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# Stopping Duct Quacks: Longevity of Residential Duct Sealants

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**ABSTRACT**

Duct leakage has been identified as a major source of energy loss in residential buildings. Most duct leakage occurs at the connections to registers, plenums or branches in the duct system. At each of these connections a method of sealing the duct system is required. Typical sealing methods include tapes or mastics applied around the joints in the system. Field examinations of duct systems have shown that these seals tend to fail over time periods ranging from days to years. We have used several test methods over the last few years to evaluate the longevity of duct sealants when subjected to temperatures and pressures representative of those found in the field. Traditional cloth duct tapes have been found to significantly under-perform other sealants and have been banned from receiving duct tightness credits in California's energy code (California Energy Commission 1998). Our accelerated testing apparatus has been redesigned since its first usage for improved performance. The methodology is currently under consideration by the American Society for Testing and Materials (ASTM) as a potential new test method. This report will summarize the set of measurements to date, review the status of the test apparatus and test method, and summarize the applications of these results to codes and standards.

## Introduction

In the U.S. forced air systems are the dominant method of heating and cooling residential buildings (Energy Information Administration (EIA) 1997). The air distribution systems require some sort of seal between duct sections, at branches and at plenum and register connections. Without these seals, duct systems would be extremely leaky and inefficient. Field studies (Jump et al. 1996; Cummings et al. 1990; Downey and Proctor 1994; Modera and Wilcox 1995) have shown that existing residential systems typically have 30-40% of the total air flow leaking in and out of the duct system. Because these ducts are often outside conditioned space, this leakage corresponds to a similar amount of energy (30-40%) being lost from the duct system instead of going to heating or cooling the conditioned space. In addition, a system with more supply leakage than return leakage causes a greater penalty than just the amount of air lost. Increased infiltration from outside replaces supply air and must be conditioned. There are also comfort, humidity and indoor air quality problems associated with return leaks drawing air from outside or unconditioned spaces within the structure (e.g., damp crawlspaces). Note that field studies (Walker at al. 1998) have shown that ducts located within the thermal envelope (e.g., in joist spaces between floors or interior partitions) can still have significant leakage to outside because these spaces are not air sealed.

Residential duct systems in the U.S. are normally field designed and assembled. There are many joints, often of dissimilar materials (e.g., plastic flex duct to sheet metal collar). The mechanical connection of the duct system components does not usually provide an air seal. High pressure differences in the vicinity of the air handler and associated plenum, mean even small holes have potentially large leakage flows. Therefore, standard practice (Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) 1985) calls for all joints in the duct system to be air sealed in addition to being mechanically fastened. However, field studies have shown that many systems are poorly sealed.

Each sealant choice has different advantages or disadvantages, but a reasonably careful job of application, can produce a good initial seal for any of them. While any sealant method can produce a good initial seal, it is not clear that all last equally well. The length of time a duct seal can last is important given that houses are said to be designed to last 30 years and flex duct systems are often rated at 15 year life. Ideally, duct seals should last at least as long as the rest of the duct system, but are often observed to fail in a few years (Walker et al. 1998). Poor installation of sealants (e.g., on dusty or oily surfaces prevalent during construction) can be a contributing factor (that will not be addressed here), but it appears that physical properties of some of the sealants themselves may result in poor seal longevity.

While some duct sealant technologies are rated (e.g. by Underwriters Laboratory 1993, 1994, 1995) on their manufactured properties, none of these ratings addresses the in-service lifetime. Selection of sealants that do not fail within the lifetime of the duct system requires the existence of relative ratings for sealant longevity. The purpose of this study was to develop such a rating method.

