Comment Received From: Pierre Delforge
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NRDC Comments on Building Energy Code Compliance Modeling Software

Additional submitted attachment is included below.

TO: CEC Buildings Standards Office

FROM: Pierre Delforge, NRDC

SUBJECT: CBECC 2022 Modeling Summary and Recommendations

DATE: September 22, 2022

1. Executive Summary

1.1 Overview

As the California Energy Commission (CEC) continues to develop the building energy code compliance software (CBECC) and begins development of the 2025 Title 24 standards, NRDC commissioned an analysis to Energy 350 to assess the remaining compliance barriers to the decarbonization of new construction in California. The compliance software is a critical component of the performance path for compliance to the code: decarbonization technologies that cannot be modeled, or are not modeled appropriately, cannot be employed by builders, creating a barrier to cost-effective decarbonization of new construction. Software modeling capabilities are also essential to allow CEC to set appropriate decarbonization baselines for the 2025 code. This memo shares our finding to inform CEC and stakeholder priorities in compliance software development.

Energy 350 conducted modeling in May through July of 2022 in the CBECC and CBECC-Res Beta software to better understand the remaining barriers to electrification in the performance path of the 2022 code. For non-residential and multifamily buildings, we knew that the system types that are unable to be modeled (namely air to water heat pumps and heat recovery chillers) were a continued barrier and wanted to determine whether the electric system types that can be modeled (packaged air-to-air heat pumps, variable refrigerant flow, and electric resistance) could beat the baseline systems and perform as expected. For residential buildings, we expected that the software would have a strong electrification signal and wanted to confirm this.

Our key research questions were as follows:

- For non-residential: can the all-electric systems that can be modeled beat the baseline system, i.e. comply without complementary measures?
- For multifamily: do minimum efficiency space heating heat pumps combined with heat pump water heaters (HPWHs) beat the baseline?
- For residential: what is the incentive to go all-electric and what is the penalty of going all-gas?

We looked at six prototype buildings using the California Energy Commission's (CEC's) prototypes: Large Office, 10- , 5- and 2-Story Multifamily, and 1- and 2-story single family. Our results are descried in detail below.

1.2 Key Findings

NON-RESIDENTIAL

Our findings show that there is not currently a feasible pathway to model all-electric central systems in CBECC. This continues to highlight the need for enhanced modeling capabilities that integrate air-to-water heat pumps (a.k.a. "heat pump boilers"), heat recovery chillers, and integrated thermal storage into the software. Our understanding is that the air-to-water heat pump functionality will be released imminently and greatly appreciate this important first step in addressing these barriers. Our modeling also highlights the problems with the VRF modeling as currently implemented. Not only was the model using the VRF system unable to comply, but its comparative performance to the heat-pump VAV system with electric resistance reheat is severely misaligned with real world performance. It appears that there are two issues with the VRF performance: conservative performance curves that do not represent the potential energy efficiency of VRF systems and fan characteristics and operating assumptions that result in much higher energy use than VRF systems installed in the field.

MULTI-FAMILY

Our findings show that there are currently feasible and realistic pathways for all electric compliance in multifamily buildings, with either packaged heat pumps or VRF systems. The electric central plant modeling capabilities needed for non-residential buildings will further enhance the ability of designers to model electric multifamily buildings that use air-to-water heat pumps and heat recovery chillers.

SINGLE-FAMILY RESIDENTIAL

Our findings show that the 2022 residential baselines provide a strong electrification signal in the 2022 code. We found that it is challenging to comply with the baselines without electrifying at least one end use (water or space heating). For moderate climate zones, we did not model a scenario that complied without installing a heat pump water heater. We think this is likely to encourage full electrification in these climate zones since builders are less likely to install gas for a furnace alone, especially in climate zones where heating loads are low.

2. Detailed Results

NON-RESIDENTIAL

We modeled the large office prototype under the two primary available all electric performance pathways. This prototype has a baseline system comprised of a multi-zone built-up variable air volume (VAV) system with variable volume fan, chilled water cooling provided by a water-cooled chiller and cooling tower, and hot water heating provided by central gas boiler. We looked at two systems in comparison to this baseline:

- A built-up VAV system that was same as the baseline design but replaced the boiler with an air-source heat pump (HP) coil with a coefficient of performance (COP) of 3.3 in the air handler and electric resistance reheat in the VAV boxes.
- A VRF system with the CBECC default efficiency curves

These systems were chosen as they are the two primary all electric central system types that can current be modeled in CBECC.

Not surprisingly, we found that neither system was able to beat the gas central system baseline. For the heat-pump built-up VAV system with electric resistance reheat, non-compliance was driven by the heating time dependent valuation (TDV) energy use and was worst in climate zones with greater heating loads. This is likely due to the use of electric resistance reheat in the VAV boxes.

A summary of the compliance margin as a percent of the standard energy budget is shown in Figure 1, where negative numbers indicate non-compliance. A building has to comply using both metrics to be considered in compliance. As can be seen in these results, this model did comply using the time dependent source energy (TDS) metric in all climate zones except for 15 but did not comply using the TDV metric in every climate zone except for 15. The result is that the proposed design failed to comply in every climate zone.

Built-Up Heat Pump VAV System with Electric Resistance Reheat

Compliance Margin as % of Standard Budget		
CZ	TDV Efficiency	TDS
1	-40%	33%
2	-15%	21%
3	-18%	32%
4	-11%	17%
5	-21%	37%
6	-7%	7%
7	-6%	6%
8	-3%	11%
9	-4%	16%
10	-4%	14%
11	-12%	15%
12	-14%	14%
13	-8%	14%
14	-12%	16%
15	1%	-49%
16	-47%	29%

Figure 1: Compliance margin as a percent of the standard budget for the large office with built-up heat pump VAV system and electric resistance reheat. Positive numbers indicate compliance, negative numbers indicates that it does not comply.

Similarly, the large office with the VRF system did not comply and, surprisingly, performed worse than the heat-pump VAV system with electric resistance reheat. The VRF system did not comply on both the TDV and TDS metric in almost every climate zone, as shown in Figure 2. Notably, the VRF system had higher energy use across multiple end-uses (heating, cooling, and fan energy use) and in particular had average fan energy use that was 4 times greater than the baseline VAV system.

VRF System

Compliance Margin as % of Standard Budget		
CZ	TDV Efficiency	TDS
1	-58%	27%
2	-57%	-6%
3	-69%	-8%
4	-64%	-45%
5	-67%	-4%
6	-58%	-129%
7	-71%	-211%
8	-58%	-130%
9	-61%	-117%
10	-60%	-88%
11	-67%	-26%
12	-60%	-21%
13	-64%	-48%
14	-69%	-42%
15	-78%	-311%
16	-74%	9%

Figure 2: Compliance margin as a percent of the standard budget for the large office with VRF system. Positive numbers indicate compliance, negative numbers indicates that it does not comply.

These findings highlight the need for the following changes in CBECC (some of which are already underway):

- The ability to model air-to-water space heating heat pumps, heat recovery chillers, and integrated storage.

- The need for improvements to the VRF modeling capabilities to better reflect real world performance. These improvements include both a need to update the underlying performance curves as well as the way fan energy use is modeled.

MULTI-FAMILY

We modeled the 2-, 5-, and 10-story multifamily buildings under two scenarios:

- Packaged heat pumps serving all dwelling units (SEER 14, HSPF 8.2)
- VRF system serving all dwelling units

These two systems were chosen because they are the all-electric system types that can be modeled in the software that are commonly used in multifamily buildings.

We found that both systems effectively complied in all climate zones except climate zones 16. The VRF system had similar performance to the packaged air-source heat pumps, although oddly resulted in improved total TDV compliance in select climate zones, which implies increased PV and/or battery usage (despite no changes to these systems). See attached power point presentation for detailed modeling results.

These results confirm the ability of all electric buildings to comply using system types currently available in CBECC. This ability will be enhanced as further capabilities to model central air-to-water heat pumps, heat recovery chillers, and integrated storage continue to be added to CBECC, as these systems are also used in multifamily buildings.

10-Story Multifamily Building with Packaged Air-Source Heat Pump

Compliance Margin as % of		
CZ	TDV Efficiency	TDS
1	1%	-1%
2	1%	0%
3	-1%	-3%
4	2%	-1%
5	0%	-1%
6	1%	-2%
7	0%	-2%
8	0%	-1%
9	0%	-1%
10	1%	0%
11	0%	0%
12	0%	-1%
13	0%	0%
14	1%	2%
15	0%	-1%
16	-8%	23%

Figure 3: Compliance margin as a percent of the standard budget for the 10-story multifamily building with packaged air-source heat pump. Positive numbers indicate compliance, negative numbers indicates that it does not comply.

10-Story Multifamily Building with VRF

Compliance Margin as % of		
CZ	TDV Efficiency	TDS
1	1%	12%
2	0%	1%
3	-2%	26%
4	-1%	1%
5	0%	38%
6	-2%	2%
7	-1%	7%
8	-1%	4%
9	-1%	3%
10	-1%	4%
11	-2%	1%
12	-1%	1%
13	-2%	0%
14	0%	5%
15	-3%	-57%
16	-8%	38%

Figure 4: Compliance margin as a percent of the standard budget for the 10-story multifamily building with VRF. Positive numbers indicate compliance, negative numbers indicates that it does not comply.

