Duct Sealing Requirements upon HVAC or Duct-System Replacement: Light Commercial Buildings

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Overview

Description

This Code Change Proposal encompasses two changes to the existing California Building Energy Efficiency Standards: 1) a requirement that duct systems be sealed and tested at the time that an air-conditioner, heat-pump, or furnace is installed in certain existing light commercial buildings, and 2) a requirement that new or replacement duct systems in that same class of buildings meet the same insulation levels as ducts in similarly designed new buildings (i.e. R-8), as well as be sealed and tested. The proposed requirements are triggered either by installation of a furnace, a packaged indoor/outdoor unit, or replacement or installation of an air handler, cooling or heating coil, or furnace heat exchanger, or by installation of a new or replacement duct system in an existing structure. In order for a duct system to be submitted to these requirements, it must meet three conditions: 1) it must be part of a system that serves 5000 ft^2 or less of conditioned floor area, 2) it must be connected to a constant-volume, single-zone HVAC equipment, and 3) the ducts must be located either outside the envelope of the building (e.g. on top of the roof), or below a roof with inadequate insulation.

If triggered, the requirement is that the ducts be sealed such that their measured leakage is less than 15% of fan flow for the supply and return ductwork combined, including the HVAC equipment cabinet and plenums, or that the duct system pass a visual smoke test and have their leakage be reduced by 60% relative to the condition before sealing.

All installations that include duct sealing shall be self-certified by the installing contractor, including leakage testing, and shall be submitted to a verification program by a third-party special inspector or building inspector. The verification program shall follow a set of procedures that are functionally equivalent to those currently used for residential new-construction duct sealing requirements.

The existence of the proposed requirements for duct sealing shall be publicized on the CEC and other public interest web sites, as well as through campaigns such as the Flex-Your-Power campaign. These requirements should also be publicized on a voluntary basis by HVAC equipment distributors.

Benefits

California, through the Title-24 California Building Energy Efficiency Standards, has made tight ducts an integral part of low-rise residential new construction in California, as well as a compliance alternative for new light commercial buildings. These changes to the Standards, enacted over the past 5 years, were based upon favorable cost-benefit analyses. The expected benefits of sealing ducts in light commercial buildings are even larger than in residential buildings, especially in existing buildings. This is due to higher, more-consistent daytime baseline consumption in commercial buildings, as well as due to higher initial leakage levels in existing light commercial buildings. The options of insulating and/or coating roof surfaces, rather than sealing ducts, were included because of the fact that sealing may not always be practical, and the proposed alternatives are shown to be equivalent to duct sealing in terms of energy savings and/or peak demand reduction produced.

Another reason to address energy efficiency in existing buildings is that more air conditioners and furnaces are installed in existing buildings as compared to new construction, both in California and nationwide. In California, a little more than 60% of this equipment is installed in existing buildings, or in other words, 50% more equipment goes into existing buildings as opposed to new construction each year. The proposed change makes the standards apply to all duct systems, no matter what type of HVAC installation is involved—newly constructed buildings, , additions, and alterations (replacements).

Duct sealing also can improve indoor air quality and safety, principally by reducing entry of outdoor pollutants into the living-space, including reduced ozone entry during smog alerts, and reduced entry of air from dusty ceiling-plenum spaces.

On a statewide level, there are approximately 140,000 furnaces, air conditioners, or heat pumps installed in existing light commercial buildings each year (Source ARI). According to research performed by Lawrence Berkeley National Laboratory, 60-65% of the duct systems in the existing buildings where this equipment is installed would meet the eligibility criteria for application of the proposed changes. In addition, according to data collected on 350 light commercial duct systems for Southern California Edison, more than 85% of the duct systems tested in the target population of light commercial buildings merited sealing, with the average combined leakage on the supply and return sides of the system adding up to 36% of fan flow. Assuming that all of the eligible HVAC equipment installations that merit duct sealing (0.625*0.85*140,000=74,000) actually receive duct sealing or an alternative at the time of equipment installation, the estimated annual statewide savings added each year that the proposed change is in effect are: 46 GWh, 0.5 million therms, and 35 MW. The assumptions behind these estimates are included in the Appendix.