The duct sealing methods examined in this study can be split into the following classes:

- **"Duct Tape"** has a vinyl or polyethylene backing with fiber reinforcement and has a rubber-based adhesive. It comes in wide variety of grades with different tensile strengths. The composition and material of the backing has some variation, with some tapes having a distinctive backing that has the appearance of cloth rather than vinyl or polyethylene. The classic duct tape is silver/gray, but is available in many colors.
- **"Clear UL181B Tape"** has a thin polyester backing (typically clear) and an acrylic adhesive. Clear UL 181B tape is often used on factory-assembled duct systems, and is becoming more common in field assembled systems.
- **"Foil Tape"** has metal foil backing and like clear UL 181B tape has an acrylic adhesive. Foil tapes are often used on rigid duct systems (e.g. duct board). Foil tapes with rubber-based adhesives exist but have not yet been tested.
- **"Butyl Tape"** typically has foil backing as well, but uses a thick (0.38 to 1.3 mm) butyl adhesive to allow it to conform to more irregular shapes.
- **"Mastic"** is a wet adhesive available in different consistencies (usually applied with a brush) that fills gaps and dries to a semi-rigid solid. Mastics may also be used together with reinforcing fibers or mesh tape.
- **"Aerosol Sealant"** is a sticky vinyl polymer that is applied to the leaks internally, by blowing aerosolized sealant through the duct system. This sealant system was developed by LBNL, and is discussed in more detail in Carrie and Modera 1995.

Two separate experiments were used to examine the longevity of these duct sealants:

1. **Baking tests.** Samples were placed in an oven and held at a steady temperature (about 65°C (150°F)) with no air flow through the test sections.
2. **Aging tests.** This was a more sophisticated experiment that alternately blew heated (95°C (203°F)) and cooled (-5°C (23°F)) air through the test sections and also cycled the pressure difference across the leaks.

This paper will present a summary of these test procedures and their results. Additional information about thermal distribution systems and duct sealing can be found at the following web page: http://ducts.lbl.gov.

## Evaluating sealant longevity performance

The longevity measurements in this study focussed on the properties of the sealants as opposed to installation issues. Therefore considerable effort was made to ensure good initial seals, by following good practice and manufacturers instructions carefully. This is particularly important for sheet metal that often has an oily residue (left over from the manufacturing process) that impairs a good initial seal and would presumably impair longevity performance. The ducts were thoroughly cleaned before applying the sealants. The exception was that no cleaning was required for mastic and aerosol sealants. For the tests in this report, the application of the sealant was meticulous and all the sample connections were measured to ensure a good seal before beginning any of the tests.

In a field application, it is not practical to take this level of care during the installation of the duct system. Access to the ducts may be limited and ducts may be or become dirty before the sealant is applied. Because tapes are particularly sensitive to these issues, some taped seals may not perform well because of their installation rather than any intrinsic fault of the tape itself. Non-tape sealants can often be more tolerant of dirt and/or able to reach all the leaks. The longevity tests discussed in this paper did not address these installation issues.

Existing UL 181 standards (Underwriters Laboratory 1993, 1994, 1995) concentrate on evaluating safety, tensile strength, and initial adhesion. They have not been developed to measure the ability of sealants to maintain the seal when subjected to the environmental conditions normally experienced by ductwork. The three longevity test methods developed for this study specifically focus on evaluating the longevity of the sealant. The longevity tests stress a standardized joint configuration with different environmental conditions. The testing includes visual observation of seal degradation and measurement of sample leakage. It should also be noted that this paper does not attempt to correlate how long the sealants last in the tests to how long they would last in a real house. This is because the range of operating conditions varies enormously between installations in individual houses.

The longevity tests were designed to use conditions of temperature, pressure and airflow that would be experienced by typical duct system installations. The testing is accelerated compared to real installations by having the ducts at a continuously high temperature in the **baking test**; and rapidly changing from hot to cold conditions in the **aging test**. For the baking test, the temperatures are at a sustained high level (65°C (150°F)) that would periodically be experienced by ducts in a hot attic (Carlson et al. 1992 and Walker et al. 1999) or by ducts close to the supply plenum of a furnace (The Uniform Mechanical Code (ICBO 1994) Canadian Natural Gas Installation Code (CGA 1995) give the same limit of 250°F (121°C)). For the aging test the high and low temperature and pressure limits are individually typical of real duct systems, but it is unlikely that a duct system would experience these rapid hot to cold and cold to hot transitions. The cycle time of ten minutes was limited by the need to warm up and cool down the test sample.

