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# HOME OWNER BEST PRACTICES GUIDE FOR RESIDENTIAL RETROFITS

I.S. WALKER

Environmental Energy Technologies Division

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ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL  
LABORATORY IS AN EQUAL OPPORTUNITY EMPLOYER.

# HOME OWNER BEST PRACTICES GUIDE FOR RESIDENTIAL HVAC RETROFITS

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## INTRODUCTION

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This best practices guide for HVAC system retrofits is aimed at homeowners who want guidance on upgrading their heating, cooling and ventilation (HVAC) systems and integrating these upgrades with other changes to their home. It has been developed around the idea of having packages of changes to the building HVAC system and building envelope that are climate and house construction dependent. These packages include materials, procedures and equipment, and are designed to remove some of the guesswork when selecting a builder, contractor, or installer. The packages are not meant to be taken as rigid requirements – instead they are systems engineered guidelines that form the basis for energy efficient retrofits. Similar approaches have been taken previously for new construction, where a systems engineering approach has been used to develop extremely energy-efficient homes that are comfortable, safe and durable, and often cost less than standard construction. This approach is best epitomized by the Building America program, whose partners have built thousands of residences throughout the U.S. using these principles. The differences between retrofitting and new construction tend to limit the changes one can make to a building, so these packages rely on relatively simple and non-intrusive technologies and techniques. The retrofits also focus on changes to a building that will give many years of service to the occupants.

Another key aspect of these best practices is that we need to know how a house is working so that we know what parts have the potential for improvement. To do this we have put together a set of simple tests that a homeowner can perform on their own together with checklists and questionnaires. The measured test results, observations and homeowner answers to questions are used to direct us towards the best retrofits applicable to each individual house. The retrofits will depend on the current condition of the building envelope and HVAC system, the local climate, the construction methods used for the house, and the presence of existing energy saving systems and/or materials. This is just like a doctor referring a patient for blood tests or x-rays before actually performing surgery.

This way the doctor can be sure that he does the right thing. To take this analogy further – we can borrow from the medical profession and say that the first thought when retrofitting a house is to do no harm, i.e., do not make changes that could make the house worse to live in.

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## WHEN DO WE THINK ABOUT UPGRADING AN HVAC SYSTEM?

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### REPAIR

When the HVAC system is not working is an ideal opportunity to make improvements. Often equipment is broken and is therefore an ideal time for replacement, together with other related upgrades from the retrofit packages. If you have a consistent maintenance program for your HVAC systems (e.g., spring tune-ups for air conditioners) you and your contractor will be aware of the need to replace equipment before it fails.

### REPLACEMENT

It is a good idea to replace rather than repair failed or failing systems if they have become unreliable. Newer equipment is often more energy efficient than older equipment. You may also want to upgrade/improve your system if you have high bills or if your utility offers rebate programs. When equipment is replaced, this is another key time to look at building and HVAC components beyond the furnace or compressor.

### REMODEL

When homes are remodeled, HVAC systems are often upgraded so that they can better condition the house, or their capacity is increased if the remodel includes the addition of rooms. Because remodeling often includes removal of floors and walls this allows more extensive retrofits – like replacing ducts or completely redesigning the duct system to make it smaller or run inside conditioned space. Because of the high disruption level associated with remodeling, relocation of air handlers, outdoor condensers and installation of economizers will also be easier.

### MOLD REMEDIATION

Significant problems with mold are becoming more common and a mold remediation program needs to include methods of keeping the house mold-free after the immediate problem is solved. This approach requires a combination of fixing problems with the building envelope (e.g., installing flashing, fixing roof leaks, sealing crawlspaces, etc.) and having a space conditioning system that controls indoor humidity and temperatures. A key to the best practices discussed here is that they can be done when a contractor is called to a house to perform other related work. Our objective is to realize the full opportunity that occurs when systems are being retrofitted, repaired or renovated.

### SYSTEM UPGRADES.

Rather than replace a system with one having the same energy efficiency, we can encourage the use of higher efficiency equipment. For furnaces the standard rating system is AFUE (Annual Fuel Utilization Efficiency) – the higher the number the better the furnace. The Federal Government sets the minimum level at 78% for most single-family applications. A simple improvement is to select a higher efficiency furnace. We recommend using condensing furnaces that have efficiencies >90%. Another advantage of condensing furnaces is that they do not require a large vertical flue and can be vented using plastic pipe that allows a lot more flexibility in placement of the furnace and integration with other appliances. For example, in some older homes, the flue size may not meet new codes if the flue is shared with a hot water heater.

The system can have many added features that ensure increased comfort, safety and durability in addition to reduced energy use. Examples include:

- System balancing: getting the right air flows into each room of the house is important from both an energy perspective and in keeping all the house comfortable. In particular, system balancing

helps to address the standard problems of upstairs being hotter than downstairs in two-story houses and distant rooms in ranch style homes getting insufficient heating or cooling. Your contractor needs to do some calculations to estimate what the right flows should be and then do some air flow testing to see if your system is working correctly. Air flows to an individual room are controlled using dampers at register grilles or dampers somewhere else in your duct system, usually found near the furnace/air handler.

- Multiple speed heating or cooling equipment to better match building loads.
- Added economizers to provide ventilation and reduce electricity consumption by reducing air conditioner energy use.
- Added zoning to increase comfort. This is particularly useful in houses that have large areas that are poorly conditioned. A classic example is a two-story house that is currently a single zone and does not get cool enough upstairs – a very common complaint.
- Better air supply grilles for more uniform temperatures in a room. This means grilles that have the right throw pattern.
- Better controllers, for example programmable thermostats, or using humidity rather than temperature control in humid climates

#### SIZING

If energy losses from the duct system are reduced with increased insulation and reduced leakage, and/or we also reduce building loads through envelope changes, then the system can be downsized. Additionally, most residential systems are already oversized and would benefit from correct sizing to reduce cyclic losses and improve part load humidity control. However, one needs to be careful: downsizing the equipment significantly without resizing the ducts could result in air balancing and register throw problems. Therefore, downsizing should also include the reduction of duct diameter with lower air flows in order maintain throw from registers for good room mixing. The extra cost of non-HVAC equipment related retrofits can be compensated for by the reduced cost of a lower capacity heating and cooling system. This strategy is being used successfully in new construction (for example by the Department of Energy's Building America Program).

#### INTEGRATED HEATING, COOLING & VENTILATION SYSTEMS.

An important aspect of healthy, durable and safe homes is to provide proper levels of ventilation. However, to ensure that ventilation is provided in an energy efficient manner it is important to integrate the operation of ventilation with heating/cooling systems.

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## OUTLINE

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This guideline will help you to better understand the important things for successfully retrofitting your homes heating, cooling and ventilation system.

This guideline starts with a screening checklist that includes target values that we expect for a healthy energy efficient home and potential retrofit actions for when a home does not meet these targets.

This is followed by a set of simple measurements you can do on your own. For more detailed measurements we recommend that you use a contractor.

In addition to the screening checklist you need to look at the general retrofit guidance that includes minimum requirements for all retrofits and a wider range of retrofit possibilities, e.g., creating a conditioned space for your HVAC system or adding economizers for free cooling and ventilation.

