CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Residential Ducts – Duct Sealing, Cooling Coil Airflow, Fan Watt Draw, and Measured Static Pressure

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team May 2011

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Table of Contents

Table of Figures

1. Purpose

The purpose of this CASE study was to evaluate four related approaches to improving HVAC system performance in residential homes:

1. Duct testing,
2. System static pressure,
3. Cooling coil airflow, and
4. Fan watt draw.

This CASE study used the field research from a Public Interest Energy Research Program project, *Efficiency Characteristics and Opportunities of New California Homes,* to evaluate how these four approaches could be used to improve residential HVAC performance. This evaluation was used to determine how these approaches could be used with the Building Energy Efficiency Standards and make proposed recommendations for 2013 Building Energy Efficiency Standards.

2. Overview

Part 1 Cooling Coil Airflow and Fan Watt Draw

a. Measure Title	Residential Ducts: Measured Cooling Coil Airflow and Fan Watt Draw
b. Description	Newly constructed residential buildings with ducted heating and cooling systems in all climate zones would have **mandatory minimum cooling coil airflow and fan watt draw** requirements with two options available for compliance. Option 1: the return duct(s) and return grill(s) must be sized according to the Return System Sizing Table. Option 2: the cooling coil air flow and fan watt draw must meet minimum measured values with HERS verification. HVAC Alterations in residential buildings that include new or replacement duct systems would have the same mandatory minimum cooling coil airflow and fan watt draw requirements. The same two compliance options for newly constructed home would be available for HVAC Alterations. For both newly constructed homes and HVAC alterations, heating only systems would be exempt from these mandatory measures.
c. Type of Change	**Mandatory Measure -** The proposed change would add two mandatory measures: Measured Cooling Coil Airflow and Fan Watt Draw **Compliance Option -**The change would remove these two measures from the list of existing compliance options for meeting the Standards using the performance approach. **Modeling** - The change would modify the calculation procedures or assumptions used in making performance calculations. The proposed change modifies but does not expand the scope of the Standards. Both measures are part of the 2008 Residential Energy Standards. The proposed changes move the two measures from the Prescriptive (Component Package D) to Mandatory Measures. The following Standards documents would need to be modified: Building Energy Efficiency Standards, ACM, and Residential Compliance Manual. In each of the documents, the description of these two measures would need to be referenced in the Mandatory Measure sections instead of the Prescriptive section. The measures would remain as HERS verification items, so modifications to the Reference Appendices are not required.

d. Energy Benefits

The Energy Benefits are based on improving the HVAC system performance in the base case house by increasing airflow from 300 to 350 cfm/ton and reducing fan watt draw from .80 to.58 watt/cfm. Increasing airflow delivers more heating and cooling energy to the home compared to the base case home. Reducing fan watt draw reduces electricity usage during fan operation. The per unit (HVAC system) and per prototype building saving are the same.

Climate Zone	Airflow 350 cfm/ton & Fan Watt Draw .58 watts/cfm	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
1	Per HVAC System & Per Prototype Building	148	0.00	-9	0.00	0.42
2		163	0.07	-7	1.02	0.51
3		95	-0.04	-4	0.58	0.25
4		163	-0.03	-4	1.70	0.46
5		105	0.00	-4	0.00	0.47
6		95	-0.04	-2	1.55	0.15
7		53	0.10	0	1.28	0.05
8		158	0.24	-2	2.87	0.12
9		243	0.36	-2	4.63	0.15
10		291	0.42	-3	5.27	0.13
11		506	0.52	-7	8.20	0.34
12		282	0.32	-7	4.53	0.37
13		527	0.55	-6	8.15	0.33
14		454	0.47	-8	6.74	0.11
15		994	0.81	-1	13.98	-2.99
16		322	0.25	-14	3.18	0.45
Averages		**287.4**	**0.25**	**-5.0**	**3.98**	**0.08**

Figure 1: Energy Benefits airflow from 300 to 350 cfm/ton and reducing fan watt draw from .80 to.58 watt/cfm

e. Non-Energy Benefits	The study that is the basis of the recommendations in this CASE study, ***Efficiency Characteristics and Opportunities of New California Homes,*** showed low airflow and high fan watt draw to be common problems in newly constructed homes. Both of these conditions lead to increased run times for HVAC equipment and longer times to cool homes after the A/C equipment is turned on. Improving airflow will decrease system run times which should result in reduced maintenance cost and longer life of equipment.

f. Environmental Impact

	Mercury	Lead	Copper	Steel	Plastic	Others Fiberglass Insulation
Per Unit Measure[1] (Flex Duct Return, Filter Grill & Filter)	NC	NC	NC	.5	.25	2
Per Prototype Building[2]	NC	NC	NC	.5	.25	2

Figure 2: Environmental Impact - Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

1. Type of unit: per HVAC system (flex duct, filter grill, fiberglass filter)
2. For description of prototype buildings refer to Methodology section below.

	On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Year)
Per Unit Measure[1]	0
Per Prototype Building[2]	0

Figure 3: Water Consumption

1. Type of unit: per HVAC system (flex duct, filter grill, fiberglass filter)
2. For description of prototype buildings refer to Methodology section below.

	Mineralization (calcium, boron, and salts	Algae or Bacterial Buildup	Corrosives as a Result of PH Change	Others
Impact (I, D, or NC)	NC	NC	NC	NC
Comment on reasons for your impact assessment	Measures require larger duct sizes for return ducts, filter grills and filters: but no impact on water quality.			

Figure 4: Water Quality Impacts

Potential increase (I), decrease (D), or no change (NC) in contamination compared to the basecase assumption, including but not limited to: mineralization (calcium, boron, and salts), algae or bacterial buildup, and corrosives as a result of PH change.

g. Technology Measures	The proposed measures do not require or encourage a particular technology. The proposed changes required improved HVAC system design and installation. The improvements in the HVAC system design use existing technology, existing materials, and existing installation skills. When using the measured airflow and fan watt draw approach, the designer/builder can make improvements in both the supply and return sides of the distribution system to ensure 350 cfm/ton airflow and .58 watt/cfm fan watt draw. If the designer/builder opts to use the return system sizing tables, larger return ducts and filter grills will be used. Using either method there is no change in the type of materials, installation skills or system technology. If the installing contractor opts to use the airflow and fan watt draw measurement method, the installing contractor will need equipment to measure both the airflow and wattage. This equipment is readily available and contractors already commonly use flow hoods to measure airflow. The equipment to measure fan watt draw is easy to use and readily available for under $100 (Watts Up brand watt meter). **Useful Life, Persistence, and Maintenance:** The life, frequency of replacement, and maintenance procedures related to the proposed changes are the same as current practice. Since only the size of the ducts and return grills are being affected, this will not affect the life, replacement or maintenance procedures.
h. Performance Verification of the Proposed Measure	The proposed changes have two compliance options, one option requires HERS verification and the other option requires building department inspection. The HERS verification (airflow measure and fan watt draw) are current HERS verifications measures: new specifications for the HERS verification are not required. Field verifications can be performed using the guidelines currently provided in the Reference Appendices. Field verification is essential to ensure that the HVAC system is operating within the design specifications. Building department field inspection will be required when the installing contractor opts to use the Return Duct and Grill Sizing Table. Building department field inspectors will need to be trained on the inspection criteria for the Return Duct and Grill Sizing Table. This training could be part of the typical training that is provided to building department during each code cycle change. The proposed changes will require that return duct size and filter grill size be indicated on documentation provided to building inspectors prior to their field inspection.

i. Cost Effectiveness

Proposed Measures: Move the following two measures from the Prescriptive Requirements to Mandatory Measures: Airflow 350 cfm/ton & Fan Watt Draw .58 watts/cfm

a	b	c		d		e		f	g	
Measure Name Airflow 350 cfm/ton & Fan Watt Draw .58 w/cfm	Measure Life (Years)	Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($)		Additional Cost[2]– Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional[3] Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of[4] Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
		Per Unit	Per Proto Building	Per Unit	Per Proto Building	Per Unit	Per Proto Bldg		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
CLZ 1	30	$192	$192	$192	$192	$0	$0	$196	-$4	-$4
CLZ 2	30	$197	$197	$197	$197	$0	$0	$715	-$518	-$518
CLZ 3	30	$192	$192	$192	$192	$0	$0	$388	-$196	-$196
CLZ 4	30	$197	$197	$197	$197	$0	$0	$1,009	-$812	-$812
CLZ 5	30	$197	$197	$197	$197	$0	$0	$220	-$23	-$23
CLZ 6	30	$192	$192	$192	$192	$0	$0	$794	-$602	-$602
CLZ 7	30	$192	$192	$192	$192	$0	$0	$621	-$429	-$429
CLZ 8	30	$197	$197	$197	$197	$0	$0	$1,397	-$1,200	-$1,200
CLZ 9	30	$197	$197	$197	$197	$0	$0	$2,233	-$2,036	-$2,036
CLZ 10	30	$197	$197	$197	$197	$0	$0	$2,522	-$2,325	-$2,325
CLZ 11	30	$308	$308	$308	$308	$0	$0	$3,989	-$3,681	-$3,681
CLZ 12	30	$197	$197	$197	$197	$0	$0	$2,289	-$2,092	-$2,092
CLZ 13	30	$308	$308	$308	$308	$0	$0	$3,961	-$3,653	-$3,653
CLZ 14	30	$340	$340	$340	$340	$0	$0	$3,200	-$2,860	-$2,860
CLZ 15	30	$340	$340	$340	$340	$0	$0	$6,535	-$6,195	-$6,195
CLZ 16	30	$204	$204	$204	$204	$0	$0	$1,696	-$1,492	-$1,492

Figure 5: Cost Effectiveness of Proposed Measures

1. Additional costs are detailed in the Analysis and Results.

2. Post Adoption Measure Costs – The post adoption measure cost is the same as the additional cost since no new materials, techniques or technologies are used for the proposed changes.

