Problems Related to Air Handler Leakage

Authors

James B. Cummings and Charles Withers, Jr.

Original Publication

Cummings, J., Withers, C., "Problems Related to Air Handler Leakage",
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.,
ASHRAE Journal, January 2008.

Publication Number

FSEC-GP-335-08

Copyright

Disclaimer

Problems Related to Air Handler Leakage

By James B. Cummings, Member ASHRAE; and **Charles Withers Jr.**

Air leakage of air-handling units (AHUs) is a subset of a much larger duct leakage problem that exists in homes. There are large energy and demand impacts associated with duct leakage. This article considers energy impacts of AHU leakage, but focuses primarily on IAQ problems and health risks caused by duct leakage, especially as they relate to the location of the AHU.

It is often desirable to locate air handlers and furnaces in unoccupied portions of the house, such as a basement, crawlspace, attic or attached garage. Placing mechanical equipment in those zones avoids use of occupied space and limits noise.

There are a number of disadvantages of locating the air handler or furnace (air handler is intended to include furnaces) in unconditioned space. Restricted access to equipment located in a crawlspace or attic may reduce the frequency and quality of servicing. Added conduction losses from the AHU and adjacent ductwork reduce system efficiency. The most serious disadvantages relate to air leakage—in the air handler cabinet, at connections to the return and supply plenums and in adjacent ductwork located in those spaces. ANSI/ASHRAE Standard 152-2004, *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems*, provides methods for measuring duct leakage and calculating the impacts of conduction and air leakage losses.

Air leakage is likely to increase the space conditioning load. This has impacts on energy waste, peak demand and occupant comfort (if the load exceeds the system's capacity). During cold weather, duct leakage can create a large increase in heating load. The low dew-point air drawn into the house by the duct leakage can produce low indoor RH. During hot and humid weather, duct leakage can create a large increase in cooling load, especially if the air leaking into the system originates from the attic. A return leak of 15% from a hot attic (120°F) (49°C) dry bulb, 80°F (27°C) dew-point temperature) can reduce the effective capacity and efficiency of a cooling system by about 50%.[1] Duct leakage also can increase indoor relative humidity (RH) during hot and humid weather, especially for supply leaks. In the case of dominant supply leaks, the building is depressurized, and this causes humid air to be drawn into the

About the Authors

James B. Cummings is program director and **Charles Withers Jr.** is senior research analyst at the Florida Solar Energy Center in Cocoa, Fla.

conditioned space (untreated) through various envelope leaks. However, return leaks produce less summer humidity impact than supply leaks because the return leak air (in most cases) runs across the cooling coil, where most of the added moisture is stripped away.[2]

Return leakage from unconditioned spaces can result in dust accumulation inside the ductwork, on the cooling coil, blower wheel, etc., which can diminish system performance and increase the likelihood of IAQ problems. If the filters are located at the return grill(s), the return ductwork operates under a greater level of depressurization, increasing return leakage airflow and causing much or all of the return leak air to bypass the filter. Both factors increase ductwork and AHU contamination.

Duct leakage may depressurize the zone where combustion appliances are located and cause drafting problems, such as spillage, backdrafting, incomplete combustion and flame rollout. Therefore, it is important, even when the AHU is located inside the house, that space depressurization be avoided to protect against combustion safety problems.[3]

Additionally, air-distribution system leakage may transport pollutants from a contaminated zone to occupied space. Attic AHUs can transport water vapor and loose insulation fibers into the house. Crawlspace or basement AHUs can transport musty odors, radon and pesticides into the conditioned space. Garage AHUs can transport carbon monoxide, fuel vapors and other vapors into the house.