For the leakage measurements of individual sealants, a standard pressure of 25 Pa was chosen because this is a typical pressure that would exist in the branches of a residential duct system. It is between the high pressures at a plenum (on the order of 100 Pa) and the low pressures at registers (on the order of 5 Pa). In addition, existing leakage measurements for duct systems installed in houses also use this reference pressure (California Energy

Commission (CEC) 1998, American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) 1999). In all the longevity tests, temperatures are kept below 93°C (200°F) because some of the tested tapes had this as an upper limit temperature rating. The aging apparatus has between 100 and 200 Pa of pressure across the sample joints (which is higher than the pressures measured in most residential duct systems) but it acts to accelerate any failure by putting a bigger mechanical stress on the seal than it would experience in a real installation. More details about the test methodology can be found in previously published reports (Walker et al. 1998; Walker et al. 1997; Walker and Sherman 2000) and will not be repeated here.

## Selection of sealants to be tested

The sealants tested in our apparatus were those tapes and sealants which are either commonly used or are being considered for use in various duct sealing programs (e.g., within utility sponsored energy efficient homes). Any tape that had a maximum temperature rating below 60°C (140°F) was excluded. Not only would it be expected to fail quickly in the longevity tests because of their higher temperatures, but any duct tape with such a poor temperature rating should not be used, because either hot attics or normal heating systems would expose ducts to such temperatures. In preparation for testing, major tape and sealant manufacturers were contacted to ensure that a wide range of available products were tested and to determine which ones have been certified by UL. Duct tapes are discussed separately from the other sealants because duct tape is the most popular method of sealing ducts in the U.S. and comes in the most grades and types. In addition, the test results showed that duct tapes performed differently from all the other sealants.

The aerosol sealant was developed by Lawrence Berkeley National Laboratory as an alternative duct sealing method. Two samples were prepared: one each for the baking and aging tests. Mastic is available in several varieties (but an order of magnitude less variety than tapes) some of which include added fibers for increased mechanical strength. The mastic product tested here did not include these reinforcing fibers and was one with a UL rating (only a few mastic products carry the UL rating). Only a few mastics are currently UL 181B-M (Underwriters Laboratory 1995) approved although many are UL 181A (Underwriters Laboratory 1993). Clear UL 181B tape is produced by several manufacturers, however, at the time these tests were performed only a single type was available. Manufacturers of clear tapes have recently changed the tapes to have perforations to allow for easier application and are producing the tapes in a range of colors. Three samples were tested: one for baking and two for aging. The second aging sample was tested because part way through the test program this product obtained a UL rating and it was important to observe if the tape had been changed in any way that affected longevity (The aging test results indicate that longevity was not changed). Butyl tapes are available with different thickness adhesive and in several tape widths. As with the other tape products, 50 mm (2 inches) wide tape was used because this is the most common width used in field installations. A single type of butyl tape was used in these tests that had a 0.38 mm (15 mil) thick adhesive layer with a metal foil backing. Three different foil tapes were tested. The tapes were from different manufacturers and had different foil thickness and formulations and all had acrylic adhesive. Figure 1 shows pictures of four of the first set of samples that were tested on the aging apparatus.