SINGLE-FAMILY RESIDENTIAL

We modeled the 1- and 2-story single family CEC prototypes under a variety of scenarios. We first took the prototype model and adjusted it to be equivalent to the prescriptive standard model in all 16 climate zones. We then conducted several scenario iterations to understand the strength of the electrification signal in the 2022 baseline systems. Specifically we looked at:

- A minimum efficiency gas with a minimally compliant gas furnace and storage gas water heater (Test 1) to understand how non-compliant this would be compared to the baseline.

- A minimum efficiency all electric model with a code compliant heat pump and minimum efficiency HPWH (Test 3) to understand the compliance of a minimum efficiency all electric design.
- A series of tests to understand whether high efficiency gas could comply:
  - High efficiency gas with a 94.6 AFUE furnace and 0.934 UEF tankless water heater (Test 2).
  - "Super High Efficiency Gas": 0.98 furnace, SEER 18 AC with multispeed compressor, Tankless DHW with UEF 0.96, compact DHW distribution, and PV maximized for compliance (Test 4).
  - Test 4B: Same as "Super High Efficiency Gas" but without compact distribution
- A series of tests to understand whether designs using tankless gas water heaters could still comply in moderate climate zones:
  - Test 5: "High Efficiency Gas DHW + HP Space Heating": HP with SEER 18 AC and 10 HSPF, tankless DHW with UEF 0.96
  - Test 5B: Same as Test 5, but without compact distribution
  - Test 5C: Same as Test 5, but with lower HP efficiency: 16 SEER and 9 HSPF.

We found that the baselines as enacted provide a strong electrification signal in all climate zones except for 16 (Mountains). We found that for climate zones 1 through 15, it was challenging for an all-gas home to comply without complementary measures like a battery or additional energy efficiency, even with super high efficiency gas appliances.

We researched whether it would be possible to continue to use gas water heating even in climate zones that set HPWH as the baseline and found that a high efficiency tankless gas water heater combined with a high efficiency heat pump was able to comply in climate zones with higher heating loads (1, 3, 12, and 16) but not the more moderate climate zones (7, 10, and 15).

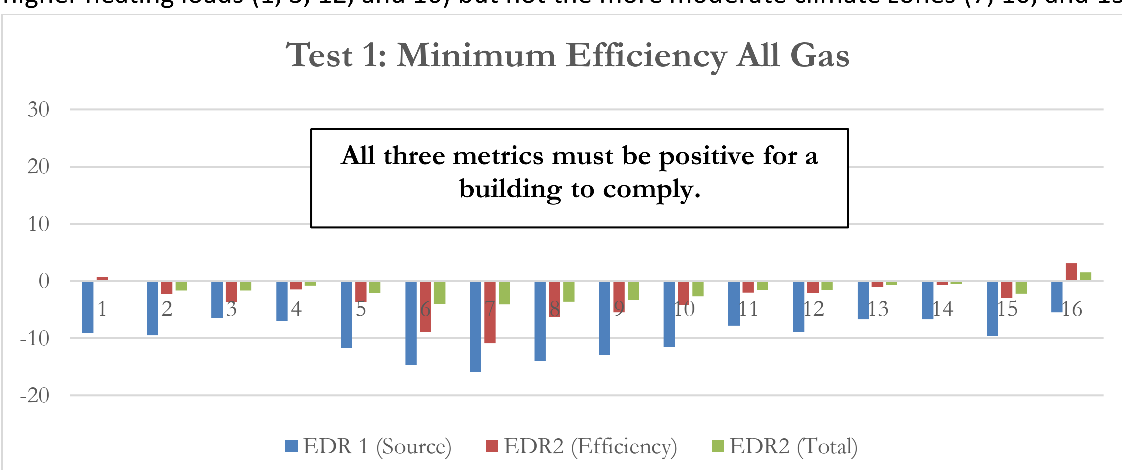


Figure 5: Results for the 2-story prototype under Test 1: a minimum efficiency gas home with a minimally compliant gas furnace and storage gas water heater.

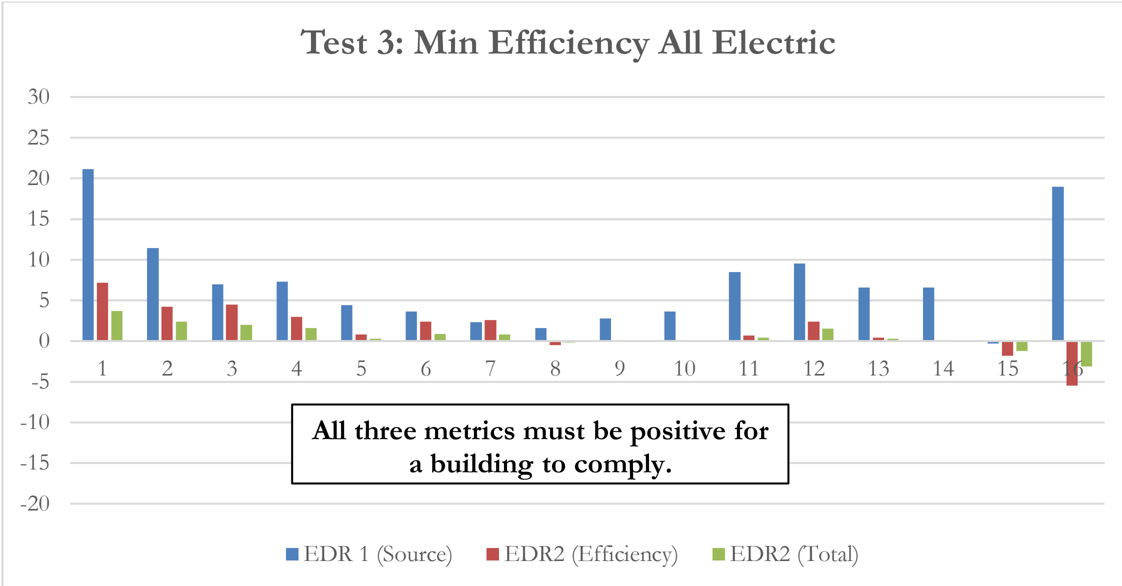


Figure 6: Results for the 2-story prototype under Test 3: a minimum efficiency all electric home with a code compliant heat pump and minimum efficiency HPWH.

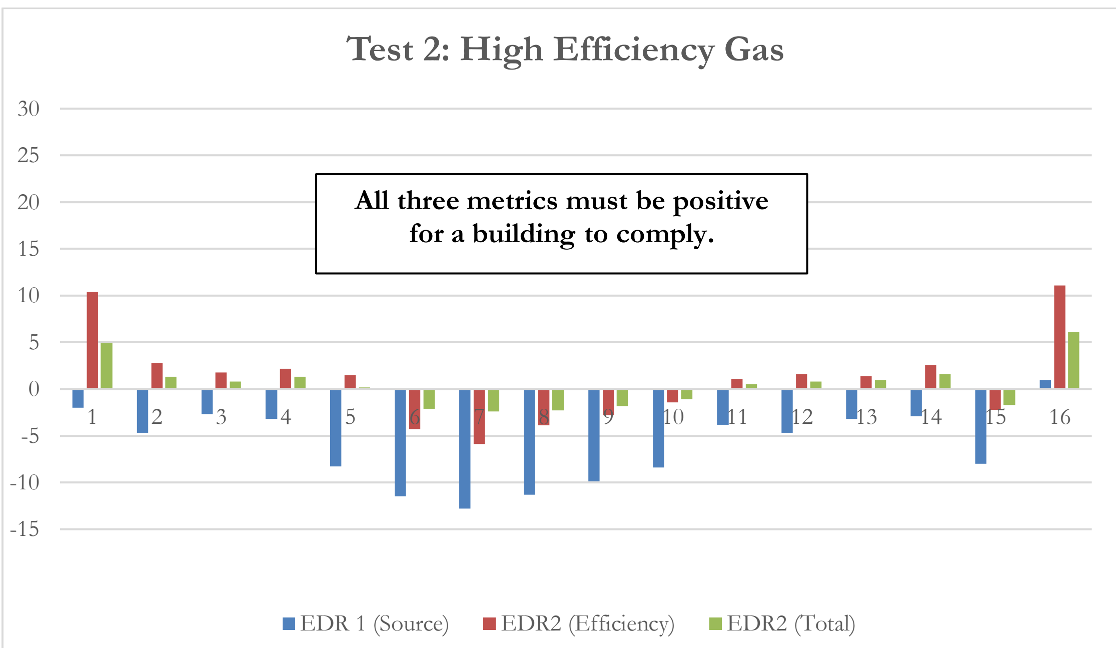


Figure 7: Results for the 2-story prototype under Test 3: a 94.6 AFUE furnace and 0.934 UEF tankless water heater.

