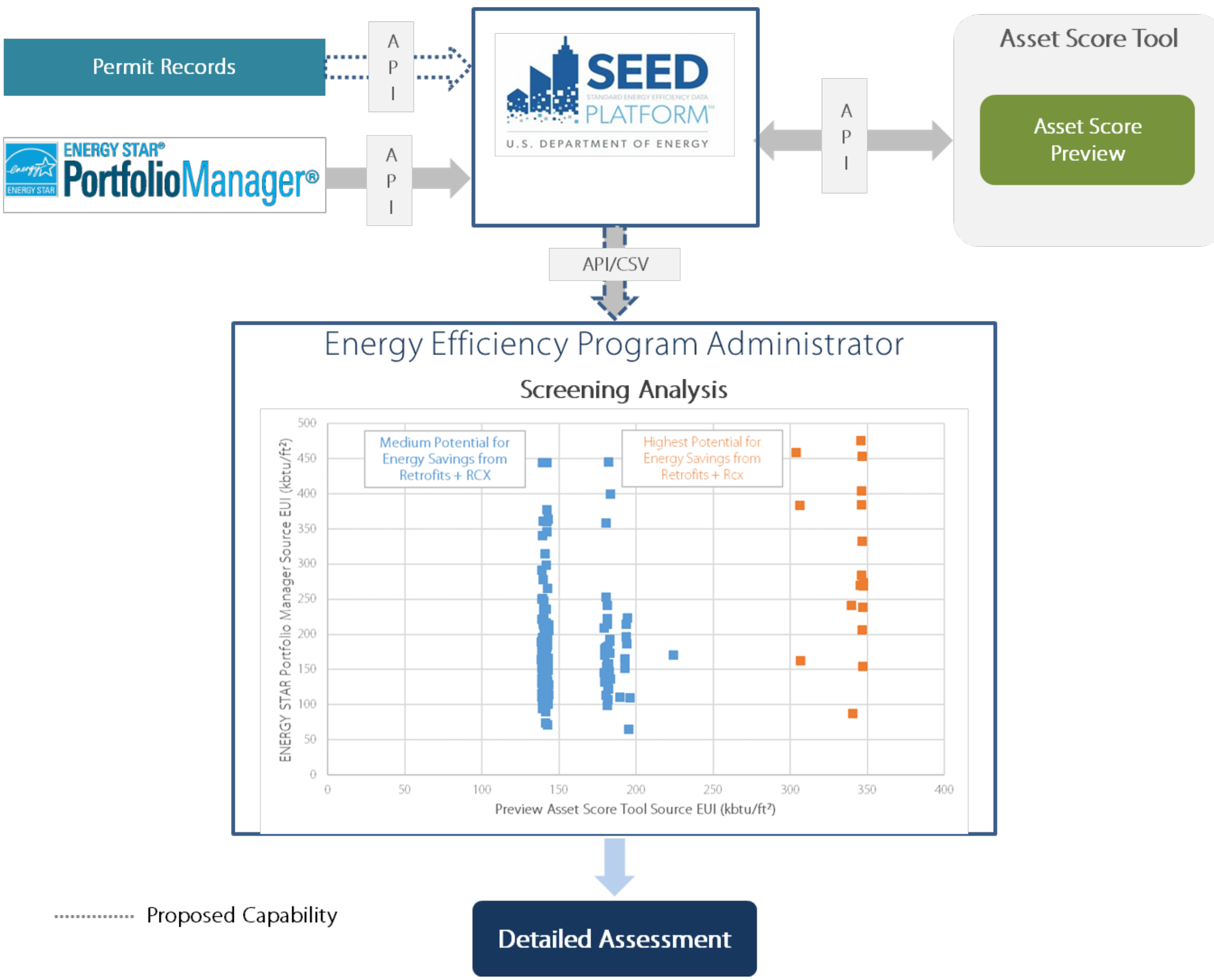


Figure 9: Screening with Preview to develop full Asset Scores

could benefit both the City and its energy efficiency program provider, the Energy Trust of Oregon, which provides assistance and incentives to building managers with retrofit projects.

Potential Future Workflow

The ideal workflow would automate and streamline the process from data collection to actual implementations of retrofits and evaluation of energy savings achieved. The workflow, as shown in Figure 10 and described in this section, proposes a scenario developed on the basis of this research project. Key elements of this workflow are discussed below.

read into SEED,[2] for further assessments and better data management.

Automated Data Transfer from Portfolio Manager

Benchmarking ordinances require building managers to report Portfolio Manager scores to their respective cities. SEED can automatically pull this data from Portfolio Manager for buildings that have been shared with SEED.

