

Air Distribution Systems

Codes and Standards Enhancement (CASE) Study

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Introduction

This Codes and Standards Enhancement (CASE) Study provides information to support including air distribution efficiency measures into the nonresidential energy efficiency standards (standards). This CASE study for air distribution systems discusses the:

- technology,
- current practice,
- economics,
- key stakeholders, and
- implementation options and recommendations for inclusion into codes.

Air distribution systems are used in a large majority of nonresidential buildings to move cooling and heating energy from central equipment to locations throughout the building. Air distribution systems also distribute ventilation air throughout the building.

Air distribution system construction in light commercial buildings is often very similar to that in residential buildings. Systems in both types of buildings are often plagued by problems that cause sizeable energy losses.

In recent years, poor quality ductwork has been recognized as a significant source of energy losses. The use of ceiling insulation located at the suspended ceiling is common and results in the ductwork being located outside the conditioned space. Leaks in ducts run in unconditioned attics result in large amounts of cooled and/or heated air being lost to the outdoors. The leaks also increase infiltration loads.

This study analyzes the savings potential of improving the air distribution system efficiency in California's nonresidential buildings.

Technology Description

Air distribution systems are the primary means of moving heating and cooling energy to spaces within a building. These systems consist of supply and return ducts or plenums through which heated or cooled air is moved.

Ideally, duct systems should be perfectly efficient, delivering to the conditioned spaces all of the air from the central equipment, with no change in temperature. In reality, however, duct systems fall short of these ideals. Ducts—and especially plenums—leak, resulting in supply air being diverted to and return air being drawn in from undesired locations. In addition, ducts usually pass through locations with temperatures different from the air inside the duct. The resulting heat transfer through the duct material changes the air temperature, usually in undesirable ways.

Nearly all nonresidential buildings utilize air distribution systems to provide space conditioning. The exceptions are buildings that are hydronically heated without central air conditioning systems and buildings where distributed space conditioning equipment is used. Distributed equipment includes space heaters, packaged terminal air conditioners, window air conditioners, and similar systems.

Air distribution systems are generally built onsite using some sort of duct material sold explicitly for that purpose. This might be lengths of flex duct, usually insulated, attached to terminal units or other duct system components; ducts constructed of sheet metal with site-applied insulation; or ducts built of ductboard, which includes insulation. Any of these can be used to connect the central air handling equipment to some sort of terminal unit in the space.

The overall air distribution system frequently includes combinations of the various duct constructions. A central plenum made of sheet metal or ductboard is often used to distribute air from the central unit,

with flex duct branches connecting the plenum to the various individual spaces.

In constructing the ductwork, pieces of the material must be connected to each other. There are numerous ways to make these connections, depending on the duct material used. Some methods, however, appear to be less durable than others and any method may be improperly installed.

Once the building has been completed, the ductwork is usually out of sight, and leaks can go undetected. Improving ductwork efficiency is best accomplished by using high quality, durable duct connections. Usually this means using some type of mechanical fastenings.

For residential construction, duct efficiency tests methods exist, such as ASHRAE Standard 152P (ASHRAE 2000). These test methods provide a means of testing the ductwork after installation and confirming that its efficiency meets specified criteria. In addition, an aerosol duct sealing method can be used to economically seal leaky ducts. This involves sealing the registers and other designed air outlets, pressurizing the ducts, and spraying an aerosol sealant into the duct. As the air leaks through the unintended openings, the aerosol sealant gradually builds up on the edges of the leak until the leak is sealed.

Current Practice

Two significant studies (RLW 1999; Felts et al. 1999) show that rooftop units provide the majority of commercial building cooling in California. Figure 1 illustrates the number of buildings in the RLW study served by packaged versus built-up (chiller) systems. Approximately 90% of the buildings in the study were served by packaged systems.