3. Maintenance Costs – There are no maintenance cost for the proposed changes.

4. **Energy Cost Savings -** the PV of the energy savings are calculated using the method described in the 2013 LCC Methodology report.

j. Analysis Tools	The proposed measures are Mandatory Measures so analysis tools are not required: measure would not be subject to whole building performance trade-offs.
k. Relationship to Other Measures	No other measures are impacted by these proposed changes.

Overview
Part 2 Residential Duct Sealing

a. Measure Title	Residential Ducts: Sealed and Tested Ducts
b. Description	The proposed change would move sealed and tested ducts from a prescriptive measure (Prescriptive Standards / Component Packages) both for newly constructed residential buildings and alterations in residential buildings to a **mandatory measure**. The currently leakage rates, application rules and exceptions would continue as specified in the 2008 Building Energy Efficiency Standards and Reference Appendices.
c. Type of Change	Describe how the measure or change would be addressed in the California Building Energy Efficiency Standards, e.g., is the proposed change likely to be a mandatory measure, prescriptive requirement, or compliance option? Would it change the way that trade-off calculations are made? The following describes the types of changes in more detail: **Mandatory Measure -** The proposed change would add one mandatory measure: Duct Sealing **Compliance Option -**The change would remove one measure from the list of existing compliance options for meeting the Standards using the performance approach. **Modeling** - The change would modify the calculation procedures or assumptions used in making performance calculations. The proposed change modifies but does not expand the scope of the Building Energy Efficiency Standards. The measure is part of the 2008 Residential Energy Standards: The proposed change moves the measure from the Prescriptive (Component Package D) to Mandatory Measures. The following Standards documents would need to be modified: Building Energy Efficiency Standards, ACM, and Residential Compliance Manual. In each of the documents, the description of the measure would need to be referenced in the Mandatory Measure sections instead of the Prescriptive section. The measures would remain as HERS verification items, so modifications to the Reference Appendices would not be required.

d. Energy Benefits

The Energy Benefits are based on improving the HVAC system performance in the base case house by comparing the prototype house modeled to Prescriptive Package D to the prototype house without duct sealing and testing. The per unit (HVAC system) and per prototype building saving are the same.

Climate Zone	Duct Sealing and Testing	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
1	Per HVAC System & Per Prototype Bldg	58.0	0.00	46.0	0.00	3.36
2		90.0	0.12	37.0	1.78	2.76
3		56.0	0.08	24.0	1.14	1.81
4		110.0	0.18	27.0	2.09	2.02
5		104.0	0.00	28.0	0.00	2.01
6		95.0	0.17	10.0	2.05	0.77
7		58.0	0.13	3.0	1.62	0.22
8		153.0	0.25	7.0	3.13	0.56
9		253.0	0.40	12.0	1.19	0.89
10		818.0	1.36	13.0	16.94	1.34
11		556.0	0.67	36.0	10.30	2.68
12		264.0	0.51	35.0	6.82	2.59
13		580.0	0.65	32.0	10.08	2.33
14		543.0	0.79	42.0	10.88	3.07
15		1329.0	1.55	5.0	22.94	0.33
16		301.0	0.45	66.0	5.97	4.84
Averages		**335.5**	**0.5**	**26.4**	**6.1**	**2.0**

Figure 6: Energy Benefits to base case HVAC from comparing the prototype house modeled to Prescriptive Package D, to the prototype house without duct sealing and testing.

e. Non-Energy Benefits	Duct sealing reduces the introduction of outside air into the duct system and the home. Leaks in the duct system usually increase the air imbalance in a house, increasing infiltration. Return system duct leaks draw air into the duct system from the location of the return ducts such as the attic or garage. Air being drawn from the attic or garage usually will have undesirable particulates or vapors from chemicals stored in garages or fumes from cars engines when the car motor is started with the car in the garage.

f. Environmental Impact

	Mercury	Lead	Copper	Steel	Plastic	Others Fiberglass Insulation
Per Unit Measure[1] (HVAC system)	NC	NC	NC	NC	NC	NC
Per Prototype Building[2]	NC	NC	NC	NC	NC	NC

Figure 7: Environmental Impact: Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

1. Specify the type of unit: per HVAC system.
2. For description of prototype buildings refer to Methodology section below.

	On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Year)
Per Unit Measure[1]	0
Per Prototype Building[2]	0

Figure 8: Water Consumption

3. Specify the type of unit per HVAC system.
4. For description of prototype buildings refer to Methodology section below.

Water Quality Impacts:

Potential increase (I), decrease (D), or no change (NC) in contamination compared to the basecase assumption, including but not limited to: mineralization (calcium, boron, and salts), algae or bacterial buildup, and corrosives as a result of PH change.

	Mineralization (calcium, boron, and salts)	Algae or Bacterial Buildup	Corrosives as a Result of PH Change	Others
Impact (I, D, or NC)	NC	NC	NC	NC
	The measure requires that contractors seal duct systems but there is no impact on water quality.			

Figure 9: Water Quality Impacts

g. Technology Measures	The proposed measure does not require or encourage a particular technology. Contractors will use supplies and materials that are readily available at the HVAC supply houses. Duct sealing techniques use the same skills that installers currently use to install HVAC systems. **Useful Life, Persistence, and Maintenance:** There is no change in the useful life, persistence or maintenance of the duct system due to sealing the duct system. Duct sealing has been used in California for over ten years at this time without any reported adverse impacts on useful life, persistence or maintenance.
h. Performance Verification of the Proposed Measure	The proposed change will use the same leakage rates, verification procedures and exceptions as currently specified in the Standards and Reference Appendices. HERS verification will be required as described in the Reference Appendices.

ii. Cost Effectiveness

a	b	c		d		e		f	g	
Measure Name	Measure Life (Years)	Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($)		Additional Cost[2]– Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional[3] Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of[4] Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
Duct Sealing and Testing		Per Unit	Per Proto Bldg	Per Unit	Per Proto Bldg	Per Unit	Per Proto Bldg		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
CLZ 1	30	$800	$800	$700	$700	$0	$0	$1,569	-$769	-$869
CLZ 2	30	$800	$800	$700	$700	$0	$0	$2,121	-$1,321	-$1,421
CLZ 3	30	$800	$800	$700	$700	$0	$0	$15,391	-$14,591	-$14,691
CLZ 4	30	$800	$800	$700	$700	$0	$0	$1,920	-$1,120	-$1,220
CLZ 5	30	$800	$800	$700	$700	$0	$0	$939	-$139	-$239
CLZ 6	30	$800	$800	$700	$700	$0	$0	$1,317	-$517	-$617
CLZ 7	30	$800	$800	$700	$700	$0	$0	$859	-$59	-$159
CLZ 8	30	$800	$800	$700	$700	$0	$0	$1,724	-$924	-$1,024
CLZ 9	30	$800	$800	$700	$700	$0	$0	$2,840	-$2,040	-$2,140
CLZ 10	30	$800	$800	$700	$700	$0	$0	$8,539	-$7,739	-$7,839
CLZ 11	30	$800	$800	$700	$700	$0	$0	$6,063	-$5,263	-$5,363
CLZ 12	30	$800	$800	$700	$700	$0	$0	$3,919	-$3,119	-$3,219
CLZ 13	30	$800	$800	$700	$700	$0	$0	$5,797	-$4,997	-$5,097
CLZ 14	30	$800	$800	$700	$700	$0	$0	$6,516	-$5,716	-$5,816
CLZ 15	30	$800	$800	$700	$700	$0	$0	$10,869	-$10,069	-$10,169
CLZ 16	30	$800	$800	$700	$700	$0	$0	$5,049	-$4,249	-$4,349

Figure 10: Cost Effectiveness of Proposed Changes

<table>
<tr><td colspan="2">1. Additional cost: The additional cost used for the cost effectiveness analysis was $600 incremental cost for duct sealing and $200 for HERS verification. This value is slightly lower (by $60) than the value used for the 2008 Standards. Duct sealing has become a more common process reducing the cost both by the installing contractor and the HERS rater. Utility incentive programs have been able to increase duct sealing in both newly constructed homes and existing homes for less than $600.

A HERS rater survey yielded a state wide average cost for duct testing of $320 if duct sealing was the sole verification measure, both newly constructed and alterations. The cost is substantially lower when multiple HERS measures are verified. Four of the largest rater firms in the state charge a flat fee per house for all HERS verifications. In this case the average cost of one HERS measure, such as duct testing, is less than $100. This is a wide disparity in costs, but since the number of HERS measures per home will likely be increasing, a mid-range cost seems reasonable. The mid-range value used for this study was $200.