Two additional problems of AHU leakage in the garage, attic, or outdoors are related to water vapor condensation. First, in some AHUs the cabinet insulation is lined with foil, in effect placing a vapor barrier on the cold side of the insulation assembly. During hot and humid weather, moist air sucked into the cabinet meets the cold foil surface causing condensation. This results in saturated cabinet insulation that becomes ineffective. Second, return leakage in the AHU cabinet between the coil and the blower can draw hot and humid air into an airstream that is about 55°F (13°C). If the dew-point temperature of the return leak air is 75°F (24°C) (a common summer dew-point temperature in the southeastern U.S.), and if the return leakage is sufficiently large, then condensation will create a "fog" that will wet the surfaces between the coil and blower, and the supply ductwork (*Figure 1*).

Air Leakage Characteristics of Air Handlers

In a sample of 69 homes, the leakage characteristics of the air handler or furnace cabinet were measured in newly constructed Florida homes.[4,5] The homes were constructed between 2001 and 2002, and were less than 12 months old at the time of testing. A calibrated blower was attached to a return grill of the air-distribution system to measure the leakage of the air-distribution system, or a portion of that system. In a majority of the cases, a panel was inserted (and sealed) into the supply plenum to isolate the supply system from the air handler and return. All grills and registers in the tested portion of the system were sealed with masking material. The leakage of the system was measured by depressurizing the system to –25 Pa (–0.10 in. w.c.) with respect to (wrt) its surrounding environment: attic, garage or indoors.

The leakage metric used was $Q_{25,total}$ ($Q_{0.10,total}$), or cubic feet per minute (cfm) of leakage at 25 Pa (0.10 in. w.c.). Throughout this article, the units for Q_{25} and $Q_{25,total}$ will be cfm at 25 Pa (0.10 in. w.c.). The test was repeated a second time with all cracks, penetrations and holes in the cabinet sealed (temporarily) by tape and/or putty. The difference in $Q_{25,total}$ between the two tests then represented the leakage of the air handler cabinet, as installed in the field. Leakage at the connection of the AHU to the supply plenum and to the return plenum was sealed and measured separately using the same subtraction methodology. The measured leakage is called total leakage, rather than leakage to outdoors, meaning that the leakage is to all immediate environments, whether indoors, outdoors or to a buffer zone. In 2007 ASHRAE established a committee, SPC193P, Method of Testing for Determining the Air-Leakage Rate of HVAC Equipment, to develop a test method of AHU cabinet airtightness.

In addition to measuring Q_{25}, normal operating static pressure was measured at two locations in the air handler cabinet and at connections of the cabinet to the two plenums with the AHU blower operating. Given Q_{25} and operational static pressure, actual (as operated) air leakage (Q) could be calculated using the equation $Q = Q_{25}\ (dP_{actual}/25)^{0.60}$ (equation derived from Equation C-1 of ANSI/ASHRAE Standard 152-2004, *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems*) where dP_{actual} is the static pressure (Pa) occurring within the AHU. The results of this field testing are found in *Table 1*.

The airtightness results from all 69 air handlers are as follows: Q_{25} in the air handlers was 20.4, Q_{25} at the return connection was 3.9, and Q_{25} at the supply connection was 1.6. These measured leakage amounts were as-found, that is, the leakage of the system was measured without making any changes to the system, with one exception. If the filter access door was off or ajar (found in two houses), then it was placed in its proper position. In one case, a missing filter access door represented Q_{25} = 189. In the other case, an ajar filter access door represented Q_{25} = 37.

Based on the measured operational pressures and the Q_{25} for each location, estimated air leakage (Q) has been calculated for the negative pressure and the positive pressure zones of the air handler, plus connections for the 69 systems. The negative pressure zone had an average (as operated) leakage of 58.8 cfm (27.8 L/s), representing 4.9% of the average 1,207 cfm (569.6 L/s) of air handler airflow. The positive pressure zone had an average leakage of 9.3 cfm (4.39 L/s), or 0.8% of air handler flow.

Variations in Pressure Related to AHU Location

From *Table 1*, the reader can observe variations in the pressure differential and airtightness test data from one AHU location to another. The degree of negative pressure in the return plenum for the garage AHUs is greater compared to the indoor location, and differs even more compared to the attic location. Variables such as filter media efficiency, filter loading, filter location, duct sizing, layout and duct leakage affect the return plenum pressure.