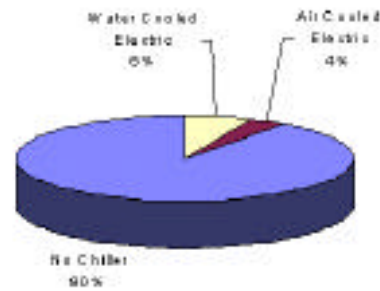


Figure 1. Market Penetration of Packaged and Built-up Systems

Figure 2 shows a frequency distribution by cooling capacity of packaged unitary systems, including: single packaged rooftop AC; single packaged rooftop heat pump; split system AC; split system heat pump; or dual fuel heat pump, without evaporative condenser. These data show that the majority of the systems are 5 tons or less, with 5 tons being the most popular unit size.

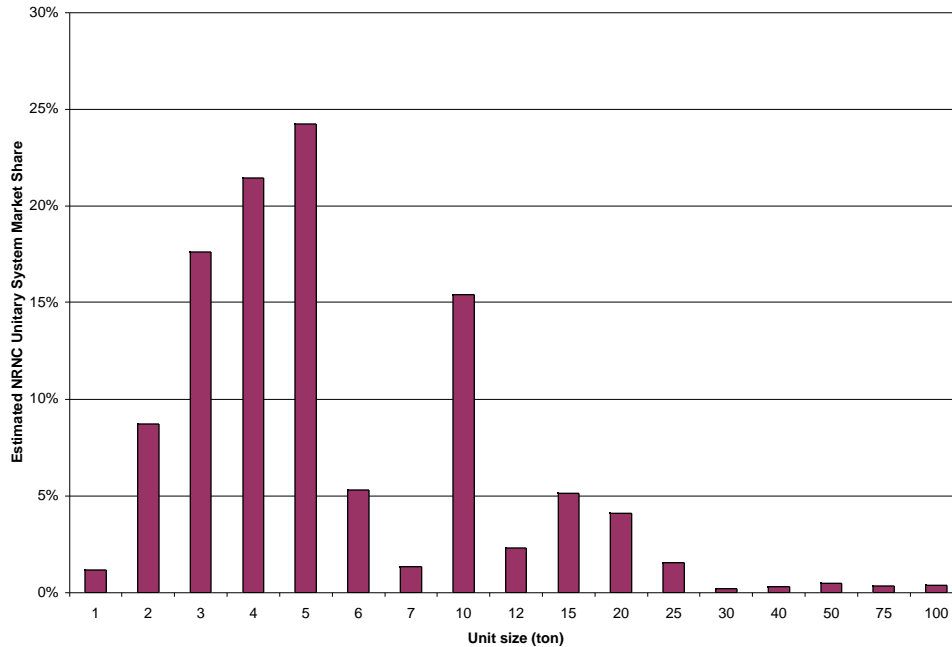


Figure 2. Market Penetration of Packaged Unitary AC and Heat Pumps by Cooling Capacity

From these data, it is evident that light commercial air distribution systems represent a significant portion of air distribution systems in California.

Most research on distribution system efficiency has been performed on residential buildings. Air leakage for residential systems is generally in the range of 10% to 20% of the fan airflow, on both the supply and return side of the fan (Modera 1999). Additional inefficiencies result from heat transfer between the air in the ducts and in the attic, particularly during cooling when the attic can be substantially hotter than the outdoors due to solar radiation.

In light commercial buildings, duct systems are typically run in the ceiling cavity between the dropped ceiling and the roof (Delp et al. 1997). This cavity is frequently outside both the air barrier and thermal barriers; in other words, it is outside the conditioned space. This situation closely parallels that in most residential buildings. In addition, the systems in these light commercial buildings usually use a cycling fan operation (Delp et al. 1997), further

extending the parallel. Delp found that the leakage area for light commercial duct systems was 2.6 times that of a typical residential system.

Problems caused by air distribution system inefficiencies include:

- Air leakage and heat transfer reduce the efficiency of the overall space conditioning system, because conditioning energy is not delivered to the desired space. Extra energy must be consumed to make up the losses.
- The effective heating or cooling capacity of the system is substantially reduced, often resulting in oversized equipment being installed to compensate. This can result in further reductions in system efficiency.
- When supply air leakage is uneven across the building, some spaces may be underconditioned or overconditioned relative to other spaces, resulting in occupant discomfort.
- Unbalanced supply duct leakage can depressurize the building. If natural

draft combustion appliances are installed (such as gas water heaters) the depressurization increases the risk of appliance backdrafting. The resulting presence of NO₂ and water in the space can degrade indoor air quality. If the appliance also has a malfunctioning burner, CO can be introduced to the space.