Environmental Impact

This change does not have any adverse environmental impacts. The only materials used are commonly used materials: building sealants, tapes, and fiberglass insulation. One potential environmental impact would be to increase the rate at which asbestos ductwork in the existing building stock is removed. The degree to which this will be the case is uncertain, as many contractors may choose the alternative measures when they encounter asbestos ductwork. It is also possible that this change may reduce combustion safety problems in light commercial buildings, at least in the case of buildings with vented ceiling-plenum spaces. Research performed by LBNL (Delp et al. 1998) suggests that supply ducts leak 25% of fan flow, whereas field work performed for Southern California Edison (Modera and Proctor, 2002) indicates total leakage of 36% of fan flow, suggesting that most systems are supply leakage dominated. Sealing supply-leakage-dominated systems should reduce building depressurization, thereby reducing combustion-safety problems.

Type of Change

The proposed change is a Prescriptive Measure that must be met whenever a light commercial furnace, evaporator coil, or packaged unit is installed in an existing light commercial building, or whenever a duct system is added to or replaced in an existing light commercial building.

The proposed change encompasses small changes to both the Standards and the ACM. In both cases, the changes are relatively minor, as outlined in the section below.

Measure Availability and Cost

The principal suppliers of this measure are the HVAC contractors who normally install HVAC equipment in existing buildings, roofing contractors, or building insulation contractors who service existing light commercial customers. The methodology and supplies required by these contractors for accomplishing the proposed changes are provided by a range of suppliers. These include duct sealant manufacturers, manufacturers of duct leakage test equipment, companies that supply training to HVAC technicians, and manufacturers of insulation and cool-roof products. There are multiple suppliers in each of these categories, and there already exist hundreds of contractors and technicians who have been trained to produce verified tight ducts through utility training programs. Many of these contractors already own the equipment required to verify duct tightness. Sealing supplies are available from multiple manufacturers.

There exists adequate capacity to meet the expected increase in demand for training, duct sealants, sealing equipment and duct insulation. In addition to the training staff and facilities at utilities, there are several companies that sell duct-improvement training and diagnostic/sealing equipment for contractors and technicians, including

Advanced Energy, Carrier-Aeroseal, Comfort Institute/Retrotec, The Energy Conservatory, and Honeywell/Enalysis. The means by which training and sealing equipment are distributed include direct sales of equipment, complete diagnostic/sales systems, and franchises that provide one-stop shopping for training, sealing/diagnostic equipment and diagnostic/sales tools.

The baseline condition that this measure is attempting to change is simple replacement of HVAC equipment without any change to the energy efficiency of the duct system to which it is connected. Currently, less than 10% of duct systems receive verified sealing or additional insulation at the time of equipment replacement, and the current standard does not require these measures. The other significant aspect of the baseline condition is that an unknown number of HVAC replacements are performed without a building permit being issued.

The costs for this change are time and materials for sealing and leakage testing of existing ducts in existing dwellings, or the incremental costs of sealing and testing replacement duct systems combined with the incremental cost of using R-8 instead of R-4.2 replacement ducts. Sealing costs are estimated to be $930, based upon observed $150/ton costs from the SCE duct sealing project (Modera and Proctor 2002), combined with a $30/system incremental cost associated with third-party verification services (DEER 2001). It should be noted that these costs are for stand-alone duct sealing without any legislative requirement. Costs should be lower when duct sealing is a standard part of every equipment installation, both because it becomes part of a bigger job (i.e. combined travel and transaction costs), and because there is no selling involved. Duct replacement with verified-tight R-8 ducts is estimated to cost $1052, based upon a combination of sealing and testing costs plus $122 in incremental duct insulation costs (Source: Owens-Corning Fiberglas). The duct sealing costs include self-verification measurement costs on every job, and third-party verification costs that correspond to current cost of field verification on one in every five jobs. Maintenance costs are not an issue for these technologies.

Useful Life, Persistence and Maintenance

For all cost-effectiveness analyses, the useful life of duct sealing and insulation was assumed to be 30 years, consistent with the values used for new construction within the current Title-24 Standards and ACM.