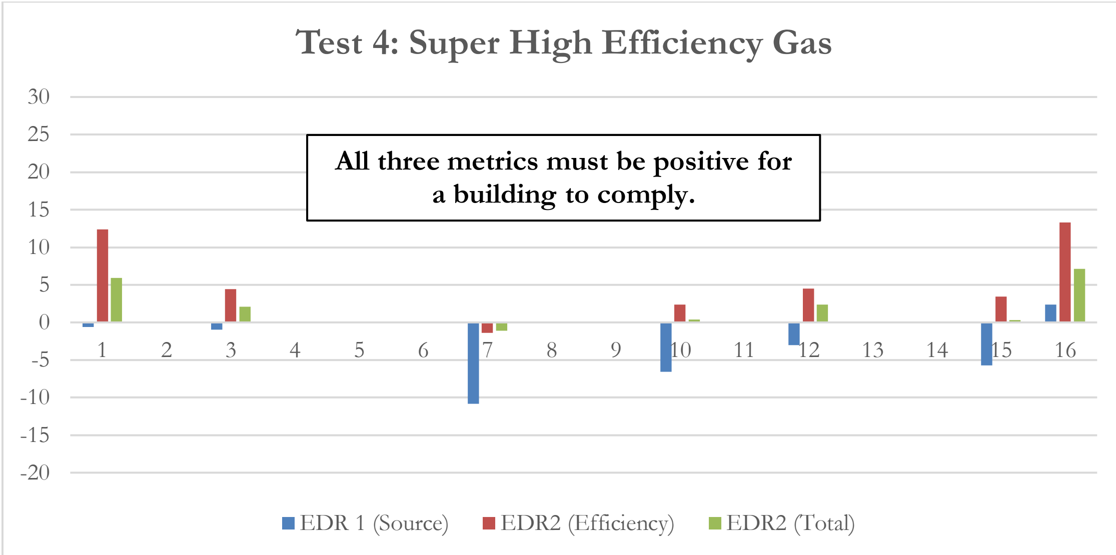


Figure 8: Results for the 2-story prototype under Test 4: a AFUE 0.98 furnace, SEER 18 AC with multispeed compressor, Tankless DHW with UEF 0.96, compact DHW distribution, and PV maximized for compliance.

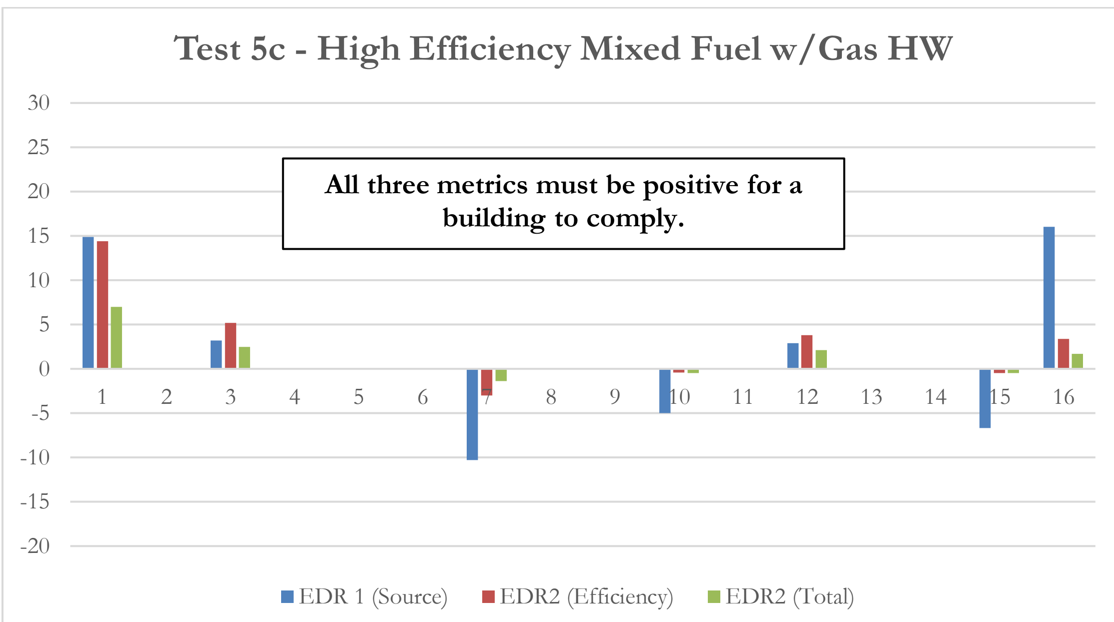


Figure 9: Results for the 2-story prototype under Test 5c: a mixed fuel building with a SEER 16 AC and 9 HSPF heat pumps and tankless DHW with UEF 0.96.

These results confirm that the single-family baselines effectively require at least one end-use to be all-electric and in moderate climate zones that water heating be provided by a heat pump water heater.

CBECC and CBECC Res Beta Software Modeling Results
August 2022

Modeling Plan/Objectives

- Objective: Identify remaining barriers to electrification in 2022 Beta Software.
  - For residential:
    - We expect the software to provide a strong electrification signal. Does it?
  - For non-residential and multifamily:
    - We know there are barriers for system types that can't be modeled – namely central heat pumps/heat recovery chillers. We have already identified these as priorities for 2025 and don't expect this to be corrected in the beta software.
    - The purpose of this testing will be to identify any barriers for electric system types that can be modeled. Are these systems able to beat the baseline system types? Do they perform as expected?
- Research questions:
  - For residential: does minimum efficiency all electric beat the baseline in all climate zones?
  - For multifamily: do minimum efficiency space heating heat pumps (single, multizone, and/or VRF) combined with HPWHs beat the baseline?
  - For non-res: can the all-electric systems that are able to be modeled (VRF or packaged heat pump) beat the baseline?

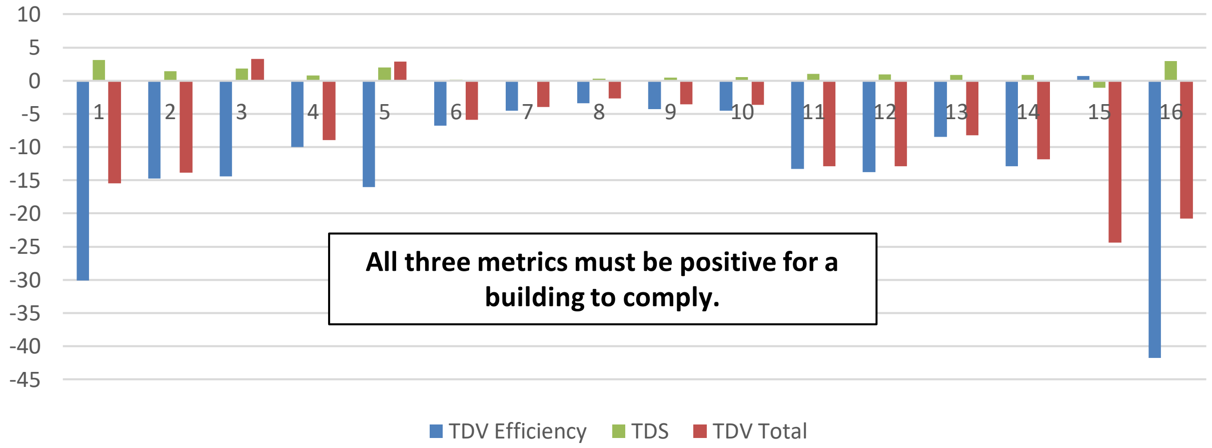
Non-Residential Modeling Summary

CBECC Modeling Summary

- Looked at 4 prototype models: Large Office and 10- , 5- and 2-Story Multifamily
- For each prototype, modeled a packaged air-to-air heat pump, a built-up VAV system with air-to-air HP coil and electric resistance reheat, and/or VRF system as appropriate.

Large Office – Heat Pump VAV w/ER reheat

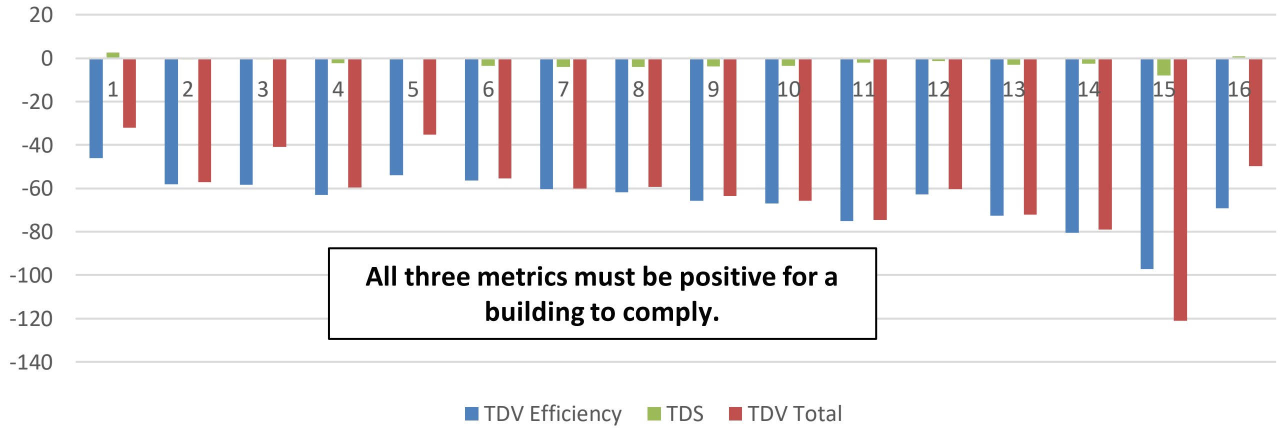
- **Baseline HVAC System:**
  - Multi-zone built-up VAV system with variable volume fan, chilled water cooling provided by a water-cooled chiller and cooling tower, and hot water heating provided by central gas boiler.
- **Proposed HVAC System:**
  - The proposed system uses the same built-up VAV system as the baseline design but replaces the boiler with an air-source HP coil with a COP of 3.3 in the air handler and electric resistance reheat in the VAV boxes.