2. Post Adoption Measure Cost: The post adoption measure cost for the installing contractor was reduced to $500 per system. For newly constructed homes, the competitive nature of the bidding process continues to drive down the cost of a standard installation procedure. For alterations, the cost will continue to be higher than newly constructed but as contractors and crew member become more familiar with the process, the time required to seal the duct system will continue to decrease.</td></tr>
<tr><td>j. Analysis Tools</td><td>The proposed measures are Mandatory Measures so analysis tools are not required: measure would not be subject to whole building performance trade-offs.</td></tr>
<tr><td>k. Relationship to Other Measures</td><td>No other measures are impacted by these proposed changes.</td></tr>
</table>

3. Methodology
Part I Cooling Coil Airflow and Fan Watt Draw

For a number of years, there has been concerns that the performance of HVAC systems in both existing homes and newly constructed homes is below the potential of the systems due to the design and installation of the HVAC system. The California Building Energy Efficiency Standards (Title 24) began addressing duct leakage over ten years ago and in subsequent code cycles included other performance based measures to improve HVAC system efficiency. This CASE Study builds on this basis by addressing duct sealing, cooling coil airflow, fan watt draw and system static pressure.

3.1.1 Data Collection

The research foundation for this CASE Study is a California Energy Commission and the California Investor Owned Utilities funded Public Interest Energy Research Program project: *Efficiency Characteristics and Opportunities of New California Homes (ECO)*. The field research, analysis and final report of the ECO project provide the foundation for three CASE studies. For this CASE study, the pertenient research findings, tables and graphs from the ECO Final Report are referenced as appropriate.

The ECO Project had two phases. In Phase One, 80 recently built homes in California were selected and surveyed. The survey included measuring HVAC system characteristics and performance. There were three findings from the ECO project that are most important for this CASE study: homes with ducted HVAC system had low cooling coil airflow, high fan watt draw, and the predominate cause of the low airflow was excessively high resistance in the return

In Phase Two, ten homes out of the original 80 homes were selected for follow-up field work. In these ten homes, HVAC system repairs were made to improve system performance. A table of the repairs is shown below.

House Number	Description of Improvements
4	Increased return size: 20" x 20" x 16" to 20" x 30" x 16" + 10
8	Added a second return
10	Added a second return
17	Moved return closer, added second return duct, new motor
24	Added third return, increased duct size from 16" to 18"
25	Added a second return
27	Increased return size: 14" x 25" x 14" to 20" x 30" x 16"
47	Added a second return
74	Air flow improvement: opened return air passage
77	Air flow improvement: fan speed, open grilles

Figure 11: Improvements to homes during field research

As noted from the table of improvements, the repairs focused on improving the return side of the HVAC system. This decision was based on the measured static pressure values in the test homes. Figure 12 from the ECO final report (shown below) shows that approximately half of the total static pressure in the average system was in the return. This indicates that improvements to the return side of the system are imperative to improving overall performance.

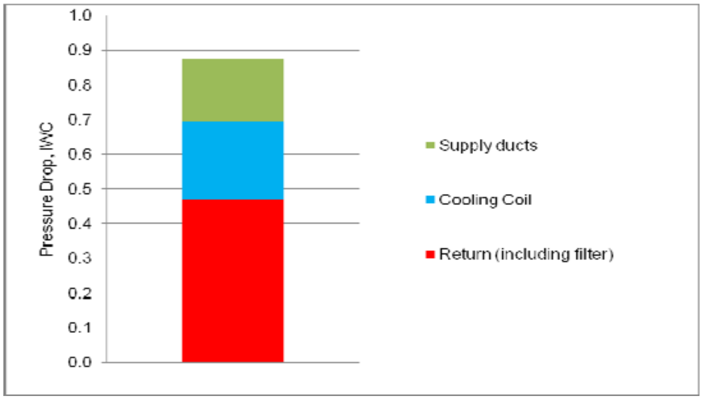


Figure 12: Cooling Airflow Average External Static Pressure

In eight out of the ten homes where improvement were performed, the return duct system was enlarged or an additional return duct was installed. The figure below shows cooling coil airflow in the ten homes in Phase Two before and after the improvements. The average system improved 35%, from 266 cfm to 359 cfm of cooling coil airflow. This improvement shows that the potential impact from improvements to the return side of the HVAC distristribution system.

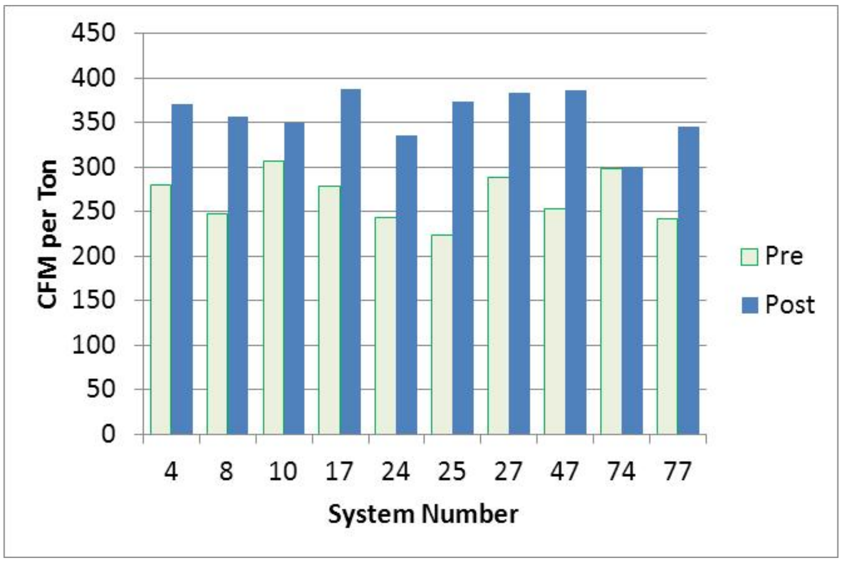


Figure 13: Improvements to return systems in CFM/ton

Figure 14 from the ECO final report (shown below) shows the percentage improvement of normalized sensible EER improvement in the ten homes in Phase Two of the project. The table shows an average improvement of 24%. This demonstrates that overall system performance can be significantly improved by reducing return side resistance (static pressure), thus increasing cooling coil airflow and overall system performance.

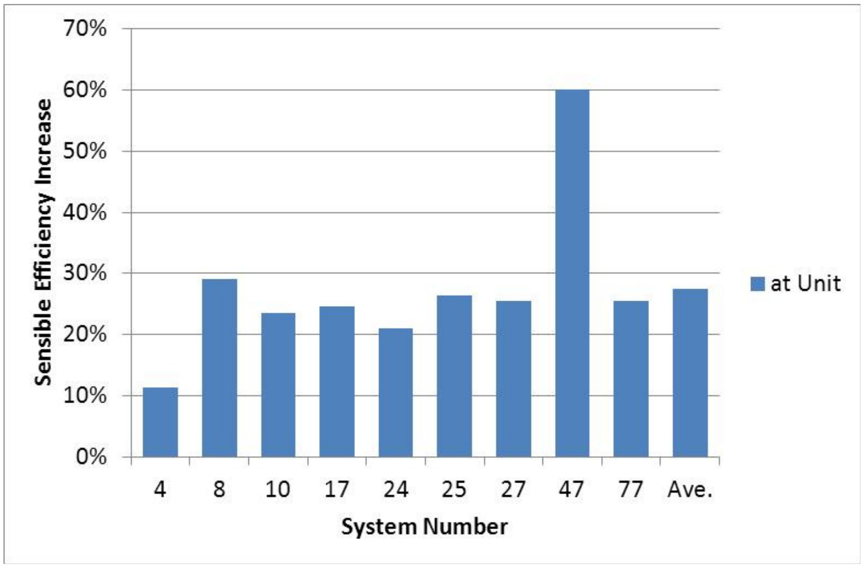


Figure 14: Normalized Sensible EER Improvement

Phase Two of the ECO Project is the basis of the recommendations for this CASE study. One goal of performing the improvements to the ten homes was to measure the potential improvement to HVAC systems using standard materials and standard installation skills; but applied with improved design criteria and improved installation techniques. The project shows the potential for improving airflow and system performance solely, when necessary, by addressing the return side of the airflowsystem. This is not to dismiss the importance of the supply side, nor to discourage good overall duct design. The challenge lies with the numerous design consideration on the supply side that makes simplifying the ACCA guidelines unreasonable. But simplifying and creating tables for the return side is reasonable. The proposed return system sizing table is based on the findings in the ten homes of the potential to improve overall system performance, even when the supply side is not designed to ACCA guidelines.

This CASE Study was also charged with reviewing the potential for establishing a maximum static pressure requirement for ducted HVAC systems. High system static pressure has long been recognized as an indication of excessive resistance in the duct system resulting in low airflow and high fan watt draw. Contrators and enginers that trouble shooting HVAC systems commonly measure static pressure to help identify problems within the system.

The rationale for establishing a maximum static pressure requirement was that installers and designers would improve system design to meet the requirement and system performance would improve. But static pressure is only a symptom of system problems not the direct cause of the problems. The direct cause is poor system design and or installation.

Thus, the decision was made to address the problems of low airflow and high fan watt draw directly by establishing mandatory requirements airflow and fan watt draw but not for static pressure. This achieves the exact same result as establishing a static pressure requirement but with easier and more direct measurements. Currently there is no industry standard for measuring static pressure that can be refered. Nor is there a large group of experienced contractors ready to start measuring system static pressure. Although measuring static pressure is a tool that is used in the HVAC industry, many installers have never measured static pressure. Neither is there experience to know that the results can be consistently duplicated between the installing contractor and a third party verifier.

For each of these reasons, the determination to establish the airflow and fan watt draw requirements achieves all of the desired results without any of the challenges of establishing a new verification requirement.