## SCREENING CHECKLIST

Observations	Potential Target value	Potential Retrofit Action
Location of HVAC system equipment and ducts	Inside conditioned space	Seal and insulates duct locations to make them more like conditioned space, or move system location.
Duct insulation <sup>1</sup>	R6 (RSI 1) to R8 (RSI 1.4) for all ducts outside conditioned space.	Add insulation to ducts
Air flows at registers	Hard to know for a home owner. But you can easily test for register flows using bag inflation techniques.	Replace registers, open/close dampers, reduce system flow resistance by straightening existing ducts or replacing them with straight runs of new ducts. Upgrade furnace blower.
Filter Condition	Clean and at least MERV 6 <sup>2</sup>	Replace dirty, low efficiency filters
Age and Condition of HVAC system	Clean and undamaged. Determine system age.	Clean the system and repair damage or Replace the system if > 15 years old
Window A/C units	EnergyStar compliant	Replace with central unit or improved distribution
Window shading	Located on south and/or west facing windows	Add shading to reduce solar loads
Solar radiation control	Radiant barrier in attic, low absorbtivity roof coatings	Add radiant barrier in attic, or low absorbtivity roof coatings
Spot Ventilation fan power consumption	2.5 cfm/W (1.2 L/s/W). A good source for these ratings is the HVI directory ( <a href="http://www.hvi.org">www.hvi.org</a> )	Replace with higher efficiency unit, remove/reduce duct flow restrictions, clean fan and ducting

<sup>1</sup> You can tell how well insulated your ducts are by simple observation. Some ducts have a jacket that has the insulation value printed on it. This is a number preceded by the letter "R". Typical numbers are 4.2, 6 and 8. As an alternative you can measure the thickness of the insulation. Typical insulation is about R2 per inch.

<sup>2</sup> MERV is an industry standard rating system for air filters, it stands for Minimum Efficiency Report Value determined using ASHRAE Standard 52.2

Measurement	Potential Target value	Potential Retrofit Action
Register air flows <sup>3</sup>	Depends on many factors, but will typically be in the range of 0.3 to 0.5 cfm/ft <sup>2</sup> of room floor area	Change total system flow, fix duct leaks and disconnected ducts.
Spot ventilation <sup>4</sup>	50 cfm each bathroom 100 cfm each kitchen	Replace fans, fix restrictive ducting
Duct leakage <sup>5</sup>	As little as possible, but aim for less than 10% of the total system air flow.	Seal ducts using mastic, aerosol sealant or good duct tapes (metal foil with butyl or acrylic adhesives NOT cloth-backed rubber adhesive (normal) duct tape)
Air handler flow <sup>6</sup>	350 cfm/ton in humid climates, 400 cfm/ton in dry climates. For heating, the furnace manufacturer will have a recommended range of temperature rise – this is best measured by a contractor.	Replace registers, open/close dampers, reduce system flow resistance by straightening existing ducts or replacing them with straight runs of new ducts. Upgrade furnace blower.

<sup>3</sup> Register flows can be estimated by homeowners using simple techniques discussed in this guide.

<sup>4</sup> Ventilation fan air flows can be estimated by homeowners using simple techniques discussed in this guide

<sup>5</sup> Duct leakage measurements are best left to an expert contractor. There are several techniques for measuring duct leakage and we recommend the use of standard test methods given in the following standard: ASTM E 1554, ASHRAE Standard 152.

<sup>6</sup> Air handler flow measurements are best left to an expert contractor. There are several techniques for measuring duct leakage and we recommend the use of standard test methods given in the following standard: ASTM E 1554, ASHRAE Standard 152. Many contractors attempt to measure air flow using a temperature rise method. This method has been shown to be highly inaccurate and therefore ask your contractor to use one of our recommended methods.

## ADDITIONAL CHECKLIST INFORMATION:

### ENERGY BILLS

Guidelines for evaluating energy bills can be found at DOE's Home Energy Saver ([homenergysaver.lbl.gov](http://homenergysaver.lbl.gov)) and the Energy Star Home Improvement Toolbox ([http://208.254.22.7/index.cfm?c=home\\_improvement.hm\\_improvement\\_index](http://208.254.22.7/index.cfm?c=home_improvement.hm_improvement_index)).

### DUCT INSULATION

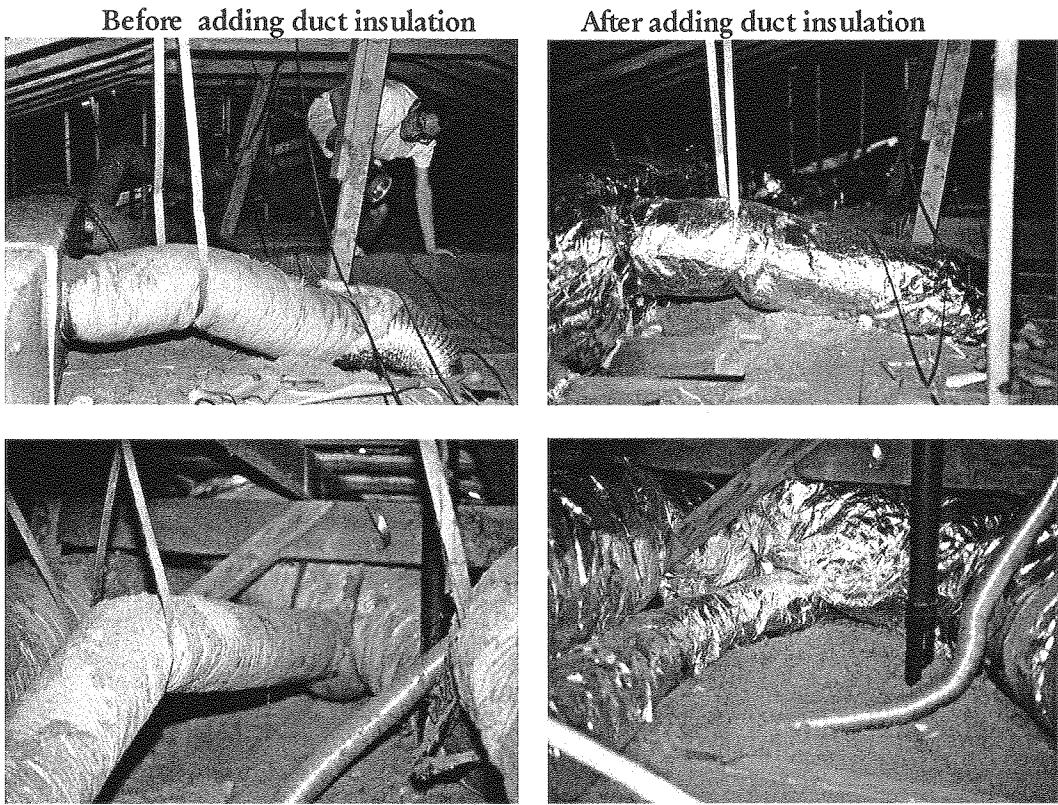
For flexible ducts, the insulation level is often printed on the outer jacket. The insulation level is the letter R followed by a number – often called the insulation R-value. Most ducts in existing homes will be marked R-4.2. For other ducts, insulation levels have to be estimated from the thickness and insulation type. We recommend a minimum of R8 for ducts outside the conditioned space. The most common method is to apply a duct wrap of glass fiber insulation. Other alternatives include burying ducts in blown-in insulation – either restrained by cardboard forms or as part of additional envelope insulation (e.g., insulation added to attic floors when ducts are lying on the attic floor). The duct insulation should include an airtight exterior vapor barrier to reduce the chance of condensation on cold duct surfaces in humid cooling climates.