Considering that filtration and duct leakage did not consistently account for the greatest differences in plenum pressure, it appears that the lower magnitude of depressurization for the attic AHU systems was related to the layout of the ductwork. In the attic, the AHU typically lies horizontally and the return and supply ducts are more in-line with the AHU without severe changes in direction. AHU installations in the garage and indoors having return ductwork dropped from an above attic space result in a 180 degree turn through a rectangular duct into the upright AHU (without turning vanes). Sixty-five percent of the garage installations, 35% of the indoor installations and 0% of the attic installations had this type of layout.

Table 1 also shows that AHU cabinet and connections leakage varies from one AHU location to another, with the greatest leakage (Q_{25}) in the garage location. However, when gas furnaces (nine units) are excluded, the leakage in the cabinet is nearly identical for the three AHU locations. The variability of leakage in *Table 1* is affected by representation from six gas furnaces located in the garage with an average cabinet leakage of $Q_{25} = 39.0$. This is about twice the average leakage found in non-gas furnace air-handling units.

While Q_{25} in the AHU cabinet is similar for the three AHU locations (excluding furnaces), the calculated operational leakage (Q) is considerably higher in the garage and indoor AHU cabinets compared to those in the attic. This is due to the considerably higher operating pressures at the return connection and in the AHU cabinet for those two locations. Recall that the airflow rate is a function of hole size (Q_{25}) and pressure differential. For details on how Q is calculated, see Reference 5.

Figure 1: Condensation on metal electric panel inside air handler. Figure 2: Refrigerant line penetration into air handler without seal.

Sample Size and Location →	Attic (23)	Garage (23)	Indoors (23)	Total (69)
Pressure at Return Connection (Pa)	−68.3	−110.2	−80.7	−86.4
Pressure in AH (–) Region (Pa)	−122.9	−160.2	−154.3	−145.5
Pressure in AH (+) Region (Pa)	98.0	108.8	113.8	107.7
Pressure at Supply Connection (Pa)	53.7	64.1	52.5	56.8
Q_{25} at Return Connection	2.0	5.9	3.8	3.9
Q_{25} in AH (–) Region	17.4	18.3	16.6	17.6
Q_{25} in AH (+) Region	1.4	5.7	1.7	2.8
Q_{25} at Supply Connection	1.7	2.2	1.0	1.6
Q_{25} sum	22.5	32.1	23.1	25.9
Q Return Connection (cfm)	3.7	14.4	7.7	8.2
Q AH (–) Region (cfm)	45.2	55.8	49.5	50.6
Q AH (+) Region (cfm)	3.2	13.8	4.2	6.7
Q Supply Connection (cfm)	2.7	3.9	1.6	2.6
Q AH (+) Connections (cfm)	54.8	87.9	63.0	68.1

Table 1: Average operating pressures (Pa), Q_{25}, and Q (calculated operational leakage) for 69 tested air-handling units. Units for Q_{25} are cfm at 25 Pa.

Impact of Air Handler Location Upon Duct System Q_{25}

Additional duct testing was performed in 20 of the 69 systems. This extended testing included measuring the overall duct system airtightness and is discussed here to show a relationship between air-handler location and duct leakage to out. The duct system airtightness testing followed the duct airtightness test method of Standard 152-2004 obtaining both *total leakage* and *leakage to out*[6] using two calibrated blowers attached to the return and supply sides of the system.

On average, 56% of the leakage of the return ductwork (including air handler) and supply ductwork was to "out" ("out" defined as outside the conditioned space, including unconditioned spaces such as attic or garage). The surprise was that the fraction of the leakage to "out" on the return side varied much more than on the supply side (*Table 2*). *For return ductwork* (including air handler), the proportion of total leakage that is to "out" is 82% for attic AHU location, 68% for garage AHU location and 29% for an indoor AHU location.

