Feasibility Study to Investigate Translational Capacity of the Selected Whole Building Rating Systems

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Executive Summary

Formed in 2015, the National Labeling Group (NLG) brought together stakeholders representing states, municipalities, organizations and technical experts involved in the building ratings and benchmarking. The overarching goal of the NLG was to inform benchmarking laws, and explore feasibility of a generic building label that may be used in conjunction with the different rating systems, and express the building performance metrics in a uniform way independent of the rating system used. It was envisioned that this approach would eliminate the market confusion from the difference in scoring used by the individual rating systems, while giving adopters the flexibility to choose which rating system(s) can be used in conjunction with the generic label in the given program or jurisdiction.

This report was commissioned by NYSERDA to provide comparative testing of whole building asset rating systems including, ASHRAE Standard 90.1 2016 Performance Rating Method, Building Energy Asset Score, and ASHRAE Building EQ As-Designed, and operational rating systems including ASHRAE Building EQ In-operation and EPA Portfolio Manager.

Feasibility of the labeling concept hinge on whether it is possible to map the native scores or grades produced by the rating systems to the generic efficiency descriptor(s). The study focused on establishing the general agreement between the rating systems, and exploring the possible mapping.

The general agreement between the rating systems was evaluated based on the two criteria - the alignment in the absolute scores, and the ranking of the building compared to its peers. The score alignment was established using the supplemental Star scale, which separated buildings into performance quartiles from 4 Stars (the best), to 1 Star (the worst). For each rating system, the range of scores was established to map the native scores to the Star quartiles, as shown in Table A. The rating systems were deemed to agree based on the score alignment criterion if they placed the building into the same Star quartile.

Table A: Mapping of Native Scores to the Star Quartiles

	1 Star	2 Stars	3 Stars	4 Stars
BEAS	1 - 4.5	5 - 7	7.5-9	9.5-10
bEQ As Designed	> 105	75 - 105	45-74	0 - 44
PRM	> 116	90 - 116	45 - 89	0 - 44
bEQ In Operation	> 100	75 - 100	45 - 74	0 - 44
EPA PM	<50	50 - 75	76 - 95	96 - 100

With the ranking criterion, the rating systems were deemed to agree if they gave the building the same rank based on its score compared to the evaluated peers. For example, the high - rise apartment peer group evaluated in the study included ten buildings in various locations and vintages. The same building received the best score in both bEQ In Operation and EPA PM out of the ten evaluated, thus bEQ in Operation and EPA PM were deemed to agree based on the ranking criterion for that building. Another building was ranked eighth in the bEQ in-Operation, and the seventh in the EPA. Thus, bEQ In Operation and EPA PM were deemed to disagree based on the ranking criteria for that building. The ranking criterion was used because if the rating systems agreed based on the raking criterion, but placed the buildings into different Star quartiles, the agreement in the absolute scores may be potentially achieved by calibrating the mapping between the native scores and the Star quartiles. When rating systems placed the building into different Star quartiles, or ranked them differently, the causes of disagreement were investigated.

The buildings used in the study included variations of high-rise and mid-rise multifamily, and medium and small office buildings varying in efficiency from typical pre-1980 construction to designs compliant with ASHRAE Standard 90.1 2013 or better. Multifamily test cases were selected as representatives of the residential building sector; office test cases were selected to represent commercial sector. Climate zones 2A and 4A were picked as the proxy of the cooling and heating dominated climates, and based on the volume of new construction and existing building floor area. Most tested configurations were based on the different vintages of the PNNL progress indicator models.

The testing showed that the rating systems were in general agreement based on one or both of the established criteria for most test cases. This confirmed that the high-level mapping between the rating systems is feasible. Most disagreements were traced to the glitches in the rating system tools or methodologies, rather than the inherent differences in the approaches. These findings, and possible updates to the rating systems, were discussed with the rating system developers including PNNL team involved with the Building Energy Asset Score, and the ASHRAE bEQ committee. The testing methodology used in the study was adjusted where possible to incorporate the upcoming changes to the rating systems. The alignment is expected to further improve as the rating systems evolve.

The study includes the recommended improvements to the rating system methodologies and tools, future testing, and the practical implications of the differences in the rating systems, to inform the decision-making of the potential adopters.

Background

The study was performed for the rated building Labeling Group facilitated by NYSERDA, which set to investigate whether it is desirable and possible to have a single building energy label adopted nationwide, define the attributes of an ideal label, and develop and implement a roadmap for the national adoption of a ubiquitous building energy label. It was envisioned that this label could be used in conjunction with the different rating systems, and express the building performance in a uniform way independent of the rating system that was used. This approach will minimize market confusion from the difference in the scoring presentation between different rating systems, while avoiding picking the "winner", to allow the individual adopters decide which rating system(s) to use in conjunction with the label. The Oregon's Home Energy Facts label is based on a similar concept, and may be used in conjunction with DOE Home Energy Score, RESNET HERS, and the Energy Performance Score.

It was envisioned that the generic label would include asset and operational rating components. Asset ratings are based on the theoretical performance of the building, quantifying the inherent efficiency of the building systems, or the *aptitude* of the building to perform well based on its design. Operational ratings are based on the annual utility bills, and thus depend on the efficiency of the building systems, quality of construction, maintenance, and occupancy patterns. In other words, asset ratings are akin to SAT scores, and operation ratings are similar to GPA; each provides unique insight and is useful for assessing performance. Just like colleges often make the admission decisions based on a combination of GPA and SAT scores, and sometimes combine the two into a single score based on a weighing logic to rank the applicants, the building energy label may show asset and operational scores separately, or combine them into a single efficiency descriptor.

Several asset and operational rating systems are currently available, and others may be developed in future. The ability to use different rating systems in conjunction with the same label depends on the rating systems of the same kind (e.g. asset ratings) being in the general agreement about the perceived efficiency of the buildings. This would allow mapping from the native scores produced by the rating systems to the performance descriptor(s) of the generic label. To explore this option, the NLG Technical Committee developed the scope of work to investigate translational capacity of the whole building rating systems including ASHRAE Standard 90.1 Appendix G Performance Rating Method (PRM), DOE Building Energy Asset Score (BEAS), and ASHRAE bEQ As-Designed asset ratings, and ASHRAE bEQ In-Operation, and EPA Energy Star Portfolio Manager (EPA PM) operational ratings. NYSERDA has funded the implementation of the study.

Overview of the Tested Rating Systems

On the highest level, the building energy rating systems are classified into Asset and Operational ratings. Asset ratings are based on the theoretical energy consumption of the rated building established by an energy simulation or a performance map. With the energy simulation approach, the rated building is modeled using an approved simulation tool to obtain the annual consumption. The performance map approach uses regression equations developed based on the database of pre-simulated models representing the existing and new building stock, with the rated building 's energy performance determined by using its characteristics as inputs to the regression equations. Operational ratings as based on the actual utility bills of the rated building , normalized by the key building characteristics such as building type, floor area, and location, to ensure apples-to-apples comparison.

Except for PRM, rating systems reviewed in the study use the source (primary) energy as the basis of the rating. Source energy is the amount of fuel required to operate a building, including energy consumed by the production of electricity, and losses due to transmission and delivery of energy from the power plant to the building. PRM rates the buildings based on the energy cost determined using either the actual utility rates of the rated building (to allow accounting for demand and time of use), or Energy Information Administration average rate for the project location.

All evaluated rating systems compare performance of the Rated building to a benchmark, but differ in how this benchmark is established. The static benchmark is based on the models reflecting typical or code required parameters at the standardized operating conditions, or typical actual usage (e.g. utility bills) of buildings of the given type and location. Building-specific benchmark tracks certain features of the rated building, so is more dependent on the building being rated. For example, PRM baseline inherits envelop shape and allocation of floor area between space types, such as common areas versus apartments in a multifamily building, from the rated building. The benchmark may be based on the actual characteristics and performance of the buildings in the peer group, such as usage data from the Commercial Building Energy Consumption Survey (CBECS), or a particular version of code, e.g. reflect prescriptive requirements of ASHRAE Standard 90.1 2004.

The scale is another important distinction between the rating systems. The scale determines how the difference in the performance of the rated building and the benchmark is quantified. The key attributes of the scale include definition of the benchmark (normalizing value), high, and low points on the scale, and the methodology used to determine the score, which may be linear or percentile. The Zero Energy Performance Index (zEPI) scale and Energy Star scale illustrate these differences. With the zEPI scale, the low point is set to net zero energy, and the benchmark corresponds to the score of 100. zEPI is a linear scale, so the score above or below the 100 point can be used to directly gauge performance of the rated building relative to the benchmark. For example, a score of 80 indicates that the energy consumption of the rated building is 20% less than the benchmark. A score of 120 indicates that the consumption is 20% greater than the benchmark. Net energy producers could achieve a negative score, while poor performing buildings could score well above 100. zEPI scale is illustrated on Figure 1 [1].

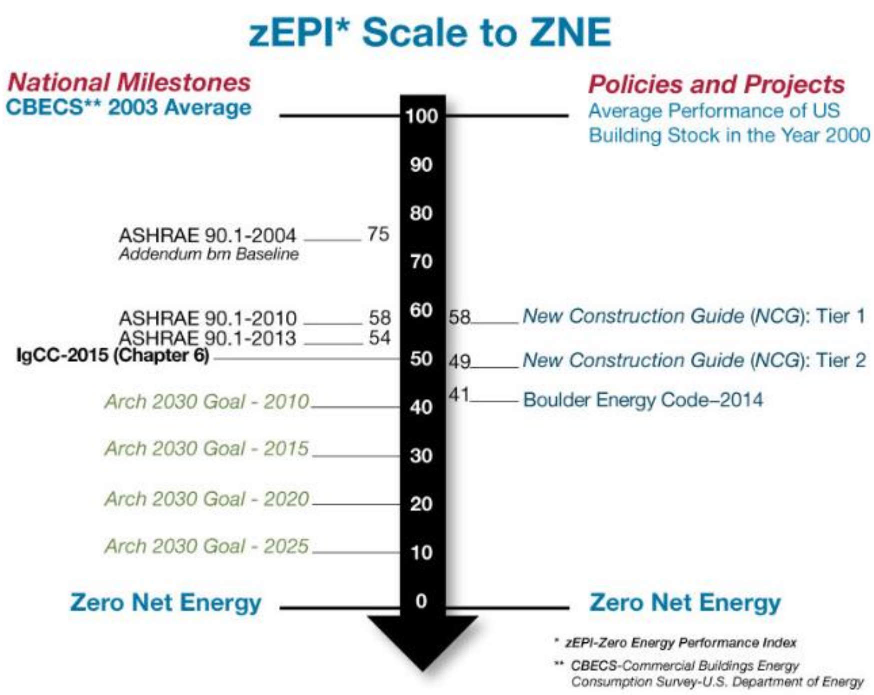


Figure 1

ENERGY STAR scale used by EPA PM is a percentile scale, with scores ranging from 1 to 100. The score of 50 indicates that the rated building performance matches the median for the buildings with the similar characteristics. A score of 75 indicates that the building is in the top 25% of its peers. The energy use of the rated building is adjusted for variables that depend on building operations, such as number of occupants or operating hours, and compared to a statistical average for a given

[1] http://newbuildings.org/code_policy/zepi/

building type. The rating depends on the distribution of buildings that fall into different performance bins, and has no direct correlation to energy use. For example, to meet an ENERGY STAR score of 99, a building might only need to be 50 percent better than the median. Further improvements in efficiency for ultra-low energy or even net-zero buildings would not register any improvement on the scale, and would retain a 99 score. Thus, the high end of the scale is essentially "compressed" and may not reflect measures that separate ultra-low energy buildings from high performance buildings. Similarly, a building with the score of 5 could vastly outperform a building with the score of 2, despite the scores being very close.