*Blown-in insulation with cardboard forms*



*Installing Duct Wrap*



Location of ducts, air handler fan, plenums, and heat exchanger/cooling coil

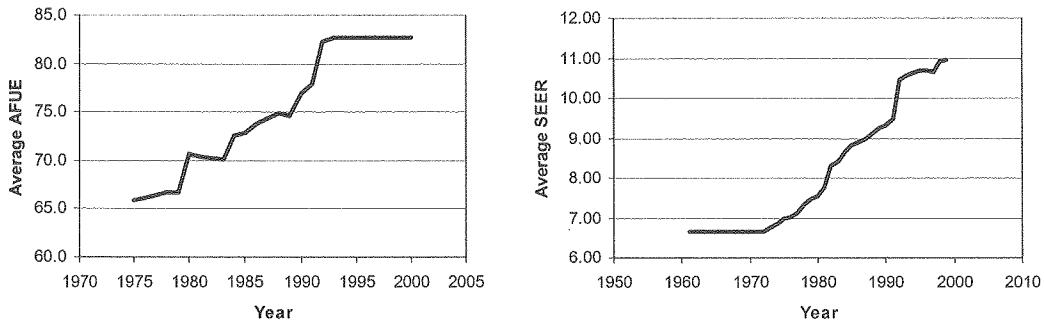
The location of these components has a significant effect on ease of access and potential for adding economizer and ventilation ducting to the system. Space restrictions can also limit the size of replacement components. As much as possible, the system should be brought inside the conditioned space. If located in the attic, then considerable system performance improvements can be had by improving the attic: by adding radiant barriers (in predominantly cooling climates) or sealing and insulating to make it an unvented attic. Similarly, when ducts are in crawlspaces, the crawlspace can be sealed and insulated. Note that sealing crawlspaces must include ground cover to reduce moisture and radon entry. In addition, some sealed crawlspaces use an exhaust fan to depressurize the crawlspace relative to the house to prevent transport of moisture, radon and other pollutants from the crawlspace to the house.



*Illustration of an unvented attic. The insulation has been moved from the attic floor to the pitched roof surfaces and all the attic vents have been sealed. Because the attic is now inside conditioned space – the ducts losses are very small.*

#### AGE AND CONDITION OF HVAC SYSTEM

A simple evaluation of the age and visual appearance of the HVAC system can be a good indicator for retrofitting. An older system will almost certainly be less efficient than newer equipment and the degradation of air seals and flue systems with age present good candidates for retrofitting. A system that shows dirty, rusting sheet metal, missing duct tape, missing fasteners, dust marked open face insulation, poor alignment of flues or air ducts, missing flues or air ducts, missing insulation, etc., is showing signs of neglect and is a good candidate for retrofitting or replacement.



*Historic values of Furnace (AFUE) and Air Conditioner (SEER) Efficiency sold in each year*

#### HOUSE INSULATION

In most retrofit cases it will be beyond the scope of the work to completely re-insulate a home, and it may be sufficient to focus on easily insulated areas such as attics and crawlspaces. The DOE/LBNL Home Energy Saver can be used to provide more guidance (<http://homeenergysaver.lbl.gov/>).

## WINDOW TYPE, AREA, ORIENTATION, SHADING AND FRAME CONDITION

Window type is a good indicator of the retrofit potential for the windows. Single-pane aluminum frame windows have poor thermal performance (and have high condensation potential) and are good candidates for replacement whereas double-pane vinyl-frame windows are much less likely to be replaced. Simple observation of frames looking for signs of moisture damage will give valuable information regarding not only window performance and likelihood of replacement – but also of high humidity conditions in the house or the presence of water leaks in and around the window openings.

## MULTIPLE HEATING/COOLING SYSTEMS

Multiple systems tend to complicate retrofit selection and implementation. Issues to investigate are:

- Are the different systems all the same age/condition – need to measure leakage/evaluate insulation separately
- Are ducts connected to the appropriate zones

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## TESTING YOUR OWN HOME

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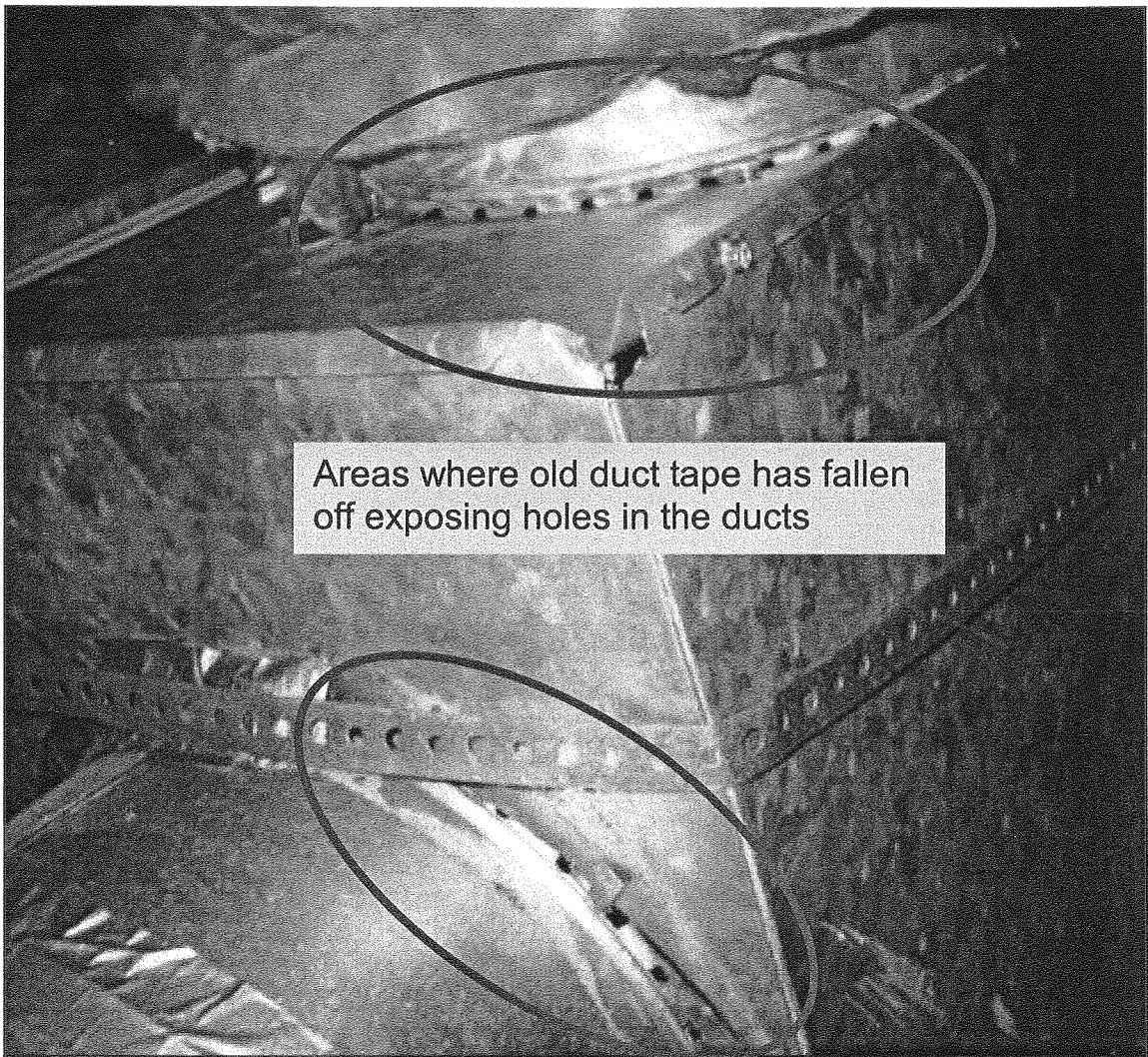
### DUCT LEAKAGE

To measure duct leakage accurately requires equipment and techniques that are beyond most homeowners. However, you can do some simple investigations on the **accessible**<sup>7</sup> part of your ducts – including those in attics, crawlspaces and garages.