Compliance Margin as % of Standard Budget		
CZ	TDV Efficiency	TDS
1	-40%	33%
2	-15%	21%
3	-18%	32%
4	-11%	17%
5	-21%	37%
6	-7%	7%
7	-6%	6%
8	-3%	11%
9	-4%	16%
10	-4%	14%
11	-12%	15%
12	-14%	14%
13	-8%	14%
14	-12%	16%
15	1%	-49%
16	-47%	29%

Large Office – VRF

- **Baseline HVAC System:**
  - Multi-zone built-up system with variable volume fan, chilled water cooling provided by a water-cooled chiller and cooling tower, and hot water heating provided by central gas boiler.
- **Proposed HVAC System:**
  - VRF System with CBECC default efficiency curve



Compliance Margin as % of Standard Budget		
CZ	TDV Efficiency	TDS
1	-58%	27%
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3	-69%	-8%
4	-64%	-45%
5	-67%	-4%
6	-58%	-129%
7	-71%	-211%
8	-58%	-130%
9	-61%	-117%
10	-60%	-88%
11	-67%	-26%
12	-60%	-21%
13	-64%	-48%
14	-69%	-42%
15	-78%	-311%
16	-74%	9%

Large Office – VRF Site Energy End Uses

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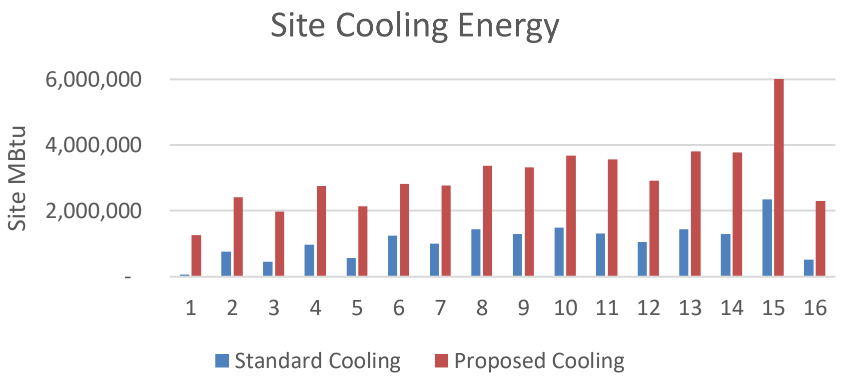
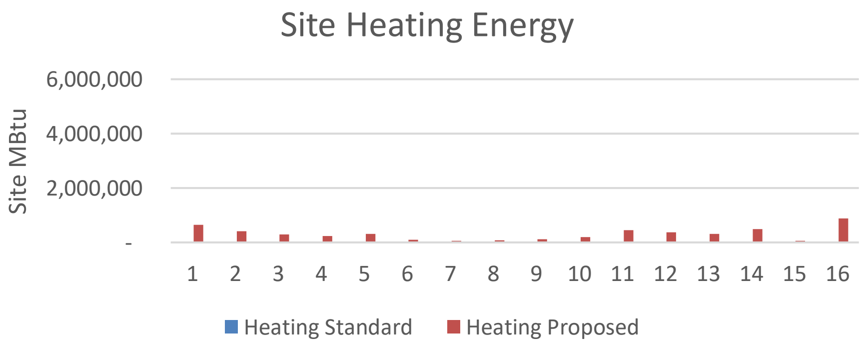
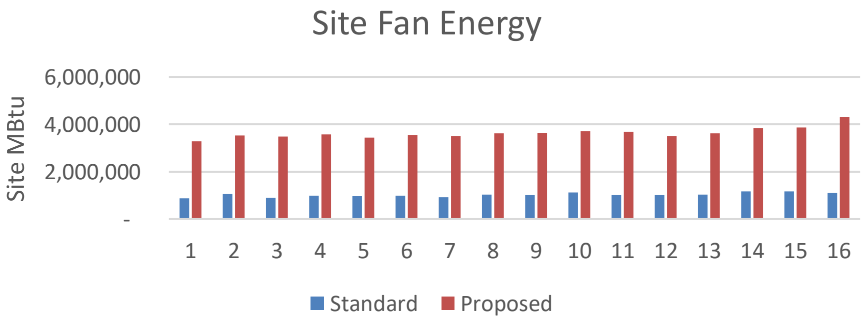
- These graphs compare the standard and proposed design modeled energy use using a common metric of site BTU.
- All three end-uses increased significantly, with cooling and fan energy driving non-compliance.







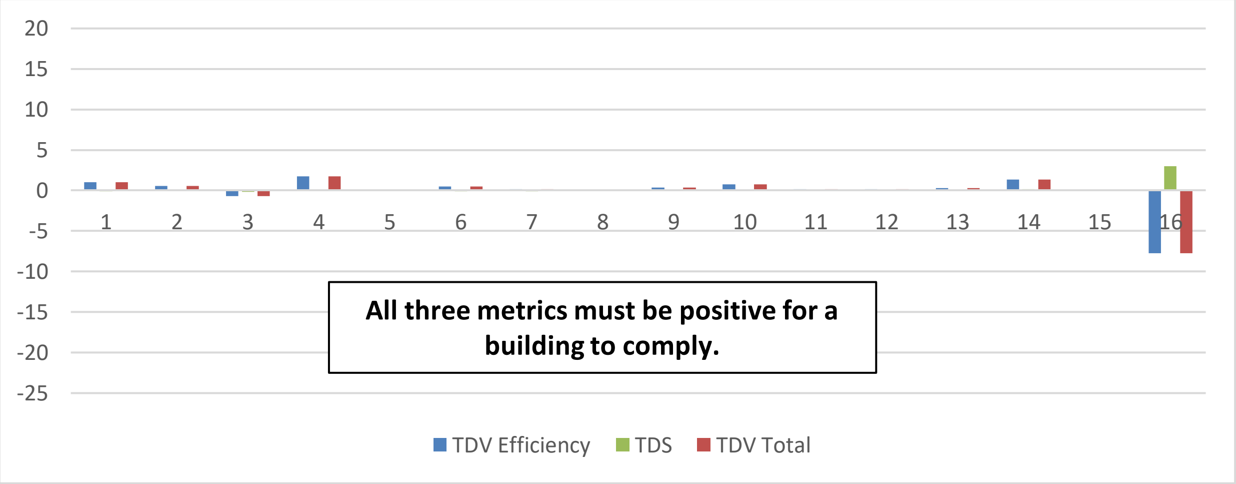
Large Office – Takeaways

- **There continues to be no feasible path to beat the gas built up VAV system baseline for large commercial buildings**
- **Highlights the need for modeling of air-to-water heat pumps**
- **Packaged HP system non-compliance driven by heating energy use (likely due to ER reheat)**
- **VRF non-compliance driven by higher energy use across multiple end-uses: Heating, Cooling, and Fan Energy Use**
  - Average fan energy use of the VRF system is 4x greater than that of the baseline system.
  - Comparative performance of VRF system to packaged HP VAV system with electric resistance reheat does not seem to align with real world performance

Multifamily Modeling Summary

10-Story Multifamily – Central Packaged ASHP

- **Baseline HVAC System:**
  - In CZ 2-15: Ducted, split system HP with ducts in the attic
  - In CZs 1 and 16: Dual fuel heat pump
- **Proposed HVAC System:**
  - Central packaged heat pump serving all dwelling units



Compliance Margin as % of		
CZ	TDV Efficiency	TDS
1	1%	-1%
2	1%	0%
3	-1%	-3%
4	2%	-1%
5	0%	-1%
6	1%	-2%
7	0%	-2%
8	0%	-1%
9	0%	-1%
10	1%	0%
11	0%	0%
12	0%	-1%
13	0%	0%
14	1%	2%
15	0%	-1%
16	-8%	23%

10-Story Multifamily – VRF

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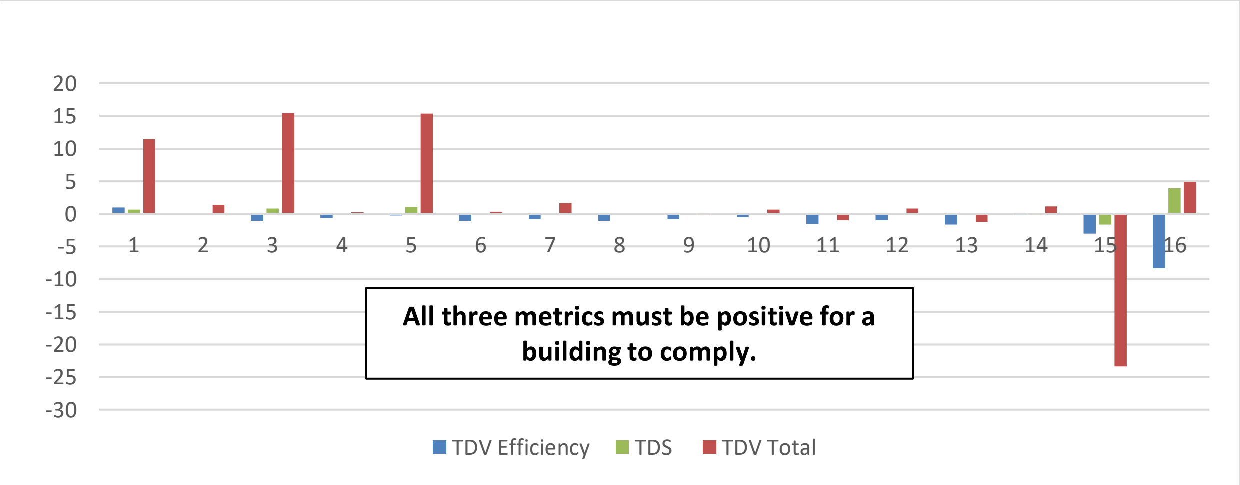
- **Baseline HVAC System:**
  - In CZ 2-15: Ducted, split system HP with ducts in the attic
  - In CZs 1 and 16: Dual fuel heat pump
- **Proposed HVAC System:**
  - VRF System with CBECC default efficiency curve