Asset ratings have several additional distinctions. Energy performance of the building may be assessed under the standardized set of conditions, such as operating hours, occupancy, thermostat setpoints, lighting runtime hours, service water heating loads, ventilation rates, etc. Alternatively, modeling inputs may reflect the actual or anticipated (for new construction) operation of the rated building, with the benchmark and rated building inputs tracking each other. The asset ratings may also differ in what building systems and components are treated as assets and affect the rating scores. For example, with PRM the advanced HVAC controls may be included in the model of the rated building, with the minimally code compliant controls modeled in the benchmark. On the other hand, bEQ As-Designed and BEAS treat many HVAC controls as energy neutral. In addition, asset rating systems may account for energy use of the entire building, or exclude some end uses such as exterior lighting. Table 1 summarizes the differences between the tested rating systems.

Table 1: Rating Systems Comparison

	bEQ As Designed	BEAS	PRM	bEQ In Operation	EPA PM
Rating Type	Asset			Operational	
Developed & Funded by	ASHRAE	PNNL / DOE	ASHRAE	ASHRAE	EPA
Benchmark	Based on CBECS, via EPA Target Finder or ASHRAE Standard 100	Based on score look-up tables with weather adjustment	Modeled for each project	Based on CBECS via EPA PM, or ASHRAE Standard 100	Based on CBECS
Scale	Linear	Progressive binning method	Linear	Linear	Percentile
Units	Source energy	Source energy	Energy cost	Source energy	Source energy
Unregulated loads and Schedules	Prescribed, based on COMNET	Prescribed, hard-wired into Asset Score Tool	Typical, as determined by modeler	Based on actual operation	Based on actual operation
Simulation Tool	Any tool compliant with 90.1	Asset Score Tool	Any tool compliant with 90.1	NA	NA
Level of detail	Detailed model based	Allows range of details from very	Detailed model based	Limited to basic building	Limited to basic building

captured for rated building	on 90.1 Appendix G	basic to more detailed, but much less than 90.1 Appendix G	on 90.1 Appendix G	parameters and operating conditions	parameters and operating conditions

Rating System Agreement Criteria

Due to the differences in the methodologies, there can be no mathematical relationship to translate performance metric produced by different rating systems to a single score. Thus, the study focused on establishing the general agreement between the rating systems based on (a) the alignment in the rating scores and (b) the alignment in the projects' rankings.

The score alignment was established using the Star scale, which separated the buildings into the performance quartiles from 4 Stars (the best), to 1 Star (the worst). The Star nomenclature was selected to differentiate from the numeric or letter grade scores used by the tested rating systems. The mapping was based on the native rating scores as opposed to the secondary outputs such as normalized source energy use intensity (EUI), to fully capture the rating systems' methodologies. For each rating system, the Star quartiles were mapped to the range of the native scores. The rating systems were deemed to agree based on the score alignment criterion if they placed the rated building into the same Star quartile.

The rating systems were deemed to agree based on the ranking criterion if they gave the building the same rank among the evaluated peers. For example, if a given multifamily building received the best score compared to the other tested multifamily buildings in the two rating systems, these rating systems were deemed to agree based on the ranking criterion. The ranking criterion was used because if the rating systems agreed on the ranking but placed the projects into different Star quartiles, the agreement in scores may potentially be achieved by calibrating the mapping from the native scores to the Star quartiles.

Table 2 shows the approximate BEAS scale markers based on the reviewed literature.

Table 2: BEAS Scale Markers

Score	Expected Performance
10	the minimum EUI that may be achieved without on-site generation
8	30% more efficient than the average buildings compliant with 90.1 2004
6-7	average building compliant with ASHRAE Standard 90.1-2004
1	lower 95th percentile of simulated EUI or the 90th percentile of the CBECS data

Table 3 illustrates PRM's Performance Cost Index (PCI) relative to 90.1 2004. PCI was estimated based on the PNNL analysis of DOE prototype models[2] and the definition of the PRM scale.

Table 3: PRM Performance Cost Index (PCI)

[2] PNNL 2013 End Use Tables_2014jun20

Proposed Design Complies with…	Hi rise Apt	Mid Rise Apts	Small Office	Medium office	Large Office
90.1 2004	100	100	100	100	100
90.1 2013	85	87	70	68	85
30% better than 90.1 2004	70	70	70	70	70
30% better than 90.1 2013	59	61	49	48	60

bEQ uses zEPI scale, with the benchmark (score of 100) approximately equal to the CBECS median for the given building type, as shown in Figure 1. The same Star mapping was used for bEQ In-Operation as for bEQ As-Designed.

The initial Star mapping for the ENERGY STAR score was set based on the EPA PM performance quartiles, with the buildings performing at or above Energy Star level (score of 75 or better) receiving 4 Stars, buildings that perform better then median but below Energy Star receiving 3 Stars, etc. Table 4 shows the initial mapping between the native rating scores and the Star quartiles.

Table 4: Initial Mapping to Star Quartiles

Star Rating	BEAS Score	PRM PCI	bEQ	ENERGY STAR Score
*	1-4.5	116 +	>=116	0-24
**	5-7	76 - 115	66-115	25-49
***	7.5-9	26-75	26-65	50-74
****	9.5-10	0-25	<=25	75-100

Testing Methodology

The scope of testing included multifamily and office buildings, to represent residential and commercial sectors. Climate Zones (CZ) 4A and 2A (Figure 2) were selected as the proxy for heating-dominated and cooling-dominated climates, based on the new construction volume and the floor area of the existing building stock.

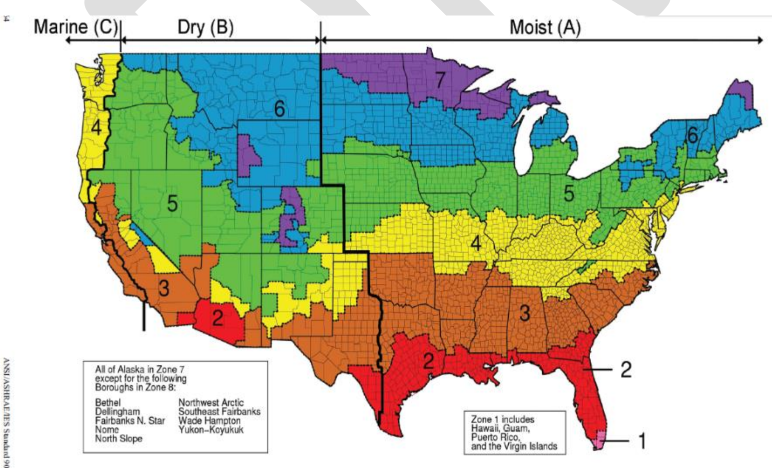


Figure 2: ASHRAE Climate Zones

To make the best use of the available budget, the test cases were based on the variations of the PNNL progress indicator (prototype) models of small and medium office building, and midrise and high-rise apartment building, as opposed to real buildings. The vintages of office and mid-rise apartment test cases included configurations minimally compliant with ASHRAE Standard 90.1 2013 and 2004, and representative of the pre-1980 construction. High-rise apartment vintages included 90.1 2004 and 90.1 2013 compliant configurations in CZ 2A and 4A. In addition, for high-rise apartment building in CZ 4A, a high-performance configuration exceeding the Passive House requirements, and configurations compliant with 90.1 2004 and 2013 with HVAC design typical for New York were evaluated. Additional configurations matching Standard 90.1 Appendix G baseline compliant with Standard 90.1 2004 were evaluated for all building types, based on the corresponding models that were developed to calculate PRM rating. Table 5 summarizes the tested configurations.

Table 5: Summary of the Tested Configurations

	Climate Zone 4A				Climate Zone 2A			Total
Vintage	Pre-1980	90.1 2004	90.1 2013	High Performance	Pre-1980	90.1 2004	90.1 2013	
Small Office (SO)	1	2	1		1	2	1	8
Medium Office (MO)	1	2	1		1	2	1	8
Mid-rise Apartment (MA)	1	2	1		1	2	1	8
High-rise Apartment (HA)		4	2	1		2	1	10

The asset rating scores were obtained for each configuration as described below.

<u>bEQ As Designed</u>

- Model configuration following the bEQ simulation requirements to determine EUI $_{standardized}$
- Enter the configuration into EPA Target Finder to determine EUI $_{median}$
- Enter results into bEQ As Designed workbook to calculate bEQ As-Designed score

<u>PRM</u>

- Model configuration following ASHRAE Standard 90.1 2016 Appendix G requirements for the proposed design
- Develop the corresponding baseline model following 90.1 Appendix G
- Calculate Performance Cost Index (PCI)

<u>BEAS</u>

- Enter configuration into the Asset Rating Tool (AST) to obtains the BEAS score

bEQ In-Operation and EPA PM ratings are based on the actual utility bills. Since utility data is not available for the theoretical configurations, the modeled consumption was used instead, effectively treating the models of the analyzed test cases as the calibrated simulations representative of the actual usage. The models did not account for heating and cooling distribution losses, thermal bridging, mulfunctioning controls, etc., thus were expected to under-estimate energy use compared to the typical real building of the given vintages. However, operating conditions used in the models may impact this expected outcome. For example, higher than typical loads from IT equipment in the office models, or of the consumer electronics and kitchen appliances in the multimfialy models, may over-estimate energy use compared to the real buildings.

The modeled consumption was entered into bEQ In-Operation workbook and EPA PM to get the scores in the respective rating systems. bEQ In-Operation and EPA PM are expected to agree on the ranking of the test cases, since the difference between the two ratings is largely limited to the rating scale. The mapping of the scores to the Star quartiles should be re-calibrated based on the actual utility bills.

Table 6 shows the models developed for the high-rise multifamily configuration representing typical NY HVAC design compliant with 90.1 2013, to illustrate the scope of analysis that was completed for each configuration in Table 5.