- Leakage that is unbalanced between the supply and return sides of the system can increase the overall building infiltration rate. This can cause increased energy consumption to heat and cool the infiltration air. (On the other hand, this infiltration air may be the primary source of ventilation for the building, improving the indoor air quality. Properly controlled ventilation systems would undoubtedly be a better means of providing this benefit.)

For larger commercial buildings, improvements in air distribution system efficiency can result in significant savings, primarily from fan power savings. The fan power consumption of these larger buildings is on the same order of magnitude as their cooling energy. Since the fans run continuously, reducing the required airflow reduces the fan power.

A recent study (Xu et al. 1999a) found that thermal losses through leakage and conduction were 30% of the supply energy. Theoretically, eliminating these 30% losses would reduce the fan power by 70%. Perhaps half of these savings are actually achievable, as it is not possible to completely eliminate the conduction losses. Also, constant air volume systems must be retrofitted to reduce the system airflow before any savings would be achieved.

There are several sources of leakage problems for conventional air distribution systems. These include:

- Use of inadequate connection methods between pieces of the duct system. Most notorious is the use of poor quality duct tape to seal connections. These

connections then fail either immediately (the tape didn't stick because the surfaces were dusty or dirty) or in a short span of time (the tape adhesive was weak or wasn't able to handle the temperature cycles encountered).

- Improper installation of the ducts, particularly not adequately connecting different pieces of the system. In other words, the installer did a shoddy job and simply did not properly connect the ducts.
- Use of building cavities as air distribution plenums. In particular, drawing return air through the ceiling plenum can result in significant leakage from the outdoors.

Each of these problems must be addressed at different points in the building's design and construction process. For example, during the design of the HVAC system, which may be done either by an engineer or an HVAC contractor, codes can require that if building cavities are used for air distribution, they must be adequately sealed. Alternatively, codes can prohibit this practice. The code can also specify acceptable means of duct construction by the mechanical contractor, which can be verified by a building inspector. Finally, a duct leakage test can be used to ensure that the air distribution system has been tightly constructed. Recent changes to the standards for low-rise residential buildings prohibit the use of building cavities as air distribution plenums and require that ducts be diagnostically tested to assure low leakage.

An alternative to contractor-installed duct sealing approaches is the use of an aerosol-based sealing technology. Once the distribution system has been constructed and there are no gross leaks (such as ducts that are not connected), an aerosol sealant is sprayed into the ducts while they are pressurized by a fan. The sealant adheres to the edges of any leaks, building up to seal the leak. This is followed by a leakage test. An alternative to extensive requirements on duct system construction is to build the

building with the air and thermal barrier collocated at the roof and extending down the outside walls of the ceiling plenum. Ductwork installed in the plenum is then inside the conditioned space, and any losses have less impact on the building's energy consumption. (This is a requirement of ASHRAE/IESNA Standard 90.1-1999, which prohibits use of a suspended ceiling as the air or thermal barrier.)

If this approach is used, the standards must specify adequate means of ensuring that the ceiling plenum is in fact inside air and thermal barrier. This is true, however, only if the ceiling plenum is not used as a return plenum. If the supply ducts are inside the return air plenum, duct losses create a short circuit and the air never makes it to the occupied space. This has a negative impact on energy consumption, although it is much less severe than when the ducts are in an unconditioned space.

The Standards previously prohibited the use of a suspended ceiling as the thermal or air barrier. The prohibition was removed, however, because of building owners' concerns about the additional cost to insulate the wall areas above the dropped ceiling and the greater difficulty in insulating the roof, as opposed to the ceiling. The potential benefits related to the distribution system were apparently not included in the decision to eliminate the prohibition.