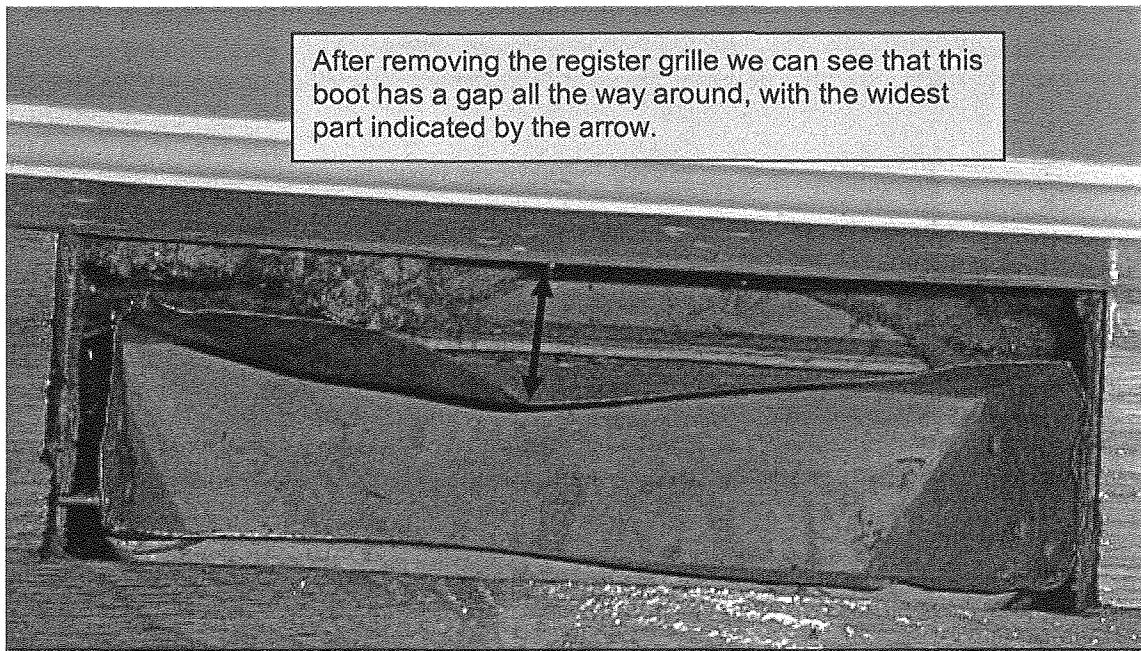
- Look for missing duct tape at the joints in the ducts – including where the ducts connect to your furnace/air conditioner.

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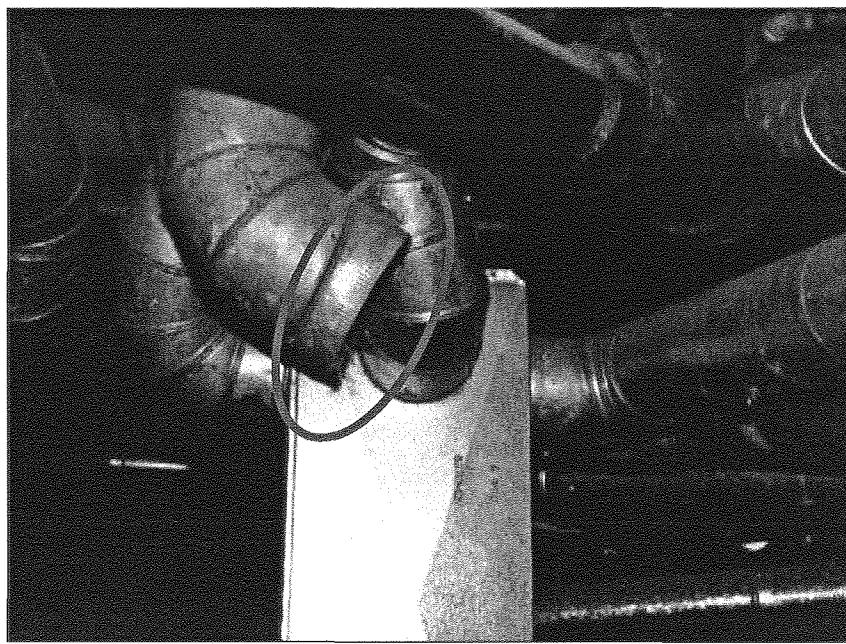
<sup>7</sup> Often there will be parts of your duct system you can't see in walls and floors, or they are hard to access, e.g., in very shallow crawlspaces. You will not be able to examine these parts of the ducts, so even if the parts you can see look OK – you might still have a leaky duct system.



- Look inside registers. Often there are large gaps between the register and the metal boot they connect to – or between the boot and the floor/wall/ceiling.



- Look for disconnected (or missing) ducts. This defect is much more common than you would expect! If you have a register with little air flow, then this can be an indication of a poor duct connection to this register. If you can, reconnect the duct and make sure that it is securely fastened. Sheet metal parts should be connected using sheet metal screws. Plastic flexible ducts need a strap to hold them in place. It is preferable to use a metal screw clamp for flexible ducts.





- If you find any obvious holes in the ducts, cover them with metal foil tape or mastic. DO NOT USE normal cloth-backed duct tape. You might need to find a contractor's supply outlet, rather than your local hardware store for the foil tape.



Building cavities used as air ducting are notoriously leaky. If you see something like this behind a grille, see if you can get a contractor to install a proper duct inside the cavity

Hole in plastic flexible duct. Note that cloth-backed duct tape was used in a previous repair and it has since fallen off. This duct section needs replacing or repairing with foil-backed tape and insulation



## TEMPERATURES AT REGISTERS

### Heating

If you feel that temperatures are too low coming out of your registers this is an indicator of several possible issues:

- Air flows are too high for the capacity of your heating system. If air is blasting out of the registers and your system makes a lot of noise than the air flow is probably too high. This can often be fixed by changing the speed of the blower fan. An HVAC contractor should be able to do this for you.

- Ducts are poorly insulated. Many older duct systems have little or no insulation and can be improved by adding insulation using commercially available duct wraps.
- Duct runs are too long. Long duct runs will exacerbate poor insulation and problems with running ducts in cold locations like attics, crawlspaces and attics. There is not much you can do about duct length, other than replace the ducts with shorter ones and move the registers to interior walls.
- Ducts are outside conditioned space in cold attics, crawlspaces, garages or unconditioned basements. Ducts exposed to cold temperatures will lose a lot of their heat before they reach the rooms in your house. Ducts can be moved inside – but this requires a great deal of effort that is probably only justified as part of a larger remodeling of the home.
- Heat pump issues. If you have a heat pump, as the outdoor temperature gets lower, the capacity of the heat pump is reduced and the temperature of the air it supplies goes down also. This is part of the normal operation of a heat-pump system, making it more difficult to decide if there is a problem. Unfortunately, while being the hardest to evaluate, heat pump systems also suffer the most from heat losses in ducts due to their low capacity when it is colder. One possibility to get a better idea of problems for a heat pump is to turn on the emergency heat (sometimes called strip-heat) that adds more heat to the air.