Performance Verification

The proposed change requires a third-party verification program. The testing protocol for the duct-sealing alternative is similar to that used for new construction, which is already outlined in Appendix G of the non-residential ACM Manual. In addition to the testing protocol, the third-party verification mechanisms also need to be specified. In this case, the proposed change will utilize the HERS rater mechanism, including the use of Third Party Quality Control Programs as outlined in section 7 of the non-residential ACM.

The key issue with respect to enforcement of this change in the Standards is the potentially significant fraction of HVAC equipment that is installed without building permits. This proposal does not address that issue directly, but rather proposes several alternatives for helping to increase the use of permits, and therefore the degree of enforcement of the proposed change. These alternatives include publicity of the change on CEC and other public interest web sites, publicity through campaigns such as the Flex-Your-Power campaign, and publicity on a voluntary basis by HVAC equipment distributors.

Cost Effectiveness

The cost effectiveness of the proposed change was evaluated based upon savings calculated using the DOE-2.2 program, which was checked against the calculation procedures currently in Appendix G of the Non-residential ACM. The energy consumption levels were generated by applying the DOE2.2 program to a prototype building with lower-performance windows and higher lighting power as compared to the new-construction prototype used to analyze similar measures in new construction. Duct sealing cost values were obtained from observed contractor costs from the 2001-2002 Southern California Edison project to reduce demand through light commercial duct sealing (Modera and Proctor, 2002), combined with costs for on-site third-party verification applied to one in every five installations (DEER, 2001). The marginal cost of going from R-4 to R-8 at duct replacement was calculated from data supplied by a large insulation manufacturer. Cost effectiveness was evaluated for five climate zones for duct sealing and for R-8 tight duct replacements, while energy consumption values were computed for the various alternatives to duct sealing. The average results for the five climate zones (3, 6,10,12 and 14) are presented below. These results are based upon assuming a 60%/40% split between vented-plenum ceiling-only-insulation and unvented-plenum ceiling&roof-insulation. All runs assumed the use of an economizer and 6% minimum outdoor air, however the results do not change significantly without economizers. All of analyses were performed using an R-19 ceiling, which, based upon the way that the Standards language is worded, actually provides a conservative estimate of the savings for insulated roofs. The reason is that when the roof insulation must always be less than or equal to the ceiling insulation, the lower the insulation level on the ceiling, the higher the overall energy use, resulting in higher absolute energy savings. Climate-by-climate results for sealing and alternatives are summarized in the appendix.

Measure	Consumer Cost	Discounted Lifetime Time Dependent Valuation Savings (5-climate average)
Duct Sealing and Testing	$ 930	$2,591
Duct Replacement w/tight R-8	$ 1052	$ 2,958

Analysis Tools

This change does not require the use of any analysis tools, as what is proposed is a set of prescriptive requirements. In situations where the performance methodology is used in lieu of prescriptive alternatives, the calculation procedures are those currently in Appendix G of the non-residential ACM, potentially modified as per another code change proposal for ducts in new construction.

The analysis tools used for this report are discussed in the Methodology section.

Relationship to Other Measures

This change will not have any significant impacts on other measures. This code change proposal was developed in conjunction with a similar duct-sealing proposal for new construction, and thus was designed to be consistent with, and to complement that proposal. This code change proposal was also designed to be as consistent as possible with the duct sealing requirements for existing residential systems.

Methodology

The lack of requirements for duct efficiency improvements at the time of HVAC replacement has been recognized as an area for improvement since 1998, and was identified by the California Energy Commission as a topic for this proceeding during the AB970 effort. Research consisted of reviewing the standards language to identify a strategy to incorporate replacement duct sealing or the equivalent into the standard. The methodology used to analyze this code change proposal is based upon savings estimates calculated using the DOE-2.2 program, which was checked against the calculation procedures currently in Appendix G of the Non-residential ACM.