Compliance Margin as % of		
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4	-1%	1%
5	0%	38%
6	-2%	2%
7	-1%	7%
8	-1%	4%
9	-1%	3%
10	-1%	4%
11	-2%	1%
12	-1%	1%
13	-2%	0%
14	0%	5%
15	-3%	-57%
16	-8%	38%

5-Story Multifamily – Central Packaged ASHP

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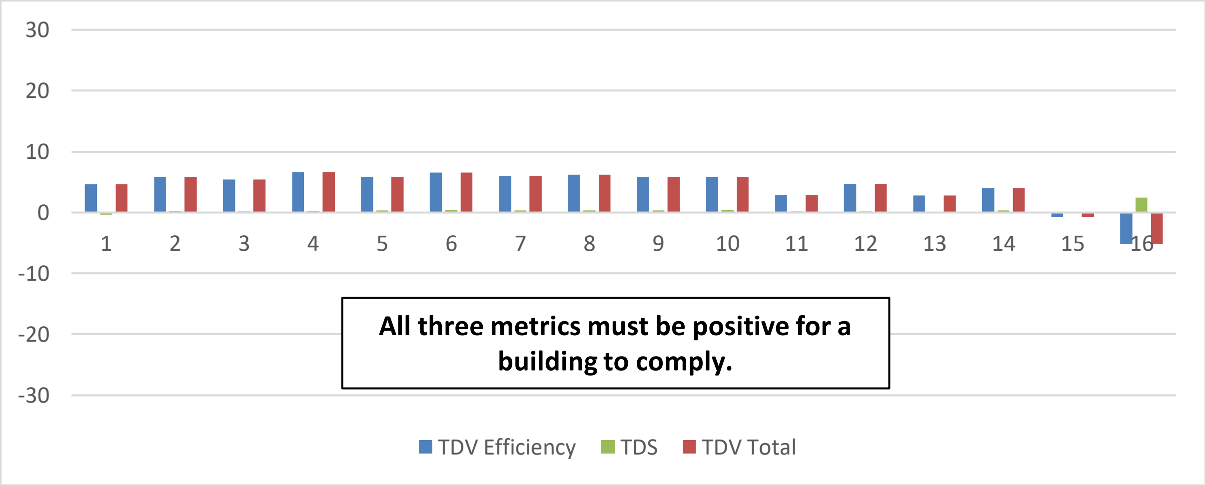
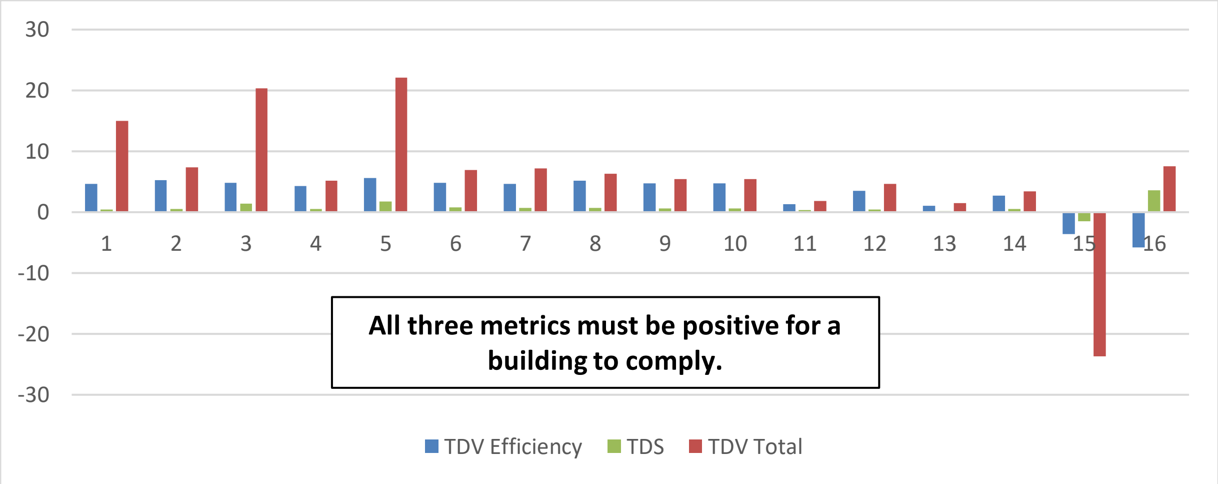
- **Baseline HVAC System:**
  - In CZ 2-15: Ducted, split system HP with ducts in the attic
  - In CZs 1 and 16: Dual fuel heat pump
- **Proposed HVAC System:**
  - Central packaged heat pump serving all dwelling units (SEER 14, HSPF 8.2)



5-Story Multifamily – VRF

- **Baseline HVAC System:**
  - In CZ 2-15: Ducted, split system HP with ducts in the attic
  - In CZs 1 and 16: Dual fuel heat pump
- **Proposed HVAC System:**
  - VRF System with CBECC default efficiency curve



2-Story Multifamily – Central Packaged ASHP

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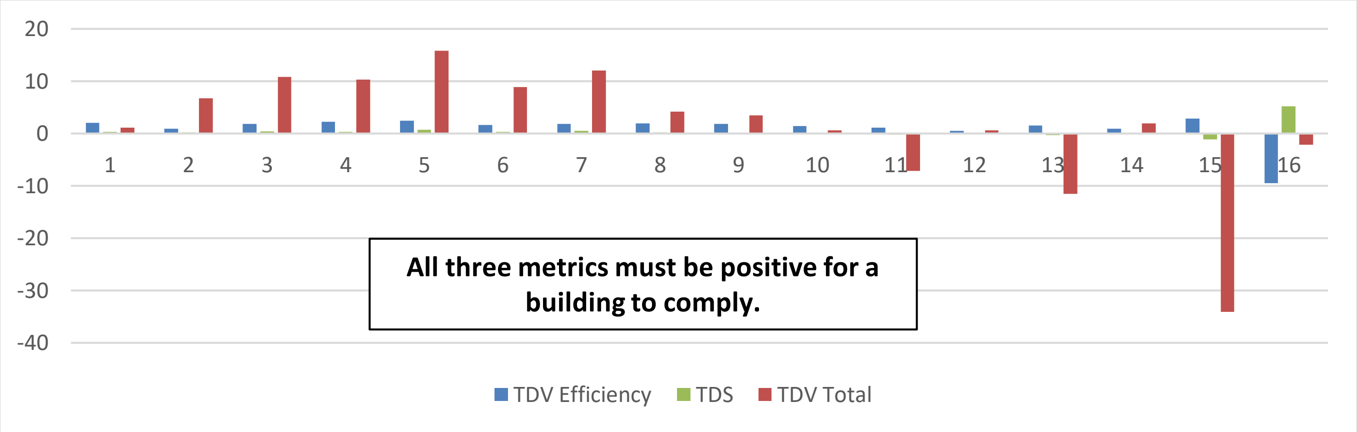
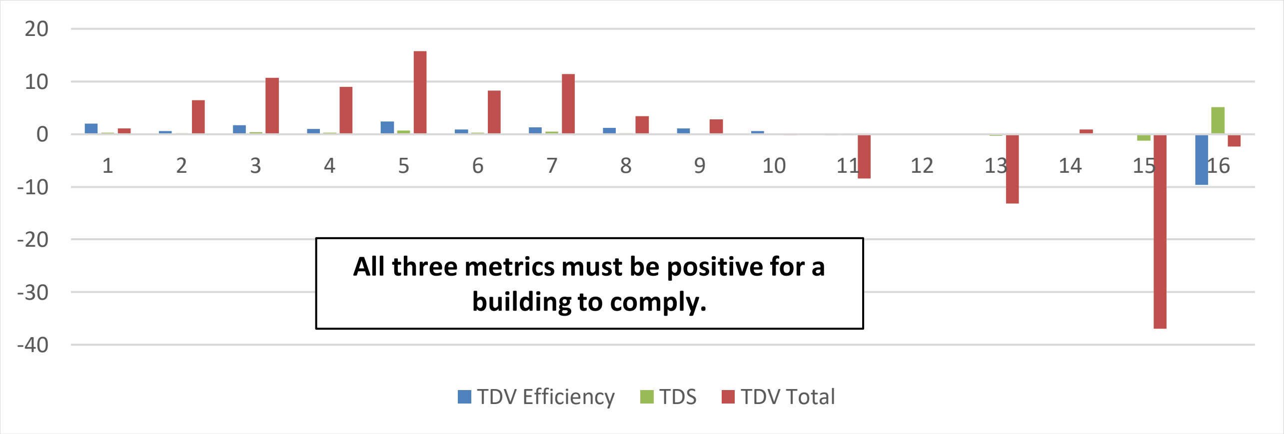
- **Baseline HVAC System:**
  - In CZ 1-15: Ducted, split system HP with ducts in the attic
  - In CZ 16: AC with furnace
- **Proposed HVAC System:**
  - Central packaged heat pump serving all dwelling units (SEER 14, HSPF 8.2)



2-Story Multifamily – VRF

- **Baseline HVAC System:**
  - In CZ 1-15: Ducted, split system HP with ducts in the attic
  - In CZ 16: AC with furnace
- **Proposed HVAC System:**
  - VRF System with CBECC default efficiency curve