SEED for Data Management

Using SEED for data management would enable the city administrator to manage building energy

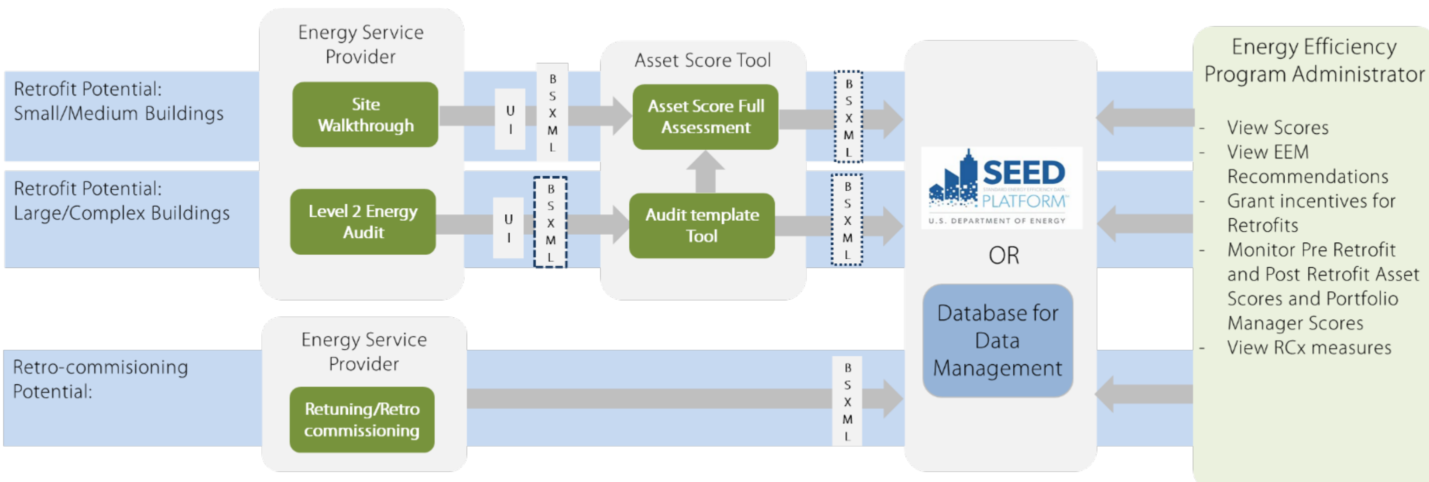


Figure 10: Potential future workflow.

Streamlined Permit Data Collection

Cities collect a lot of permit data, but most is stored in formats that makes it difficult to access later. Collection of key building data points in a standard format, like BuildingSync, would allow this data to be used for future assessment projects (BuildingSync 2018).[1] Inclusion of an additional data point related to number of floors can allow Preview assessments to be generated in the future. BuildingSync files could be written out from a city's public records database and

performance data. The SEED Platform helps users easily combine data from multiple sources, using the unique building ID utilized by the city, clean and validate the data, and share the information with others. SEED can read BuildingSync schema files and has an API capability that can automatically pull data from Portfolio Manager. Having all data sources in a structured database enables analysis of these various data sources to inform building energy efficiency programs.

[1] BuildingSync is a common schema for energy audit data that can be used by different software and databases for data exchange.

[2] The Standard Energy Efficiency Data Platform (SEED) is a data platform for managing portfolio-scale building performance data from various sources.

Automated Preview Assessment for Benchmarked Buildings

The streamlined permit data collection process would enable the data to be managed in the SEED Data Platform. The permit data, along with the Portfolio Manager data in SEED, could be automatically evaluated, using the Asset Score API, to generate Preview score ranges for the benchmarked buildings. The initial Preview score ranges have several assumptions based on typical building construction practices, and specifying additional information can reduce the uncertainty associated with the Preview score range. However, the initial Preview score range, along with the Portfolio Manager score, provides sufficient information for an initial screening that can identify buildings with potential for energy savings through further assessments. Preview scores require more information, specifically about the HVAC system type and lighting fixture type, to improve the accuracy of the score and reduce the uncertainty associated with it. Though this information is easy to generate, a city would either need to require it as a part of the permit process or require building managers to submit Preview scores along with Portfolio Manager scores.

Additional analysis, through a comparison of the Preview EUI and Portfolio Manager EUI, can identify whether the potential for savings would be through retrofits or retuning/retro-commissioning. This information can provide valuable guidance to the energy efficiency program administrator for targeted assessments. Buildings with potential for savings through RCx could be targeted with incentives for building tune-ups or RCx, and buildings with potential for savings through retrofits could be targeted with incentives for generating an Asset Score or a Level 2 energy audit.