Table 6: Analysis for High-rise Apartment Configuration

<table>
<tr><th></th><th>Location</th><th>HVAC</th><th>Vintage</th><th>Operating Conditions & Unregulated Loads</th><th>Simulation Tool</th><th>Scoring Tool</th></tr>
<tr><td>Rated Building</td><td>New York City</td><td>HW baseboards, room ACs, corridor RTU</td><td>2013</td><td>Based on EPA Energy Star High Rise Multifamily Guidelines</td><td>NA</td><td>NA</td></tr>
<tr><td>bEQ As Designed</td><td>Baltimore TMY3 weather file</td><td colspan="2">Same as rated building</td><td>From COMNET Appendices B & C</td><td rowspan="3">eQUEST 3.65</td><td>bEQ As Designed Workbook</td></tr>
<tr><td>PRM Proposed Design</td><td rowspan="5">New York City TMY3 weather file</td><td colspan="3">Same as rated building</td><td rowspan="2">Spreadsheet</td></tr>
<tr><td>PRM Baseline</td><td>PTAC</td><td>2004</td><td>Same as rated building</td></tr>
<tr><td>BEAS</td><td colspan="2">Same as rated building</td><td>Hardwired in Asset Score Tool</td><td>Asset Score Tool</td><td>Asset Score Tool</td></tr>
<tr><td>bEQ In Operation</td><td colspan="3">Same as rated building</td><td rowspan="2">eQUEST 3.65</td><td>bEQ In Operation Workbook</td></tr>
<tr><td>EPA PM</td><td colspan="3">Same as rated building</td><td>EPA PM</td></tr>
</table>

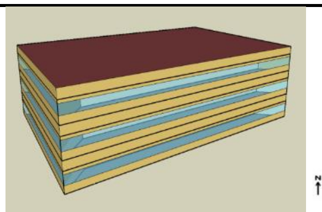
eQUEST models were completed by Nick Allen-Sandoz, who is a Professional Engineer and has ASHRAE's Building Energy Modeling Professional certification, thus meeting bEQ requirements. BEAS and EPA PM analysis was completed by Eva Skorupka.

Test Cases and Observations

Medium Office Configurations

The analyzed medium office configurations are shown in Table 7. All configurations were assumed to have the same operating conditions and unregulated loads as the PNNL progress indicator models, which are based on the Commercial Building Energy Consumption Survey (CBECS).

Table 7: Medium Office (MO) Configurations



53,600 ft^2, 3 story, steel-frame walls, 33% window to wall ratio except 40% in MO 7 and MO8.

Run #	CZ	HVAC	Service Water Heating Fuel	Vintage	Run Label
MO 1	4A	VAV DX ERH Ec	Gas	2013	MO - 4A - VAV DX ERH Ec - 2013
MO 2	4A	VAV DX ERH	Gas	2004	MO - 4A - VAV DX ERH Ec - 2004
MO 3	4A	CV DX Gas	Gas	pre-1980	MO - 4A - CV DX Gas - pre-1980
MO 4	2A	VAV DX ERH Ec	Gas	2013	MO - 2A - VAV DX ERH - 2013
MO 5	2A	VAV DX ERH	Gas	2004	MO - 2A - VAV DX ERH - 2004
MO 6	2A	CV DX Gas	Gas	pre-1980	MO - 2A - CV DX Gas - pre-1980
MO 7	4A	VAV DX GRH Ec	El. Resistance	2004	MO - 4A - VAV DX GRH Ec - 2004
MO 8	2A	VAV DX ERH	El. Resistance	2004	MO - 2A - VAV DX ERH - 2004

HVAC Legend

VAV DX ERH: Variable air volume, DX cooling, electric resistance reheat, no economizer
VAV DX ERH Ec: Same as VAV DX ERH, but with economizer
VAV DX GRH Ec: Variable air volume, DX cooling, gas hot water reheat, economizer
CV DX Gas: Constant volume DX cooling gas furnace heating, no economizer

Vintage Legend

Pre-1980: Typical pre-1980 construction, based on the NREL Reference Models[3]
2004: Minimally complies with ASHRAE Standard 90.1 2004
2013: Minimally complies with ASHRAE Standard 90.1 2013

Table 8 shows the ranking of the configurations in each rating system. The configuration with the best score in the given rating system is shown in the first column (i.e. ranked #1). Several configurations are shown with the same rank if they received the identical scores, thus tying for the same place. Pre-1980 configurations are highlighted in red, configurations compliant with 90.1 2004 are highlighted in light brown, and configurations compliant with 90.1 2013 are highlighted in green, based on the expected efficiency.

[3] https://energy.gov/eere/buildings/existing-commercial-reference-buildings-constructed-1980

Table 8: Ranking of the Medium Office Configurations

1	2	3	4	5	6	7	8
BEAS							
MO - 4A - VAV DX ERH Ec - 2013		MO - 4A - VAV DX GRH Ec - 2004	MO - 4A - VAV DX ERH Ec - 2004	MO - 2A - VAV DX ERH - EHW - 2004	MO - 2A - VAV DX ERH - GHW - 2004	MO - 2A - CV DX Gas - pre-1980	MO - 4A - CV DX Gas - pre-1980
MO - 2A - VAV DX ERH - 2013							
bEQ As Designed							
MO - 4A - VAV DX ERH Ec - 2013	MO - 2A - VAV DX ERH - 2013	MO - 4A - VAV DX ERH Ec - 2004	MO - 4A - VAV DX GRH Ec - 2004	MO - 2A - VAV DX ERH - GHW - 2004	MO - 2A - VAV DX ERH - EHW - 2004	MO - 4A - CV DX Gas - pre-1980	MO - 2A - CV DX Gas - pre-1980
PRM							
MO - 2A - VAV DX ERH - 2013	MO - 4A - VAV DX ERH Ec - 2013	MO - 2A - VAV DX ERH - GHW - 2004	MO - 4A - VAV DX GRH Ec - 2004		MO - 4A - VAV DX ERH Ec - 2004	MO - 2A - CV DX Gas - pre-1980	MO - 4A - CV DX Gas - pre-1980
			MO - 2A - VAV DX ERH - EHW - 2004				
bEQ in Operation							
MO - 4A - VAV DX ERH Ec - 2013	MO - 2A - VAV DX ERH - 2013	MO - 4A - VAV DX GRH Ec - 2004	MO - 4A - VAV DX ERH Ec - 2004	MO - 2A - VAV DX ERH - GHW - 2004	MO - 2A - VAV DX ERH - EHW - 2004	MO - 4A - CV DX Gas - pre-1980	MO - 2A - CV DX Gas - pre-1980
EPA PM							
MO - 4A - VAV DX ERH Ec - 2013		MO - 4A - VAV DX GRH Ec - 2004	MO - 4A - VAV DX ERH Ec - 2004	MO - 2A - VAV DX ERH - GHW - 2004		MO - 4A - CV DX Gas - pre-1980	MO - 2A - CV DX Gas - pre-1980
MO - 2A - VAV DX ERH - 2013				MO - 2A - VAV DX ERH - EHW - 2004			

As seen from Table 8, the rating systems were in general agreement on the relative performance of the configurations, with the 90.1 2013 compliant configurations getting the two best scores, and pre-1980 configurations recognized as the worst performers. The scores of each configuration are shown in Table 9.

Table 9: Native Rating Scores of the Medium Office Configurations

Rating System Scores					
	BEAS	**bEQ As Designed**	**PRM**	**bEQ In Operation**	**EPA PM**
MO - 4A - VAV DX ERH Ec - 2013	7.5	67	86	51	92
MO - 4A - VAV DX ERH Ec - 2004	5.5	78	107	65	82
MO - 4A - CV DX Gas - pre-1980	3.5	108	146	91	58
MO - 2A - VAV DX ERH - 2013	7.5	71	73	51	92
MO - 2A - VAV DX ERH - GHW - 2004	4.5	83	94	68	79
MO - 2A - CV DX Gas - pre-1980	4.0	122	138	100	49
MO - 4A - VAV DX GRH Ec - 2004	6.5	79	100	61	86
MO - 2A - VAV DX ERH - EHW - 2004	5.0	89	100	69	79

The initial mapping ranges in Tables 4 were calibrated based on these results. For asset rating systems, the mapping placed 90.1 2013 compliant configurations into the 3 Star quartile, the 90.1 2004 – compliant configurations into the 2 Star quartile, and pre-1980 configurations into the 1 Star quartile.

For the operational rating system, the 4 Star rating was set to EPA PM Score of 95 (top 5% of peers), 3 Stars rating to EPA PM score of 75 – 95 (Energy Star or better), 2 Stars to 50-75 range, and 1 Star to buildings with scores below 50 (worse than half of the peers). bEQ In-Operation mapping was set to place the projects into the same Star quartiles as with EPA PM.

The resulting ranges are shown in Table 10. bEQ and PRM scales do not have the fixed maximum and minimums, so the native score of 175 (over 75% higher energy use than the benchmark) was set as the worst, and the best score was set to 0 (net zero building). Table 11 shows the Star ratings for each configuration based on the mapping in Table 10.

Table 10: Star Rating Mapping Based on the Medium Office Configurations

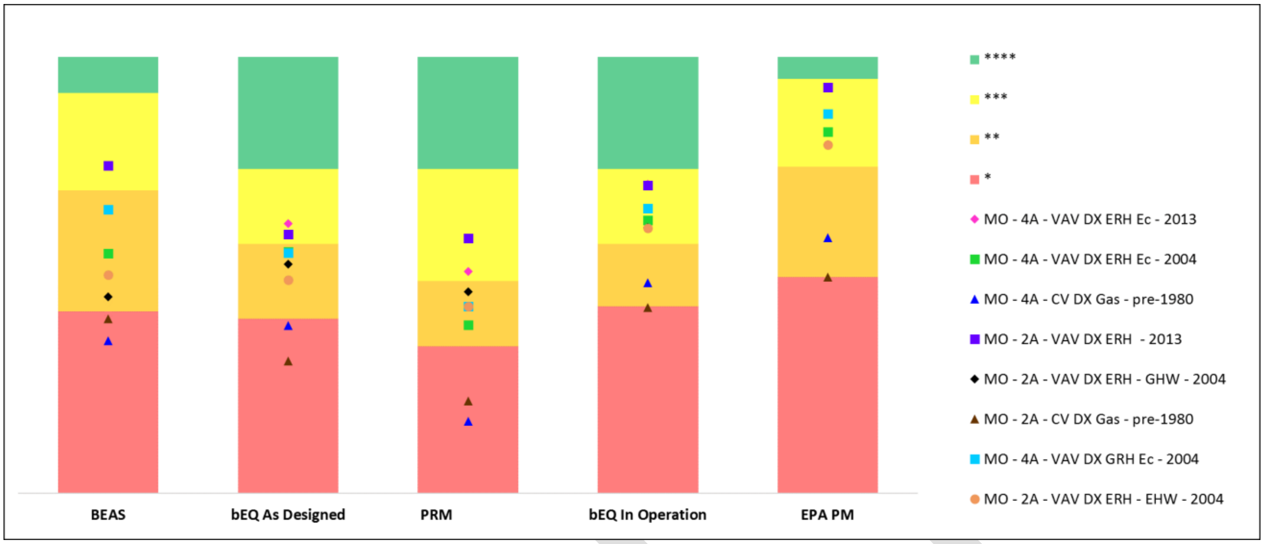
	Worst Native Score	* Boundary	** Boundary	*** Boundary	(**** Boundary)
BEAS	1	4.5	7	9	10
bEQ As Designed	175	105	75	45	0
PRM	175	116	90	45	0
bEQ In Operation	175	100	75	45	0
EPA PM	1	50	75	95	100