Multifamily – Takeaways

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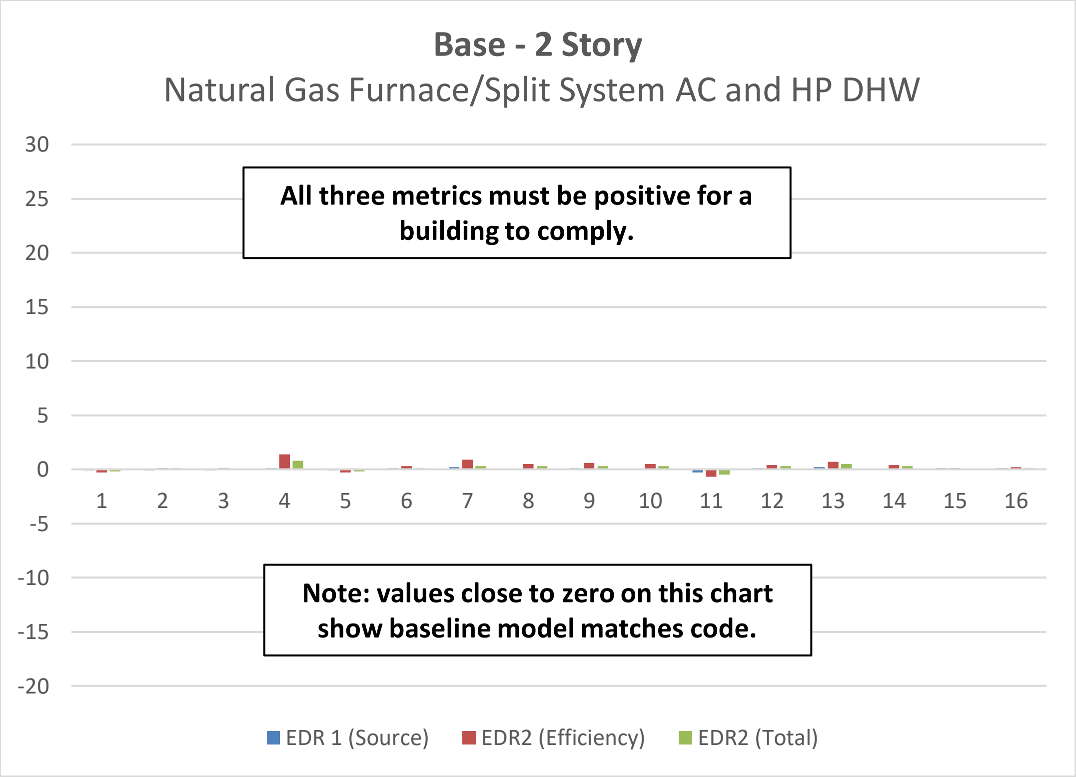
- There appear to be feasible pathways to all-electric compliance with existing ASHP system modeling capabilities for multifamily buildings except for Climate Zone 16.
- VRF compliance is similar to ASHP compliance, but oddly increased total TDV compliance for the 5 and 10-story buildings in select climate zones.

Residential Modeling Summary

CBECC Res Modeling Summary

- Residential Modeling Process:
  - Modified CBECC Res 1- and 2-story prototype models to meet the prescriptive standard in all 16 climate zones (“Base” scenario). This model has a natural gas furnace and heat pump water heater in all climates, forcing the standard design to have a HPWH in the baseline in all climate zones.
  - Took this minimally compliant model and conducted three tests:
    - Test 1: Minimum efficiency gas with a minimally compliant gas furnace and storage gas water heater
    - Test 2: High efficiency gas with a 94.6 AFUE furnace and 0.934 UEF tankless water heater.
    - Test 3: Minimum efficiency all electric model with a code compliant heat pump and minimum efficiency HPWH.
  - To further test whether gas systems would be able to comply we also tested the following two scenarios.
    - Test 4: “Super High Efficiency Gas”
    - Test 5: “High Efficiency Gas DHW + HP Space Heating”

2-Story Model Results – Baseline Model



- Baseline model updated to match the standard design/minimally comply with code.
- Includes a minimum efficiency natural gas furnace w/AC and a heat pump water heater.
- All test scenarios were made as iterations to this model.

2-Story Model Results – Test 1 Minimum Efficiency Gas

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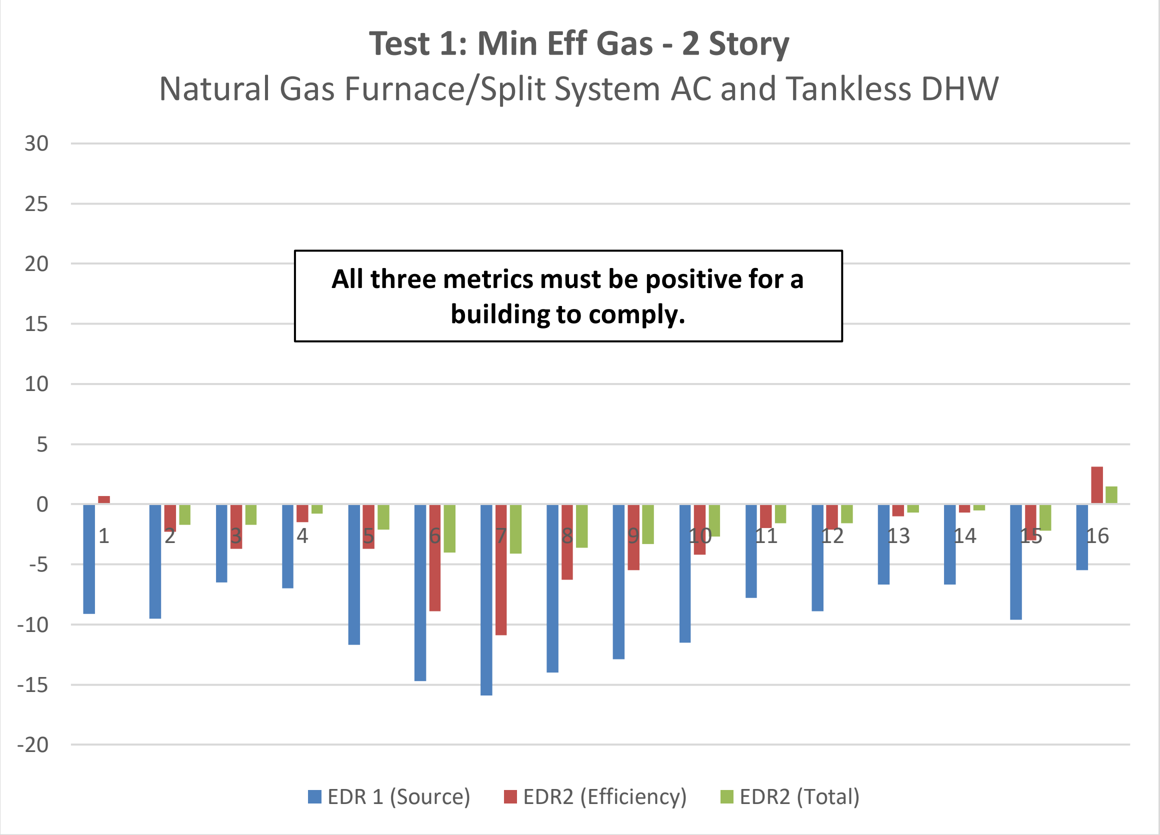

- Minimum efficiency furnace/split AC
- Minimum efficiency tankless gas water heater

2-Story Model Results – Test 2 High Efficiency Gas

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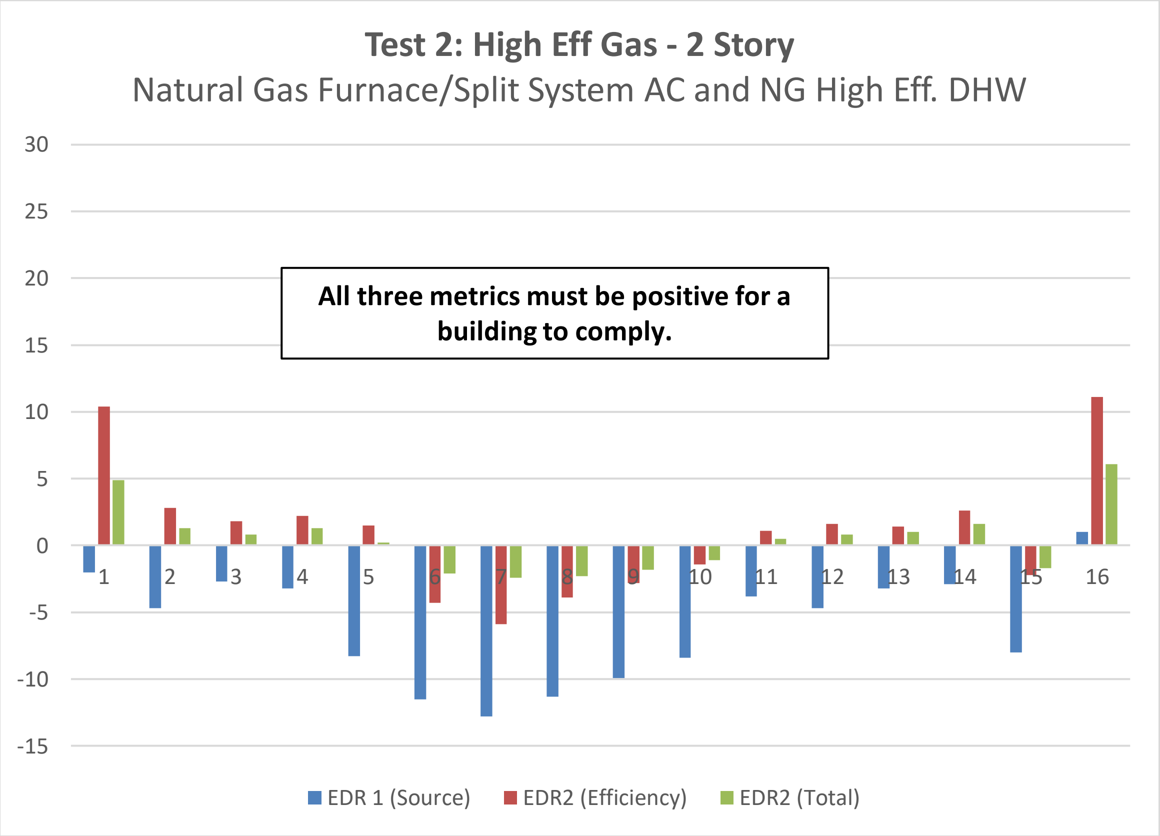