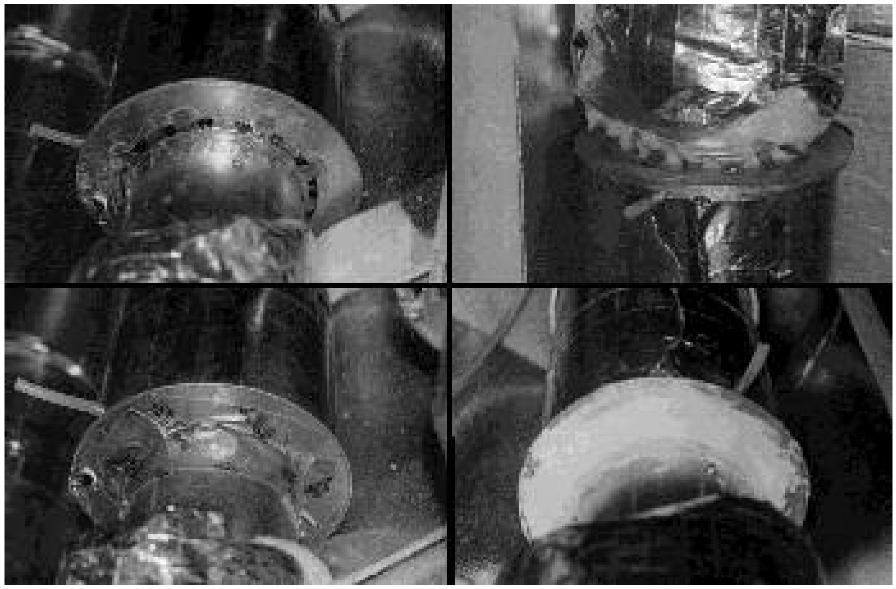

**Figure 1. Four samples connections for the aging test. Clockwise from top left: clear UL 181B tape, aerosol sealant, mastic and 181B-FX duct tape**

There is a wide range of duct tape products available that claim to be suitable for duct sealing, but there is often little in their specifications or product literature to differentiate them. While there is general agreement that there are several grades of duct tape it is not clear what that means. For example one major manufacturer lists 16 different duct tapes (not including color variation) and 8 foil tapes. Some of these tapes have their product codes printed on the tape, some on the cores, and some do not have any product number on them. Some are listed as “Code Approved” (e.g., by codes from Building Officials and Code Administrators International or U.S. Department of Housing and Urban Development). There was nothing exceptional in the product specifications to separate the approved from non-approved tapes. Catalogues call the different tape grades Economy, Utility, General Purpose, Contractor, Industrial, Professional, Premium and even Nuclear! They are all listed as being used on HVAC ducts. Several companies have recently produced UL 181B-FX (Underwriters Laboratory 1995) tapes that were not listed in product catalogs when this study was performed.

## Longevity Test Results

When the aging experiments were started it was expected that it would take weeks to begin to see degradation in performance. Surprisingly, some of the sealants failed in a matter of days. Most of the failure modes to date have been what might be termed catastrophic rather than gradual. In other words, the seal does not gradually become poorer with time, rather the seal remains tight until rapid failure occurs. This is in some ways fortunate because determining an exact numerical failure criterion is somewhat arbitrary. Nevertheless, the failure criterion was selected based on the results of preliminary testing such that a good seal is adequately differentiated from a failed seal. Failure was determined by comparing the leakage of the sample to the flow through the holes in the sample before any sealant was applied. The criterion was that a seal has failed when it lets more than 10% of unsealed flow pass through. Analysis of the test results showed that the passing or failing of a sample is not strongly dependent on this failure criterion. i.e., sealants did not fail a little bit (e.g. at 20% of unsealed leakage) and then stop. Most samples were tested past this 10% failure criterion and showed continual degradation. Over 30 different samples have been tested by baking and aging. We also made visual evaluations of the sealants, e.g., some samples had visible catastrophic failure when the tape fell off.

Figures 2a and 2b show how leakage of some samples changed with the length of time that the samples were in the test apparatus. The initial high leakage number (about 17 $m^3$/hour (10 cfm) @ 25 Pa) is the leakage of the sample connection before the sealant was applied. All of the rubber backed tapes showed visible signs of failure within about 3 days of the start of the test. Visible signs include shrinkage of the vinyl or polyethylene backing and wrinkling and delamination of the vinyl or polyethylene backing and the reinforcing mesh from the adhesive. The measured leakage for the duct tapes shown in Table 1 showed that samples had about 10% to 20% of the unsealed leakage after two weeks. The “Premium” tape failed completely (it fell off the test section), but the other tapes had just started to delaminate at this time. This complete failure was due to separation of the backing from the adhesive (some of the adhesive was left behind on the sheet metal). A second sample of the Premium Grade tape was tested to see if this was a repeatable failure; it lasted about 7 days before complete failure (note that this second sample is not shown in the figures). The foil backed tapes, the clear tape, the aerosol and the mastic show no visible or measurable signs of degradation after these two weeks of testing.