This shows that placement of the AHU in an attic space results in a much larger amount of air leakage to an "outdoor" environment that is much more thermally hostile. Placement

of the AHU in the attic also requires the return to be placed into the attic, whereas more of the return ductwork for other units was inside the house. Location of the air handler does not change the supply side "leakage to out" proportion much since supply ducts are located in the attic in all of these homes regardless of where the AHU is placed.

AH location	Return			Supply		
	Q_{25}	$Q_{25,total}$	% of Total Leak That Is Outside	Q_{25}	$Q_{25,total}$	% of Total Leak That Is Outside
Attic	32	39	82%	62	109	57%
Garage	43	63	68%	88	171	51%
Indoors	15	51	29%	63	120	53%

Table 2: Average duct system tightness and portion of duct leakage that is to outdoors [($Q_{25,out}$/$Q_{25,total}$) × 100] in 20 houses.

Figure 3 (Left): Example of panel leakage in electric heat AHU. Figure 4 (Right): Thermostat control wire penetration leak area.

Causes of AHU Leakage

Regardless of manufacturer, the AHU is designed with a metal cabinet requiring refrigerant and electric penetrations, and removable access panels. To integrate the AHU into the entire system, the contractor must make connections and penetrations into the air handler cabinet. In many cases, the manufacturer provides seals supplied that the installer can use to complete the installation. However, the study found that of all the items an installer could have sealed, only an area-weighted 16% were sealed. O-ring style gaskets were rarely installed leaving a gap between the refrigerant line and cabinet (*Figure 2*).

AHU cabinet leakage is distributed differently between gas and non-gas AHU systems. For gas furnaces, it is estimated (based on visual inspection) that about 80% of AHU leakage (Q_{25}) was due to panel leakage, 15% due to cooling coil box and 5% due to wire penetration. For non-gas AHUs, failure to install O-ring gaskets represented an estimated 50% of cabinet leakage. The other 50% was related to panel leakage, especially at the filter access (*Figures 3* and *4*).

Achieving a tight air handler would be more likely if manufacturers deliver units that are airtight with engineered penetration points that require little effort on the part of the installer to maintain airtightness. Leakage at seams could be eliminated by requiring tighter panel fit tolerances and using thick panel gaskets in access panels. Penetration leakage could be improved by using flexible slip-fit style gaskets built into the cabinet that compress tightly around refrigerant and electrical line penetrations, that would only require the installer to push lines through the gasket. The authors estimate that eliminating leakage at seams and line penetrations could reduce AHU leakage by at least 90%.

Carbon Monoxide Transport From an Attached Garage

ANSI/ASHRAE Standard 62.2-2007, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings,* addresses the problem of air contaminant transport. It addresses two pathways from garage to the occupied space: doorways and the air-distribution system. Section 6.5 states "When an occupiable space adjoins a garage, the design must prevent migration of contaminants to the adjoining occupiable space. Doors between garages and occupiable spaces shall be gasketed or made substantially airtight with weather stripping. HVAC systems that include air handlers or return ducts located in garages shall have total air leakage of no more than 6% of total fan flow when measured at 0.1 in. w.c. (25 Pa), using California Title 24 or equivalent." Of these two pathways, duct leakage would appear to represent a much greater contaminant transport risk.

To examine the level of risk, carbon monoxide (CO) transport experiments were performed in two single-story, concrete masonry unit (CMU), slab-on-grade Florida homes. *Table 3* presents characteristics of the two houses. In House 1, the AHU was located outdoors and no ductwork was located in the garage. The single door from the garage to the den was substantially airtight with gasketing. In House 2, the AHU, all of the return, and a small portion of the supply ductwork was located in the garage. Testing of the air-distribution system in House 2 found that $Q_{25,out}$ was 49 cfm (23 L/s) or 4.9% of the AHU nominal flow rate. Therefore, based on Section 6.5 of Standard 62.2-2007, the AHU qualifies to be located in the garage.