Asset Score Assessments, Level 2 Audits and Automated Data Transfer

Buildings with potential for energy savings through retrofits could be analyzed using Asset Score Tool or detailed Level 2 energy audits. Larger, more complex buildings could go through a detailed energy audit process to identify energy efficiency measures. Using Asset Score Tool's BuildingSync output, this data could be transferred to SEED or made available to the program administrator through Asset Score Tool's "Dashboard" feature, which could be developed to allow program administrators to view reports of submitted buildings. This Dashboard could be used by program administrators to flag buildings that are a good candidate for rebates. After the retrofit process, they could monitor the improvement in Asset Scores for the post-retrofit building.

RCx Assessments and Automated Data Transfer

The quadrant analysis would identify buildings that would be good candidates for RCx. Once identified, the energy efficiency program administrator could provide incentives for the RCx process.

Conclusion

With cities, states and jurisdictions adopting benchmarking and auditing ordinances, there are huge amounts of data that could be used to inform investments in energy efficiency programs. This research project determined that developing Asset Scores based on site visits is preferable to mining City building permit data. In addition, we recommend the use of benchmarking data to develop Asset Score Previews as a first step to screen buildings and engage managers to develop full Asset Scores, and ultimately identify the best measures to improve their building energy efficiency. Where full Asset Scores are available, completion of a quadrant matrix with ENERGY STAR scores is recommended to determine which buildings present the best opportunities for operational/ behavioral improvements and upgrades to physical building systems. This workflow and the tools will help cities, utility incentive administrators and energy service providers develop programs for analysis, data management and screening of buildings with the greatest energy savings potential.

TECHNICAL APPENDIX A: DATA FLOWS

In addition to the data collection and analysis described above, the project team also completed work to make analysis of a large number of buildings using Portfolio Manager and Asset Score Tool straightforward for other cities to implement. There were three efforts in this task to develop replicable systems for generating Asset Scores from city data: (1) establishing a DOE Standard Energy Efficiency Data (SEED) instance for the City of Portland and uploading the data for buildings covered by the benchmarking ordinance, (2) connecting SEED with the Asset Score Application Programming Interface (API), and (3) connecting SEED with the Preview API. DOE developed the SEED Platform™ to provide public agencies and other organizations with a standardized but flexible, cost-effective, secure, enterprise data platform to manage portfolio-scale building performance data from a variety of sources. As shown in Figure A1, this work was conducted by Earth Advantage, an organization that is a Technical Ally of DOE's SEED Platform Collaborative and a SEED Hosting Provider.

The goal of this work is for other cities to use the tools developed here to automatically generate Preview results for all buildings for which they have benchmarking data and have those results stored in their own instance of the SEED Platform. Additionally, those cities could automatically retrieve any full Asset Score results and store those in SEED as well.

For the work in Portland, first, a new SEED instance was created for the City of Portland and populated with Portfolio Manager data for the buildings that had previously reported under the City's benchmarking ordinance. To facilitate ongoing upload of this data, the City and Earth Advantage defined a data template that will allow annual upload of benchmarking data into the SEED instance. This City of Portland data template also includes additional building information fields beyond those in Portfolio Manager, such as the number of floors, which is a required input for generating Asset Scores. Other cities may see the need to define their templates differently to meet programmatic needs.