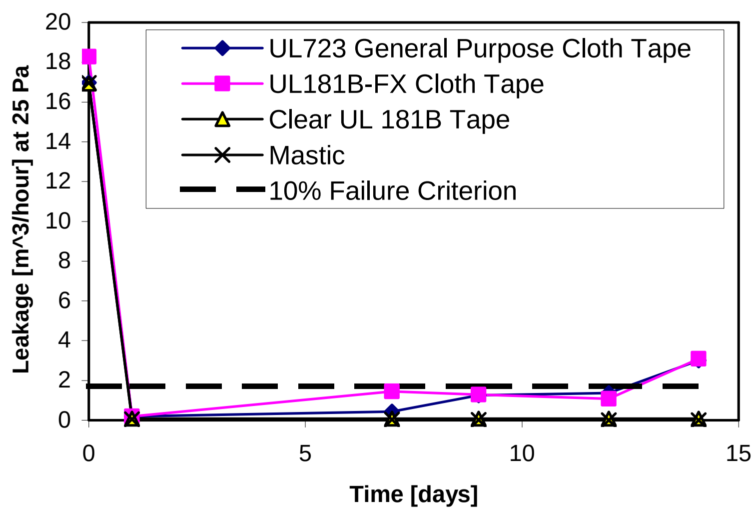


**Figure 2a. Changing test sample leakage at 25 Pa, from the aging apparatus**

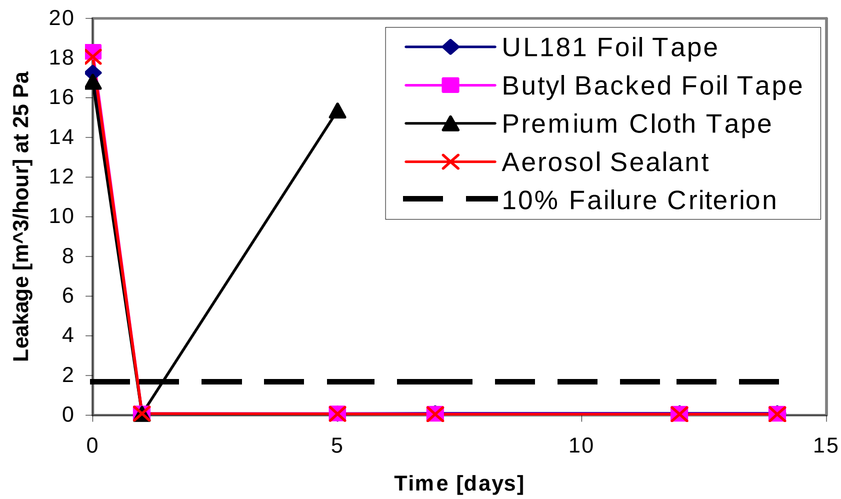


**Figure 2b. Changing test sample leakage at 25 Pa from the aging apparatus**

Table 1 summarizes the test results for the 18 failed duct tape samples. Most of the duct tape samples failed within in a week in the aging test. The aging and baking test results indicate that there is no clear advantage for the UL 181B-FX listed tapes; although they last longer (on average) than the non-UL tapes they still fail prematurely, compared to the other sealants. Although only duct tapes were observed to fail, four duct tape samples did not reach the 10% leakage failure criterion over the three month test period. However, in each of the four cases, the tapes showed some leakage and visual degradation.