Table 11: Star Rating of Medium Office Configurations

	BEAS	bEQ As Designed	PRM	bEQ In Operation	EPA PM
MO - 4A - VAV DX ERH Ec - 2013	***	***	***	***	***
MO - 4A - VAV DX ERH Ec - 2004	**	**	**	***	***
MO - 4A - CV DX Gas - pre-1980	*	*	*	**	**
MO - 2A - VAV DX ERH - 2013	***	***	***	***	***
MO - 2A - VAV DX ERH - GHW - 2004	**	**	**	***	***
MO - 2A - CV DX Gas - pre-1980	*	*	*	*	*
MO - 4A - VAV DX GRH Ec - 2004	**	**	**	***	***
MO - 2A - VAV DX ERH - EHW - 2004	**	**	**	***	***

Figure 3 illustrates the mapping ranges and placement of the configurations within the Star quartiles. The height of each bar is normalized to cover the full range of the native scores in the given rating system. Since the higher scores correspond to higher performing buildings in BEAS and EPA PM, and worse performing buildings in PRM and bEQ, the PRM and bEQ bars are flipped for the uniform presentation. For example, BEAS scale extends from 1 (the worst score) to 10 (the best score), thus the projects with the BEAS score of 1 are placed at the bottom of the bar, with the BEAS score of 10 at the top of the bar, and with the BEAS score of 4.5 around the middle of the bar. bEQ scale extends from 0 (the best score used for the mapping) to 175 (the worst score used for the mapping), thus projects with bEQ score of 175 or greater are placed at the bottom of the bar, the projects with bEQ score at or below 0 are placed at the top of the bar, and the project with the score of 88 is placed around the middle. The Star quartiles are shown in different colors, with the range of native scores corresponding to 4 stars shown in green, 3 stars in yellow, 2 star range in orange, and 1 star range in dark red.

Figure 3: Medium Office Mapping to the Star Rating

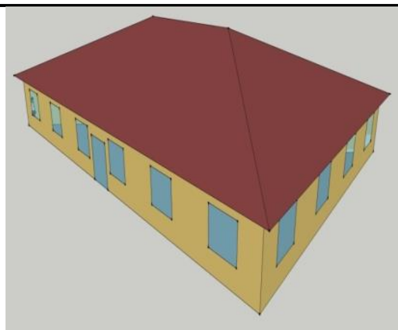


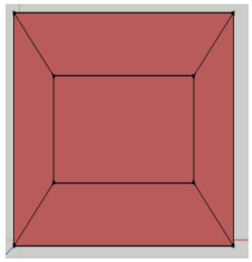
Operational ratings were in agreement on on the ranking, and placed the test cases into the same or better Star quartiles compared to the asset ratings, which was expected.

Small Office Configurations

The analyzed small office configurations are shown in Table 12.

Table 12: Small Office (SO) Configurations





5,500 square foot, 1 story, ~20% window to wall ratio except 31% in SO 7 and SO 8, wood frame walls, CBECS operating conditions and unregulated loads

Config #	CZ	HVAC	Service Water Heating Fuel	Vintage	Run Label
SO 1	4A	ASHP+GF	Electric	2013	SO - 4A - 2013 - ASHP+GF
SO 2	4A	ASHP+GF	Electric	2004	SO - 4A - 2004 - ASHP+GF
SO 3	4A	DX+GF	Gas	pre-1980	SO - 4A - pre-1980 - DX+GF
SO 4	2A	ASHP+GF	Electric	2013	SO - 2A - 2013 - ASHP+GF
SO 5	2A	ASHP+GF	Electric	2004	SO - 2A - 2004 - ASHP+GF
SO 6	2A	DX+GF	Gas	pre-1980	SO - 2A - pre-1980 - DX+GF
SO 7	4A	DX+GF	Electric	2004	SO - 4A - 2004 - DX+GF
SO 8	2A	ASHP+ER	Electric	2004	SO - 2A - 2004 - ASHP+ER

HVAC Legend

ASHP+GF: Continuously running constant volume air-source heat pump with gas furnace back up heating

DX+GF: Continuously running constant volume units DX cooling, gas furnace heating

ASHP+ER: Continuously running constant volume air-source heat pump with electric resistance back up heating

Vintage Legend

Pre-1980: Typical pre-1980 construction, based on the NREL Reference Models[4]

2004: Minimally complies with ASHRAE Standard 90.1 2004

2013: Minimally complies with ASHRAE Standard 90.1 2013

The rating systems were in general agreement on the raking of the small office configurations, with the configurations compliant with 90.1 2013 getting the two best scores, and pre-1980 configurations getting the two worst scores, as illustrated in Table 13.

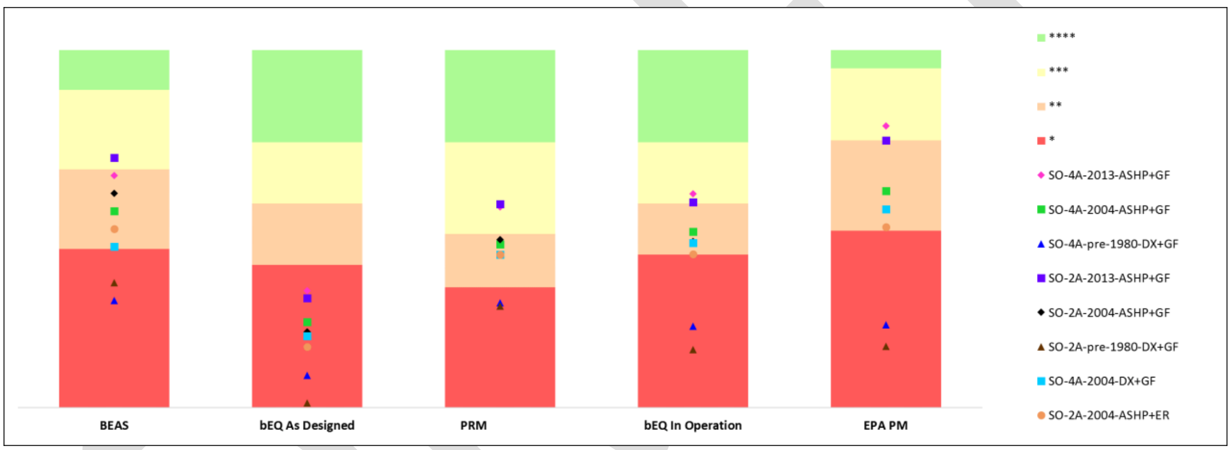
[4] https://energy.gov/eere/buildings/existing-commercial-reference-buildings-constructed-1980

Table 13: Ranking of the Small Office Configurations

1	2	3	4	5	6	7	8
BEAS							
SO-2A-2013-ASHP+GF	SO-4A-2013-ASHP+GF	SO-2A-2004-ASHP+GF	SO-4A-2004-ASHP+GF	SO-2A-2004-ASHP+ER	SO-4A-2004-DX+GF	SO-2A-pre-1980-DX+GF	SO-4A-pre-1980-DX+GF
bEQ As Designed							
SO-4A-2013-ASHP+GF	SO-2A-2013-ASHP+GF	SO-4A-2004-ASHP+GF	SO-2A-2004-ASHP+GF	SO-4A-2004-DX+GF	SO-2A-2004-ASHP+ER	SO-4A-pre-1980-DX+GF	SO-2A-pre-1980-DX+GF
PRM							
SO-2A-2013-ASHP+GF	SO-4A-2013-ASHP+GF	SO-2A-2004-ASHP+GF	SO-4A-2004-ASHP+GF	SO-4A-2004-DX+GF		SO-4A-pre-1980-DX+GF	SO-2A-pre-1980-DX+GF
				SO-2A-2004-ASHP+ER			
bEQ in Operation							
SO-4A-2013-ASHP+GF	SO-2A-2013-ASHP+GF	SO-4A-2004-ASHP+GF	SO-2A-2004-ASHP+GF	SO-4A-2004-DX+GF	SO-2A-2004-ASHP+ER	SO-4A-pre-1980-DX+GF	SO-2A-pre-1980-DX+GF
EPA PM							
SO-4A-2013-ASHP+GF	SO-2A-2013-ASHP+GF	SO-4A-2004-ASHP+GF	SO-2A-2004-ASHP+GF		SO-2A-2004-ASHP+ER	SO-4A-pre-1980-DX+GF	SO-2A-pre-1980-DX+GF
			SO-4A-2004-DX+GF				

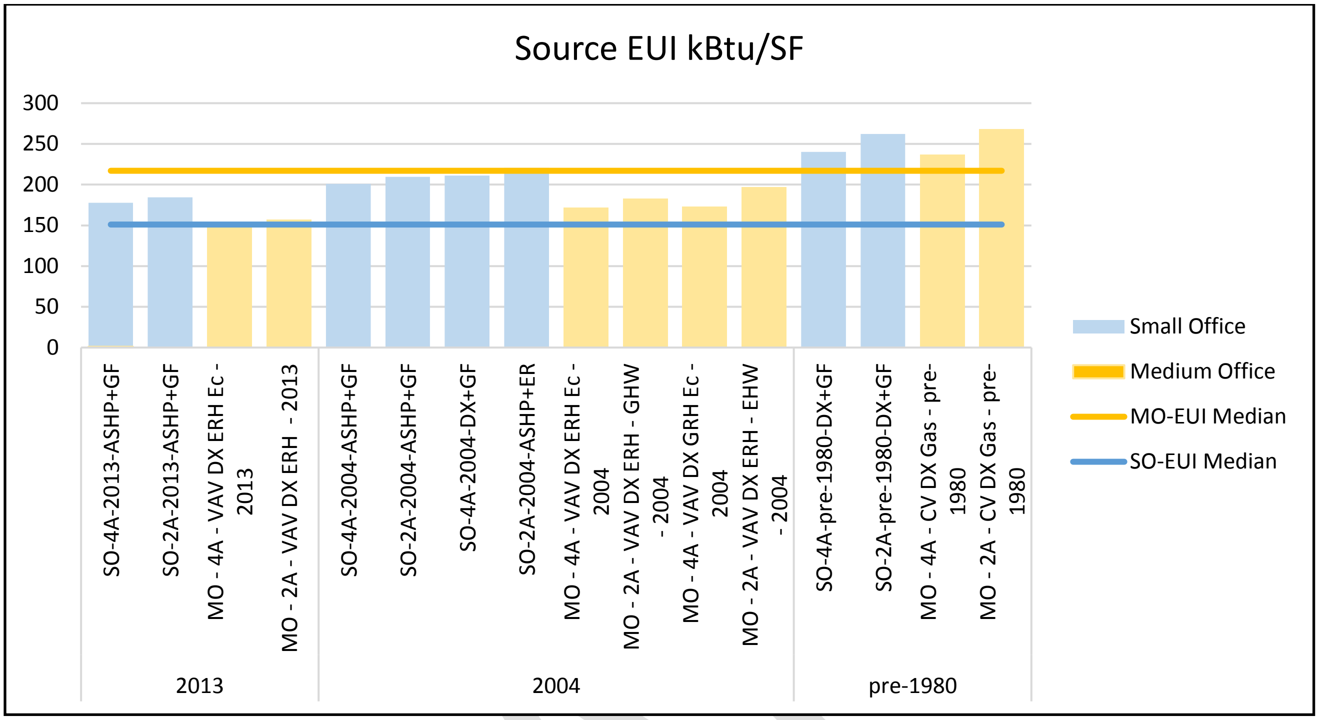
Figure 4 shows the mapping of the small office configurations to the Star quartiles.