## Cooling

If you feel that temperatures are not cool enough at supply registers this is an indicator of several possible issues:

- Air flows are too high for the capacity of your cooling system. You may also notice that your system does not control the humidity in the house if the air flow is too high. If air is blasting out of the registers and your system makes a lot of noise than the air flow is probably too high. This can often be fixed by changing the speed of the blower fan. An HVAC contractor should be able to do this for you.
- Ducts are poorly insulated. Many older duct systems have little or no insulation and can be improved by adding insulation using commercially available duct wraps.
- Duct runs are too long. Long duct runs will exacerbate poor insulation and problems with running ducts in hot locations – particularly attics. There is not much you can do about duct length, other than replace the ducts with shorter ones and move the registers to interior walls.
- Ducts are outside conditioned space in hot attics, crawlspaces, or garages. Ducts exposed to high temperatures will lose a lot of their cooling before they reach the rooms in your house. Ducts can be moved inside – but this requires a great deal of effort that is probably only justified as part of a larger remodeling of the home.

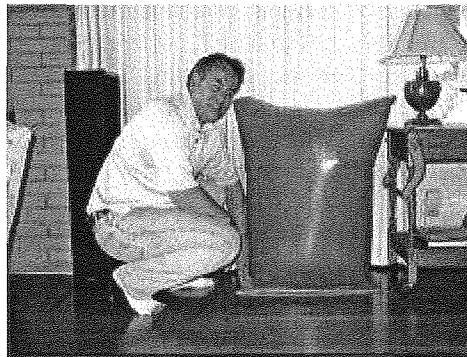
## GARBAGE BAG TEST

This test is a good way to measure air flows at forced air system grilles or exhaust fans. When you purchase a garbage bag its volume is usually written somewhere on the packaging. Normally this volume is given in gallons, but normal HVAC practice is to state air flows in cubic feet per minute or CFM. So, we need to convert the

volume from gallons to cubic feet by multiplying the number of gallons by eight. For example, a 30 gallon bag is  $30 \times 8 = 240$  cubic feet. Place a garbage bag over the supply grille you want to measure and using a stopwatch record how many seconds it takes to fill the bag. Divide the number of seconds by 60 to get minutes and multiply by the number of cubic feet. This gives you a result in CFM. As a check on your estimate, typical residential registers have flows in the 50 to 150 cfm range. Some small internal rooms will have less than 50 cfm and some large grilles (for example in the kitchens of houses with open plan cooking/eating/living areas) may have more than 150 cfm. More information can be found in the bag filling instructions part of this document and at

[http://www.cmhc-schl.gc.ca/en/burema/gesein/abhorse/abhorse\\_ce46.cfm](http://www.cmhc-schl.gc.ca/en/burema/gesein/abhorse/abhorse_ce46.cfm)

and in Home Energy magazine articles <http://www.homenergy.org>.



#### TOILET PAPER TEST

Bathroom exhaust fans often have little or no air flow due to poor installation and/or accumulation of dust. To see if your bathroom exhaust fan has any flow, a very simple test is to hold a piece of toilet paper near the fan entry and see if it sucked toward the exhaust. Although this test will not tell you exactly how much air flow there is through the exhaust, it does provide a simple indicator of the need to replace or repair the exhaust fan.

#### CONDENSATION & MOISTURE

If there is condensation on windows or walls for more than a few hours of the day, then this is an indicator that the affected parts of the building are too cold and/or you have high indoor humidity levels. Cold floor slabs are another condensation site that can lead to health issues due to mold growth and dust mites, particularly in carpet placed over cold concrete. Pull back a corner of your carpet and see if it is damp underneath. Often damp carpet has a characteristic musty smell that is a sign that it has been damp for an extended period of time.

Mold can only grow in a limited range of temperature and moisture conditions. The temperature mold likes is about the same as people like, so you are not going to be able to control mold by making your house a lot hotter or colder. This means that we need to control the condensation on building surfaces. Condensation happens when a surface is cold enough that moisture in the air can condense on the surface. The surface temperature for condensation gets lower as the moisture content of the air increases. So, to control condensation we need to look at two things: 1. controlling how much moisture is in the air, and 2. controlling surface temperatures.

1. Controlling moisture in the air

- Eliminate outdoor sources such as rain water penetration, ground water, leaky pipes, etc.
- Vent sources such as cooking and bathing directly to outside using exhaust fans
- Use a humidistat that turns the air conditioner on and off by measuring the indoor humidity instead of the indoor temperature
- Operate a stand alone dehumidifier
- Use a properly sized air conditioner. An oversized unit will operate for short periods of time and for an air conditioner to remove moisture from the house air it needs to operate for long periods of time --20 minutes or longer.

2. Controlling surface temperatures

- In winter don't let surfaces get too cold. This means having a well insulated building envelope. Windows are often the most likely place to see condensation because they are poor insulators compared to walls. Replacing windows with higher performing double-glazed units will usually eliminate this problem. Condensation is less likely on walls, but can happen where insulation is poorly installed, or the framing of the house acts as a thermal bridge. Adequately heating all of your home is equally important. Closing off rooms and not heating them makes them colder, but does not stop humid house air getting in and condensing on the cold surfaces. Sometimes, in an effort to save energy, people turn down their thermostats. This action can often lead to condensation problems as the interior surfaces of the house get colder.
- In summer, don't let surfaces get too cold. In many humid climates it is more humid outdoors than indoors and, unlike in winter, the indoor surfaces are not where we get condensation and mold growth. Instead we can have condensation inside wall, floor and ceiling spaces. Adding vapor barriers on the outside of wall assemblies, together with insulation to the inside of the vapor barrier can reduce these problems. Also reducing air leakage through the house envelope will limit this source of moisture while also reducing energy use.



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## RETROFIT GUIDANCE

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The companion guide for contractors (<http://ducts.lbl.gov/HVACRetrofitguide.html>) gives detailed packages of retrofits for home energy improvements. When you talk to your contractors, encourage them to read this guide, and read it yourself if you want to better understand what your contractor is proposing to do with your home.

### BASIC MINIMUM REQUIREMENTS

There are several requirements that apply to all HVAC retrofits:

- Select efficient air conditioning and heating equipment – At least SEER 12, HPSF 7.9 (and chose as high an EER as possible) and 90% AFUE.
- All replacement combustion appliances in the conditioned space must be sealed combustion or power vented.
- Do not use cloth duct tape to seal ducts.
- Use steel cable clamps on flex duct connections.

Use air filters with MERV 6 (or better) pleated filters. If possible, change the filter slot to accommodate 2 in. (or greater) pleated filters.