Research needs in this area are limited. Investigation of the in-service life of various qualities of duct tape, and the factors which affect their life, would be desirable. A test procedure to certify proprietary duct connection methods would also be useful.

Economics

Improved air distribution systems can significantly reduce the energy consumption of buildings. Consider, for example, a single-story building with an unsealed distribution system in California climate zone 12. Using data from the 1998 CEC residential Alternative Calculation Methods

(ACM) manual, this system will have seasonal average efficiencies of 75% in heating and 67% in cooling. After duct sealing, these efficiencies increase to 82% in heating and 76% in cooling, saving 9% of the heating energy and 12% of the cooling energy.

Researchers (Delp et al. 1997), however, found that leakage in light commercial buildings was 2.6 times that in residential buildings, indicating that the above estimates may be very conservative. On the other hand, ducts in commercial buildings are somewhat more likely to be inside the conditioned space, reducing the potential savings.

Analysis using the DOE-2.1E energy simulation program and ASHRAE Standard 152P algorithms was conducted under this study. We examined a number of prototype buildings, and made simulation studies of three buildings: a medium-size office, a store in a strip mall and a full-service restaurant.

Other buildings were not simulated for several reasons. Some of the buildings did not use ducts for the primary systems (such as packaged terminal air conditioners used in hotels and schools). Some buildings had systems with minimal ductwork outside the conditioned space (warehouse-style retail stores, for example). And for some buildings we were unable to do adequate DOE-2 modeling (for a large office building where only fan power effects are expected, DOE-2 cannot simulate return side leakage).

The three modeled buildings were simulated with three cases: 30% leakage above the ceiling insulation (base case), 10% leakage above the ceiling insulation, and 30% leakage with the insulation extended up the walls and roof of the attic/plenum. The air change rate of the attic/plenum was unchanged for the three cases. Simulations were done for four California locations: Fresno, Mt. Shasta, Oakland and Palm Springs.

For the strip store, ASHRAE Standard 152P calculations were done for buildings in Oakland and Fresno. The 152P calculation was not done for Palm Springs and Mt. Shasta because the spreadsheet used did not include weather data for these locations, and a particular seasonal temperature value is required which was not available.

The strip store is a 9600-ft₂ retail store located at the end of a strip mall. The entire store is served by a single packaged VAV system. The building is modeled with the roof insulation at the suspended ceiling.

The medium-size office is a three-story office building totaling 49,000 ft₂. The building has three central VAV systems, one serving each floor, with all central equipment located in a penthouse. The duct leakage model addressed only the system serving the top floor, assuming that the ductwork for this system is located in the penthouse, with the roof insulation located below the ductwork. Ductwork for the other two systems is assumed to drop from the penthouse through a central shaft, with horizontal runs between floors, in conditioned space.

The full-service restaurant is a single-story 9060-ft₂ restaurant/lounge. The kitchen is served by a packaged single-zone system with the rest of the building served by a packaged multizone system. The ductwork

for the multizone system is run through the attic. The kitchen system ductwork also runs through the attic, but was not included in the duct loss analysis. DOE-2.1E cannot model losses from more than one system into a single zone.

The simulation results are shown in the following tables. Tables 1 through 3 show annual electricity consumption in kWh and the annual peak demand in kW, for the medium office, restaurant, and strip store, respectively. Tables 4 through 6 show kWh and kW savings for the 10% leakage and 30% leakage with extended insulation cases. Tables 7 through 9 show the savings in percentage terms.

For all three buildings and all four locations, energy and demand savings of duct sealing are dramatic. Reductions in cooling energy range from 9% to 18% for the single-story buildings, and 3% to 4% for the three-story office. Reductions in demand are even greater, ranging from 12% to 27% for the store and restaurant, 3% to 5% for the office.

Savings for the extended insulation without duct sealing are not nearly so dramatic, but are still substantial for the single-story buildings (except for the Mt. Shasta cases). Given that extended insulation can be expected to be at least as expensive as duct sealing, it is clear that duct sealing should be the primary strategy.