Figure 4: Small Office mapping to the Star Rating



bEQ As Designed scores were the outliers, placing all Small Office configurations into the lowest 1 Star tier. Many Small Office configurations were inherently less efficient (i.e. had higher $EUI_{standardized}$) than the Medium Office configurations of the similar vintages – for example, all small office configurations had constant volume fan systems, compared to the variable volume distribution in most Medium Office configurations. However, the bEQ As Designed score is the ratio of $EUI_{standardized}$ to EUI_{median}, with EUI_{median} determined based on the EPA Target Finder following bEQ As-Designed instructions. In addition to the higher $EUI_{standardized}$, the Small Office configurations also had a lower EUI_{median} compared to the Medium Office configurations, resulting in the poor scores. This pattern is illustrated in Figure 5.

Figure 5: EUI $_{standardized}$ and EUI $_{median}$ for Small and Medium Office Configurations



A more stringent EUI $_{median}$ for small office compared to the medium office does not appear justified for bEQ as Designed scoring, since the bEQ As Design modeling ruleset has the same operating conditions and unregulated load assumptions for office buildings irrespective of their floor area, and the difference in the EPA Target Finder source EUI may be driven by differences in how the larger buildings are used and operated, including the additional loads such as elevators that are present in the larger buildings.

The PRM baseline showed an opposite trend, with the higher Source EUI of 123 – 134 for medium office configurations, compared to 136 – 159 EUI for small office configurations. Show graph.

The bEQ In Operation and EPA PM scores were lower than BEAS and PRM asset scores, largely due to the lower EPA PM median EUI, similar to the Target Finder EUI $_{median}$ described above. However the impact was not as dramatic as in bEQ As Designed, because energy use of each configuration entered into EPA PM was based on the models with CBECS-based defaults, and had a lower EUI (103 – 213 kBtu/SF source EUI) compared to the annual usage of the corresponding models with the COMNET assumptions (178-263 kBtu/SF source EUI) that was entered into EPA Target finder.

The Star Ratings of the small office configurations are shown in Table 14.

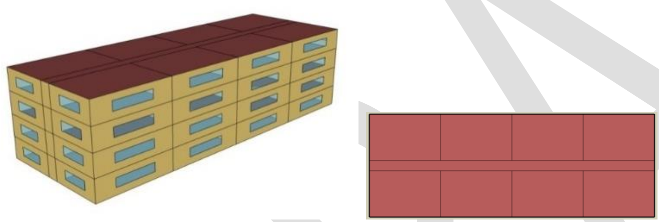
Table 14: Star Rating of Small Office Configurations

	BEAS	bEQ As Designed	PRM	bEQ In Operation	EPA PM
SO-4A-2013-ASHP+GF	**	*	***	***	***
SO-4A-2004-ASHP+GF	**	*	**	**	**
SO-4A-pre-1980-DX+GF	*	*	*	*	*
SO-2A-2013-ASHP+GF	**	*	***	***	**
SO-2A-2004-ASHP+GF	**	*	**	**	**
SO-2A-pre-1980-DX+GF	*	*	*	*	*
SO-4A-2004-DX+GF	*	*	**	**	**
SO-2A-2004-ASHP+ER	**	*	**	**	*

Mid-rise Apartment Configurations

The analyzed mid-rise apartment configurations are shown in Table 15.

Table 15: Mid-Rise Apartment (MA) Configurations



33,744 square foot, 4 stories, 39 apartments, 20% window to wall ratio, steel frame walls, CBECS operating conditions and unregulated loads

Config #	CZ	HVAC	Service Water Heating Fuel	Vintage	Run Label
MA 1	4A	DX+GF	Electric	2013	MA - 4A - 2013 - DX+GF
MA 2	4A	DX+GF	Electric	2004	MA - 4A - 2004 - DX+GF
MA 3	4A	DX+GF	Gas	pre-1980	MA - 4A - pre-1980 - DX+GF
MA F 4	2A	DX+GF	Electric	2013	MA - 2A - 2013 - DX+GF
MA F 5	2A	DX+GF	Electric	2004	MA - 2A - 2004 - DX+GF
MA 6	2A	DX+GF	Gas	pre-1980	MA - 2A - pre-1980 - DX+GF
MA 7	4A	PTAC	Gas	2004	MA - 4A - 2004 - PTAC
MA 8	2A	PTHP	Gas	2004	MA - 2A - 2004 - PTHP

HVAC Legend
DX+GF: Continuously running split system DX units with gas furnace serving each apartment and common spaces

PTAC:	Continuously running Packaged Terminal Air Conditioners with HW gas boiler
PTHP:	Continuously running Packaged Terminal Heat Pump
Vintage Legend	
Pre-1980:	Typical pre-1980 construction, based on the NREL Reference Models[5]
2004:	Minimally complies with ASHRAE Standard 90.1 2004
2013:	Minimally complies with ASHRAE Standard 90.1 2013

All mid-rise apartment configurations received the bEQ As Designed scores over 175, with the $EUI_{standardized}$ exceeding EUI_{median} by over 75%, and thus falling into the 1 Star range. The exceedingly high $EUI_{standardized}$ was driven by the COMNET plug loads, interior gas appliance, and refrigeration – related model inputs that are prescribed by the bEQ simulation rules. These loads accounted for over 80% of $EUI_{standardized}$, and appear to be grossly exaggerated. In addition to directly contributing to the EUI, these loads translate into the internal heat gains, shifting the balance between heating and cooling. The issue was reported to the ASHRAE bEQ committee, and the plans are in place to update the related COMNET values. To allow the meaningful analysis, the bEQ As Designed results for mid-rise and high-rise apartment configurations shown below are based on using CBECS assumptions instead of COMENT, and are labeled "bEQ As Designed CBECS". The resulting score ranking is shown in Table 16.

Table 16: Ranking of the Med-rise Apartment Configurations

BEAS							
MA - 2A - 2004 - PTHP	MA - 2A - 2013 - DX+GF		MA - 4A - 2013 - DX+GF			MA - 4A - 2004 - DX+GF	MA - 4A - pre-1980 - DX+GF
	MA - 4A - 2004 - PTAC		MA - 2A - 2004 - DX+GF				
			MA - 2A - pre-1980 - DX+GF				
bEQ As Designed CBECS							
MA - 2A - 2004 - PTHP	MA - 4A - 2004 - PTAC	MA - 2A - 2013 - DX+GF	MA - 4A - 2013 - DX+GF	MA - 2A - 2004 - DX+GF	MA - 4A - 2004 - DX+GF	MA - 2A - pre-1980 - DX+GF	MA - 4A - pre-1980 - DX+GF
PRM							
MA - 4A - 2004 - PTAC		MA - 2A - 2013 - DX+GF	MA - 4A - 2013 - DX+GF	MA - 2A - 2004 - DX+GF	MA - 4A - 2004 - DX+GF	MA - 2A - pre-1980 - DX+GF	MA - 4A - pre-1980 - DX+GF
MA - 2A - 2004 - PTHP							
bEQ in Operation							
MA - 4A - 2004 - PTAC	MA - 2A - 2004 - PTHP	MA - 2A - 2013 - DX+GF	MA - 4A - 2013 - DX+GF	MA - 4A - 2004 - DX+GF	MA - 2A - 2004 - DX+GF	MA - 2A - pre-1980 - DX+GF	MA - 4A - pre-1980 - DX+GF
EPA PM							
MA - 4A - 2004 - PTAC	MA - 2A - 2004 - PTHP	MA - 4A - 2013 - DX+GF		MA - 4A - 2004 - DX+GF		MA - 2A - pre-1980 - DX+GF	MA - 4A - pre-1980 - DX+GF
		MA - 2A - 2013 - DX+GF		MA - 2A - 2004 - DX+GF			

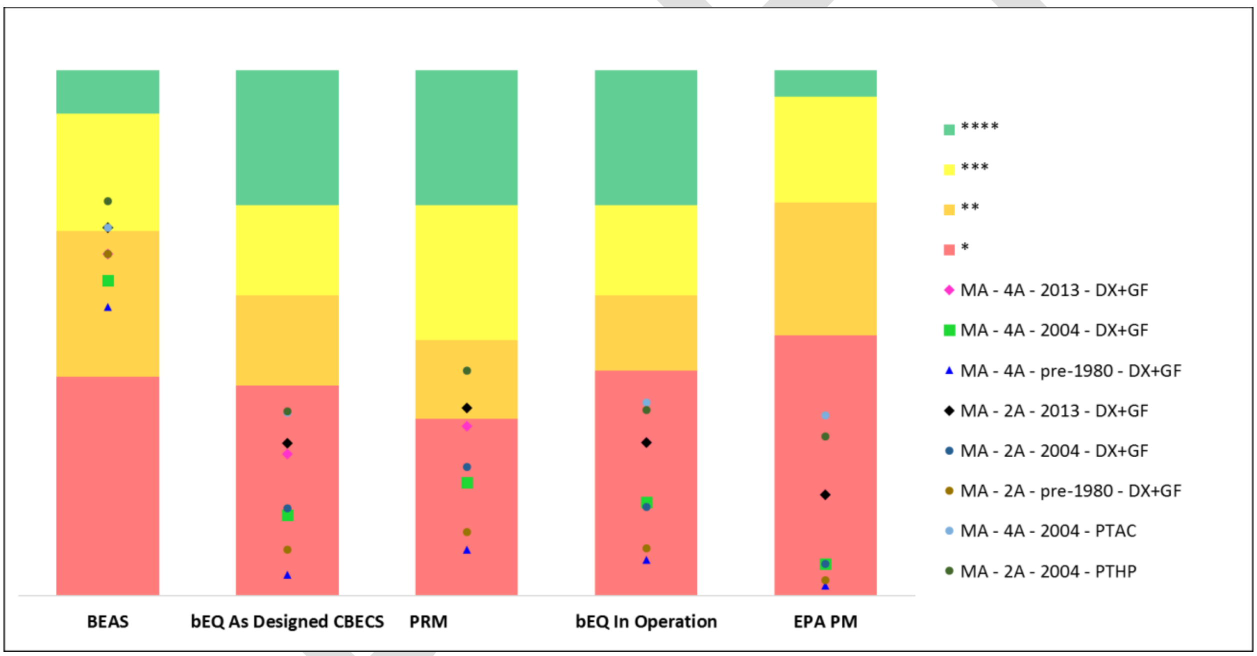
The rating systems were in general agreement in placing 90.1 2004 – compliant configurations with gas service water heating ahead of configurations with electric water heating, even those compliant with 90.1 2013. This rightfully recognized the substantial difference in performance that may exist between buildings compliant with the same version of code.