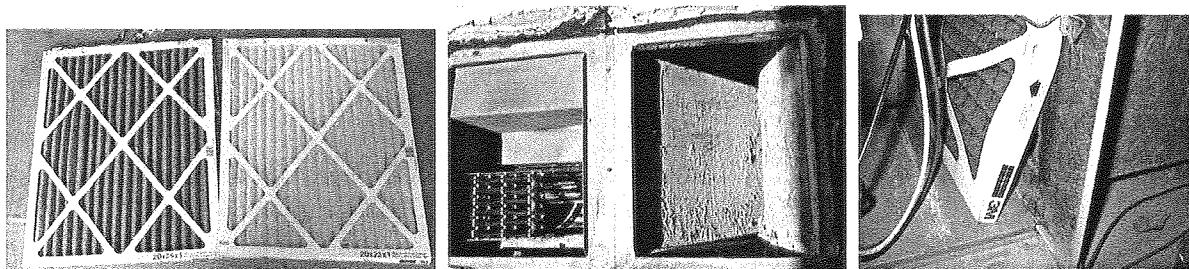
**Seal and insulate duct locations** – attics or crawlspaces. This action brings the ducts inside the conditioned space - thus minimizing their losses. In humid climates there is the additional benefit of reducing the chances of condensation on cold ducts in contact with outdoor air. However there are some caveats regarding sealing attics in warm humid climates as care must be taken to avoid moisture penetration of the roofing materials that can lead to buckling and failure of shingles. A good method for avoiding these problems is to use an impermeable underlayment beneath the shingles. More details are available at [http://www.buildingscience.com/resources/roofs/unvented\\_roof.pdf](http://www.buildingscience.com/resources/roofs/unvented_roof.pdf) and [http://www.buildingscience.com/resources/roofs/Unvented\\_Attic\\_Discussion.pdf](http://www.buildingscience.com/resources/roofs/Unvented_Attic_Discussion.pdf). Crawlspace sealing must include a ground cover to reduce moisture and radon entry into the crawlspace.

**Move registers.** Instead of having long duct runs out to the exterior walls, improved windows and envelope insulation allow the registers to be placed closer to the center of the building. This situation results in much shorter duct runs that reduce duct losses and cost less.

**Add an economizer.** In dry cooling climates, an economizer can significantly reduce compressor operation and result in energy savings at the same time as providing ventilation air. If the economizer is connected to the forced air system (as is usually done) it will help to ensure good thermal and fresh air mixing throughout the house. Sealed and well-insulated ducts are a requirement for using an economizer. Because the optimum air flow for economizers is often less than the standard air handler flow, it is important to have an air handler that operates efficiently at lower speeds – usually this means specifying an ECM motor. Economizer operation needs to be carefully checked to make sure that the flow control dampers are operating properly – including pressure relief dampers. The outdoor air should be filtered before it enters the house. This can most easily be accomplished by introducing the outdoor air into the forced air system before the filters. This means that filters will not be placed at return grilles and will probably be placed at the air handler filter slot or in the economizer air flow control system itself. The filters are then in a location not easily observed by the homeowner, so some effort is required to make the homeowner aware of this so that they will still make regular filter changes.

**Add ventilation.** Several potential methods exist: kitchen/bath exhaust, single supply into central system (with continuous central air handler operation), single supply into central system that operates periodically (for example BSC's AirCycler™ system used in their Building America houses (<http://www.buildingscience.com/resources/mechanical/default.htm>)). Ventilation air may require filtration, or be conditioned by a very small cooling system. The ventilation system needs to be integrated with the economizer operation (they may even be the same physical components, just with a different control strategy depending on system operating characteristics). For example, economizer air flow is typically much higher than ventilation air flow. Adding ventilation is particularly important if the building envelope has been significantly tightened by sealing leaks or adding insulation. Various ventilation standards give guidance on mechanical ventilation requirements. A good rule of thumb is to provide 7.5 cfm (3.5 L/s) per person (where the number of persons is determined by the higher of the number of bedrooms +1 or the known number of occupants) combined with local pollutant exhausts in kitchens and bathrooms. For intermittent operation, kitchen fans should be sized at a minimum of 100 cfm and bathroom fans at 50 cfm (25 L/s). Kitchen fans should always be vented to outside and not recirculate. Many houses have existing kitchen and bathroom fans that usually operate poorly – creating lots of noise but not moving much air. Replacement fans should be chosen to be energy efficient and quiet. To achieve good flow, the fan ducting to outside may have to be repaired or replaced. Do not vent to attics, crawlspaces or garages – the venting must be directly to outside.

**Use improved filters and/or filter slots to eliminate filter bypass and filter slot leakage.** An important issue with retrofits is to have a system that provides a safe and healthy environment for the occupants and proper filtration is a key aspect of this. Use filters with a minimum MERV 6 rating. If possible, use enlarged filter slots that allow deeper (2 or 4 inch) pleated filters. These deeper filters will have lower pressure drops and will therefore use less air handler fan power. The lower pressure drop also means that the return ducts downstream of the filter operate under a lower negative pressure, thus reducing duct leakage effects.

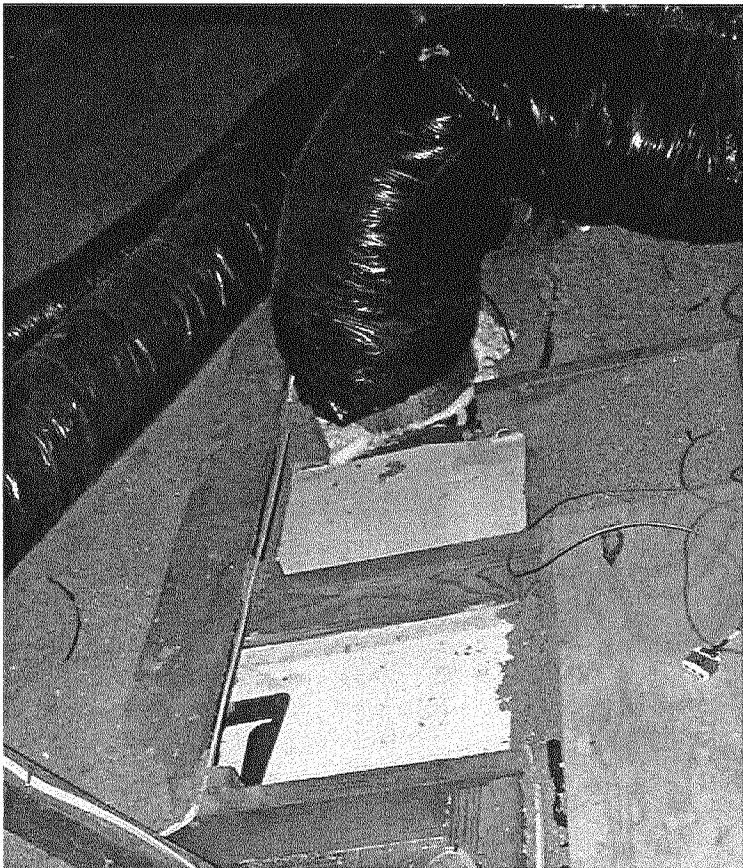


*These illustrations show dirty and clean pleated filters, a very dirty coil that had been exposed to unfiltered air and a poorly installed filter that leads to filter bypass and most of the air flowing through this system would be unfiltered.*

**Add solar shading** to existing windows in predominantly cooling climates.

**Improve envelope thermal performance.** Air sealing of the building envelope is a good way to reduce the energy used to condition the house. It also allows better control of the indoor conditions by using controlled mechanical ventilation, it increases the effectiveness of economizers and allows significantly better indoor humidity control. Target large openings first. Adding insulation to all parts of a building envelope is only really practical as part of a complete building renovation or repair. However adding insulation to attic spaces to reduce ceiling heat transfer can be effective – in particular – if ducts on attic floors can be buried in a thick layer of additional insulation there are large benefits from reduced duct losses. In situations where it is difficult to obtain code approval for sealing attic spaces completely, this covering of the ducts in added insulation is a reasonable second

best option. However, it is not recommended to bury ducts in humid climates due to the potential for condensation on the cold duct surfaces.