Testing at House 1 began by running a 2003 Ford Focus Station Wagon in the closed garage. CO levels in the garage rose within minutes to 18 parts per million (ppm) and remained at that level for a period of 35 minutes, at which time the car was turned off. Clearly this vehicle was not going to produce lethal levels of CO in the garage or the house during this experiment. To produce

Advertisement formerly in this space.

elevated CO in the garage, a five-year-old four-stroke lawn mower was turned on for a period of 80 minutes. Although operation of a lawnmower in a garage is unlikely, a 1996 NIOSH alert noted frequent accidental CO poisonings from small combustion appliances such as pressure washers, saws and generators in confined spaces.[7] Indoor CO concentrations never exceeded 24 ppm while CO levels in the garage rose to 2,300 ppm (*Figure 5*).

CO levels in the house are a function of the quantity of CO transported and the house infiltration rate. CO transport is a function of CO concentration at the source, pathways from garage to house, and the driving force. The peak CO concentration of 2,300 ppm in the garage provided the source. Pathways occurred through the wall and doorway between the garage and house, as well as from the garage-to-attic into the house. The driving force (house at –0.4 Pa) was created by continuous operation of a 70 cfm bathroom fan. The interface between the garage and the attic is relatively tight. Nevertheless, attic CO levels rose to as high as 133 ppm. The ratio of indoor CO to garage CO was approximately 1 to 100.

House	Number of Stories	Year Built	ft^2	ACH50	$Q_{25,out}$	House dP	Return Leak cfm
1	1	1965	1750	6.8	151	–0.4	137
2	1	1995	1280	4.0	48.6	+0.9	48

Table 3: Test house characteristics.

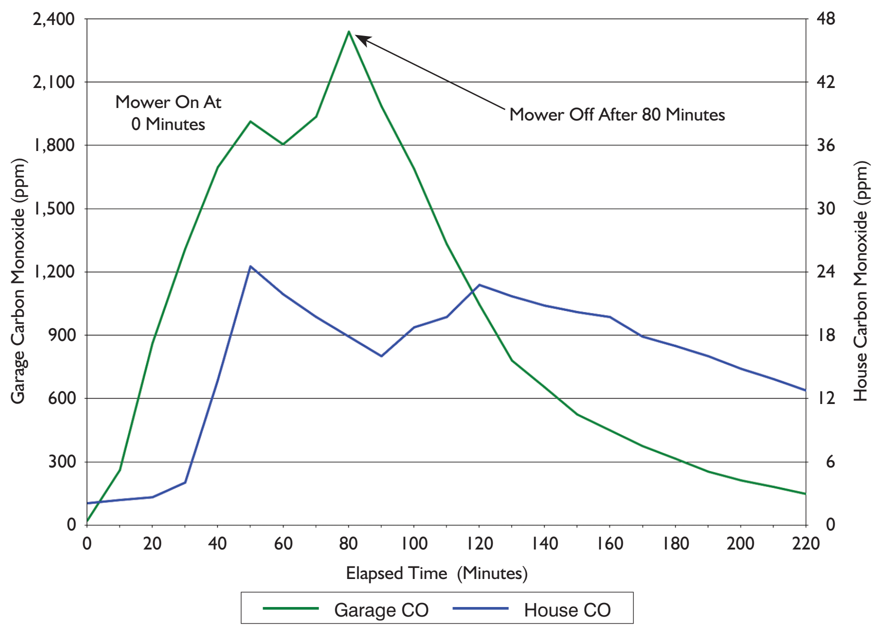

Figure 5: House 1 CO in house and garage shown with house pressure wrt garage.

CO levels were sampled at one point inside the wall separating the garage from the den. With the garage CO level at 400 ppm, the concentration in the wall cavity was found to be 303 ppm. Interestingly, when the door between the den and the central hallway was closed, supply air from the continuously running AHU fan created a positive 2.3 Pa pressure in the den wrt the garage and the CO concentration in the wall cavity dropped to 30 ppm within two minutes. This clearly demonstrates that direction of airflow and driving force are critical elements in CO (or any contaminant) transport.