[5] https://energy.gov/eere/buildings/existing-commercial-reference-buildings-constructed-1980

There were disagreements between BEAS and other rating systems in the ranking of some test cases. For example, BEAS assigned the same score of 6.5 to configuration complaint with 90.1 2013, 90.1 2004, and typical pre-1980 construction. The 90.1 2004 and pre-1980 configurations were both in climate zone 2A, and though the pre-1980 configuration had about 30% higher source EUI based on the Asset Rating Tool, they were assigned the same BEAS score. Also, a configuration in climate zone 4A minimally compliant with 90.1 2004 with PTACs in apartments received a better BEAS score than configuration compliant with 90.1 2013 that had continuously running split system DX units with gas furnaces due to much higher fan energy use. This was because the Asset Score Tool (AST) assumes a default static pressure drop for PTACs that is lower compared to the split system and rooftop units, for which the pressure drop is calculated based on the design airflow.

The score mapping is shown in Figure 6, and indicates significant disagreement in the scoring. Very low bEQ As Designed scores indicate that CBECS-based modeling inputs that were used in lieu of COMNET are still too conservative, and result in the exaggerated energy use compared to the utility data of actual buildings used to establish EUI $_{median}$. This also affected the operational scores, which were based on the models with CBECS operating conditions.

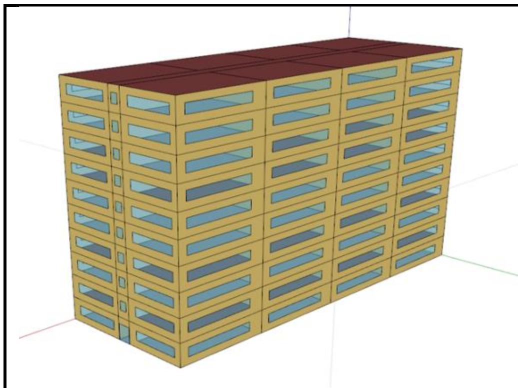
Figure 6: Mid-rise Apartment Mapping to the Star Rating

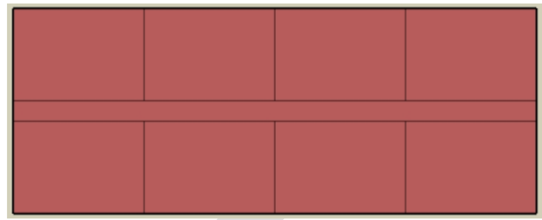


High-rise Apartment Configurations

The high-rise apartment configurations are described in Table 17.

Table 17: High Rise Apartment (HA) Configurations





84,360 square foot, 10 stories, 79 apartments, 30% window to wall ratio, gas water heating

Config #	Climate Zone	Locations	HVAC	Vintage	Operating Conditions & Unregulated Loads	Run Label
HA 1	4A	Baltimore	WSHP	2013	CBECS	HA - 4A - 2013 - WSHP - CBECS
HA 2	4A	Baltimore	WSHP	2004	CBECS	HA - 4A - 2004 - WSHP - CBECS
HA 3	2A	Houston	WSHP	2013	CBECS	HA - 2A - 2013 - WSHP - CBECS
HA 4	2A	Houston	WSHP	2004	CBECS	HA - 2A - 2004 - WSHP - CBECS
HA 5	4A	NYC	BB & RTU & ERV	PH	MF	HA - 4A - PH - BB & RTU & ER - MF
HA 6	4A	NYC	BB & RTU	2013	MF	HA - 4A - 2013 - BB & RTU - MF
HA 7	4A	NYC	BB & RTU	2004	MF	HA - 4A - 2004 - BB & RTU - MF
HA 8	4A	NYC	PTAC	2004	MF	HA - 4A - 2004 - PTAC - MF
HA 9	4A	Baltimore	PTAC	2004	CBECS	HA - 4A - 2004 - PTAC - CBECS
HA 10	2A	Houston	PTHP	2004	CBECS	HA - 2A - 2004 - PTHP - CBECS

HVAC Legend

WSHP: Continuously running Water Source Heat Pumps

PTAC: Continuously running Packaged Terminal Air Conditioners with HW gas boilers

ERV: Energy recovery ventilators in each apartment and on corridor RTU

BB & RTU: Hot water baseboards and cycling room AC in apartments, RTU in corridors, continuously running exhaust fans in apartments, OA via RTU

Vintage

2004: Minimally complies with ASHRAE Standard 90.1 2004

2013: Minimally complies with ASHRAE Standard 90.1 2013

PH: Exceeds Passive House standard (applies to high rise multifamily only)

Operating Conditions and unregulated loads:

CBECS: Based on PNNL progress indicator models; used in all test cases unless noted otherwise.

MF: As prescribed by EPA Energy Star Simulation Guidelines for High Rise Multifamily

The score ranking is shown in Table 18

Table 18: High-rise Apartment Score Ranking

1	2	3	4	5	6	7	8	9	10
BEAS									
HA - 4A - PH - BB & RTU & ER - MF		HA - 4A - 2013 - WSHP - CBECS			HA - 2A - 2004 - WSHP - CBECS	HA - 4A - 2013 - BB & RTU - MF	HA - 4A - 2004 - BB & RTU - MF	HA - 4A - 2004 - WSHP - CBECS	
HA - 2A - 2004 - PTHP - CBECS		HA - 4A - 2004 - PTAC - MF						HA - 2A - 2013 - WSHP - CBECS	
		HA - 4A - 2004 - PTAC - CBECS							
bEQ As Designed CBECS									
HA - 4A - PH - BB & RTU & ER - MF	HA - 4A - 2013 - BB & RTU - MF	HA - 4A - 2004 - BB & RTU - MF	HA - 2A - 2013 - WSHP - CBECS	HA - 4A - 2004 - PTAC - MF		HA - 2A - 2004 - PTHP - CBECS	HA - 4A - 2013 - WSHP - CBECS	HA - 2A - 2004 - WSHP - CBECS	HA - 4A - 2004 - WSHP - CBECS
				HA - 4A - 2004 - PTAC - CBECS					
PRM									
HA - 4A - PH - BB & RTU & ER - MF	HA - 4A - 2013 - BB & RTU - MF	HA - 4A - 2004 - BB & RTU - MF	HA - 2A - 2013 - WSHP - CBECS	HA - 4A - 2004 - PTAC - MF			HA - 4A - 2013 - WSHP - CBECS	HA - 2A - 2004 - WSHP - CBECS	HA - 4A - 2004 - WSHP - CBECS
				HA - 4A - 2004 - PTAC - CBECS					
				HA - 2A - 2004 - PTHP - CBECS					
bEQ in Operation									
HA - 4A - PH - BB & RTU & ER - MF	HA - 4A - 2013 - BB & RTU - MF	HA - 4A - 2004 - BB & RTU - MF	HA - 4A - 2004 - PTAC - MF	HA - 2A - 2013 - WSHP - CBECS	HA - 4A - 2004 - PTAC - CBECS	HA - 2A - 2004 - PTHP - CBECS	HA - 4A - 2013 - WSHP - CBECS	HA - 2A - 2004 - WSHP - CBECS	HA - 4A - 2004 - WSHP - CBECS
EPA PM									
HA - 4A - PH - BB & RTU & ER - MF	HA - 4A - 2013 - BB & RTU - MF	HA - 4A - 2004 - BB & RTU - MF	HA - 4A - 2004 - PTAC - MF	HA - 2A - 2013 - WSHP - CBECS	HA - 4A - 2004 - PTAC - CBECS	HA - 4A - 2013 - WSHP - CBECS		HA - 4A - 2004 - WSHP - CBECS	
						HA - 2A - 2004 - PTHP - CBECS		HA - 2A - 2004 - WSHP - CBECS	

There were disagreements between BEAS and other asset rating systems in the relative efficiency of some configurations. For example, 90.1 2004 – compliant configuration has tied for the best place in BEAS, compared to 5th place in PRM and 7th place with bEQ. The key factors contributing to the high BEAS rank of this configuration included inability of the Asset Scoring Tool to capture fan energy savings associated with the baseboard heating, and erroneously high pump energy use for all configurations with hot water baseboard heating. The issues were reported to the BEAS team, and are being addressed.

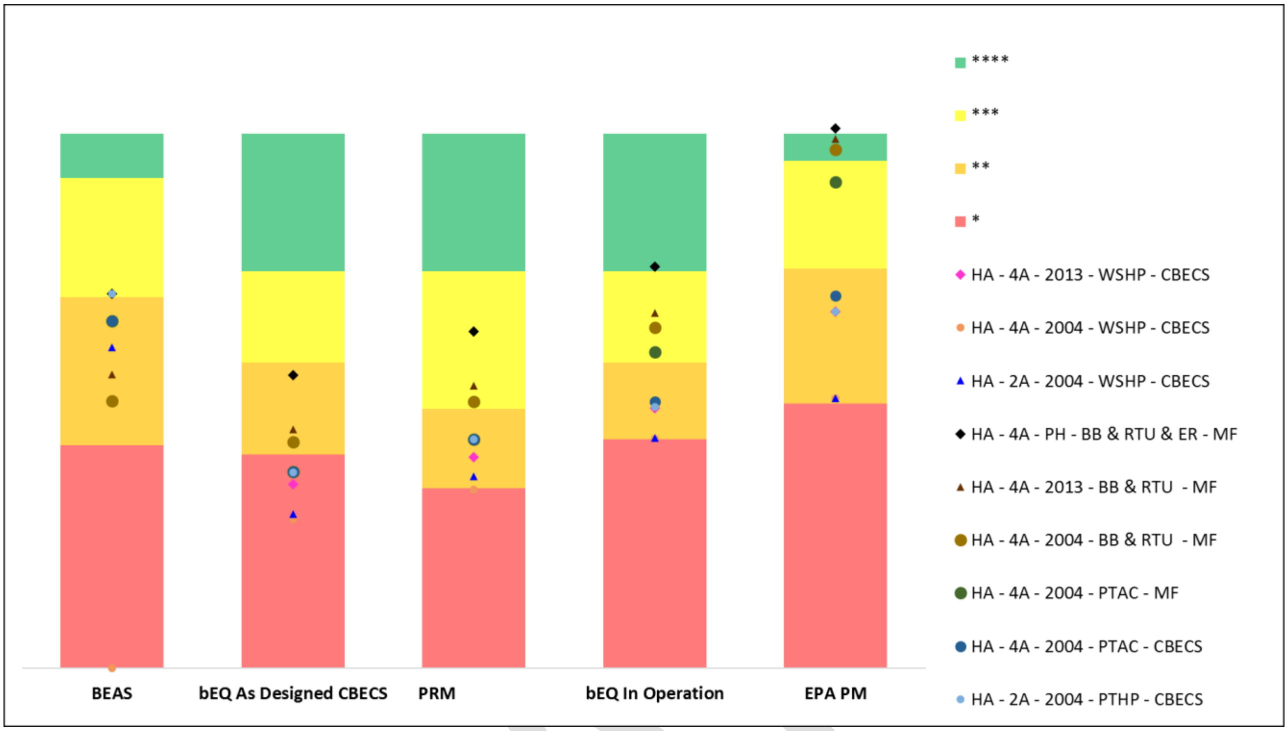
It is of note that two test cases with the identical designs but different operating conditions and unregulated load assumptions received identical asset scores, but significantly different operational scores, as shown in Table 19.