To estimate the cost effectiveness of duct tightening, a series of simulation studies were undertaken. First, a simple "box" prototype model was developed to test the capabilities and evaluate the response of the DOE-2.2 program to several duct efficiency and operating condition assumptions. The eQUEST program was used to develop the basic DOE-2.2 input file. Manual changes were made to the input file to complete the analysis. A description of the simple box model is shown below:

Model Parameter	Value
Shape	Rectangular, 50x40
Conditioned floor area	2000 SF
No Floors	1
Floor to ceiling	9 ft
Plenum ht	3 ft
Window/wall ratio	20%
Window SC	Varies by climate zone
Window U-Value	Varies by climate zone
Exterior wall const	8 in. concrete tilt-up construction insulated
Ext wall R-Value	Varies by climate zone
Infiltration rate	0.3 ACH in occupied zone, varies in attic
Roof construction	Built-up roof over plywood deck
Roof absorptivity and emissivity	Abs = 0.8; emiss = 0.9
Ceiling construction	Acoustic tile
Lighting power density	2 W/SF
Equipment power density	0.5 W/SF
Operating schedule	7 am - 6 pm M-F
No. People	11
Outdoor air	15 CFM/person (minimum 6% of flow)
HVAC system	PSZ
Size	6 ton (CZ 3,6) 10 ton (CZ 10,12,14)
CFM	2100 CFM (CZ 3,6) 3500 CFM (CZ 10,12,14)
SHR @ ARI conditions	0.7
EER	8.5
Fan power	0.28 W/CFM
Supply duct surface area	27% of floor area, per ACM
Duct leakage	36% total leakage; evenly split between supply and return (18% supply, 18% return) for leaky case, 15% total leakage for tight case
Duct insulation R-value	R-4.2, with an air film resistance of 0.7 added to account for external and internal air film resistance. R-8 evaluated for some runs.
Return leak from outside air	0%
Return system type	ducted

Results

See proposed standards language below.

Recommendations

Proposed Standards Language

The proposed changes to the Standards below are predicated on duct sealing and insulation requirements being applied to new construction also, as proposed in a companion code change proposal. Should such requirements not be enacted for new construction, the changes proposed herein would need to be modified so as to make them applicable only to alterations.

The proposed changes differ from those originally presented at the July 18, 2002 workshop. The modifications to the proposal were made: 1) to respond to comments received relative to the original proposal, and 2) to maintain consistency with the residential code and ACM changes. Specific changes to the proposal include: 1) increasing the maximum allowable leakage level from 10% to 15% of fan flow, 2) allowing 60% sealing of the existing leakage plus smoke testing as an alternative, and 3) allowing standard roof insulation as an alternative to duct sealing. The principal impact of these changes is to make it easier to meet the sealing requirements by means of manual duct sealing. In addition, the trigger for the duct-sealing requirement was modified so as to reduce the probability of repairing rather than replacing the HVAC equipment to avoid the duct-sealing requirement. This change was made to address concerns raised during and subsequent to the July 18, 2002 workshop.

Section 144 (k) shall be modified as follows:

(k) **Air Distribution System Duct Leakage Sealing.** All duct systems shall be sealed to a leakage rate not to exceed 6% of the total fan flow if the duct system:

1. Is connected to a constant volume, single zone, air conditioners, heat pumps or furnaces, and

2. Serves less than 5,000 square feet of floor area; and

3. Has more than 25% duct surface area located in one or more of the following spaces:

A. outdoors, or

B., a space directly under a roof where the U-factor of the roof is greater than the U-factor of the ceiling, or

C. a space directly under a roof with fixed vents or openings to the outside or unconditioned spaces, or

D. an unconditioned crawlspace; or

E. other unconditioned space.

The leakage rate shall be confirmed through field verification and diagnostic testing, in accordance with procedures set forth in the Nonresidential ACM Manual.

EXCEPTION TO Section 144(k) 3 B: Where the roof by itself meets the requirements of 143(a) 1 C.

Section 149 (b) 1 shall be modified as follows:

~~B~~C. New space-conditioning systems or components other than space conditioning ducts shall meet the requirements of Section 144; and

D. New space-conditioning ducts shall meet the requirements of section 124; and if they meet the criteria of section 144(k) 1., 2., and 3., be sealed as confirmed through field verification and diagnostic testing in accordance with procedures for sealing of existing duct systems as specified in the Nonresidential ACM manual, to meet one of the following requirements:

i. The measured total duct leakage shall be less than 15% of fan flow, or ii The duct leakage shall be reduced by more than 60% relative to the leakage prior to the equipment having been replaced, and a smoke test shall demonstrate that all accessible leaks have been sealed.