**Table 1. Summary of Duct Tape Failures**

| # of Test Samples | Test Type | Description | Typical Failure Time | Final leakage at end of testing (fraction of unsealed leakage) |
|---|---|---|---|---|
| 8 | Aging | 5 different grades | 7 days | 20%-70% |
| 5 | Aging | 181B-FX | 10 days | 70%-100% |
| 4 | Baking | 3 different grades | 34 days | 30%-80% |
| 1 | Baking | 181B-FX | 60 days | 25% |

Because the baking test does not stress the samples with low temperatures or a pressure difference across the sealant, time to failure is longer than for the aging test. There are some cases where duct tapes have failed the aging test, but the same tapes in the baking tests have not. A visual inspection of these baked samples reveals that the duct tape samples have delaminated and the heat has apparently caused the rubber adhesive to harden. It appears that some of the samples have hardened in such a way as to maintain their seal rather like a mastic material. Because this process of hardening to maintain the seal has happened without any pressure being applied, it is unlikely to happen similarly in real installations (as shown by the aging results).

Table 2 summarizes the results from all of the other sealants. These sealants did not fail after several months and can be considered to have better longevity performance than the duct tape. Significantly, the other tapes (butyl, foil and clear UL 181B) did not exhibit the shrinking of the backing and the delamination shown by the duct tapes. The aerosol and mastic showed no visible or measurable signs of degradation.

**Table 2. Summary of non duct tape test results**

| # of Test Samples | Test Type | Description | Duration[1] | Comments |
|---|---|---|---|---|
| 1 | Aging | Butyl Tape | 3 months | 15mil; Foil Backed |
| 1 | Aging | Aerosol | 3 months | |
| 1 | Aging | Mastic | 3 months | 181A |
| 1 | Aging | Foil Tape | 3 months | 181A-P only |
| 1 | Aging | Foil Tape | 1 month | 181A-P & 181B |
| 1 | Aging | Clear UL 181B Tape | 3 months | |
| 1 | Aging | Clear UL 181B Tape | 1 month | 181A & 181B |
| 1 | Baking | Clear UL 181B Tape | 4 months | 181 |
| 1 | Baking | Aerosol | 4 months | |
| 1 | Baking | Foil Tape | 4 months | 181A-P |

1- Note that duration does not indicate time to failure. It is the length of time the samples were tested in the apparatus.

## On-going Activities

The aging results described above were all done with our first test apparatus and mostly completed by 1999. Since those experiments were done, we have redesigned and rebuilt the aging apparatus. The new apparatus conforms generally to the specifications of the ASTM draft test and incorporates many improvements encountered during the first stage operation. The major additional capability is testing at steady hot or cold temperatures (i.e. no cycling) with the leakage site pressurized. We added this ability in order to determine if a simpler longevity test of heating or cooling only could be used. The main appeal of a simpler test is the reduction in equipment investment, set up and operating oversight. In addition, the new apparatus can test a total of 38 samples simultaneously. The standard test sections are 100 mm (4 inch) duct collars mounted in a 112 mm (4.5 inch) hole, however, the apparatus has space for 150 mm (6 inch) ducts up to 700 mm (28 inches) long. We are planning to test other types of duct connection, such as factory assembled duct board splitter boxes in the future, and the apparatus has been designed to accommodate these larger sample sections.

Preliminary results are the same as for the other tests discussed in this paper – i.e. the only sealants to fail are duct tapes. The failures occur fastest when heating only (in about one to three weeks), with slower failures during cycling. The tapes being cooled have not failed yet, but their leakage is slowly increasing. These results indicate that heating only may be a simpler alternative for longevity testing (compared to the complex cyclic testing we have done for this study).

## Codes and Standards

There are several codes and standards that are either relevant to duct sealing, or have used the results of our duct sealing results. Both Underwriters Laboratory and ASTM are concerned with laboratory testing of duct sealant products. The CEC and EPA include restrictions on duct sealant materials in their duct programs.

**Underwriter's Laboratory.** The UL 181 standards are referred to in many codes and specifications related to thermal distribution. Currently several products that have good longevity fail to meet the appropriate standard or have no appropriate UL standard to reference. Individual manufacturers are addressing this concern by either modifying their products or working with UL to develop appropriate testing.