An approximate characterization of the pathway and estimate of CO transport rate can be made. Based on measured house airtightness, a crude assumption that the leakage of the house envelope is uniformly distributed, the house being at –0.4 Pa (–0.0016 in. w.c.) wrt the garage, and the wall common to the house and garage represents 6% of the house surface area, we calculate the infiltration rate from garage to house to be a relatively small 4.3 cfm (2.03 L/s).

Testing at House 2 was performed in much the same manner as at House 1. The same lawn mower was operated in the closed garage for a total of 92 minutes. At the end of 25 minutes, the garage CO level had increased to 1,570 ppm, and with the AHU remaining off, indoor CO had risen to only 3 ppm. At 25 minutes, the AHU was turned on and left running continuously for 68 minutes. Indoor CO levels began to increase immediately upon the activation of the AHU, rising to 300 ppm after 23 minutes of AHU operation (*Figure 6*). Garage and indoor CO levels peaked at 3,207 ppm and 600 ppm, respectively. NIOSH has a ceiling rate of 200 ppm that should not be exceeded at any time and has established an 8-hour time weighted average (TWA) "recommended exposure limit" of 35 ppm.[8] It is of concern that the ratio of indoor CO to garage CO was about 20 times higher in House 2 than in House 1, indicating that AHU leakage and associated duct leakage create serious contaminant transport issues.

Testing found that the return leak fraction for the House 2 system was 6.9%, or 48 cfm (22.7 L/s), based on a tracer gas methodology.[9] So, the question arises; what level of duct system tightness would be necessary to make House 2 safe from CO poisoning risk? If we select 35 ppm as a maximum permissible level, then the leakage that could be permitted would have to be on the order of 20 times less than what currently exists in that house. The return leak fraction, which is currently 6.9%, would need to be reduced to about 0.35%. In practical terms, this is an unachievable level of airtightness. The authors conclude that AHUs should not be located in the garage.

Conclusions

AHUs are substantially leaky. On average, the return leakage in the cabinet alone in 69 homes was found to be 50.6 cfm (23.9 L/s) (actual as-operated leakage), which is 4.2% of the total system measured airflow rate. This level of leakage rep-

Advertisement formerly in this space.

resents a substantial energy penalty when that air is drawn from an unconditioned space, especially an attic space. A 4.2% return leak from attic air at 120°F (49°C) and 80°F (27°C) dew-point temperature cooled and dehumidified to 75°F (24°C) and 55°F (13°C) dew point temperature causes a 19% increase in energy use. When one considers that locating the AHU in the attic also results in a high proportion of the return leakage from return ducts to also be from the attic, the energy and peak demand implications of the attic location are enormous. The attic is not a good location for AHUs.

Health risks also may result from AHU leakage. As demonstrated by the experiments at House 2, the return leakage occurring in a tighter than average system, and one that meets the 6% total duct leakage requirement of Standard 62.2-2007, created a transport mechanism that was more than capable of producing dangerous levels of CO in the living space. By contrast, the house without the AHU or ductwork in the garage, demonstrated little potential for CO poisoning risk, even though the house was operating at negative pressure throughout the experiment. The garage also is not a good location for AHUs.