3.1.2 Energy and Cost Savings

Costs were calculated through collection of costs estimates for materials for return duct, return filter grills, and return filters for both systems designed to ACCA guidelines and systems designed to the propsed Return System Sizing Table. Cost effectiveness was calculated using the 2008 LCC Methodology prepared for the CEC by AEC.[1]

3.1.3 Cost Data Collection

Cost data collection was achieved through a combination of quotes from HVAC supply houses, prices from retails stores, and prices from on-line sales. Labor cost was set at $60/hour for incremental time of on-site installers ($60/hour was established in the ECO project). All labor is additional time on site so does not include travel time or travel expenses.

HERS verification costs varies with the number of HERS measures being verified. When there is only one HERS measure the cost of verification is higher per measure than when there are multiple measures. When cooling coil airflow and fan watt draw are specified, there will always be at least one other HERS measure, Duct Leakage, to be verified. The HERS verification cost that was used assumed multiple HERS verifications resulting in a lower per measure verification cost.

3.1.4 Lifecycle Cost Calculation

Lifecycle cost analysis was calculated using methodology explained in the California Energy Commission report *Life Cycle Cost Methodology 2008 California Building Energy Efficiency Standards*, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = \Delta C - (PV_{TDV} * \Delta TDV)$$

Where:

ΔLCC	change in lifecycle cost, ($/sqft)
ΔC	cost premium associated with the measure, ($/sqft)
PV_{TDV}	present value of a TDV unit (30-year), ($)
ΔTDV	TDV energy savings

1 Architectural Energy Corporation, Life Cycle Cost Methodology 2008 California Building Energy Efficiency Standards, October 21, 2005.

A 30-year lifecycle was used for the LCC methodology. LCC calculations were completed for the Prototype D building.

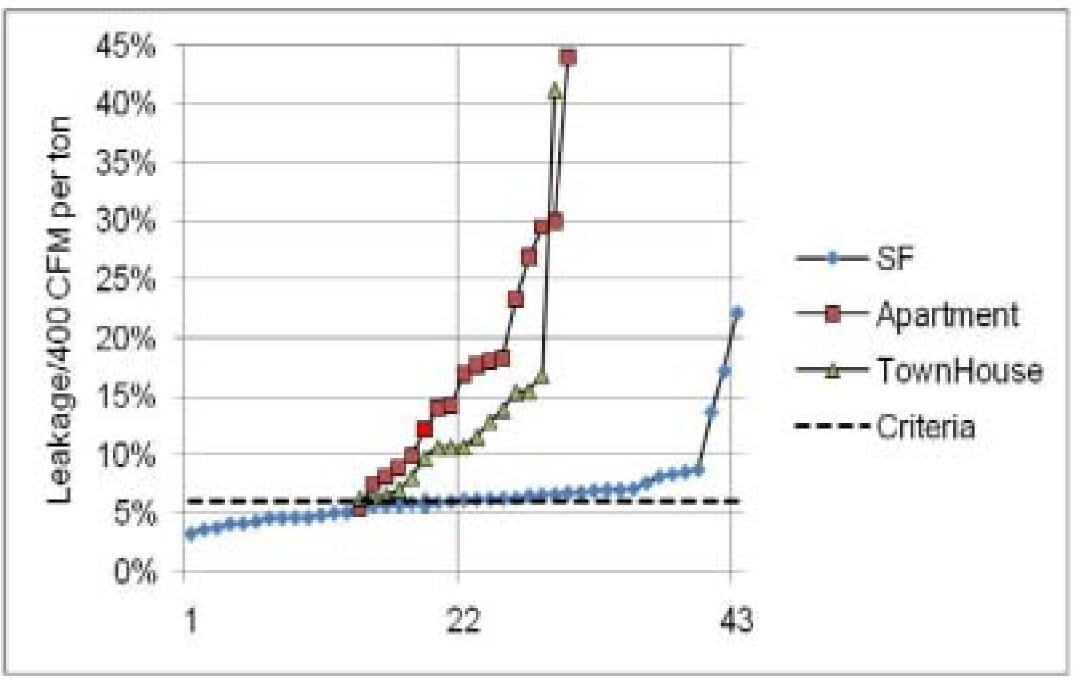
3. Methodology Part II – Duct Sealing

The proposed modification to the Residential Building Energy Standards is to make duct sealing a mandatory measure. Duct sealing and testing has been part of the Residential Energy Standards since the 1998 code cycle. For the 1998 code it was a compliance option and in 2005 it was included in Prescriptive Package D. It has been shown to be cost effective in previous code cycles and again is shown to be cost effective in this CASE study.

3.1.5 Data Collection

The research foundation for this portion of this CASE Study is the same as discussed earlier in this report: *Efficiency Characteristics and Opportunities of New California Homes (ECO).*

The ECO Final Report shows duct leakage in the 80 homes in Phase One of the field research. The homes are groups by occupancy type.



Source: Data – Rick Chitwood

Figure 15: Duct Leakage by Building Type (ECO Final Report)

Figure 15 shows that the median duct leakage for single family homes is almost exactly at the current Title 24 standard of 6%; but there are three homes with substantially higher leakage rates.

Duct leakage for multifamily homes (apartments and townhouses) is much higher. The median leakage for apartments is over 15% and for townhouses it is just over 10%. The ECO field team did not review the Title 24 compliance documentation for these homes, but the duct location likely was modeled as"ducts in conditioned space". The duct system in multifamily homes is commonly located in hallway soffits thereby meeting the criteria of ducts in conditioned space.

Most of the air leakage from ducts in conditioned space is assumed to be leaking from the ducts into conditioned space. But in multifamily units this is not necessarily true. It is difficult to visually determine if duct leakage in a multifamily dwelling unit is leaking to outside the building, into other dwelling units or back into the subject dwelling unit. **Error! Reference source not found.**5 from the ECO Final Report separates the duct leakage between total leakage and leakage to outside.

Figure 16: Duct Leakage Rate for Apartment and Town Houses (ECO Final Report)

The leakage to outside is a significant portion of the duct leakage in both apartments and town houses. The ECO Final Report (Table 23, pg 44) shows that 72% of the apartment units had the duct system 100% in conditioned space or in soffits. For town house, only 5% of the units had ducts 100% in conditioned space or in soffits. This is clearly reflected in the town house graph showing that for most units, total duct leakage and leakage to outside is very similar.

The ECO field research shows that single family homes, on the average, have very reasonable duct leakage rates, but there are still some homes with significant duct leakage. Requiring mandatory duct sealing and testing will have little impact on most builders but will substantially improve duct leakage rates in the homes that currently are being built with high rates of duct leakage.

Since duct sealing has been shown to be cost effective both in past code cycles and in this CASE study, making it a mandatory measure will increase its impact in the coastal climate zones and in the multifamily market. The leakage rates and exceptions would remain as currently structured in the Reference Appendices with one exception as noted in the next paragraph.

For multifamily building, it is proposed that duct sealing be mandatory regardless of duct location. HVAC systems with ducts 100% in conditioned space or in soffits have significant leakage to outside which would be addressed if duct sealing and testing is a mandatory measure.

3.2 Energy and Cost Savings

Cost effectiveness was calculated using the 2008 LCC Methodology prepared for the CEC by AEC.[2]

3.2.1 Cost Data Collection

Duct sealing has been increasingly used by HVAC contractors over the last ten years, but the incremental cost to perform duct sealing remains difficult to acertain. Contractors are reluctant to provide their actual time or cost for multiple reasons. One of the most important reasons is that most contractors do not separate out the job time to perform duct sealing from the other tasks associated with each part of the job. Contractors that perform careful time analysis are usually not willing to give away their data to potential competitors.

The HERS verification cost was determined via a survey of all HERS raters and a survey of several of the large rater firms.

The cost of sealing ducts and the HERS verification costs are not values that can be looked up in a catalogue, but vary but contractor and job. The values used in the cost effectiveness analysis are based current surveys and costs used in previous cost effectiveness analysis.

3.2.2 Lifecycle Cost Calculation

HMG calculated lifecycle cost analysis using methodology explained in the California Energy Commission report *Life Cycle Cost Methodology 2008 California Building Energy Efficiency Standards*, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = \Delta C - (PV_{TDV} * \Delta TDV)$$

Where:

ΔLCC	change in lifecycle cost, ($/sqft)
ΔC	cost premium associated with the measure, ($/sqft)
PV_{TDV}	present value of a TDV unit (30-year), ($)
ΔTDV	TDV energy savings

A 30-year lifecycle was used for the LCC methodology. LCC calculations were completed for the Prototype D building.

2 Architectural Energy Corporation, Life Cycle Cost Methodology 2008 California Building Energy Efficiency Standards, October 21, 2005.

4. Analysis and Results Part I - Cooling Coil Airflow and Fan Watt Draw

4.1 Field Survey Data Summary

As described in Section 3 of this report, this CASE Study draws from the *Efficiency Characteristics and Opportunities of New California Homes* (ECO) project for both its field findings and recommendations.

The ECO Project Phase One findings that address this CASE study are: (see the original report for a complete listing of all Findings)

"The average air conditioner performed well below expectations with low airflow across the indoor coils averaging 322 CFM per ton of cooling capacity."

"The split system air conditioner evaporators drew an average 650 watts per 1000 CFM of airflow."

"Only 28% of the systems tested met the 2008 California Title 24 Standards for cooling airflow and fan power. The predominant cause of low airflow in these units was excessively high return system static pressure (including the filter)."