Table 19

	BEAS	bEQ As Designed CBECS	PRM	bEQ In Operation	EPA PM
HA - 4A - 2004 - PTAC - MF	6.5	111	100	72	90
HA - 4A - 2004 - PTAC - CBECS	6.5	111	100	88	69

The Score Mapping is shown in Figure 7.

Figure 7: High-rise Apartment Score Mapping



Discuss reason for high in-operation scores.

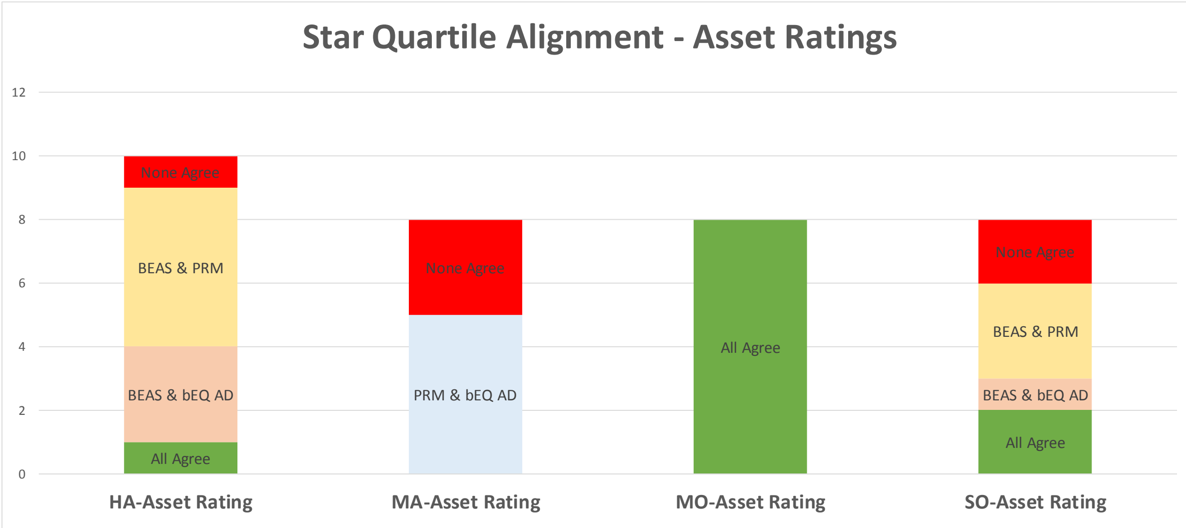
Findings

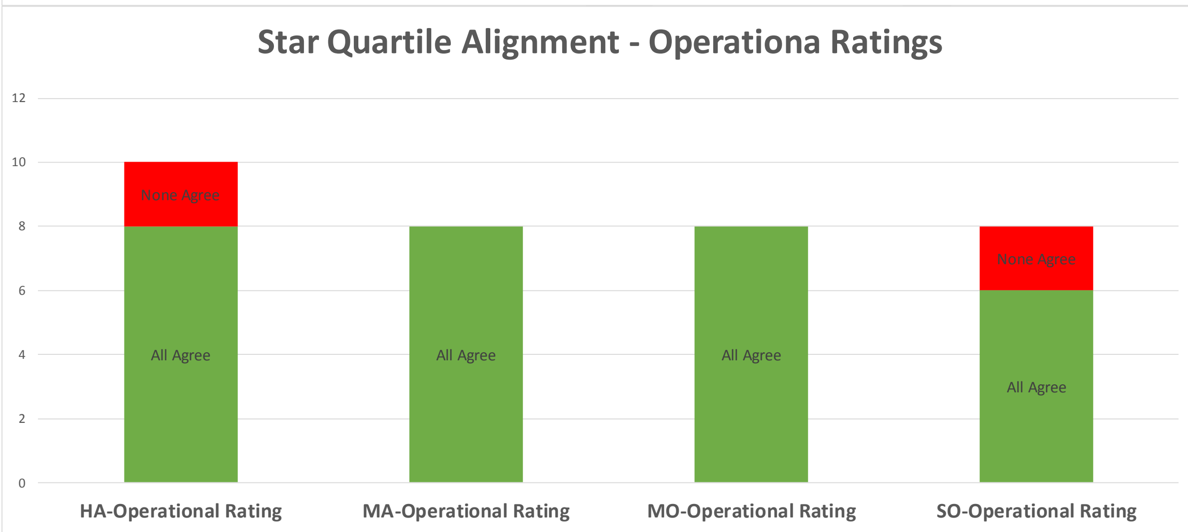
Alignment Statistics

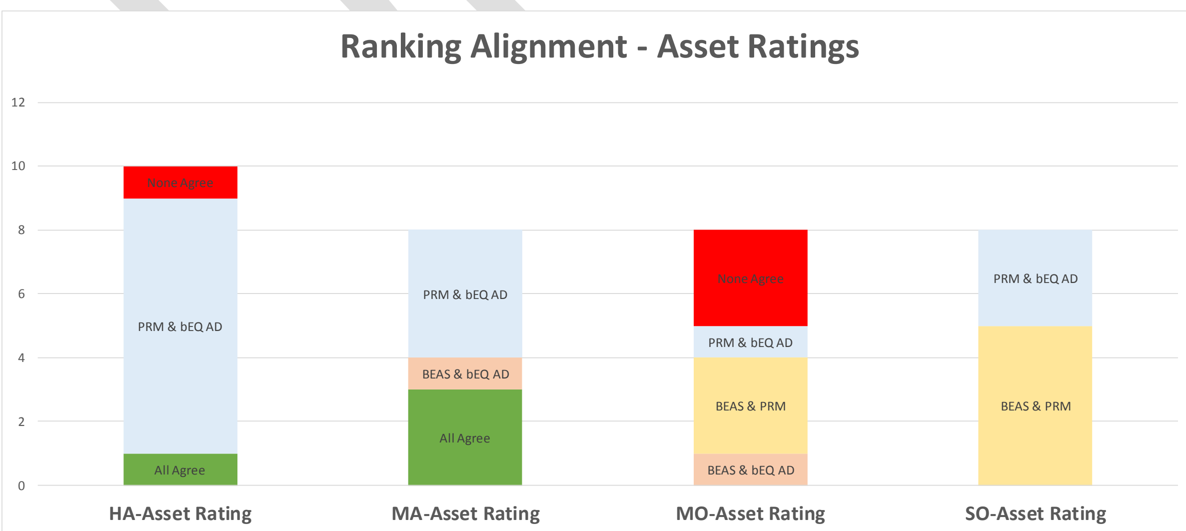
The alignment based on the two criteria used in the study are shown in Figure 8. Alignment between BEAS, PRM, and bEQ As Designed asset rating systems is shown separately from the EPA PM and bEQ In Operation rating systems, as asset and operational scores are not expected to align. Visually, operational ratings appear to show better agreement than the asset ratings, however this is partly due to the fact that 3 different asset ratings were considered in the study, compared to the two operational ratings. Asset rating alignment will improve after the items discussed in the following section are addressed.

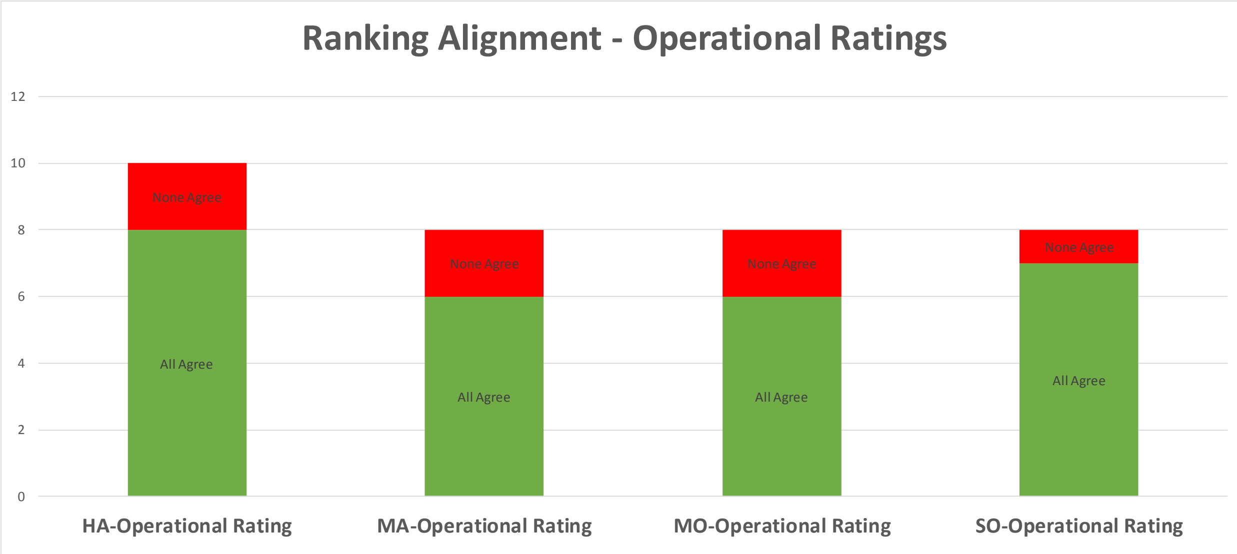
Star quartile mapping was calibrated based on the rating results for the Medium Office configurations, thus there is the full alignment in the Star Quartiles for this building type.

Figure 8: Alignment Statistics









Key Reasons for Disagreement in the Asset Ratings

1. Building Systems Treated as Assets

There are some differences between the rating systems in the building components that they consider to be assets, or integral part of the building that affect its inherent performance. The efficiency levels of these components affect the ratings, while non-asset components are modeled the same (i.e. energy neutral) in the benchmark and the rated building. The sample differences are illustrated in Table 20, based on the selected features of the high-rise apartment configurations.