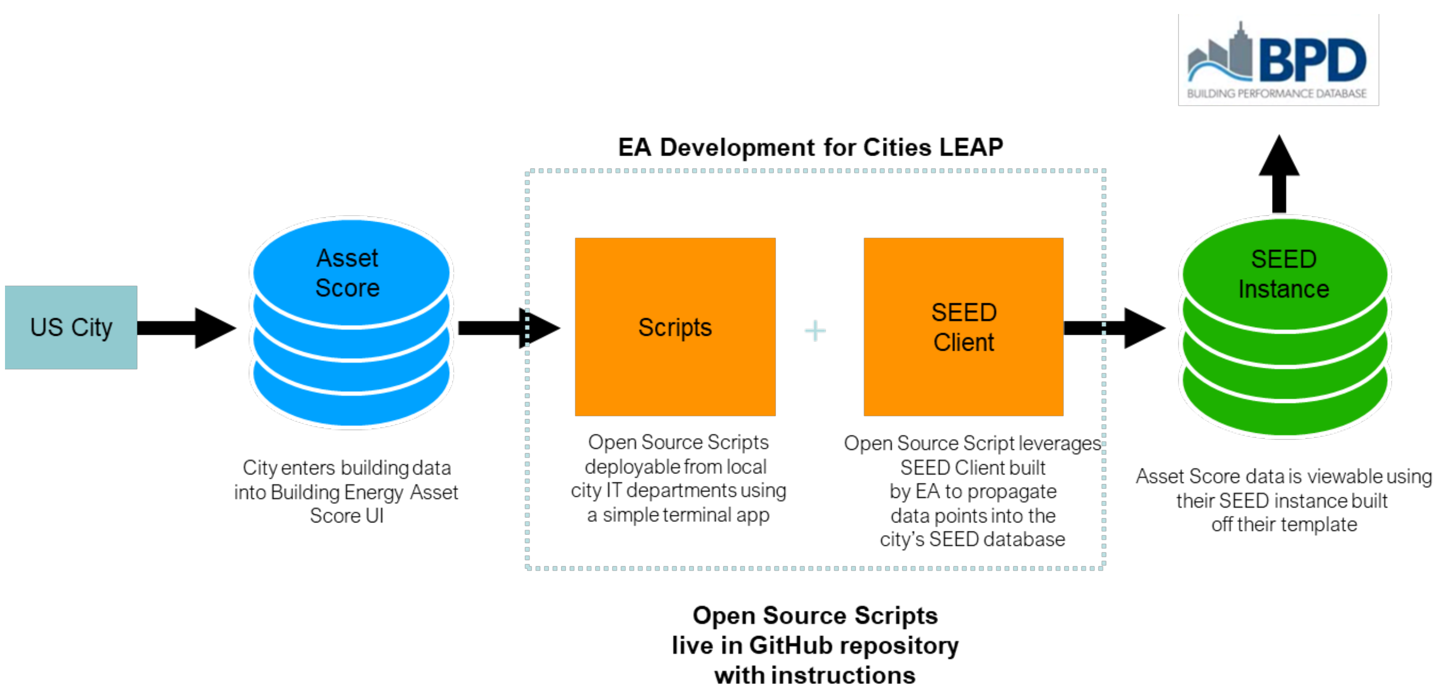


Figure A1: Data flow using open source scripts.

This project marked the first time that an outside organization has connected to either the Preview API or the Asset Score API. As a result of this work, both APIs are now fully functional and more documentation exists for future API users. Initially, the project team considered using the Asset Score API to both send building characteristics and retrieve results, but the complexities of creating the building geometry description that Asset Score tool uses were beyond the scope of this project. Instead, the team decided to send and receive data with the Preview API, but to only receive data from the Asset Score API. This means that for this project, the data required for Asset Score was manually entered into Asset Score Tool's user interface. Figure A2 shows that flow of data.

DOE is currently developing the capacity for the Asset Score API to use the BuildingSync XML data schema to allow third-party energy audit software tools to score buildings. In the future, this will make it easier for other jurisdictions to collect Asset Score input data, because there will be the opportunity to capture that data from other channels, not just direct data entry into Asset Score Tool itself.

The proper functioning of the two API calls was established with artificial building data, but once the systems were in order, the team was able to send the data for 250 buildings to Preview and received results on 181 of those. The results are available for review in SEED. The open-source code will automatically create new columns in SEED for the Preview and Asset Score results.

The open-source code that automates the transfer of data between SEED, Preview and Asset Score does not exist in the form of a third-party software program, nor has it been integrated into either SEED or Asset Score. At this juncture, a developer stills needs to download the code from GitHub and run it themselves to create the connectivity. The GitHub links are provided at the end of this appendix. Many cities would have their own developers on staff that could handle this level of effort, or an interested party could work with a SEED Hosting