In Phase Two, ten homes were selected from the original group of 80. Upgrades were made to the HVAC systems in those ten homes and additional cooling system tests were performed. The relevant Finding from Phase II is listed below:

"Repairs/upgrades on the nine units in Phase Two resulted in an average efficiency improvement of 24%"

"The most common and successful repair was reducing the flow resistance of the return duct system between the house and the furnace/air conditioner."

The improvements to the HVAC systems in Phase Two increased cooling coil airflow by 35% over the existing conditions and improved normalized EER at the unit by 24%. The findings from the ECO Final Report indicating the condition of existing HVAC systems and the potential for improved system performance via reasaonable system enhancements are the bais for the proposed recommendations from this CASE study.

4.2 Development of Proposed Measures

The proposed recommendations for Part I of this CASE study are to provide two options to improve cooling coil airflow and fan watt draw. Option 1 is a mandatory measure for 350 cfm/ton cooling coil airflow minimum and .58 watts/cfm fan watt draw maximum. Option 2 is to size the return air system according to the Return System Sizing Table.

The ECO project shows that there is substantial room for improvement in the both airflow and fan watt draw with new HVAC systems. This CASE study studied the findings from the ECO project, and in consultation with the ECO project team, developed the proposed recommendations.

High static pressure is a “symptom” of poor HVAC system design: HVAC systems typically have low airflow and high fan watt draw because of high static pressure. Setting a static pressure standard would address this symptom, but only indirectly. It is much more direct to set a mandatory standard for airflow and fan watt draw rather than trying to control airflow and fan watt draw by setting a standard for static pressure. Measuring airflow and fan watt draw in installed system is easily performed; both contractors and HERS raters are familiar with the procedure. To establish a new procedure for static pressure measurements would be more challenging since the industry, at the present time, does not commonly measure static pressure.

In the 2008 Building Energy Standards, airflow and fan watt draw are prescriptive requirements in climate zones 10 – 15 but are not required in the other climate zones. Informal discussions with HERS raters indicate that airflow and fan watt draw are not commonly used HERS measures in newly constructed homes. Changing the required airflow and fan watt draw from prescriptive to mandatory measures will have the immediate impact of improving two of the deficiencies that the ECO project found in HVAC systems. Thus, the recommendation is to make minimum airflow and maximum fan watt draw mandatory measures for heating and cooling systems.

The 2008 Building Energy Standards established the levels of 350 cfm/ton air flow and .58 watts/cfm fan watt draw. These 2008 Standard levels were based on survey data of HVAC fan motors and the minimum required airflow for proper air conditioner operation. It was determined at that time that nearly any fan motor could meet the criteria with a properly designed duct system. It is recommended that the 2013 Standards used the same airflow and fan watt draw standards, but make them mandatory measures.

Realizing that builder and HVAC contractors are sometimes reluctant to rely upon a standard that cannot be measured until after the system is installed and functional, a second option for compliance was developed that avoids that challenge. The second option is a set of return duct and filter grill sizing tables that can be used in lieu of measuring airflow or fan watt draw. Return systems installed using the return system sizes in the proposed tables, have a reasonable expectation that both the airflow and fan watt draw specifications will be met. Airflow and fan watt draw measures will not be required if the return system sizing tables are used, rather building inspectors would verify that the correctly sized duct and filter grills are installed.

The ECO Final Report Section 4.2 Discussion states, “*This study showed the primary driver of the low airflow is the restrictive nature of the return system*.” The ECO project measured static pressure in the homes in their study: specifically the measurements included the static pressure in the supply ducts, return system and the cooling coil. The ECO report shows that approximately 50% of the total static pressure in the average system is attributed to the return system including the filter.

The proposed sizing tables address only return duct and grill sizing, not supply systems. There are too many variables with supply ducts to create a simple sizing table. But return systems are typically straightforward enough that sizing tables are reasonable. The ECO Final Project Report Section 4.2.2 Table 25: Prescriptive Return Systems, describes the field experience and findings from Phase Two of the project and discusses the development of the return system sizing tables. The return system sizing tables are designed to result in a maximum static pressure drop in the return system of 0.0375 IWC. The proposed return system sizing tables in this CASE study are based on sizes developed in the ECO project, Table 25.

The proposed return duct and filter grill sizes are larger than ACCA guidelines since the sizing tables only address the return system. If an HVAC system is designed to ACCA standards for both supply and return, the airflow and fan watt draw likely will meet the proposed airflow and fan watt draw specifications. However, since the tables only address the return system, the return system must be oversized to compensate for the potential of an undersized supply. Another reason for the larger proposed duct sizes is that the field survey found that return systems commonly have restrictions such as excessive bends, compression of the duct and restrictions at the entry to the furnace/air handler blower compartment. Each of these factors reduces airflow below what is typically expected through that particular size flex duct.

The proposed return system size tables are shown below. Separate tables are provided for systems with a single return and systems with multiple returns.

Single Return			
Tons	Nominal Airflow	Return Duct Size (inches)	Return Grill Gross Area
1.5	600	16	500 sq. in.
2	800	18	600 sq. in.
2.5	1000	20	800 sq. in.
3	1200	Multiple returns required	
3.5	1400		
4	1600		
5	2000		

Figure 17: Single return: proposed return system sizes

Multiple Return Systems				
Nominal Capacity (Tons)	Return # 1	Return # 2	Return Grills Gross Area	
	Duct Size (inches)	Duct Size (inches)		
1.5	12	10	500	sq. in.
2	14	12	600	sq. in.
2.5	14	14	800	sq. in.
3	16	14	900	sq. in.
3.5	16	16	1000	sq. in.
4	18	18	1200	sq. in.
5	20	20	1500	sq. in.

Figure 18: Multiple return: proposed return system sizes

The proposed airflow standard of 350 cfm/ton minimum and fan watt draw of .58 watt/cfm maximum would apply in the following situations:

a. Newly constructed single family and multifamily homes in all climate zones when a ducted heated and cooling system is installed. Heating only systems are exempt. Applies to both split systems and package systems.

b. HVAC alterations when there is a ducted heating and cooling system if a completely new duct system is installed or the entire existing duct system is replaced. Heating only systems are exempt. Applies to both split systems and package systems.

4.2.1 Energy and Cost Savings

The figure below presents the prototype building used to calculate energy benefits, environmental impacts, and cost effectiveness.

	Occupancy Type	Area (Square Feet)	Number of Stories	Other Notes
Prototype 1	Single Family, Residential	2700	2	This is the default prototype D as found in the new CALRES tool and also as described in the 2008 Title 24 ACM.

Figure 19: Building prototype characteristics

A multi-step process was used to determine the incremental cost of return systems sized according to the Return Sizing Table compared to systems sized to ACCA guidelines. The process is described below with the tables used in the calculations.

1. A return duct and return filter grill sizing table was developed based on ACCA guidelines. ACCA does not provide specific duct sizes, rather it provides a methodology to calculate the duct sizes based on system parameters. The following figure was developed based on typical flex duct systems located in vented attics, following the ACCA guidelines.

Flex Duct Return - ACCA Guidelines			
Nominal Capacity (Tons)	Return Duct Size (inches)	Return Grill Gross Area (sq. in.)	Example Grill Size (inches)
1.5	14	400	20 X 20
2	16	480	24 X 20
2.5	16	600	30 X 20
3	18	720	36 X 20
3.5	18	800	40 X 20
4	20	800	40 X 20
5	2 - 16"	1124	2 - 30 & 20

Figure 20: Flex return duct and grill sizing according to ACCA Guidelines

2. The cost of the materials for a return system sized according to the ACCA guideline were secured. The cost was calculated for both R-6 and R-8 flex duct.
3. Three HVAC supply houses were contacted to secure contractor prices for flex duct and return filter grills. Supply houses often time have different prices depending on the volume of business they do with a contractor; we requested the mid-range price. The prices from the supply houses were averaged.
4. The three HVAC supply houses that were contacted for prices do not currently stock R-4.2 flex duct. The quoted price for R-4.2 duct was approximately the same as R-6 flex duct since it had to be special ordered. Thus, cost were only calculated for R-6 and R-8 flex ducts. In the three climate zones where R-4.2 duct insulation is the current prescriptive standard, the costs for R-6 flex duct were used.
5. The prices for 2" MERV 8 pleated filters were secured from three sources: HVAC supply houses, retail stores and the internet. Since filters are consumer products they are readily available at retail stores and over the internet in addition to HVAC supply houses.
6. 30% contractor markup was added to material costs to approximate typical contractor pricing.