**American Society of Testing and Materials.** There is currently no consensus or ANSI-approved standard for evaluating duct sealant longevity, however ASTM Committee E6.41 is developing a test method. The test sections are of the plenum to collar joint type shown in Figure 1. The test sections use ducts of 4 to 8 inch (100 to 200 mm) diameter round sheet metal mechanically connected using sheet metal screws. The sealant is applied after ensuring that surfaces to be sealed are clean and free from dust, dirt and excess lubricants used in the manufacture of many sheet metal duct fittings. The test sections are tested before and after they are sealed by measuring the leakage flowrate when the sample is pressurized to 25 Pa. The test sections are removed from the longevity apparatus on a weekly basis to have the leakage test performed. The longevity test apparatus is required to operate in a similar way as the aging tests performed for this study:

1. The bulk (average) flow velocity through each test section is 5 to 7.6 m/s (1000 to 1500 ft/min).
2. Pressure difference between the inside of the test section and its surroundings is 100 to 200 Pa (0.4 to 0.8 inches of water).
3. The lowest test section surface temperature is 0°C to 5°C (32°F to 41°F).
4. The highest test section surface temperature is 66°C to 82°C (150°F to 180°F).
5. Cycle time is between 8 and 12 minutes.
6. Temperatures and pressures are continuously monitored.

**California Energy Commission (Title 24).** The version of the State energy code of California, adopted in June of 1999 allows builders to get extra credit for building an efficient duct system through the Alternative Calculations Manual (ACM) compliance procedure. To obtain the energy efficient duct credit in the ACM the air leakage at 25 Pa (0.1 inch of water) must be less than 6% of air handler fan flow (for comparison, the default duct leakage is set to 22%), and the air leakage must be verified by measurement. Because of the poor longevity characteristics of duct tape, the CEC believes that ducts will not stay sealed when this product is used. Accordingly, the performance credit is not available for ducts sealed with duct tape.

**EPA ENERGYSTAR® Ducts.** EPA's ENERGYSTAR® duct program has been developed for retrofit, repair and replacement applications rather than new construction, although it is expected that this program will be applied in the future to new houses. The ENERGYSTAR® duct program has both a prescriptive specification and a performance specification. The prescriptive method requires duct leakage to be less than 10% of air handler flow (measured using fan pressurization) and duct insulation to be a minimum of R4 (RSI 0.7), but any ducts with less than R4 (RSI 0.7) must be insulated to at least R6 (RSI 1). The performance specification is an efficiency of 85%. The efficiency is to be calculated using the methods in proposed ASHRAE Standard 152P [ASHRAE 1999]. In order to prevent the cases of duct systems that achieve high efficiency using 152P, but would be considered poor for other reasons, the EnergyStar program requires that the maximum allowable leakage is 25% of air handler flow for systems that use the efficiency calculation option. This program also specifies the required system airflows in order to reduce the duct (and equipment) inefficiencies introduced by having airflows that are too high or too low. As with the CEC ACM requirements, cloth backed rubber adhesive duct tape is not considered an acceptable sealant in this program.

**Other duct efficiency programs**
The following programs currently give limits on allowable duct leakage.

**City of Austin Electric Department (CAED).** CAED specifies leakage to be less than 5% of air handler flow and/or pressure pan (Conservation Services Group (1993) p. 44) readings all have to be less than 1 Pa.
**State of Oregon.** The specification is for the leakage to be less than or equal to 0.06 cfm at 50 Pa (0.2 inches of water) per square foot of conditioned space (1.1 $m^3$/hour per square meter). For an air-conditioned California home with an air handler flow of about 0.7 cfm/$ft^2$ (13 $m^3$/hour/$m^2$) (CEC 1998), this leakage specification corresponds to 6% of air handler flow at 25 Pa (0.1 inches of water). An alternative is to have pressure pan readings less than 1 Pa.
**City of Irvine IQ+ program.** The specification is that the 25 Pa leakage flow is numerically less than the floor area in square feet divided by 20. This corresponds to an allowable leakage of 50 cfm at 25Pa/1000$ft^2$ (0.9 $m^3$/hour/$m^2$).
**Pacific Gas & Electric (PG&E)**. The PG&E Comfort home program includes duct leakage testing at 25 Pa, with a limit of 12% of the nominal air handler flow that is fixed at 400 cfm/ton.

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