Table 1. DOE-2 Predicted Medium Office Electricity Consumption

City	Case	Annual kWh	Peak kW
Fresno	30%	497,886	180.3
	10%	478,067	171.3
	Ext Insul	495,787	179.2
Mt. Shasta	30%	475,245	170.5
	10%	457,521	163.5
	Ext Insul	473,941	169.9
Oakland	30%	474,120	168.0
	10%	457,650	161.6
	Ext Insul	473,150	167.2
Palm Springs	30%	503,126	184.0
	10%	484,357	177.6
	Ext Insul	500,955	183.4

Table 2. DOE-2 Predicted Restaurant Electricity Consumption

City	Case	Annual kWh	Peak kW
Fresno	30%	620,227	174.6
	10%	515,849	146.7
	Ext Insul	599,815	156.1
Mt. Shasta	30%	486,577	127.2
	10%	413,132	108.3
	Ext Insul	493,030	125.7
Oakland	30%	472,154	118.4
	10%	402,259	104.0
	Ext Insul	466,880	106.5
Palm Springs	30%	724,000	190.2
	10%	593,287	153.8
	Ext Insul	714,587	181.1

Table 3. DOE-2 Predicted Retail Store Electricity Consumption

City	Case	Annual kWh	Peak kW
Fresno	30%	250,092	105.2
	10%	214,965	79.9
	Ext Insul	242,939	100.3
Mt. Shasta	30%	179,202	63.1
	10%	160,554	52.4
	Ext Insul	180,068	63.3
Oakland	30%	192,904	75.9
	10%	175,585	61.0
	Ext Insul	190,945	72.5
Palm Springs	30%	310,159	122.9
	10%	254,804	89.9
	Ext Insul	299,176	115.5

Table 4. DOE-2 Predicted Medium Office Electricity Savings

City	Case	KWh Savings	Peak kW Savings
Fresno	30%	-	-
	10%	19,819	9.0
	Ext Insul	2,099	1.1
Mt. Shasta	30%	-	-
	10%	17,724	7.0
	Ext Insul	1,304	0.6
Oakland	30%	-	-
	10%	16,470	6.4
	Ext Insul	970	0.8
Palm Springs	30%	-	-
	10%	18,769	6.4
	Ext Insul	2,171	0.6

Table 5. DOE-2 Predicted Restaurant Electricity Savings

City	Case	KWh Savings	Peak kW Savings
Fresno	30%	-	-
	10%	104,378	27.9
	Ext Insul	20,412	18.5
Mt. Shasta	30%	-	-
	10%	73,445	18.9
	Ext Insul	-6,453	1.5
Oakland	30%	-	-
	10%	69,895	14.4
	Ext Insul	5,274	11.9
Palm Springs	30%	-	-
	10%	130,713	36.4
	Ext Insul	9,413	9.1

Table 6. DOE-2 Predicted Retail Store Electricity Savings

City	Case	KWh Savings	Peak kW Savings
Fresno	30%	-	-
	10%	35,127	25.3
	Ext Insul	7,153	4.9
Mt. Shasta	30%	-	-
	10%	18,648	10.7
	Ext Insul	-866	-0.2
Oakland	30%	-	-
	10%	17,319	14.9
	Ext Insul	1,959	3.4
Palm Springs	30%	-	-
	10%	55,355	33.0
	Ext Insul	10,983	7.4

Table 7. DOE-2 Predicted Medium Office Electricity Savings

City	Case	KWh Savings	Peak kW Savings
Fresno	30%	-	-
	10%	4%	5%
	Ext Insul	0%	1%
Mt. Shasta	30%	-	-
	10%	4%	4%
	Ext Insul	0%	0%
Oakland	30%	-	-
	10%	3%	4%
	Ext Insul	0%	0%
Palm Springs	30%	-	-
	10%	4%	3%
	Ext Insul	0%	0%