Return System Built to ACCA Sizing Guidelines w/ **R-6 Flex Duct**							
Nominal Capacity (tons)	Duct Size (inches)	Duct Cost (R-6)	Return Grill	2" Filter Grill	2" Filter	Material Cost	Material Cost w/ 30% markup
1.5	14	$51.18	20x20	$18.01	$10.42	$79.61	$103.49
2	16	$59.53	25x20	$19.35	$10.97	$89.85	$116.80
2.5	16	$59.53	30x20	$23.63	$14.00	$97.16	$126.30
3	18	$68.83	36x20	$35.00	$18.10	$121.93	$158.51
3.5	18	$68.83	40x20	$45.00	$24.12	$137.95	$179.33
4	20	$84.74	40x20	$45.00	$24.12	$153.86	$200.02
5	2 - 16's	$119.05	2 - 30 x 20	$47.26	$28.00	$194.31	$252.61

Figure 21: R-6 flex return duct and grill sizing according to ACCA Guidelines

Return System Built to ACCA Sizing Guidelines w/ **R-8 Flex Duct**							
Nominal Capacity (tons)	Duct Size (inches)	Duct Cost (R-8)	Return Grill	2" Filter Grill	2" Filter	Material Cost	Material Cost w/ 30% markup
1.5	14	$65.82	20x20	$18.01	$10.42	$94.25	$122.53
2	16	$78.65	25x20	$19.35	$10.97	$108.98	$141.67
2.5	16	$78.65	30x20	$23.63	$14.00	$116.28	$151.17
3	18	$93.09	36x20	$35.00	$18.10	$146.19	$190.05
3.5	18	$93.09	40x20	$45.00	$24.12	$162.21	$210.87
4	20	$119.27	40x20	$45.00	$24.12	$188.39	$244.91
5	2 - 16's	$157.31	2 - 30 x 20	$47.26	$28.00	$232.57	$302.34

Figure 22: R-8 flex return duct and grill sizing according to ACCA Guidelines

7. Two similar tables were developed based on the Proposed Return System Sizing table that includes larger ducts, larger filter grills and larger filters.
8. If the system includes multiple returns, additional labor cost was included to allow for the time to install the second return duct and filter grill.
9. The same process that was used to calculated the cost of the system sized to ACCA guidelines was used to secure these costs and the same 30% contractor markup was applied to the materials.

Return Air System Built to Proposed Return Sizing Table w/ **R-6 Ducts**									
Nominal Capacity (tons)	Duct Size (inches)	Duct Cost (R-6)	Return Grill	2" Filter Grill	2" Filter	Material Cost	Material Cost w/ 30% markup	Incremental Labor Cost @ $60/hr	Duct & Grill Cost
1.5	16	$59.53	20x25	$19.35	$10.97	$89.85	$116.80	$0.00	$116.80
2	18	$68.83	20x30	$23.63	$18.10	$110.56	$143.73	$0.00	$143.73
2.5	14 & 14	$102.36	2 - 20x20	$36.02	$20.84	$159.22	$206.99	$120.00	$326.99
3	16 & 14	$110.71	20x30 & 15x20	$41.64	$24.63	$176.98	$230.07	$120.00	$350.07
3.5	16 & 16	$119.05	2 - 25x20	$38.70	$21.94	$179.70	$233.61	$120.00	$353.61
4	18 & 18	$137.65	2 - 30x20	$47.26	$28.00	$212.91	$276.79	$120.00	$396.79
5	2 - 18's & 14	$188.83	2 - 30x20 & 15x20	$65.27	$38.63	$292.73	$380.55	$180.00	$560.55

Figure 23: R-6 Ducts and grill sizing for return air systems according to Proposed Return Sizing Table

Return Air System Built to Proposed Return Sizing Table w/ **R-8 Ducts**									
Nominal Capacity (tons)	Duct Size (inches)	Duct Cost (R-6)	Return Grill	2" Filter Grill	2" Filter	Material Cost	Material Cost w/ 30% markup	Incremental Labor Cost @ $60/hr	Duct & Grill Cost
1.5	16	$78.65	20x25	$19.35	$10.97	$108.98	$141.67	$0.00	$141.67
2	18	$93.09	20x30	$23.63	$18.10	$134.82	$175.27	$0.00	$175.27
2.5	14 & 14	$131.65	2 - 20x20	$36.02	$20.84	$188.51	$245.06	$120.00	$365.06
3	16 & 14	$144.48	20x30 & 15x20	$41.64	$24.63	$210.75	$273.97	$120.00	$393.97
3.5	16 & 16	$157.31	2 - 25x20	$38.70	$21.94	$217.95	$283.34	$120.00	$403.34
4	18 & 18	$186.18	2 - 30x20	$47.26	$28.00	$261.44	$339.87	$120.00	$459.87
5	2 - 18's & 14	$252.00	2 - 30x20 & 15x20	$65.27	$38.63	$355.90	$462.67	$180.00	$642.67

Figure 24: R-8 Ducts and grill sizing for return air systems according to Proposed Return Sizing Table

4.2.2 Cost-effectiveness

The incremental cost was calculated for installing a return air system sized according to the proposed requirements compared to a return system sized to ACCA guidelines. The system costs included the current duct insulation R-value and the size of the A/C system for the prototype house for each climate zone. The load calculations from the CalRes computer simulations were used as the basis for the air conditioning equipment size selection. The A/C size is smaller than typical common practice but larger than best practice as advised by whole house performance contractors.

Incremental Cost					
Climate Zone	Duct R-Value (2008 T-24)	System Size (nominal tons)	Cost for Return Air System Installed According to ACCA Guidelines	Cost for Return Air System Installed Accorded to Proposed Return Duct Table	Incremental Cost (materials & labor) Based on System Size and Duct R-Value
1	6	3	$159	$350	$192
2	6	4	$200	$397	$197
3	6	3	$159	$350	$192
4	6	4	$200	$397	$197
5	6	4	$200	$397	$197
6	4.2	3	$159	$350	$192
7	4.2	3	$159	$350	$192
8	4.2	4	$200	$397	$197
9	6	4	$200	$397	$197
10	6	4	$200	$397	$197
11	6	5	$253	$561	$308
12	6	4	$200	$397	$197
13	6	5	$253	$561	$308
14	8	5	$302	$643	$340
15	8	5	$302	$643	$340
16	8	3	$190	$394	$204

Figure 25: Incremental cost of installing return air systems sized according to the proposed requirements, compared to a return system sized to ACCA guidelines.

Once the incremental cost of the systems sized to the proposed Return Sizing Table was completed, the energy cost savings was calculated. The 2013 CALRES software was used to calculate the energy cost savings per system/building.

The prototypical building was modeled in each climate zone with the 2008 Package D measures: except airflow was set at 300 cfm and fan watt draw was set at .80 watts/cfm. The prototypical building was then modeled in each climate zone, again with the same Package D set of measures: except this time airflow was set at 350 cfm/ton airflow and the fan watt draw was set at .58 watt/cfm. The savings were calculated based on the dollar/KTDV value provided for the LCC analysis.

Climate Zone	TDV KBtu/sf-yr			Total
	Airflow 300 cfm/ton Fan watt draw .80 watts/cfm	Airfow 350 cfm/ton Fan Watt Draw .58 watts/cfm	Savings	
1	49.31	48.89	0.42	$196
2	62.83	61.30	1.53	$715
3	43.10	42.27	0.83	$388
4	62.41	60.25	2.16	$1,009
5	39.87	39.40	0.47	$220
6	45.52	43.82	1.70	$794
7	35.17	33.84	1.33	$621
8	60.03	57.04	2.99	$1,397
9	87.12	82.34	4.78	$2,233
10	100.70	95.30	5.40	$2,522
11	152.86	144.32	8.54	$3,989
12	105.51	100.61	4.90	$2,289
13	150.36	141.88	8.48	$3,961
14	139.59	132.74	6.85	$3,200
15	214.07	200.08	13.99	$6,535
16	109.43	105.80	3.63	$1,696

Figure 26: Energy cost savings per system/building from proposed return air measures

The cost-effectiveness varies considerably by climate zone, with the proposed measures being barely cost-effective in the mild climate zones. The proposed recommendations only apply when air conditioning is installed in a home. The proposed recommendations are not cost-effective for homes with heating only HVAC systems, so heating only systems are not included in the recommendations.

In the hot climate zones the proposed recommendations are very cost-effective, which is completely expected by measures that improve air conditioning system efficiency.

4.2.3 Modeling Rules and Algorithms

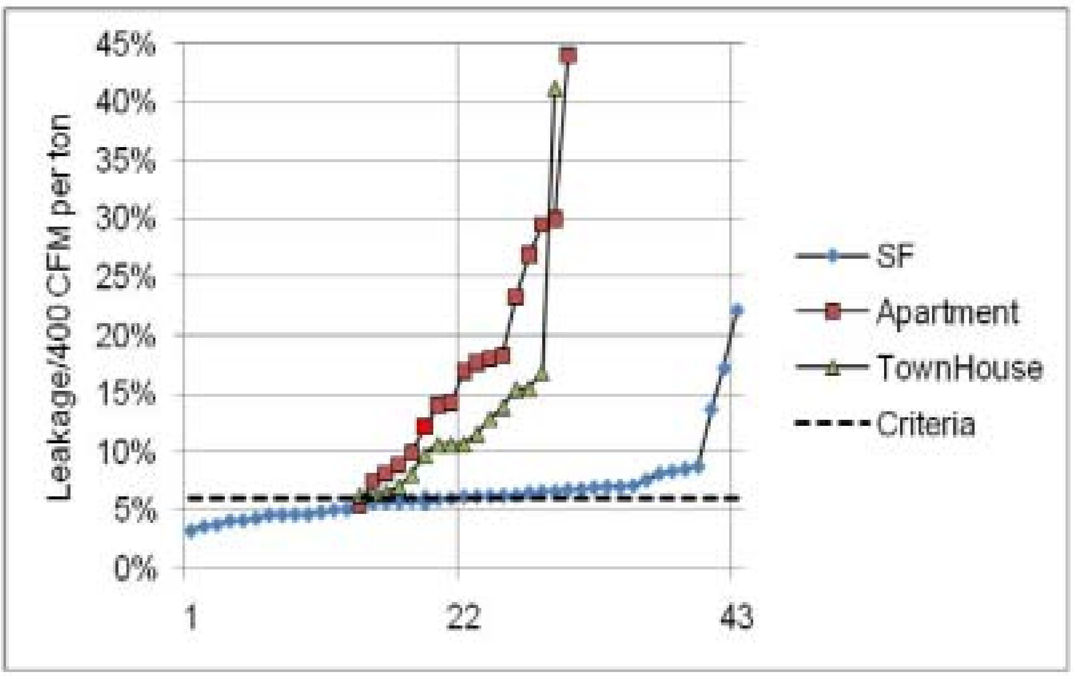
The modeling rules and algorithms used for the proposed changes are currently used in the modeling software. No additional changes or modifications will be required.