Table 20: Sample Difference in Asset Definition

	PH-MF	WSHP-2013-CBEC	ASSET?		
			BEAS	bEQ As Designed	PRM
Infiltration cfm/ft² @ 75Pa	0.04; as tested	0.40; default	No(Note 1)	Yes	Yes
ERV in apartments	Yes	No	No(Note 2)	Yes	Yes
Apartment fan energy and control	Cycling window ACs; Continuous ERVs	Continuously running WSHPs	No(Note 3)	Yes	Yes
Low flow fixtures	Yes	No	Yes	No	Yes(Note 4)
Apartment lighting W/ft²	0.5 (based on actual)	0.45 (CBEC)	Yes(Note 5)	Yes, hardwired	Yes, hardwired
Energy Star ® appliances	Yes	No	No	No	Yes(Note 4)

Notes:

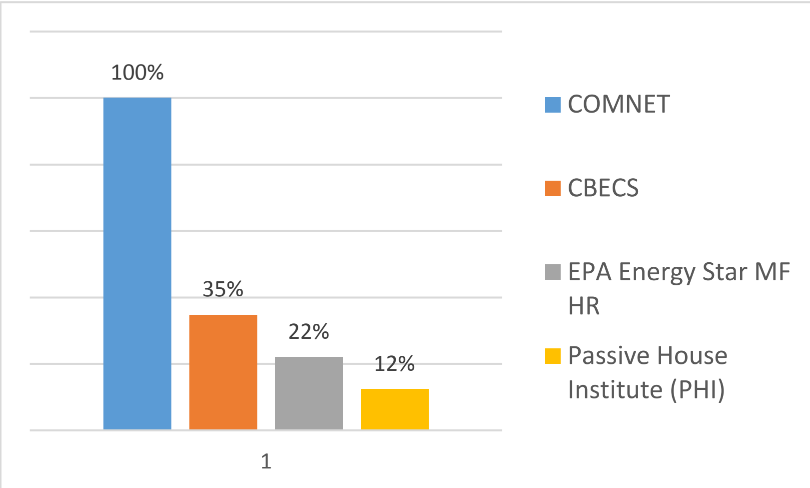
1. Plan to add in future.
2. Envisioned as asset, but Asset Score Tool cannot capture zone-level ERV.
3. Envisioned as asset, but Asset Score Tool could not capture cycling window AC
4. Modeled as asset, following EPA for Energy Star High Rise Multifamily Simulation Guidelines, as allowed by PRM for above-code applications.
5. In-unit lighting is treated as an asset irrespective of whether it is hard-wired or not.

This may have a profound impact on the asset ratings – for example a very air-tight multifamily building with the Energy Recovery Ventilators (ERV) in apartments, which are the common features of passive house projects, will not have a better score compared to a building without ERV and leaky envelope.

2. Operating conditions assumptions.

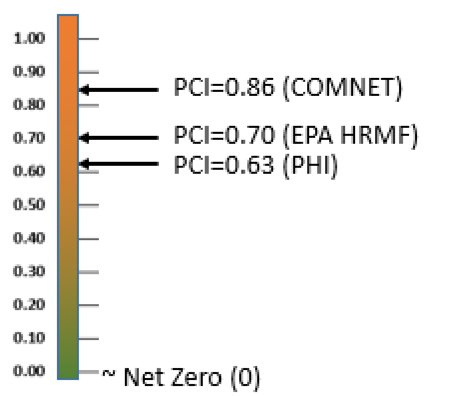
With BEAS and bEQ As Designed, the standard prescribed operating conditions and unregulated load assumptions are used in the rated building models. PRM leaves these inputs at user's discretion, to allow closer alignment between the model and the actual building. However, there is a significant disagreement between different reputable sources regarding the "typical" values, as illustrated in Figure 9. Given this variation, it is unclear how an appropriate project-specific values can be established for projects modeled in commercial setting.

Figure 9: Miscellaneous Equipment kBtu/SF in a Sample Multifamily Building



This creates an opportunity for gaming as illustrated in Figure 10, which shows the PRM rating (the PCI) of the same multifamily project modeled with the operating conditions and unregulated loads prescribed by COMNET, EPA Energy Star for Multifamily High-rise, and Passive House Institute.

Figure 10: Impact of the Operating Conditions on PRM Score



bEQ As Designed requires the use of COMNET operating conditions when determining EUI $_{standardized}$. For multifamily buildings, these assumptions result in unrealistically high energy use, and thus must be reviewed and updated.

3. Simulation Tool Capabilities and Policies

BEAS Asset Score Tool (AST)

a. Input ranges prevented capturing attributes of some designs. For example, width of corridors in multifamily configurations was 5.5 ft, but AST limits the width to no less than 10 feet; one pre-1980 configurations had U-1.25 windows, but AST has U-1.2 maximum.
b. Lighting is entered by specifying type, wattage and number of lighting fixtures, which complicates capturing diverse lighting designs common in commercial buildings. Adding the lighting power density input option would streamline input, and is aligned with the data

available from the code compliance analysis which may be available for new construction projects.

c. Some systems common in multifamily buildings were not supported, such as hydronic baseboards and bathroom and kitchen exhaust fans. The baseboard support was added as the study was in progress, however the implementation did not reflect fan energy savings, and showed an exaggerated pump energy consumption. These issues were reported to AST development team, and are being addressed.
d. One mid-rise apartment configuration with water-source heat pump could not be completed due to issues with AST tool, which were reported and are being addressed.
e. Some of the simulations took a long time to complete, and required involvement of AST development team. The PNNL staff that provided the technical support was knowledgeable and responsive.
f. Add examples of AST simplifications.

bEQ As Designed

Discuss uncertainty associated with using different simulation tools for EUI standardized in conjunction with EPI median from Target Finder. Include Graph comparing E+ results to EQUEST for equivalent configurations.

4. Adjustment for Level of Service

There are differences in how the variation in the level of services is treated by each rating system. This is illustrated using the exterior lighting and cooling example.

Exterior Lighting

With PRM, the same exterior lighting applications must be included in both the benchmark and rated building models. For example, if project includes a parking lot, the rated building (the proposed design) is modeled with the installed lighting for existing buildings or specified lighting for new construction projects, and the benchmark is modeled with the parking lot of the same area and lighting minimally compliant with 90.1 2004.

With bEQ As Designed, the installed or specified exterior lighting is included in the rated building model, increasing $EUI_{standardized}$, but does not affect the benchmark (EUI_{median}), thus penalizing projects that have exterior lighting.

BEAS does not account for exterior lighting at all, effectively not treating it as an asset.

Cooling

PRM requires modeling cooling in all conditioned spaces whether or not cooling system is installed or specified. If cooling system is not specified, it must be modeled as energy neutral, with the goal to neither penalize nor reward the rated buildings without cooling.

With bEQ As Designed, the rated building is modeled with either the actual cooling or specified cooling systems, or with cooling system minimally compliant with the applicable current code, with intent to neither penalize nor reward the buildings without cooling.

BEAS does not account for cooling in projects where it does not exist or specified, effectively rewarding projects without cooling. For example, pre-1980 mid-rise multifamily test case (MA - 4A - pre-1980 - DX+GF) received BEAS score of 5.5 when it was modeled with cooling, and BEAS score of 7 when it was modeled as not cooled. For projects that are modeled without cooling but have cooling load, the simulation would show unment cooling load hours, however this information is not shown on the generated reports, and the score is still generated.

5. Units of Comparison

PRM score is calculated based on energy cost, versus source energy used by other rating systems. Projects may use utility tariffs that include demand and time of use charges. All other rating systems measure performance based on source energy, thus the rating scores will not be affected by design features that reduce peak demand or shift it away from peak hours.

6. Benchmark

bEQ As Designed benchmark is based on the EPA Target Finder for the building types that it supports. This causes issues when the prescribed (COMNET) operating conditions that must be used in the model to determine EUI_{median} differ significantly from the "typical", as was observed in the multifamily configurations. Furthermore, the methodology of EPA PM may affect the bEQ scores in unexpected way, as was observed in the Small Office configuration.

Recommendations

Adoption

1. Adopters will benefit from forming an independent entity to oversee validation and testing of the rating systems.
2. bEQ As Designed and PRM may be more appropriate for larger, more complex building, while BEAS may be best used on smaller projects due to limited AST capabilities.
3. PRM and bEQ As Designed require much more detailed energy modeling compared to BEAS. However, the required modeling is aligned with the requirements of ASHRAE Standard 90.1 Appendix G, which is the path of compliance with the energy code in many jurisdictions including New York. Thus, the models required for PRM and bEQ As Designed ratings may be a by-product of code compliance submittals for some new construction projects. Once the initial models are developed, they may be kept as part of the building records, along with as-built models, and updated overtime to reflect the retrofits. Jurisdictions should consider the synergies between the rating systems and code compliance and various local laws when evaluating adoption costs.
4. ASHRAE bEQ and EPA PM have an existing quality control (QC) infrastructure including rater qualifications, submittal requirements, quality control, and certification process through ASHRAE and EPA respectively. PRM may have existing local adoption framework in the states and municipalities that allow compliance with the energy code via ASHRAE Standard 90.1 Appendix G, through local incentive programs for green buildings that utilize PRM, or national programs such as LEED NC. BEAS does not currently have an adoption framework; thus, it must be created by jurisdictions that want to allow BEAS ratings.

5. Due to approximate nature of BEAS ratings, adopters may consider allowing it for smaller, simpler projects where detailed modeling is not cost effective, and use bEQ As Designed or PRM for the larger projects.
6. Adopters should have the supplemental guidelines to ensure equivalency in rigor and methodologies of the allowed rating systems. For example, with BEAS many of the inputs may be left unfilled, which may lead to gaming. For example, service water heating system is not a required input, and if left unfilled no service hot water usage is modeled, resulting in more favorable rating. The supplemental guidelines may expand on the rating system rules, for example require that all inputs available in BEAS Asset Score Tool are filled based on the actual parameters of the rated building. Similarly, supplemental guidelines may prescribe operating conditions and unregulated load assumptions that must be used in conjunction with PRM.
7. The detailed peer-reviewed matrix comparing asset definitions in each rating system must be developed, to help adopters make educated decision when selecting the rating system(s), and to correctly interpret the scores and opportunities to improve them.

Asset Rating Systems

1. It appears possible and desirable to align asset definition between the rating systems, such as based on the aspects of design regulated by Standard 90.1.
2. Similarly, the same operating conditions and unregulated load assumptions should be used by all rating systems that require use of the standardized as opposed to project-specific assumptions.

bEQ As Designed:

1. Review COMNET modeling assumptions and schedules to ensure reasonable scoring. Calibrate prescribed assumptions to ensure appropriate bEQ As Designed scores based on the adopted scale, e.g. below ~ 75 for PNNL prototypes compliant with 90.1 2004.
2. Examine independent variables used by EPA PM to generate EUI median, and adjust simulation and / or methodology for determining bEQ median to ensure reasonable scoring.

BEAS

1. Enhance Asset Score Tool (AST) support of common configurations and high performance buildings
2. Evaluate and adjust AST input restrictions to support wider range of designs and vintages.
3. Review defaults used when data points are not directly entered by user, to ensure worst-case scenario scoring, to incentivize more detailed data entry. With the current defaults, many configurations received higher scores when minimum allowed data was entered compared to more detailed input. For example, when service water heating is not specified for multifamily projects, AST assumed no water heating usage, resulting in a better score.
4. Automation produces more consistent results, but these results may be consistently wrong, and mistakes are hard-wired and must be fixed through patches to the software, which require time.

PRM

1. Lack of prescribed operating conditions hinders use of PRM for asset rating, and creates opportunities for gaming; continue tightening baseline simulation rules.

Future Testing

1. Expand testing to additional building types
2. Expand testing to include more complex theoretical buildings such as the large office prototype
3. Use actual buildings for testing
4. Test impact of modeler on results for the rating systems
5. For bEQ As Designed and PRM, test the impact of simulation tools on results.

Bibliography TBD

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[2] California Commercial Building Energy Asset Rating System (BEARS): Development Report; Prepared for California Energy Commission by PECI, March 2013

[3] ASHRAE Standard 214