Often there are large building cavities or chases that are open to outside via attics, crawlspaces or garages. This is an example of a sealed chase viewed from the attic. The large white rectangles are duct board insulation that has been used to block off large open areas



Other leaks have much smaller dimensions – often they are just cracks, and are best sealed using foam



**Use indirect evaporative cooling instead of a refrigerant based system.** For example, the Davis Energy Group “nightbreeze” system ([http://www.davisenergy.com/nb\\_page.htm](http://www.davisenergy.com/nb_page.htm)) uses indirect evaporative cooling to provide cooled water to cooling coils for a forced air conditioning system.

**Add ceiling fans** to more evenly distribute cooling in rooms/spaces that are supplied by smaller air flows from downsized systems. It is best to select energy efficient ceiling fans such as the fan developed at FSEC: <http://www.fsec.ucf.edu/bldg/active/bdac/prototype/cfan.htm>

**Use register grilles** that have reduced pressure drops and noise, and better throw into the room for better mixing. Grilles should be chosen and located such that the high velocity air does not enter the occupied parts of the room directly. Noise and pressure-drop reduction is aided by selecting grilles with curved blades and by placing air flow control dampers at plenum take-offs (this also reduces duct system pressures and therefore has the potential to reduce leakage).

**Replace windows with improved double pane units.** Because of the expense this retrofit would probably only be performed in conjunction with HVAC retrofits for separate reasons, e.g., condensation problems with existing windows or problems with existing windows so that they would have to be replaced anyway. Depending on climate, low emittance coatings are available at little increased cost and can contribute to better control of solar loads (either increasing solar gains in heating climates or reducing them in cooling climates).

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## APPENDIX A: HOW TO MEASURE AIR FLOW AT YOUR REGISTERS. STEP ONE: BAG FILLING INSTRUCTIONS

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### HOW TO CHOOSE YOUR BAG

**Don't use bags that are too thin.** Bags made from thinner material often do not fill uniformly because the air flow from the register blows them about too much. If the bag sides flap a lot and you find that measuring the same register twice gives results that differ by more than 20%, then try a bag with thicker material.

**Use the right sized bags.** Bags that fill in under two seconds will have increased errors because of resolution issues in timing how fast the bag is filled. Conversely, bags that are too large for a given register flow will have increased leakage around the edges of the bag before it fills completely and may not generate enough pressure to push a bag into its final shape. *Aim for a fill time of 2 to 20 seconds.*

### SUPPLY AIR FLOWS

The key issues are: sealing around the edge of the bag (to prevent air leaving the bag before it is full), having the bag keep its shape during filling for consistent filling and picking the correct time to start and stop the time keeping watch. These problems are best overcome using a frame around the opening of the bag and a shutter to rapidly open the bag and start the filling process. A sheet of cardboard makes a good shutter.

Using a solid frame is preferred (Figure A-1), but if you have odd shaped registers or registers that have limited access (Figure A-4) then use a wire frame (Figure A-2).

#### Step-by-step instructions.

1. Empty the bag.
2. Place a sheet of cardboard over the bag opening (as shown in Figure A-1).
3. Place this assembly close to the register without blocking the flow. About six inches (15 cm) from the register is OK.
4. Rapidly pull the cardboard away as the frame of the bag is pressed around the opening around the register. The key here is to coordinate the rapid removal of the cardboard with the placement of the bag over the register.
5. Start the stopwatch at the same time that the frame of the bag is pressed around the register. The sound of the frame hitting the surface around the register gives a consistent audible signal for starting the stopwatch.
6. Stop the stopwatch when the bag is full. For most air flows the bag "pops" into its final shape (as illustrated in Figure A-4) but for lower flows it is less easy to determine when the bag is "full". Doing multiple tests and averaging them can reduce this problem.
7. Calculate the air flow rate by dividing the volume of the bag by the time it takes to fill.

## EXHAUST (OR RETURN) AIR FLOWS

For exhaust air flows you need to either measure at the outlet on the exterior of the building using the same procedure as for supply registers, or if access is difficult, use the method below.

### Step-by-step instructions.

1. Fill the bag with as much air as possible.
2. Place the bag over the exhaust opening. This is the tricky part because you need to try to keep the bag filled with air as you move it into place. This takes some practice. It is a good idea to repeat the test several times and average the results, or discard results that are inconsistent.
3. Start the stopwatch at the same time that the frame of the bag is pressed around the exhaust. The sound of the frame hitting the surface around the register gives a consistent audible signal for starting the stopwatch.
4. Stop the stopwatch when the bag is empty.
5. Calculate the air flow rate by dividing the volume of the bag by the time it takes to empty.

### ALTERNATIVE EXHAUST METHOD

Keeping the bag properly filled as it is moved into place over the exhaust can be difficult and frustrating. As an alternative, a more complex method can be used. You will need a friend to help you with this method (Figure A-5).

1. Cut a hole about the size of your bag opening in a cardboard box and attach your bag to the opening.
2. The face of the cardboard box opposite where the bag is attached will be placed over the exhaust, so cut a hole on this side too (or remove it all together).
3. Cut another hole in the side of the box that allows you to blow air into the box using a hairdryer (or other air blower).
4. Use a cardboard shutter to close the open end of the box that will be placed over the exhaust.
5. Fill the bag by blowing air into the box using the hairdryer.
6. Place the box over the exhaust.
7. Quickly remove the cardboard shutter and turn off the hairdryer (you should also cover the hair dryer inlet with your hand).
8. Start the stopwatch as the shutter is removed.
9. Stop the stopwatch when the bag is empty.
10. Calculate the air flow rate by dividing the volume of the bag by the time it takes to empty.

## CALCULATIONS

Normally household air flows are in cfm or *cubic feet per minute*. But a garbage bag is usually sold with a volume printed on the box in gallons. So we need to change the volume from gallons to cubic feet. One cubit foot is  $7\frac{1}{2}$  gallons. To get the number of cubic feet of air in your bag when it is full we need to divide the number of gallons by  $7\frac{1}{2}$ . For example, lets say we have a garbage bag with a volume of 30 gallons. 30 (gallons) divided by  $7\frac{1}{2}$  (cubic feet per gallon) is 4 cubic feet. Now we know the volume, we need to think about time. A normal stopwatch will measure in seconds, not minutes. So we need to divide our measured time in seconds by 60 to get the time in minutes. Let's say it took 5 seconds to fill the bag. Then our time in minutes is 5 divided by 60, which is one twelfth (0.83) of a minute. To get our flow in cfm, we take our volume (4 cubic feet) and divide by the time it took (one twelfth of a minute) and get a flow of 48 cfm.