The ability to model higher airflow or lower fan watt draw would continue to be compliance options as allowed in the 2008 Energy Standards.

Analysis and Results
Part II - Duct Sealing

4.3 Field Survey Data Summary

The *Efficiency Characteristics and Opportunities of New California Homes (ECO)* project provided the field research and analysis used for this CASE study. The ECO project measured the duct leakage in each of the homes with duct systems that were part of the study. The ECO Final Report Figure 23 (shown below) shows duct leakage in the 80 homes subdivided according to building type.



Source: Data – Rick Chitwood

Figure 27: Duct Leakage by Building Type

Duct leakage for single family homes shows a median value very close to the current Title 24 standard of 6% leakage. While most of the home are very close to the 6% standard, three homes have substantially higher leakage rates. While these values are lower than the current untested duct leakage values of 22% for homes built since 2001, the three home with higher leakage rates still indicate room for improvement in duct sealing and testing.

Duct leakage for multifamily homes (apartments and townhouses) is higher than for single family homes. The median leakage for apartments is over 15% and for townhouses it is just over 10%. The ECO field team did not review the Title 24 compliance documentation for these homes. But for the apartment units, it is reasonable to assume most of the the duct system was modeled with "ducts in conditioned space". The duct systems were usually located in hallway soffits that meets the criteria of the ducts being in conditioned space, which is very common in apartment buildings.

When ducts are located in conditioned space, the modeling assumption is that most of the air leakage from ducts is leaking into conditioned space. But in multifamily units this is not necessarily true. It is difficult to visually determine if duct leakage in a multifamily dwelling unit is leaking to outside the building, into other dwelling units or back into the dwelling unit. **Error! Reference source not found.** from the ECO Final Report separates the duct leakage between total leakage and leakage to outside.

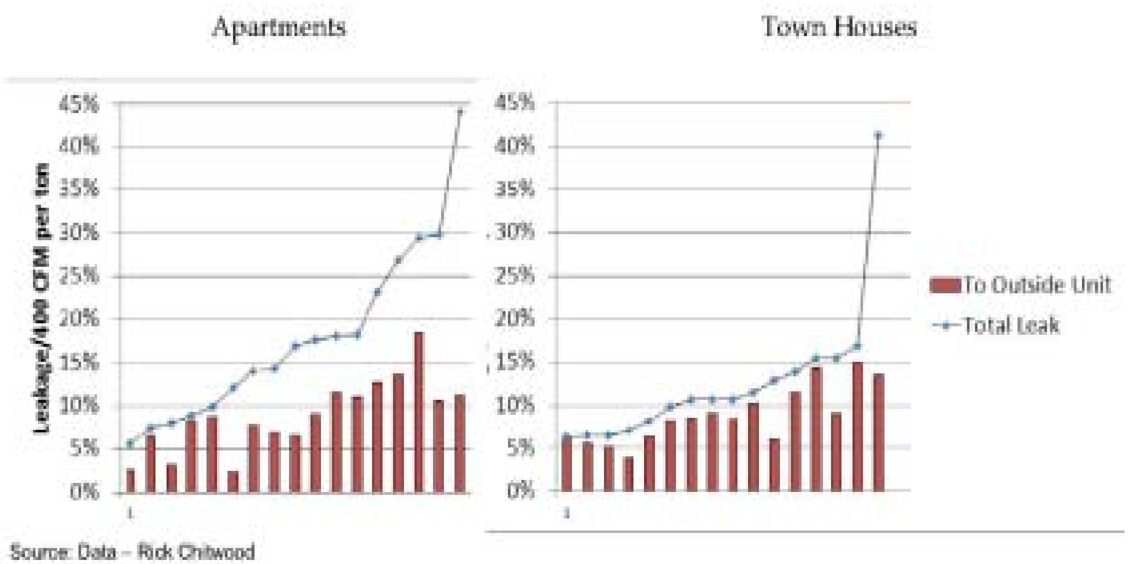


Figure 28: Duct Leakage Rate for Apartment and Town Houses (ECO Final Report)

The ECO Final Report Table 23 (pg 44) shows that 72% of the apartment units had the duct system 100% in conditioned space or in soffits. For town house, only 5% of the units had ducts 100% in conditioned space or in soffits. This is clearly reflected in the town house graph showing that for most units, total duct leakage and leakage to outside is very similar.

The graph for apartment duct leakage shows that even when the ducts are in conditioned space, much of the duct leakage continues to be leakage to outside.

The ECO field research shows that single family homes, on the average, have very reasonable duct leakage rates, but there are still some homes with significant duct leakage. Requiring mandatory duct sealing and testing will have little impact on most builders but will substantially improve duct leakage rates in the homes that currently are being built with high rates of duct leakage.

Since duct sealing has been shown to be cost effective both in past code cycles and in this CASE study, making it a mandatory measure will increase its impact in the coastal climate zones and in the multifamily market. The leakage rates and exceptions would remain as currently structured in the Reference Appendices with one exception as noted in the next paragraph.

For multifamily building, it is proposed that duct sealing be mandatory regardless of duct location. HVAC systems with ducts 100% in conditioned space or in soffits have significant leakage to outside which would be addressed if duct sealing and testing is a mandatory measure.

4.4 Energy and Cost Savings

The 2013 CalRes software was used to model the prototypical house using the algorithm that is already in the software for duct sealing. The prototypical house was modeled in each climate zone according to 2008 Prescriptive Package D which includes duct leakage at 6% (8% within the calculation). The prototypical house was then rerun without duct leakage being selected, setting the duct leakage rate at 22% since the house was built post 2001.

The second column below is the TDV kBtu/sf-yr values of the prototypical house modeled to prescriptive package D for each climate zone. The third column has one change in the computer model, duct testing is not included. The fourth column shows the difference (savings) between the conditions and the next column shows the value of the energy savings.

Climate Zone	TDV Kbtu/sf-yr			Total
	Package D Design	Package D without Duct Sealing	Savings	
1	45.95	49.31	3.36	$1,569
2	57.24	61.78	4.54	$2,121
3	10.15	43.1	32.95	$15,391
4	58.3	62.41	4.11	$1,920
5	37.86	39.87	2.01	$939
6	42.7	45.52	2.82	$1,317
7	33.33	35.17	1.84	$859
8	53.85	57.54	3.69	$1,724
9	76.86	82.94	6.08	$2,840
10	82.42	100.7	18.28	$8,539
11	123.91	136.89	12.98	$6,063
12	87.13	95.52	8.39	$3,919
13	122.24	134.65	12.41	$5,797
14	112.36	126.31	13.95	$6,516
15	162.9	186.17	23.27	$10,869
16	98.62	109.43	10.81	$5,049

Figure 29: Energy and cost savings per climate zone

The additional cost used for the cost effectiveness analysis was $600 incremental cost for duct sealing and $200 for HERS verification. This value is slightly lower (by $60) than the value used for the 2008 Standards.

Securing duct sealing cost is difficult for a variety of reasons. Contractors commonly do not have hard values or were not willing to provide costs. Informally several contractors were asks if $600 is a reasonable estimate of the cost of sealing ducts including the cost of the duct test. For newly constructed, the answer was always yes. For existing homes, the answer was, usually but there are always exceptions. When ask if the cost of duct testing had declined and would continue to decline and it becomes more common, a majority of contractors agreed.

Duct sealing in newly constructed homes is straightforward in most cases. The cost for sealing ducts in existing homes is much more variable due to all the variations that occur in existing homes.

A HERS rater survey yielded a state wide average cost for duct leakage verification of $320 if duct sealing was the sole verification measure, both for newly constructed and alterations. This is the cost for a verified unit, excluding the potential economy of sampling. The cost is substantially lower when multiple HERS measures are verified. Four of the largest rater firms in the state charge a flat fee per house for all HERS verifications. In this case the average cost of one HERS measure, such as duct testing, is less than $100. This is a wide disparity in costs, but given that sampling reduces the verification cost, and the number of HERS measures per home is likely to increase, a mid-range cost seems reasonable. The mid-range value used for this study was $200.

The post adoption measure cost for the installing contractor was reduced to $500 per system. For newly constructed homes, the competitive nature of the bidding process continues to drive down the cost of a standard installation procedure. For alterations, the cost will continue to be higher than newly constructed but as contractors and crew member become more familiar with the process, the time required to seal the duct system will continue to decrease.

4.5 Cost-effectiveness

Results of the cost-effectiveness analysis are presented in Section 2 of this report. The measure is cost-effective in all climate zones. Climate zones 5 (central coast) and 7 (San Diego) are the two climate zones with lowest level of cost effectiveness. This is reasonable and to be expected since these very mild climate zones have minimal heating or cooling. But since duct sealing is cost effective even in the mildest climates in California, it is very cost effective in the other climate zones. This is a strong statement of the rationale for making duct testing a mandatory measure.