- AFUE 94.6 Furnace
- SEER 14/EER 11.7 AC
- UEF 0.934 tankless gas water heater

2-Story Model Results – Test 3 Minimum Efficiency Electric

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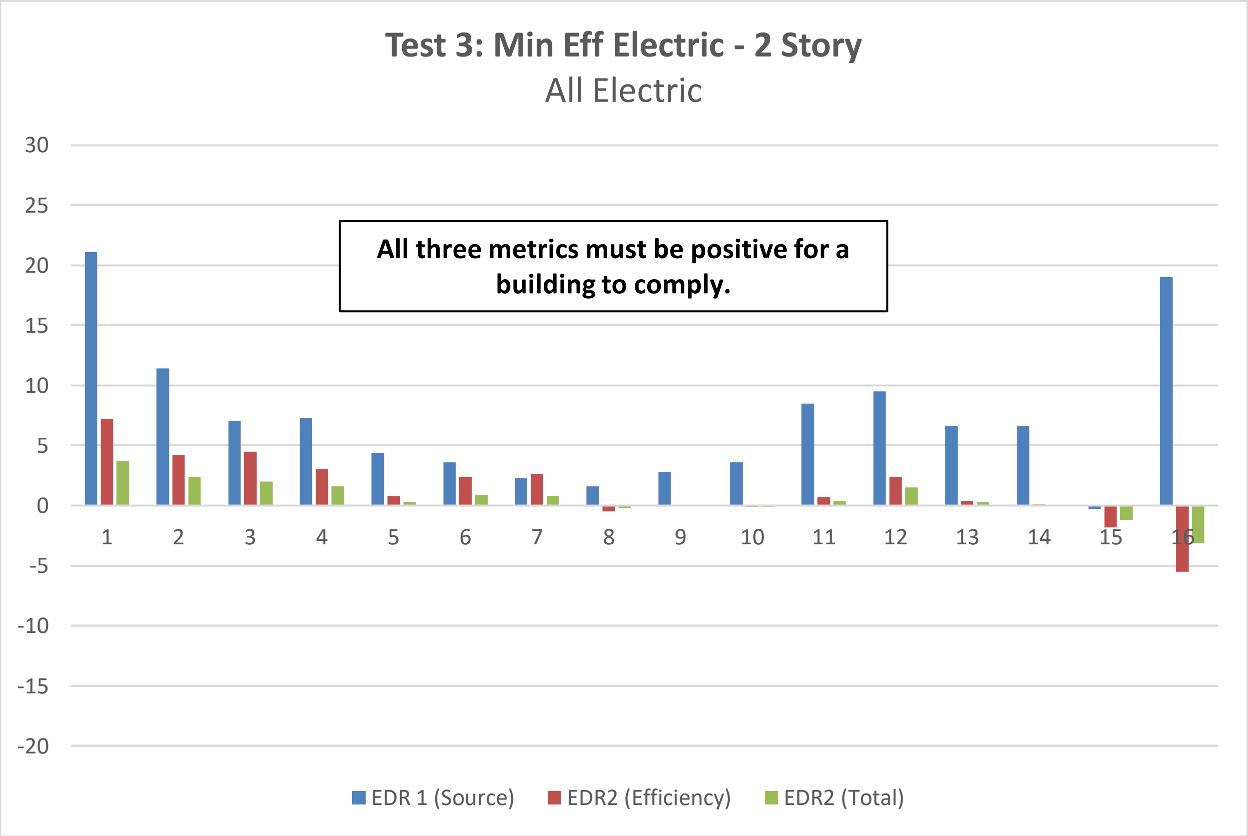
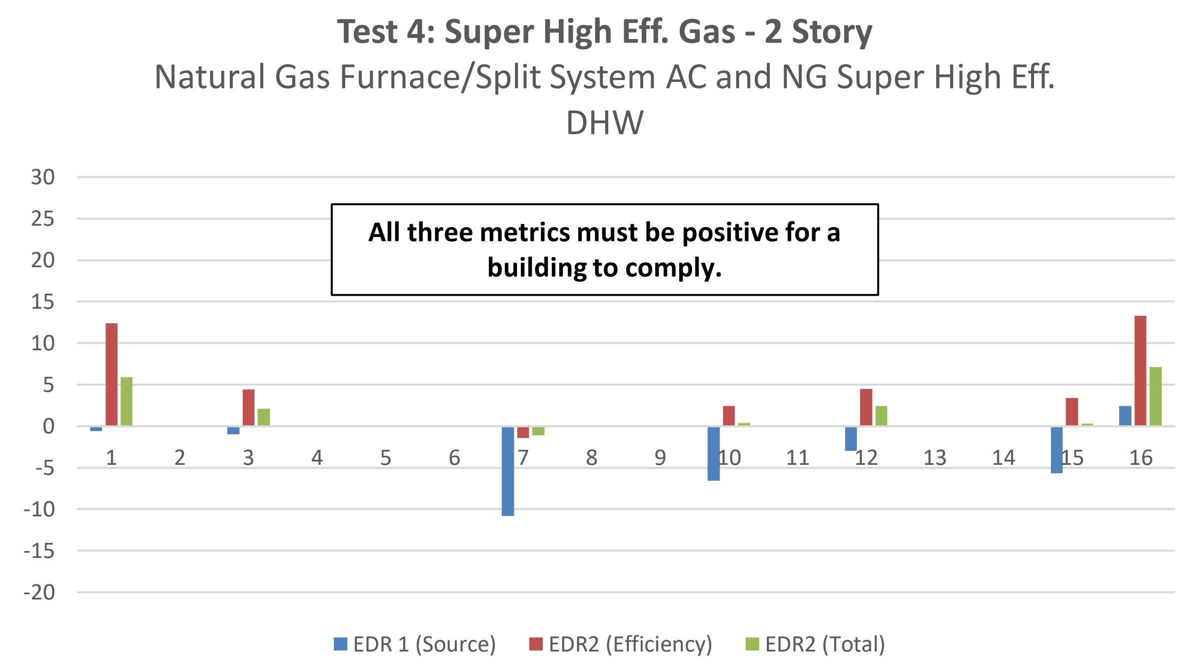


- Min efficiency HP
- Min efficiency HPWH

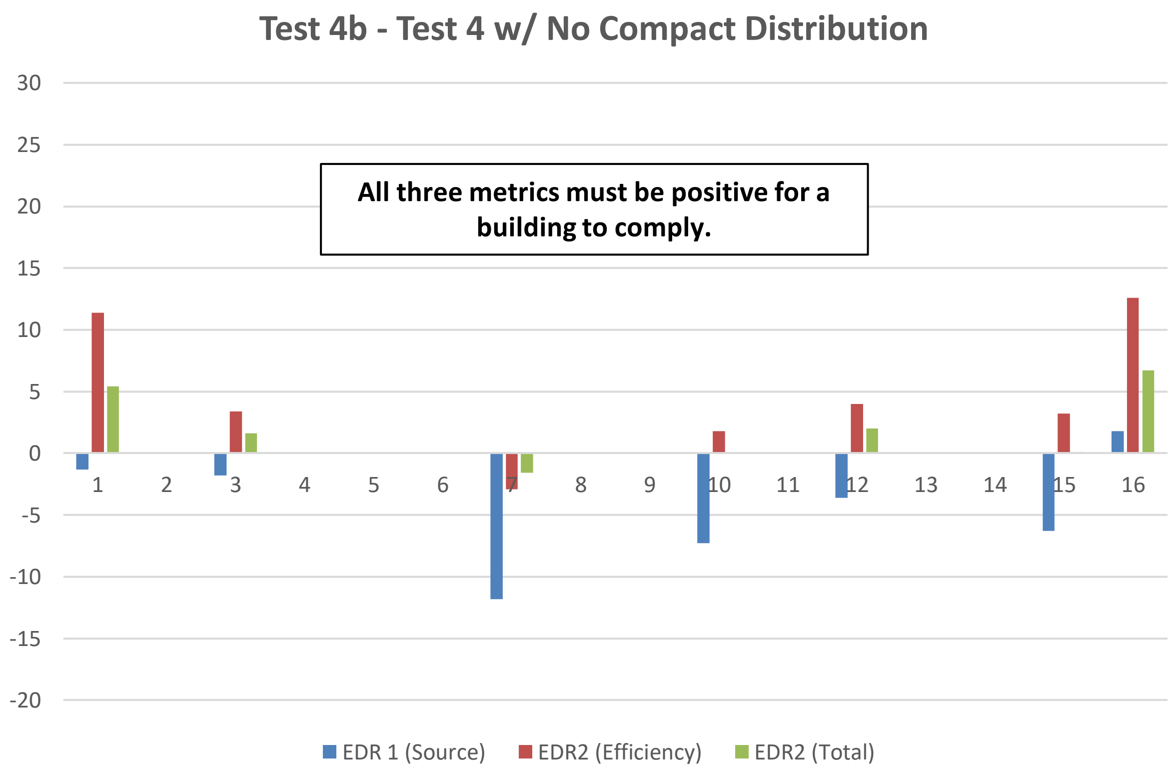
2-Story Model Results – Test 4 Super High Efficiency Gas