Table 8. DOE-2 Predicted Restaurant Electricity Savings

City	Case	KWh Savings	Peak kW Savings
Fresno	30%	-	-
	10%	17%	16%
	Ext Insul	3%	11%
Mt. Shasta	30%	-	-
	10%	15%	15%
	Ext Insul	-1%	1%
Oakland	30%	-	-
	10%	15%	12%
	Ext Insul	1%	10%
Palm Springs	30%	-	-
	10%	18%	19%
	Ext Insul	1%	5%

Table 9. DOE-2 Predicted Retail Store Electricity Savings

City	Case	KWh Savings	Peak kW Savings
Fresno	30%	-	-
	10%	14%	24%
	Ext Insul	3%	5%
Mt. Shasta	30%	-	-
	10%	10%	17%
	Ext Insul	0%	0%
Oakland	30%	-	-
	10%	9%	20%
	Ext Insul	1%	4%
Palm Springs	30%	-	-
	10%	18%	27%
	Ext Insul	4%	6%

These savings are dramatic, particularly the demand reductions achieved in the retail store. For the small systems modeled, the fan and compressor will be single-speed equipment and the instantaneous demand will not be decreased. Over an averaging period that is longer than the cycle time of the system, however, the equipment will run for a shorter time, and demand will be reduced proportionally.

As an independent check on these results, the ASHRAE Standard 152P algorithms were used to check the impact on distribution system efficiency of the reduction in leakage from 30% to 10% for the strip store in Oakland and Fresno. These results are shown in Tables 10 and 11.

Table 10. ASHRAE 152P Calculated Distribution System Efficiencies - Retail Store

Leakage	Oakland		Fresno	
	30%	10%	30%	10%
Heating, design	44%	57%	42%	57%
Heating, seasonal	52%	63%	53%	65%
Cooling, design	42%	55%	33%	49%
Cooling, seasonal	75%	80%	64%	72%

Table 11. Savings Based on ASHRAE 152P Calculation of Distribution System Efficiency and Comparison to DOE-2 Results - Retail Store

City	152P Savings		DOE2 Savings	
	Oak.	Fres	Oak.	Fres
Cooling, design	23%	33%	20%	24%
Cooling, seasonal	7%	11%	9%	14%

The DOE-2 and 152P results are consistent, despite some significant problems in making the comparison. For example, in making the 152P calculation, we assumed that two-thirds of the leakage was on the supply side and one-third on the return side, whereas in the DOE-2 calculation, all the leakage is from the supply side. Also, the 152P calculation assumes a cycling fan operation, whereas DOE-2 models a continuous fan operation.

Costs for duct sealing are relatively low. Post-construction aerosol duct sealing is

expected to be about \$250 per system (Modera 2000a). This includes sealing the ducts and performing a leakage test. Systems in light commercial buildings serve about 360 square feet per ton of cooling (Delp et al. 1997). If an average system is 4 tons, this works out to about \$0.18 per square foot ($\$250 / (360 \text{ ft}_2/\text{ton} \times 4 \text{ tons})$).

But improving installation methods and quality control is the preferred way to reduce duct leakage. Costs for this are uncertain, but are similar to aerosol-based sealing.

The life of a properly installed air distribution system should be as long as the rest of the building, and shouldn't require maintenance. Some duct assembly methods are prone to early failure, however, as described above.

If these methods can be adequately identified and prohibited, the life of the duct leakage reductions should be quite long. Life of the aerosol-based sealing technology is uncertain, but six years of testing resulted in no failures (Modera 2000b).

Commissioning of the air distribution system by performing leakage tests is essential to verify that the system has been properly installed. Leakage tests should be based on methods prescribed in ASHRAE Standard 152P. Additional algorithms are currently being developed to appropriately address commercial applications.

In summary, the savings available from commercial air distribution system efficiency improvements are much larger than the uncertainties associated with the analytical tools. Particularly for smaller buildings, where a large fraction of the air distribution system is located in unconditioned space, it is clear that addressing these systems in the commercial portions of the Standards is warranted.

Key Stakeholders

There are several key stakeholders with an interest in air distribution system efficiency. These include architects, engineers, contractors, building owners, occupants, policy makers and code officials. Changes in air distribution system efficiency requirements will most directly affect the contractors who install the systems and the code officials who verify and approve them. Building owners, occupants, contractors, architects and engineers will also be affected by the slight increases in building construction costs.