4.6 Modeling Rules or Algorithms.

The modeling rules and algorithms used for the proposed changes are currently used in the modeling software. No additional changes or modifications will be required.

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices
Part 1 – Cooling Coil Airflow and Fan Watt Draw

Section 150(m)11

11. Ducted split system central air conditioners and ducted split system heat pumps shall meet either of the following.

A. Simultaneously demonstrate, in every zonal control mode, an airflow equal to or greater than 350 CFM/ton of nominal cooling capacity and a fan watt draw equal to or less than 0.58 W/CFM as specified in Reference Residential Appendix RA3

B. The return duct(s) and return grill shall be sized in accordance with Table 150-D or Table 150-E

Table 150-D Return System Sizing Table

Single Return		
Tons	Return Duct Size (inches)	Return Grill Gross Area
1.5	16	500 sq. in.
2	18	600 sq. in.
2.5	20	800 sq. in.
3	Multiple returns required	
3.5		
4		
5		

Table 150-D Return System Sizing Table

Multiple Return Systems				
Nominal Capacity (Tons)	Return # 1	Return # 2	Return Grills Gross Area	
	Duct Size (inches)	Duct Size (inches)		
1.5	12	10	500	sq. in.
2	14	12	600	sq. in.
2.5	14	14	800	sq. in.
3	16	14	900	sq. in.
3.5	16	16	1000	sq. in.
4	18	18	1200	sq. in.
5	20	20	1500	sq. in.

Section 151(f)

7. Space heating and space cooling. All space heating and space cooling equipment shall comply with minimum Appliance Efficiency Regulations as specified in Sections 110 through 112 and meet the requirements of subsections A and B:

A. When refrigerant charge measurement or charge indicator display is shown as required by TABLE 151-B , TABLE 151-C or TABLE 151-D, ducted split system central air conditioners and ducted split system heat pumps shall:

i. Have temperature measurement access holes (TMAH) saturation temperature measurement sensors (STMS), and proper refrigerant charge confirmed through field verification and diagnostic testing in accordance with procedures set forth in the Reference Residential Appendix RA3.2; or ii. Be equipped with a charge indicator display (CID) clearly visible to the occupant. The display shall demand attention when the air conditioner fails to meet the requirements contained in Reference Joint Appendix JA6.2. The display shall be constantly visible and within one foot of the thermostat. Systems equipped with a CID shall meet the requirements of Residential Field Verification and Diagnostic Test Procedures of Reference Residential Appendix RA3.4 and the specifications of Reference Joint Appendix JA6.

B. ~~When airflow and fan watt draw is shown as required by TABLE 151-B TABLE 151-C or TABLE 151-D, d~~Ducted split system central air conditioners and ducted split system heat pumps shall:

i. Central forced air system fans shall simultaneously demonstrate, in every zonal control mode, an airflow equal to or greater than 350 CFM/ton of nominal cooling capacity and a fan watt draw equal to or less than 0.58 W/CFM as specified in Reference Residential Appendix RA3; and

~~ii. Have a hole for the placement of a static pressure probe (HSPP) or a permanently installed static pressure probe (PSPP) in the supply plenum downstream of the air conditioning evaporator coil.~~

~~The size, location, and labeling shall meet the requirements specified in Reference Residential Appendix RA3.3~~.

Section 152(b)1.G (change current section G to H and current section H to I)

G. 11. Ducted split system central air conditioners and ducted split system heat pumps shall meet either of the following.

A. Simultaneously demonstrate, in every zonal control mode, an airflow equal to or greater than 350 CFM/ton of nominal cooling capacity and a fan watt draw equal to or less than 0.58 W/CFM as specified in Reference Residential Appendix RA3

B. The return duct(s) and return grill shall be sized in accordance with Table 150-D or Table 150-E

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices Part 2 – Duct Sealing

Section 150

(m) **Air-distribution System Ducts, Plenums, and Fans.**

1. **CMC compliance.** All air-distribution system ducts and plenums, including, but not limited to, mechanical closets and air-handler boxes, shall be installed, sealed and insulated to meet the requirements of the CMC Sections 601, 602, 603, 604, 605 and Standard 6-5, incorporated herein by reference. Portions of supply-air and return-air ducts and plenums shall either be insulated to a minimum installed level of R-4.2 (or any higher level required by CMC Section 605) or be enclosed entirely in conditioned space. Connections of metal ducts and the inner core of flexible ducts shall be mechanically fastened. Openings shall be sealed with mastic, tape, or other duct-closure system that meets the applicable requirements of UL 181, UL 181A or UL 181B or aerosol sealant that meets the requirements of UL 723. If mastic or tape is used to seal openings greater than 1/4 inch, the combination of mastic and either mesh or tape shall be used.

   Building cavities, support platforms for air handlers, and plenums defined or constructed with materials other than sealed sheet metal, duct board or flexible duct shall not be used for conveying conditioned air. Building cavities and support platforms may contain ducts. Ducts installed in cavities and support platforms shall not be compressed to cause reductions in the cross-sectional area of the ducts.

   Duct systems shall be sealed, as confirmed through field verification and diagnostic testing, in accordance with procedures specified in the Reference Appendices.

   Note: Requirements for duct sealing do not apply to buildings with space conditioning systems that have no ducts.

Section 151

10. **Space conditioning ducts.** All ducts shall either be in conditioned space or be insulated to a minimum installed level as specified by TABLE 151-B, TABLE 151-C or TABLE 151-D and meet the minimum mandatory requirements of Section 150(m).

    ~~When duct sealing is shown as required by TABLE 151-B, TABLE 151-C or TABLE 151-D~~. ~~d~~Duct systems shall be sealed, as confirmed through field verification and diagnostic testing, in accordance with procedures specified in the Reference Residential Appendix RA3.

    NOTE: Requirements for duct sealing ~~and duct insulation in Tables 151-B, 151-C, and 151-D~~ do not apply to buildings with space conditioning systems that have no ducts.

    NOTE: Requirements for ~~duct sealing and~~ duct insulation in Tables 151-B, 151-C, and 151-D do not apply to buildings with space conditioning systems that have no ducts.

Section 152

D. When more than 40 feet of new or replacement space-conditioning ducts are installed in unconditioned space, the new ducts shall meet the requirements of Section 150(m) and the duct insulation requirements of Package D Section 151(f)10~~. If ducts are installed in climate zones 2, 9, 10, 11, 12, 13, 14, 15, or 16, t~~The duct system shall be sealed, as confirmed through field verification and diagnostic testing in accordance with procedures for duct sealing of existing duct systems as specified in the Reference Residential Appendix RA3, to meet one of the following requirements:

i. If the new ducts form an entirely new duct system directly connected to the air handler, the measured duct leakage shall be less than 6 percent of fan flow and meet the airflow requirements of Reference Residential Appendix RA3; or

ii. If the new ducts are an extension of an existing duct system, the combined new and existing duct system shall meet one of the following requirements:

a. The measured duct leakage shall be less than 15 percent of system fan flow; or

b. The measured duct leakage to outside shall be less than 10 percent of system fan flow; or

c. The duct leakage shall be reduced by more than 60 percent relative to the leakage prior to the installation of the new ducts and a visual inspection, including a smoke test, shall demonstrate that all accessible leaks have been sealed; or

d. If it is not possible to meet the duct sealing requirements of subsection a, b, or c, all accessible leaks shall be sealed and verified through a visual inspection and a smoke test by a certified HERS rater.

EXCEPTION to Section 152(b)1Dii: Existing duct systems that are extended, which are constructed, insulated or sealed with asbestos.

E. ~~In climate zones 2, 9, 10, 11, 12, 13, 14, 15, and 16, w~~When a space-conditioning system is altered by the installation or replacement of space-conditioning equipment (including replacement of the air handler, outdoor condensing unit of a split system air conditioner or heat pump, cooling or heating coil, or the furnace heat exchanger) the duct system that is connected to the new or replacement space-conditioning equipment shall be sealed, as confirmed through field verification and diagnostic testing in accordance with procedures for duct sealing of existing duct systems as specified in the Reference Residential Appendix RA3, to one of the following requirements.

i. The measured duct leakage shall be less than 15 percent of system fan flow; or

ii. The measured duct leakage to outside shall be less than 10 percent of system fan flow; or

iii. The measured duct leakage shall be reduced by more than 60 percent relative to the measured leakage prior to the installation or replacement of the space conditioning equipment and a visual inspection, including a smoke test, shall demonstrate that all accessible leaks have been sealed; or

iv. If it is not possible to meet the duct requirements of i, ii, or iii, all accessible leaks shall be sealed and verified through a visual inspection and a smoke test by a certified HERS rater.

EXCEPTION 1 to Section 152(b)1E: Duct systems that are documented to have been previously sealed as confirmed through field verification and diagnostic testing in accordance with procedures in the Reference Appendix RA3.

EXCEPTION 2 to Section 152(b)1E: Duct systems with less than 40 linear feet in unconditioned spaces.

EXCEPTION 3 to Section 152(b)1E: Existing duct systems constructed, insulated or sealed with asbestos.

6. Bibliography and Other Research

Proctor, John, Rick Chitwood, Bruce A. Wilcox. (Proctor Engineering Group, Ltd., Chitwood Energy Management, Bruce A. Wilcox). 2011. ***Efficiency Characteristics and Opportunities of New***