- Furnace efficiency 0.98
- SEER 18 AC with Multispeed Compressor
- Tankless DHW efficiency 0.96
- Compact DHW distribution
- Maximum PV for compliance

2-Story Model Results – Test 4B Super High Eff Gas, No Compact Dist

ENERGY350



- Same as previous slide with no compact distribution

2-Story Model Results – Test 5 Super High Eff HP and Gas DHW

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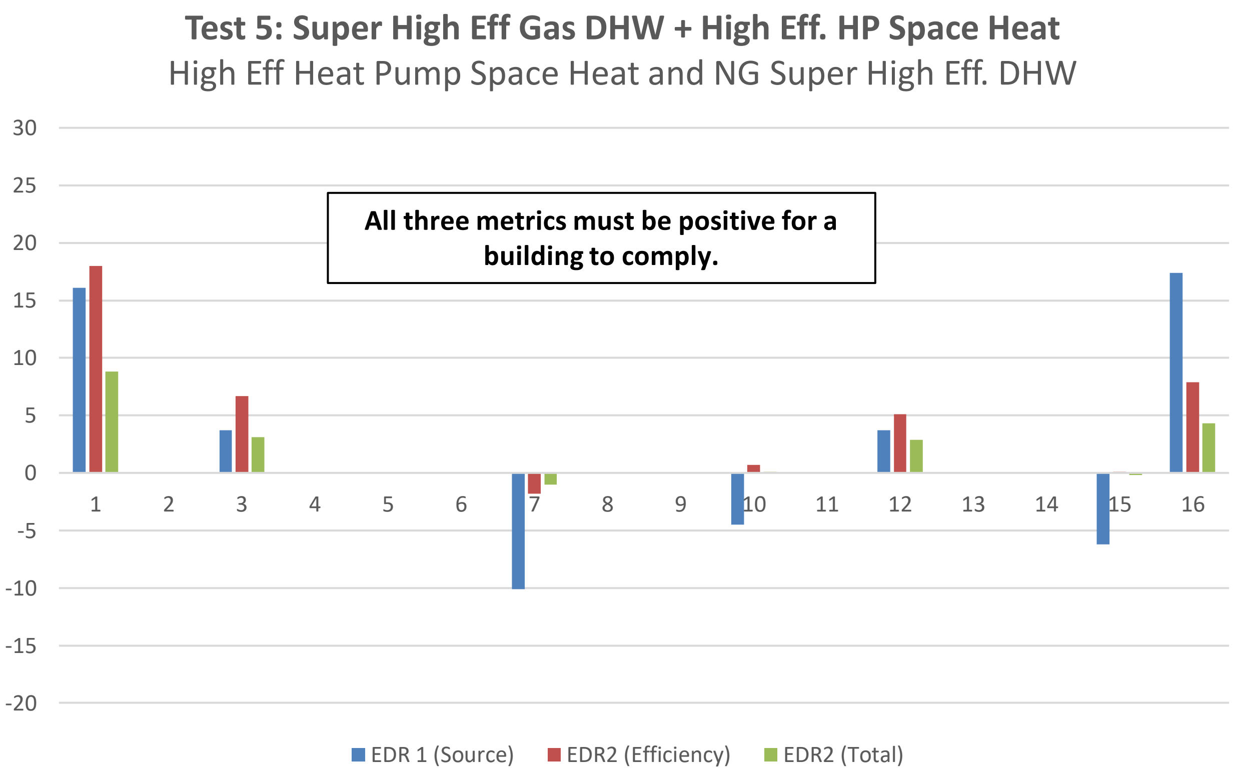
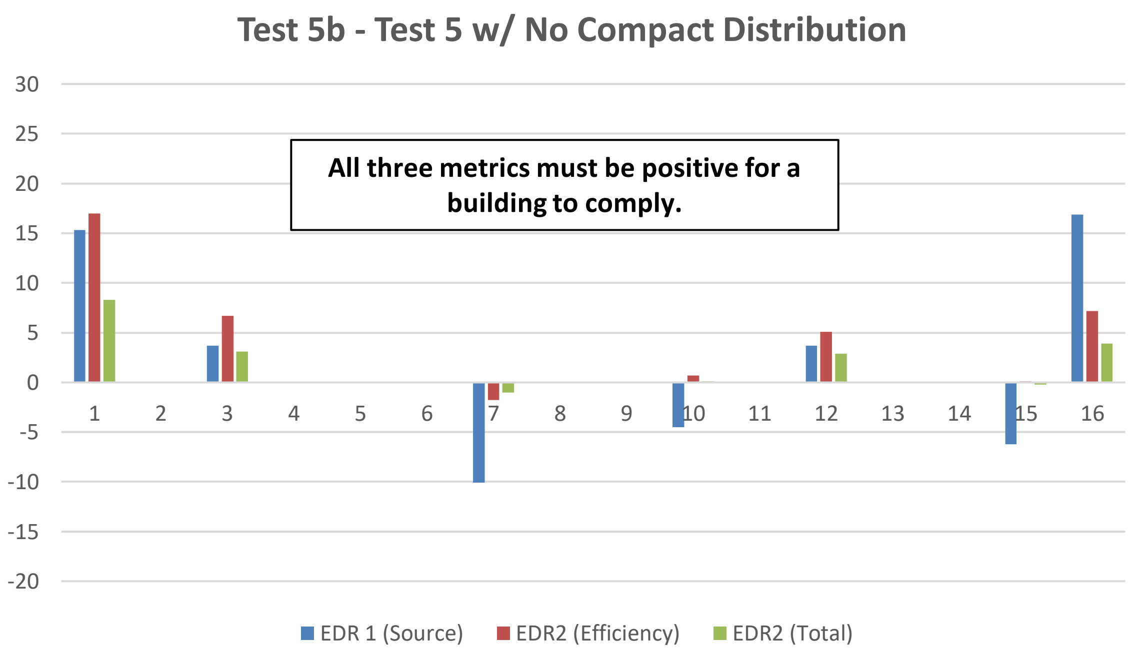


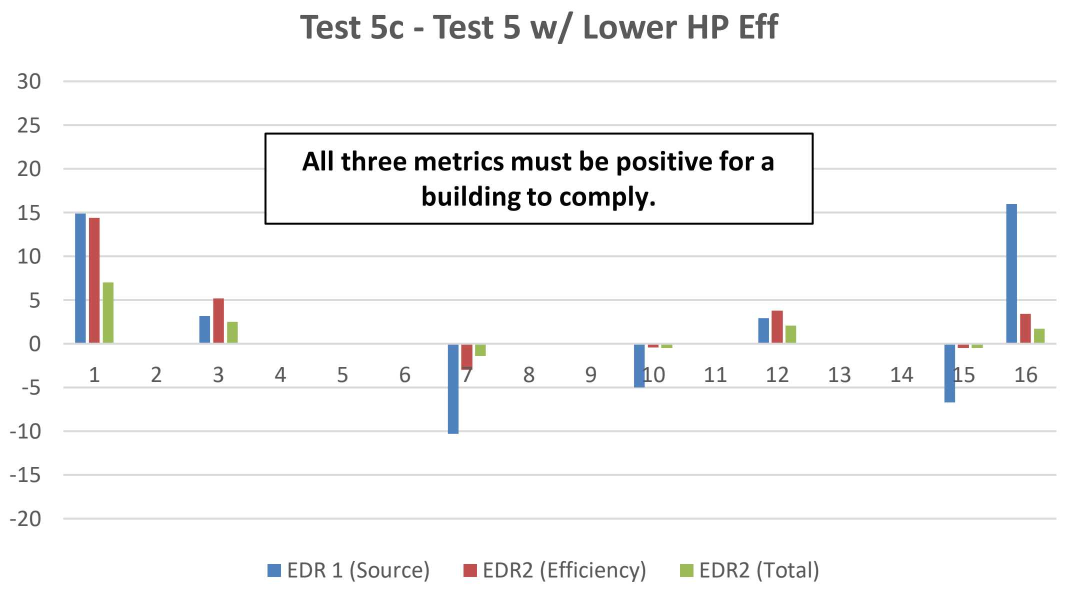
- HP with SEER 18 AC with Multispeed Compressor and 10 HSPF Heating
- Tankless DHW efficiency 0.96

2-Story Model Results – Test 5b Super High Eff HP and Gas DHW no compact distribution



- Same as previous slide with no compact distribution

2-Story Model Results – Test 5c Medium Eff HP and Gas DHW



- HP with SEER 16 AC with Multispeed Compressor and 9 HSPF Heating
- Tankless DHW efficiency 0.96

Residential Modeling Conclusions

- Overarching conclusions:
  - Heat pump baselines provide a strong electrification signal by making it difficult to comply with gas in almost all climate zones (except for 16)
  - High efficiency gas appliances alone are not enough to qualify in all climate zones except for climate zone 16.
  - The all-electric model is effectively compliant in all CZs except for 16.
- Minor detailed findings/potential bugs:
  - Heat pump set points do not set back at night, whereas furnace set points do, leading to slightly higher heating loads for models using heat pump space heating.
  - Attic construction in CZ 4 has a U-value of 0.055 instead of 0.049 for what appears to be the same R-19 insulation assembly
  - In climate zones 10-15, the standard model defaults to a roof emittance of 0.85 when code requires 0.75