Finally, owners and occupants will benefit from the dramatic reductions in energy consumption and, depending on demand billing methods (averaging period), demand reductions.

Implementation Strategies and Recommendations

Under the Standards, residential buildings receive an energy credit for tight duct systems. Verification of duct performance by testing is required. Duct performance in nonresidential buildings is not addressed.

Energy savings calculations for improvements in residential duct efficiency are adequately described, particularly in ASHRAE Standard 152P. These calculations, however, assume that the air handler cycles with the heating or cooling device. In addition, the Standard assumes that the thermal and air barriers of the building are collocated, i.e., that a duct is inside or outside both barriers. This is not the case in nonresidential buildings.

There is a need for additional research to provide better tools to evaluate duct efficiency improvements in nonresidential buildings. To validate the overall energy savings available through air distribution system improvements, additional research is also needed to characterize the air

distribution systems in commercial buildings.

Even without that research, however, the savings available from air distribution system efficiency improvements are so large that early inclusion in the Standards is warranted. As such, the implementation strategies and recommendations are as follows:

Update the Alternative Calculation Method (ACM) to Credit Duct Sealing

The Non-Residential ACM should be modified to include the impact of duct leakage and insulation levels on heating equipment efficiency and cooling equipment efficiency for individual single-zone unitary (packaged) equipment serving 5000-ft² or less via ductwork located in the space between an insulated ceiling and the roof.

The impacts of duct leakage and duct insulation on HVAC system efficiency should be calculated using the algorithms similar to those used for low-rise residential buildings. (see Appendix F of the 1998 Residential ACM). The impact of duct efficiency should be accounted for in the standard building as well as the proposed building.

In nonresidential calculations, assumptions for the standard buildings should assume a leakage of 22% of fan flow, split equally between supply and return ducts (same as residences). If the proposed nonresidential building is diagnostically tested by a Home Energy Rating System (HERS) rater to have tight ducts (less than 6% of fan flow for supply and return ducts combined), then the duct efficiency of the proposed building can be calculated using 8% total duct leakage split equally between supply and return ducts. Similarly, if the proposed building is verified by a HERS rater to have duct insulation levels above the standard R-4.2 level, then the duct efficiency of the proposed building shall be calculated using the documented insulation level.

Support Air Distribution Sealing through Utility Programs

The benefits of tighter ducts in nonresidential buildings are potentially substantial. California utilities—with their extensive experience in designing and implementing residential duct sealing programs—could transfer this experience to nonresidential programs. This would lead to the development of additional information on the costs and benefits to improving nonresidential air distribution systems. It would also provide immediate benefits to ratepayers and business owners by reducing the energy and demand costs associated with poorly sealed air distribution systems.

Research Air Distribution System Performance and Improve Tools

In the longer term, prescriptive requirements should be developed for all commercial buildings. Additional research will be needed, however, before such requirements can be developed. This research includes:

- Better characterization of buildings to establish appropriate baseline values;
- Work to develop duct efficiency measurement protocols for commercial buildings; and
- Development of modeling tools that can be used to predict the impact of commercial building duct efficiency improvements, and account for:
 - fan operation (continuous or cycling),
 - system type,
 - relative location of the ducts, thermal barrier and air barrier,
 - number of floors,
 - duct construction method,
 - climate, and
 - occupancy.

In particular, DOE2.1E needs to be significantly enhanced to allow widespread use for duct efficiency modeling. Currently, there are considerable problems with the algorithms, and the keywords are complex,

difficult to use, and highly sensitive to error. Algorithm problems include:

- All leakage occurs on the supply side of the system.
- All losses go to a single zone.
- Only one system can have losses to a given zone (multiple systems located in a single plenum cannot be accurately modeled).
- Building and zone infiltration is not sensitive to duct leakage.