E. When a space-conditioning system is installed or replaced (including replacement or installation of the air handler, cooling or heating coil, or furnace heat exchanger), the existing duct system, if it meets the criteria of section 144(k)1.,2., and 3., shall be sealed, as confirmed through field verification and diagnostic testing in accordance with procedures for sealing of existing duct systems as specified in the Non-Residential ACM manual, to one of the requirements of section 149(b)1 D; and

EXCEPTION 1 to Section 149 (b) 1 E: Installation or replacement of only the outdoor condensing unit of a split system air conditioner or heat pump.

EXCEPTION 2 to Section 149 (b) 1 E: Buildings altered so that the duct system no longer meets the criteria of Section 144(k)1., 2., and 3.

EXCEPTION 3 to Section 149 (b) 1 E: Duct systems that are documented to have been previously sealed as confirmed through field verification and diagnostic testing in accordance with procedures in the Non-Residential ACM manual.

Proposed ACM Language

The proposed changes to the ACM are as follows:

The modifications shall made to Section 7 are incorporated into the ACM per the new-construction duct performance proposal.
The following text shall be added to Section 4 of Appendix G:

Apparatus

4.2.1.1 Smoke-Test Verification of Accessible-Duct Sealing (Existing Buildings)

The apparatus for verifying best-effort duct sealing shall also include means for generating non-toxic visual smoke for identifying leaks in accessible portions of the duct system. This apparatus may consist of a theatrical smoke generator, or a smoke bomb. In both cases, adequate smoke must be generated to assure that any accessible leaks will have to emit visibly identifiable smoke.

Test Procedures

4.3.8.2 Diagnostic Duct Leakage

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When the diagnostic leakage test is performed for existing duct systems pursuant to Section 149 (b)1.D. or Section 149 (b)1.E. of Title 24, Part 6, the procedures described in Section 4.3.8.2.3 shall be followed.

....

4.3.8.2.3 Diagnostic Duct Leakage in Existing Buildings

For existing duct systems, the requirements of Section 149 (b)1.C. or Section 149 (b)1.D. of Title 24, Part 6 shall be considered satisfied if one of the following two conditions is met:

1. the measured total duct leakage is less than 15% of the total fan flow, where the duct leakage shall be determined pursuant to the procedures in section 4.3.8.2.1, and the total fan flow shall be determined pursuant to section 4.3.7,

OR

2. the duct system passes the following two tests on every job: a) duct leakage has been reduced by more than 60% relative to the leakage prior to the equipment having been replaced, determined pursuant to section 4.3.8.2.1 before and after sealing the duct system, AND b) a smoke test is performed according to section 4.3.8.2.3.1 in the presence of a third-party tester to show that best efforts have been made to seal accessible leaks.

4.3.8.2.3.1 Smoke-Test Verification of Accessible-Duct Sealing

The objective of the smoke test is to confirm that best efforts have been made to seal all accessible leaks, and shall be comprised of the following steps:

1) Injection of either theatrical or smoke-bomb smoke into a fan pressurization device that is maintaining duct pressure between 25 and 50 Pa relative to the duct surroundings, with all grilles and registers (as well as any intentional outdoor air intakes) in the duct system sealed.

2) Visual inspection of all accessible portions of the duct system during smoke injection.

3) The system shall be deemed to have passed the test if any of the following conditions are met:

   i. There is no visible smoke exiting the accessible portions of the duct system.

   ii. The only smoke emanating from the system can be clearly identified as coming from the HVAC equipment rather than the ducts.

Proposed Non-Residential Manual Language

The Non-Residential Manual will also need to be modified to make it consistent with the proposed changes to the Standard and the Non-Residential ACM. The residential manual should also include additional alternatives to duct sealing.

Bibliography and Other Research

Papers and standards used to complete this report include:

ASHRAE Standard 152P: Method of Test for Determining the Energy Efficiency of Residential Thermal Distribution Systems under Seasonal and Design Conditions. Second Public Review Draft 08/01.

2001 DEER Update Study Final Report, Prepared by Xenergy Inc. August 2001.

W. W. Delp, N. Matson, D. J. Dickerhoff, D. Wang, R. C. Diamond, M. P. Modera "Field Investigation of Duct System Performance in California Light Commercial Buildings", ASHRAE Trans. 104(II) 1998, June 1998.