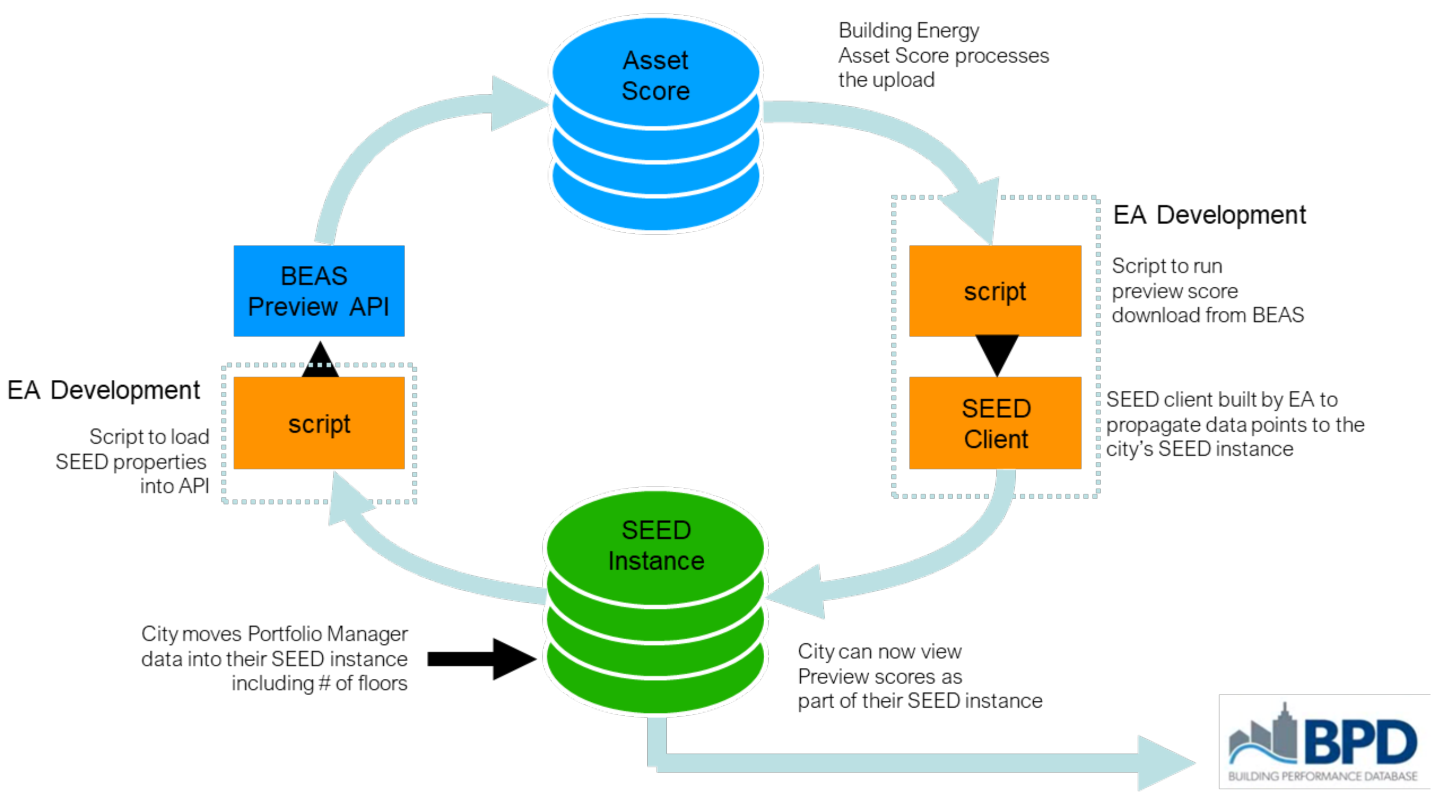


Figure A2: Automatic generation of Preview scores from building data in SEED.

Provider to conduct this on their behalf. The latter scenario would make sense if the city was already contracted with the SEED Hosting Provider to be the custodian of their benchmarking data. The former is likely to be the case for cities that have robust IT capabilities and may even be already hosting their own instance of SEED. Figure A2 illustrates how the project team used the newly developed tools to automatically generate Preview scores from building data stored in SEED.

The efforts of this project have made it relatively easy for any jurisdiction to produce Preview results for buildings that are reporting under a benchmarking ordinance. In the future, that should become much easier for full Asset Scores as well. As mentioned above, the use of the BuildingSync XML data schema by energy audit software tools will allow the capture of all the building characteristics needed to generate an Asset Score. This would help streamline and automate this process further, making it easier for cities to analyze a large dataset.

The following are links to public code on GitHub that was developed to automate connectivity between the SEED Platform and Asset Score:

- https://github.com/GreenBuildingRegistry/jwt-oauth2
  JWT OAuth (rfc7523) implementation extended from oauthlib and Django OAuth Toolkit
- https://github.com/GreenBuildingRegistry/usaddress-scourgify
  Clean US addresses following USPS pub 28 and RESO guidelines
- https://github.com/GreenBuildingRegistry/py-bes
  A Python client for accessing the Building Energy Asset Score API
- https://github.com/GreenBuildingRegistry/py-seed
  SEED API call
- https://github.com/GreenBuildingRegistry/dubplate
  An immutable dict like data structure with added metadata
- https://github.com/GreenBuildingRegistry/yaml-config
  Python client for reading yaml based config files

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Energy Asset Score: Data Collection Short Form - *Full Input Mode*

Building Name:	
Data collected by:	
Email, phone:	
Date of Data Collection:	

This Short form contains all of the minimum required data fields necessary to generate an Energy Asset Score using the Full Input Mode of the tool. This form may be used for a single-use type rectangular building. Use the Data Collection Long Form - Full Input Mode for additional shaped buildings, mixed-use types, complex HVAC systems, and/or available optional fields and detailed instructions for data entry.