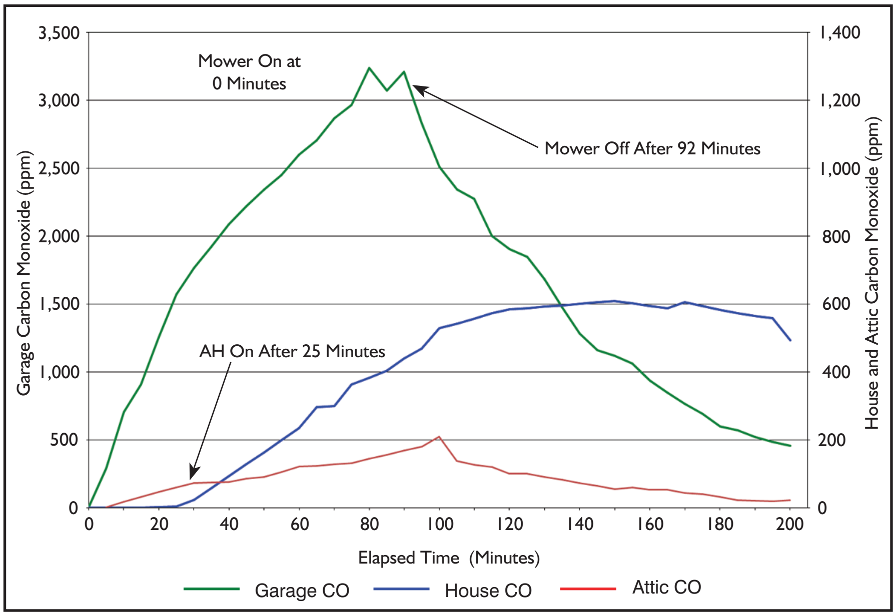

Figure 6: House 2 CO in house, garage and attic.

Advertisement formerly in this space.

The best location for AHUs is inside the house, because leakage of air between the conditioned space and the air-distribution system causes little to no energy or IAQ consequences. However, two important rules should apply for indoor AHU locations. First, avoid use of building cavities as part of the return system, which can lead to high levels of return leakage from the attic, outdoors, basement, etc. Second, avoid zone depressurization that can lead to moisture (water vapor) intrusion or combustion safety problems.

A common argument against locating the AHU in the house is that it uses conditioned space. One effective solution is to place the AHU in the garage but carefully isolate it from the the open area of the garage. This can be done by enclosing the AHU in a closet, tightly sealing the walls between the closet and the garage and providing door access to the closet only from indoors or from outdoors. In this design, it is important to allow the closet to be partially vented back to the conditioned space, so that if there is return leakage in the closet, it will draw air primarily from the occupied space.

References

1. Cummings, J.B. and J.J. Tooley. 1989. "Infiltration and pressure differences induced by forced air systems in Florida residences." *ASHRAE Transactions* 95:551 – 560 (Figure 3).
2. Henderson, H.I., et al. 2007. "Mitigating the Impacts of Uncontrolled Air Flow on Indoor Environmental Quality and Energy Demand in Non-Residential Buildings." Final Report DOE Project No. DE-FC-36-02GO12012. www.cdhenergy.com/reports/UAF_Final_Report_complete.pdf.
3. Canadian Mortgage Housing Corporation. 1988. *Chimney Safety Users' Manual: Procedures for Determining the Safety of Residential Chimneys.*
4. Cummings, J.B., et al. 2003. "*Air Handler Leakage: Field Testing Results in Residences*." *ASHRAE Transactions* 109(1):496 – 502.
5. Cummings, J.B., et al. 2002. "Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage; Final Report." FSEC-CR-1357-02, Cocoa, Fla.: Florida Solar Energy Center.
6. ANSI/ASHRAE Standard 152-2004, *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems.*
7. National Institute for Occupational Safety and Health. 1996. "Preventing Carbon Monoxide Poisoning from Small Gasoline-Powered Engines and Tools. NIOSH ALERT: 1996." Atlanta: Department of Health and Human Services (NIOSH) Publication No. 96-118.
8. National Institute for Occupational Safety and Health. 2005. "NIOSH Publication No. 2005-149: NIOSH Pocket Guide to Chemical Hazards." Atlanta: Department of Health and Human Services, Centers for Disease Control & Prevention.
9. Cummings, J.B. 1989. "Tracer gas as a practical field diagnostic tool for assessing duct system leaks." *Proceedings of 6th Annual Symposium on Improving Building Systems in Hot and Humid Climates*.