W. W. Delp, N. Matson, D. J. Dickerhoff, D. Wang, R. C. Diamond, M. P. Modera "Field Investigation of Duct System Performance in California Light Commercial Buildings (Round II)." Proceedings of ACEEE Summer Study, Pacific Grove, CA, August 1998.

M.P. Modera, J. Proctor, "Combining Duct Sealing and Refrigerant Charge Testing to Reduce Peak Electricity Demand in Southern California", Final Project Report for Southern California Edison, July 2002.

Experts whose contributions are incorporated into this proposal are listed in the acknowledgements section below.

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Robert Scott (CHEERS) Mr. Scott provided a perspective on the ability and desire of CHEERS raters to support the third-party testing requirements of this proposal

Dave Ware (Owens Corning) Mr. Ware provided cost data for using R-8 ducts instead of R-4.2 ducts.

Appendix

Savings Estimates

The statewide savings estimates are based upon the following assumptions

- 140,000 furnaces and/or air conditioners installed in existing light commercial buildings each year;
- 62.5% of the duct systems located above ceiling insulation;
- 85% of installations leak enough to trigger sealing requirement;
- all triggered installations are addressed (i.e., 74,000 efficiency improvements);
- all installations have central A/C;
- all installations have base-case efficiency levels of AFUE-80 and EER-8.5;
- elevated savings associated with heat pumps or electric furnaces are excluded;
- savings from duct replacements or outdoor ductwork not included in statewide total;
- 37.5% of existing buildings have insulated ceilings and vented attics, 25% have insulated ceilings and roofs with no ventilation, and 37.5% have insulated roofs and no venting;
- improvements split uniformly between the five climate zones simulated;
- 30-year life for duct sealing and insulation measures;
- $0.129 value per KBtu for TDV savings estimates (Time Dependent Valuation (TDV) Economics Methodology, John McHugh, HMG, http://www.h-m-g.com/TDV/index.htm)
- Peak demand reduction calculated based upon maximum draw determined by DOE 2.2 for different options.

Figure A.1 Duct Sealing Savings for Various Climates and Roof Configurations (R-19 ceiling)