Year completed (or year of last major retrofit)		**Gross floor area**		ft²	
Building location	STREET				
	CITY		STATE		POSTAL CODE
Building footprint dimensions (ft)	LENGTH	WIDTH	**Number of floors**		

Building Use Type

- ☐ Assisted Living
- ☐ City Hall
- ☐ Community Center
- ☐ Courthouse
- ☐ Education
- ☐ Library
- ☐ Lodging
- ☐ Medical Office
- ☐ Multi-family(4 stories +)
- ☐ Multi-family(less than 4 stories)
- ☐ Office
- ☐ Parking Garage ☐ Ventilation only
- ☐ Post Office
- ☐ Police Station
- ☐ Religious Building
- ☐ Retail
- ☐ Senior Center
- ☐ Warehouse non-refrigerated

Construction Properties

Roof type
- ☐ Built-up with Concrete Deck
- ☐ Built-up with Metal Deck
- ☐ Built-up with Wood Deck
- ☐ Metal Surfacing
- ☐ Shingles/Shakes

Floor type
- ☐ Concrete Slab
- ☐ Slab on Grade
- ☐ Steel Joist
- ☐ Wood Frame

Wall type
- ☐ Brick/stone on Masonry
- ☐ Brick/stone on Steel Frame
- ☐ Brick/stone on Wood Frame
- ☐ Metal Panel/Curtain Wall
- ☐ Siding on Steel Frame
- ☐ Siding on Wood Frame

Window framing type
- ☐ Metal
- ☐ Metal with Thermal Breaks
- ☐ Wood/Vinyl/Fiberglass

Window glass type
- ☐ Single-pane
- ☐ Double-pane
- ☐ Double-pane w/ Low-E
- ☐ Triple-pane
- ☐ Triple-pane w/ Low-E

Window-to-Wall Ratio (Continuous Layout)

# of Windows (Discrete Layout)

Dimensions (Width and Height in ft.)

Lighting

Fixture	Lighting type (CFL; Fluorescent T5/High Output T5; Fluorescent T8/ Super T8; Fluorescent T12/ High Output T12; High-Pressure Sodium; Incandescent/Halogen; LED; Mercury Vapor; Metal Halide)	Mounting type (Recessed, Surface, Pendant)	Watts per Lamp	Lamps per Fixture	Lighting fixture details (Enter either Total # of Fixtures OR % Area Served)	
					# of Fixtures	% Area Served
a.						
b.						

Heating/Cooling

Distribution equipment type ☐ Air Handler Unit (AHU) ☐ Zone Equipment

HVAC System Type
- ☐ Packaged Terminal Air Conditioner
- ☐ Four Pipe Fan Coil Unit
- ☐ Packaged Terminal Heat Pump
- ☐ Packaged Rooftop Air Conditioner
- ☐ Packaged Rooftop Heat Pump
- ☐ Packaged Rooftop VAV with Hot-Water Reheat
- ☐ Packaged Rooftop VAV with Electric Reheat
- ☐ VAV with Hot-Water Reheat
- ☐ VAV with Electric Reheat
- ☐ Warm Air Furnace
- ☐ Ventilation Only (for Parking Garage Use Type)
- ☐ Water-Loop Heat Pump
- ☐ Ground Source Heat Pump
- ☐ Dedicated Outdoor Air System

Cooling Source
- ☐ No cooling
- ☐ DX Coil
- ☐ Plant Loop: Chiller
- ☐ Plant Loop: District Chilled Water
- ☐ Plant Loop: Condenser

Compressor Type (If Plant: Chiller)
- ☐ Scroll/Screw
- ☐ Reciprocating
- ☐ Centrifugal

Condenser Type (If Plant: Chiller)
- ☐ Air
- ☐ Water

Condenser Plant Type
- ☐ Cooling Tower
- ☐ Ground Heat Exchanger

Heating Source
- ☐ No heating
- ☐ Central Furnace
- ☐ Heat Pump (electric)
- ☐ Plant Loop: Boiler
- ☐ Plant Loop: District Hot Water

Heating fuel (If Source=Boiler/Furnace)
- ☐ Natural Gas
- ☐ Electricity
- ☐ Fuel Oil
- ☐ Propane