The EnergyPlus simulation program currently under development by DOE will be much better at modeling duct efficiency problems, although the program's current development plans leave some key gaps. EnergyPlus models HVAC systems as a network of nodes. Each of the nodes representing the duct system can include air losses, and these losses will properly affect the remainder of the duct system as well as the zones where the node is located and the zones served by the system. Current plans, however, do not include modeling of thermal losses through the ducts' walls, such as occur when ducts are located in a hot attic. Current plans also do not include specific duct efficiency input commands.

It may be desirable for California to fund work to ensure that EnergyPlus will include all needed capabilities, with straightforward input requirements, for use as a compliance tool.

Bibliography

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Delp, W. W., N. E. Matson, E. Tshudy, M. P. Modera, and R. C. Diamond. 1997. Field investigation of duct system performance in California light commercial buildings. Lawrence Berkeley National Laboratory, Report #40102.

Eight California light commercial buildings, containing a total of 15 systems, were studied to characterize factors significant to duct system performance. They found that 50% of the buildings had the ceiling cavity outside the thermal and air barrier, and that the leakage area per square foot of floor area averaged 2.6 times (360%) that of residential buildings. The duct systems were constructed using methods similar to that of residential buildings, with 60% of the buildings using all metal duct systems, with the remainder flex-octopus. All the buildings used packaged rooftop units with the ductwork in the ceiling cavity. Most of the units operated with cycling fans (apparently all but one).

Felts et al. 1999. Roof top unit technical potential assessment, working papers. Pacific Gas and Electric Company.

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Modera, M. P. 2000a. Personal communication with Bruce Wilcox.

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Modera, M. P. 2000b. Email to Roger Hedrick.

Described life of Aroseal duct sealing technology. No known seal failures after 6 years of installations in residential

buildings. Accelerated life testing with no failures to >70,000 cycles, where duct tape failed at 200-1,500 cycles.

Modera, M. P. 1999. Commercial thermal distribution systems final report for CIEE/CEC. Lawrence Berkeley National Laboratory, Report #44320.

Summarizes the state of research on commercial duct leakage; compares it to residential data. Includes equations describing the various loss mechanisms, and discusses the various assumptions. Discusses in detail the ability of DOE-2.1E to model duct losses.

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Describes the results of surveys that characterize the commercial building stock in California. Includes distribution system type and various components of system energy consumption. Provides case studies on a small subset of buildings.

RLW Analytics et al. 1999. California non-residential new construction baseline study. California Board for Energy Efficiency.

Conducted by RLW in association with Architectural Energy Corporation and the Hescong Mahone Group. Developed from a database of over 800 onsite surveys compiled during evaluations of NRNC DSM programs operated by PG&E, SCE and SDG&E.

Provides statewide coverage of the new construction marketplace.

Xu, T., R. F. Carrie, D. J. Dickerhoff, W. J. Fisk, J. McWilliams, D. Wang and M. P. Modera. 1999a. Performance of thermal distribution systems in large commercial buildings. Lawrence Berkeley National Laboratory, Report #44331.

Five systems in three large offices and one supermarket were studied, each of which served at least 2000 m² (21,000 ft²). Air leakage areas (ELA25) were measured in the range of 0.1 to 7.7 cm² per square meter of floor area, which resulted in leakage of up to 1/3 of the fan-supplied airflow in constant volume systems. Leakage varied by system and section of the same system. Energy impacts were due to additional fan power requirements.

Xu, T., O. Bechu, R. Carrie, D. Dickerhoff, W. Fisk, E. Franconi, O. Kristiansen, R. Levinson, J. McWilliams, D. Wang, M. Modera, T. Webster, E. Ring, Q. Zhang, C. Huizenga, F. Bauman, and E. Arens. 1999b. Commercial thermal distribution systems final report for CIEE/CEC. Lawrence Berkeley National Laboratory, Report #44320.

Characterized thermal distribution systems in large and light commercial buildings, evaluated adding duct performance to the commercial portion of Title 24, tested aerosol duct sealing for large commercial application and evaluated protocols to be applied to large commercial systems. Described in detail the commands available in DOE-2.1E for modeling duct leakage, including a discussion of the limitation of such modeling.