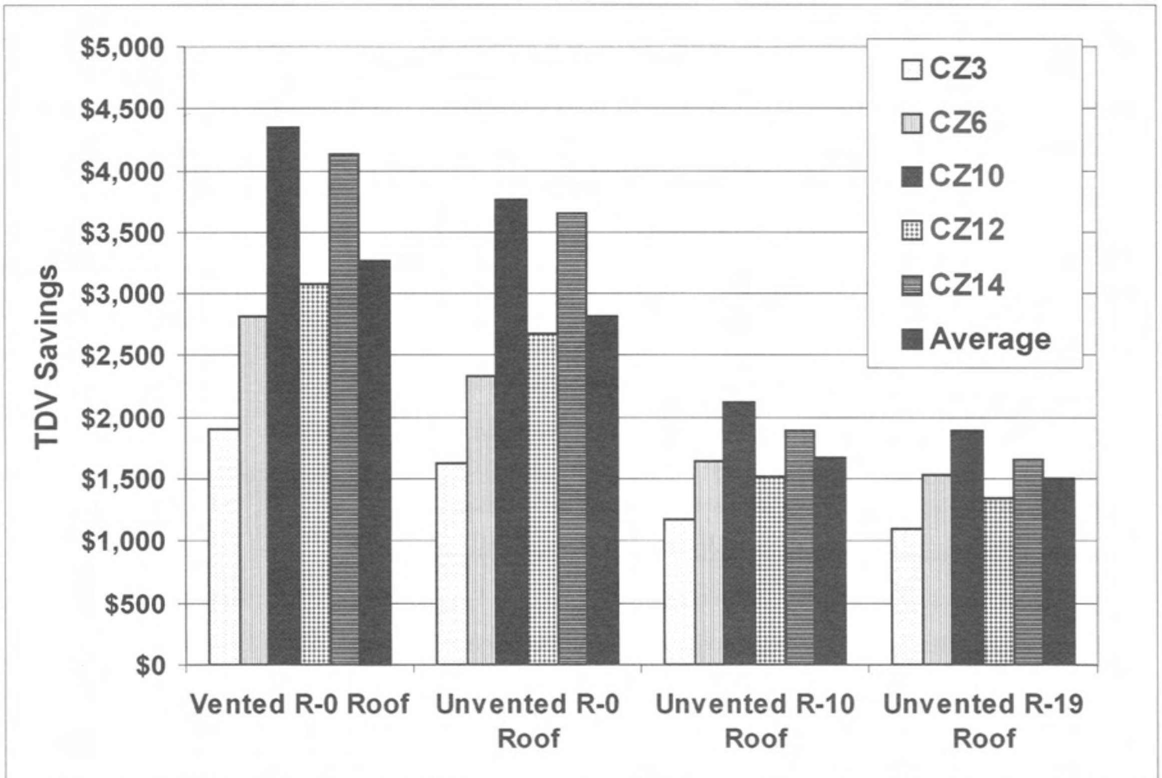
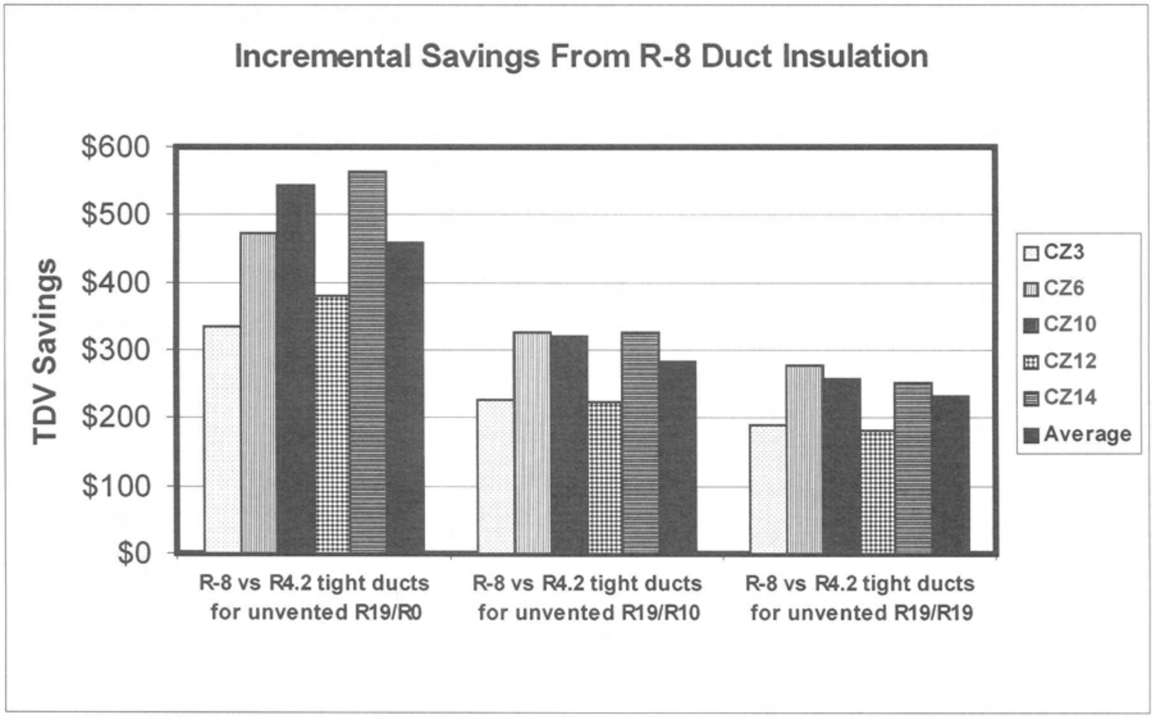


Figure A.2 Climate by Climate Analysis of R-8 Duct Insulation



Cost Estimates

The statewide cost estimates are based upon the following assumptions

- Duct sealing costs of $150/ton, augmented to include third-party field verification cost of $30/system, which corresponds to an effective field verification rate of one in five systems installed;
- Marginal costs for duct replacement include the cost of sealing, as well as increased material cost associated with installing R-8 instead of R-4.2 ducts (Material Cost Data obtained from Dave Ware, Owens Corning Fiberglas).