District heat type
- ☐ Hot Water
- ☐ Steam

Draft Type (If Plant: Boiler)
- ☐ Mechanical
- ☐ Other Draft

Sink/Source (If Heat Pump)
- ☐ Air
- ☐ Ground
- ☐ Water

(*currently not available)

http://energy.gov/eere/buildings/building-energy-asset-score

Data Collection Short Form version 2/3/17

TECHNICAL APPENDIX C: BUILDING INPUT DETAILS

Table C1: Building Input Details: Asset Scores

Building Information				
Building ID	Current Asset Score	Potential Asset Score	Year of Construction	GFA (ft^2)
8633	5	9	1980	51,492
8642	6.5	8.5	2002	271,263
8645	4.5	8.5	1999	449,064
8646	5.5	7	1999	70,200
8647	7.5	9	1995	116,625
8691	1	6	1987	49,500
8692	6	7.5	1989	59,940
8698	6.5	9	1984	109,602
8699	3.5	8.5	1975	72,000
8700	7	7	2009	83,224
8724	6.5	8	2009	95,764
8738	2.5	7	2008	93,510
8752	1.5	7	2002	64,680
8753	5	9	1985	233,044
8828	2.5	8.5	1999	113,401
8829	1	8	1970	42,408
8830	1	8	1972	204,480
8879	3	8.5	1978	294,526
8923	5.5	8.5	1950	178,090
8924	2	8	1963	302,744
8926	4.5	7	1946	100,000
8927	6.5	8.5	1964	81,000
8928	5	9	1983	280,600
8929	2.5	9	1981	220,000
8930	7	8	2009	56,250
8931	5.5	9	1995	67,350

Table C2: Building Input Details: Construction Assembly

Building Infor-mation	Construction Assemblies								
	Roof		Wall		Window				
Building ID	Type	Assembly U Value (Btu/hr-sqft F)	Type	Assembly U Value (Btu/hr-sqft F)	Framing Type	Glass Type	U Value (Btu/hr-sqft F)	SHGC	WWR
8633	Built-up w/ metal deck	0.087	Brick/Stone on masonry	0.130	Metal Frame	Double pane	0.80	0.68	10%
8642	Built-up w/ concrete deck	0.063	Brick/Stone on masonry	0.108	Metal w/ Thermal Breaks	Double Pane w/ Low-E	0.43	0.27	90%
8645	Built-up w/ concrete deck	0.480	Brick/Stone on masonry	0.110	Metal w/ Thermal Breaks	Double Pane w/ Low-E	0.30	0.43	50%
8646	Built-up w/ metal deck	0.063	Brick/Stone on masonry	0.110	Metal w/ Thermal Breaks	Double Pane	0.57	0.64	25%
8647	Built-up w/ metal deck	0.060	Brick/Stone on steel frame	0.060	Metal w/ Thermal Breaks	Double Pane	0.57	0.43	25%
8691	Shingles/Shakes	0.032	Brick/Stone on Masonry	0.130	Metal Frame	Double pane	0.72	0.46	65%
8692	Built-up W/ metal deck	0.087	Brick/Stone on Steel Frame	0.062	Metal Frame	Double pane	0.72	0.46	40%
8698	Metal Surfacing	0.163	Brick/Stone on Steel Frame	0.073	Metal Frame	Double pane	0.72	0.46	15%
8699	Built-up w/ concrete deck	0.073	Brick/Stone on steel frame	0.062	Metal Frame	Double pane	0.72	0.46	40%
8700	Built-up w/ concrete deck	0.063	Brick/Stone on steel frame	0.055	Metal with Thermal Breaks	Double Pane with Low E	0.43	0.33	33%
8724	Metal surfacing	0.104	Metal panel/Curtain Wall	0.104	Metal w/ Thermal Breaks	Double pane	0.29		50%
8738	Built-up w/ concrete deck	0.063	Brick/Stone on steel frame	0.045	Metal Frame	Double pane	0.72	0.47	80%
8752	Built-up w/ concrete deck	0.036	Brick/Stone on steel frame	0.062	Metal Frame	Double Pane with Low E	0.29		70%
8753	Built-up w/ concrete deck	0.073	Brick/Stone on steel frame	0.062	Metal Frame	Double pane	0.72	0.47	40%
8828	Built-up w/ concrete deck	0.063	Brick/Stone on steel frame	0.057	Metal Frame	Double pane	0.72	0.47	80%
8829	Built-up w/ concrete deck	0.073	Brick/Stone on steel frame	0.082	Metal Frame	Double pane	0.72	0.68	70%
8830	Built-up w/ concrete deck	0.073	Brick/Stone on steel frame	0.122	Metal Frame	Single Pane	1.17	0.81	80%
8879	Built-up w/ concrete deck	0.073	Brick/Stone on steel frame	0.062	Metal Frame	Double pane	0.72	0.47	60%
8923	Built-up w/ concrete deck	0.073	Brick/Stone on masonry	0.690	Metal Frame	Single Pane	1.17	0.54	75%
8924	Built-up w/ concrete deck	0.105	Metal panel/Curtain Wall	0.240	Metal Frame	Double pane	0.72	0.47	90%
8926	Built-up w/ concrete deck	0.073	Brick/Stone on masonry	0.224	Metal Frame	Single Pane	1.17	0.54	80%
8927	Built-up w/ metal deck	0.136	Brick/Stone on masonry	0.130	Metal Frame	Double pane	0.72	0.68	90%
8928	Built-up w/ concrete deck	0.073	Metal panel/Curtain Wall	0.163	Metal Frame	Double pane	1.00	0.47	90%
8929	Built-up w/ concrete deck	0.046	Brick/Stone on steel frame	0.066	Metal Frame	Double pane	0.72	0.47	45%
8930	Built-up w/ metal deck	0.051	Brick/Stone on steel frame	0.066	Metal Frame	Double pane	0.33	0.36	35%
8931	Built-up w/ wood deck	0.059	Brick/Stone on steel frame	0.043	Wood/Vinyl/Fiberglass	Single Pane	0.89	0.48	30%