A simple formula is:

$$cfm = 8 \times \frac{\text{bag volume(gallons)}}{\text{time(seconds)}}$$

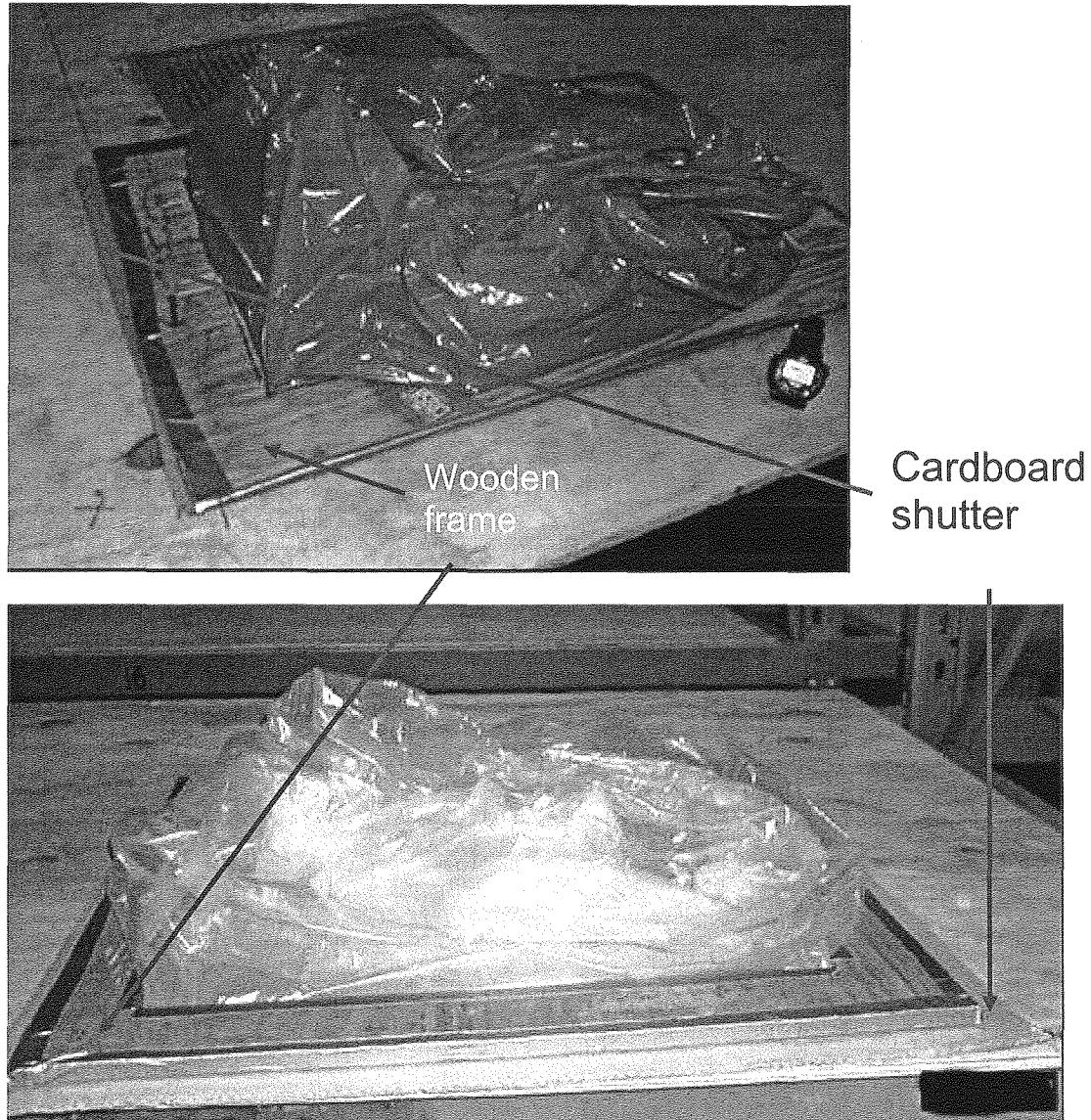


Figure A-1. Bags with a wooden frames and cardboard “shutter”



Figure A-2. Blue garbage bag popped into shape at the end of a measurement

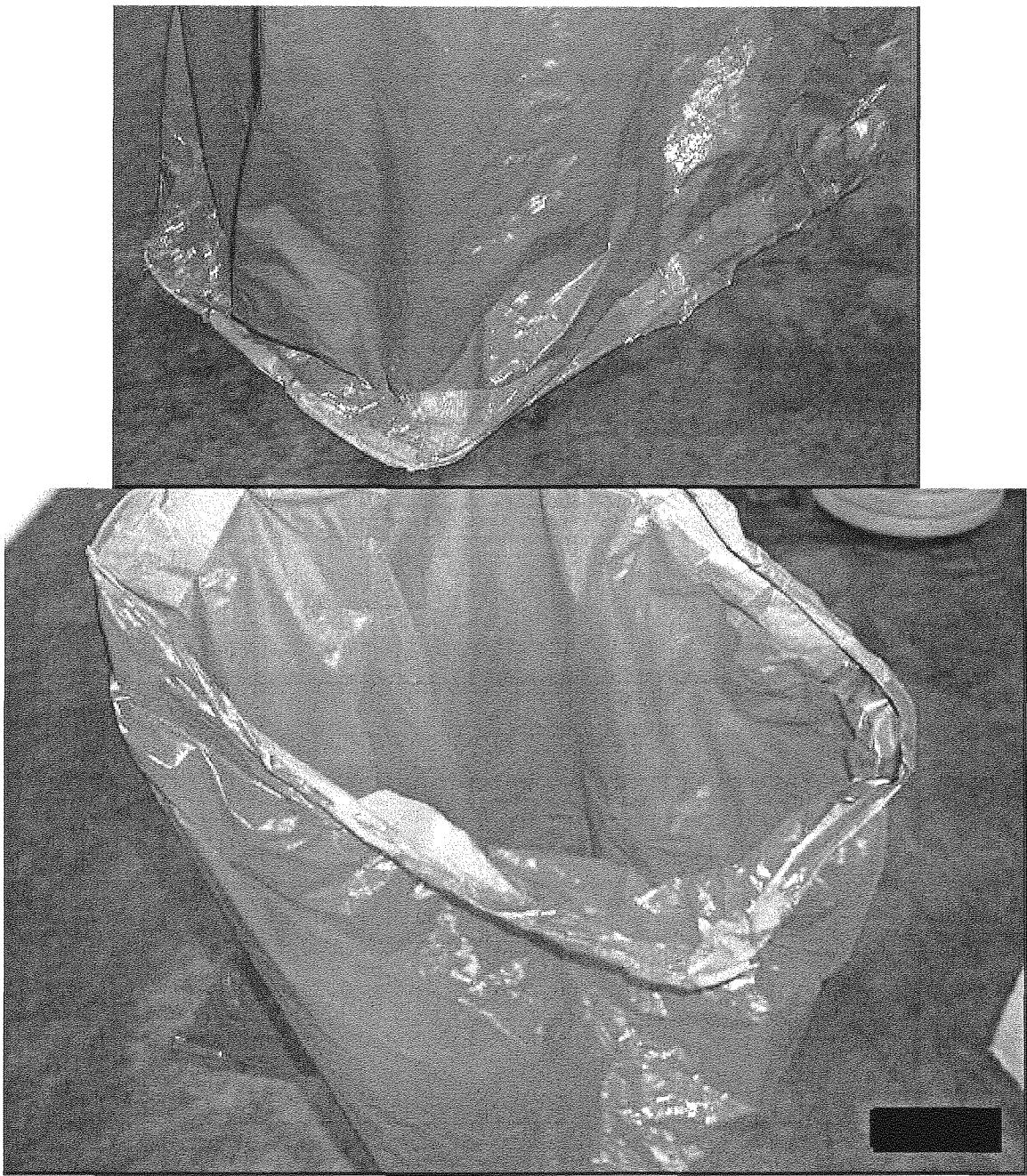


Figure A-3. The edge of the bag opening is wrapped around the wire frame and taped to it.



**Figure A-4. Example of a register that is hard to access. The only way to measure flow at a register like this is by using a bag with a flexible wire coat hanger around its entry that can be formed into a shape to fit in the available space**



**Figure A-5. Exhaust measurement using a hairdryer and cardboard box  
(Building Science Corp)**