Table C3: Building Input Details: HVAC System

Building Information	HVAC Systems						
		Heating System			Cooling System		
Building ID	**System Type**	Heating Source	Fuel Type	Efficiency Value (Thermal Efficiency, COP)	Cooling Source	Efficiency Value (COP)	Fan Control
8633	VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	80%	Water Cooled Chiller	3.67	VAV
8642	VAV Electric Reheat	Furnace	Gas Fired	80%	District Chilled Water	NA	VAV
8645	P-VAV Electric Reheat	Electric Reheat	Electric	100%	DX	3.98	VAV
8646	Water Loop Heat Pumps	Heat Pump	Electric	4.20	DX	4.2	CAV
8647	VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	87%	Water Cooled Chiller	3.37	VAV
8691	VAV Electric Reheat	Electric Reheat	Electric	100%	DX	2.85	VAV
8692	VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	78%	Air Cooled Chiller	2.836	VAV
8698	SZ VAV	Hot Water Boiler	Gas Fired	65%	Water Cooled Chiller	3.54	VAV
8699	VAV- Hot Water Reheat	Hot Water Boiler	Gas Fired	71%	DX	2.85	VAV
8700	Air Source Heat Pump	Heat Pump	Electric	3.27	DX	3.13	CAV
8724	VAV Electric Reheat	Furnace	Gas Fired	77%	No Cooling	NA	VAV
8738	VAV Electric Reheat	Furnace	Electric	100%	DX	2.8	VAV
8752	VAV Electric Reheat	Furnace	Electric	100%	DX	2.85	VAV
8753	VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	69%	Water Cooled Chiller	6.01	VAV
8828	VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	80%	Water Cooled Chiller	5.1	VAV
8829	VAV Hot Water Reheat	Hot Water Boiler	Electric	100%	Water Cooled Chiller	5.5	VAV
8830	VAV Hot Water Reheat	Hot Water Boiler	Electric	100%	Water Cooled Chiller	6.5	VAV
8879	VAV Hot Water Reheat	Hot Water Boiler	Electric	100%	Air Cooled Chiller	2.76	VAV
8923	P-VAV Electric Reheat	Electric Reheat	Electric	100%	DX	1.67	VAV
8924	VAV Hot Water Reheat	Hot Water Boiler	Fuel Oil	77%	Air Cooled Chiller	2.76	VAV
8926	Water Loop Heat Pumps	Heat Pump	Electric	4.20	DX	3.86	VAV
8927	Packaged Single Zone VAV	Hot Water Boiler	Fuel Oil	74%	DX	2.85	VAV
8928	VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	73%	Air Cooled Chiller	2.83	VAV
8929	VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	69%	Air Cooled Chiller	2.76	VAV
8930	P-VAV Hot Water Reheat	Hot Water Boiler	Gas Fired	88%	Air Cooled Chiller	2.93	VAV
8931	P-VAV Electric Reheat	Furnace	Gas Fired	65%	Air Cooled Chiller	2.6	VAV

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