

# Infiltration and Pressure Differences Induced by Forced Air Systems in Florida Residences

J.B. Cummings

J.J. Tooley, Jr.

## ABSTRACT

*Five homes were tested by tracer gas and blower door to assess infiltration caused by leaks in air distribution systems. These homes are not a random sample and therefore may not give an accurate representation of Florida housing. Techniques used to determine the amount of return leak and the amount of infiltration caused by duct leaks are described.*

*Average infiltration with the air handler running was 1.42 air changes per hour (ach), while with the air handler off, it averaged only 0.14 ach. The infiltration rate with the air handler running is equivalent to an average 290 cubic feet per minute (cfm) (0.1369 m<sup>3</sup>/sec). Return leaks were much larger than supply leaks in all five homes. The return leak fraction averaged 21.6%, or an average of 263 cfm (0.142 m<sup>3</sup>/sec). Blower door tests found average air changes per hour at 0.20 in H<sub>2</sub>O (50 pascals [Pa]) (ach50) to be 11.79 and the duct system represented 19% of the total leak area in three houses.*

*Return plenums were repaired and the tests were repeated. Infiltration with the air handler on dropped from 1.42 ach to 0.31 ach. The return leak fraction dropped from 21.6% to 2.6%. Duct system ELA was determined for only three homes. While only 43% of the duct leak area or 8% of the house ELA was sealed, the reduction in infiltration when the air handler was running was nearly 80%.*

*After the repairs were made, tests were performed to assess the impact of closing interior doors on the infiltration rate of the home. When the interior doors were closed, and the air handler was running, infiltration jumped from an average 0.31 ach to 0.91 ach.*

## INTRODUCTION

Infiltration impacts energy use and indoor humidity conditions in residential buildings. Duct-system leaks produce more infiltration than wind and stack effects in many homes. This impact is even more severe in cooling climates if the leak air originated in a hot attic. We present results from computer simulations of infiltration of outdoor air. We then examine the impacts of attic-infiltration air upon air-conditioner cooling performance.

Review of previous research indicates that infiltration in homes is greatly affected by air-handler operation. We

present results from tracer-gas tests and fan-pressurization tests on five homes before and after duct-system repair. We conclude that return plenum leaks can have major impacts on energy use, air-conditioner capacity, and indoor comfort, and that they are relatively easy and cost effective to repair.

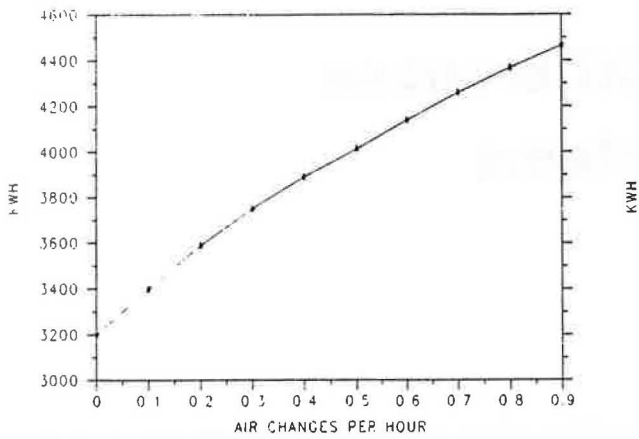
## COMPUTER SIMULATION OF INFILTRATION

Infiltration rates are very important to understanding energy use and indoor humidity conditions in residential buildings. In hot, humid climates, influx of outdoor air adds to the cooling load and raises indoor relative humidity. Computer simulation results using TARP (Thermal Analysis Research Program), modified to account for moisture adsorption and desorption into and out of building materials and furnishings, and using typical meteorological year (TMY) weather data, are presented in Figure 1 (a,b,c) for Orlando, FL. The simulated house is a typical Florida home: 1500 ft<sup>2</sup> (139.4 m<sup>2</sup>) slab-on-grade, single-story block wall construction with R3 (h·ft<sup>2</sup>·°F/Btu) (0.53 m<sup>2</sup>·°C/W) wall insulation, R19 (h·ft<sup>2</sup>·°F/Btu) (3.35 m<sup>2</sup>·°C/W) attic insulation, and 224 ft<sup>2</sup> (20.8 m<sup>2</sup>) of single-pane windows. A typical SEER = 8.0 air conditioner is used.

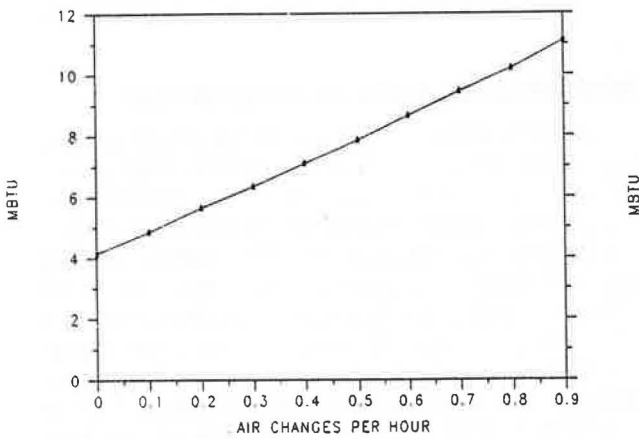
As the infiltration rate is increased from 0.10 to 0.90 ach, annual cooling electricity use rises from 3400 kWh to 4469 kWh, a 31% increase (Figure 1a). Increase in sensible heat gain is very small, since the average outdoor temperature is only 3°F (1.7°C) greater than indoors. Increase in latent load is large because the humidity ratio is about 75% higher outdoors than indoors (0.0175 vs. 0.0100 lb/lb). Eighty-five percent of the added load from infiltration is latent heat. Heating load is more sensitive to increased infiltration. It rises 127% when infiltration is increased from 0.10 to 0.90 ach, from 4.9 to 11.1 million Btu (5.2 to 11.71 GJ) per year (Figure 1b).

Duct system leaks can produce a much greater impact upon energy use and peak electrical demand during the cooling season than naturally occurring infiltration. The magnitude of the energy gain to the house can be assessed by looking at the difference in the average enthalpy of the air leaving and entering the house. In natural infiltration, indoor air leaving the house has about 31 Btu/lb (54.1

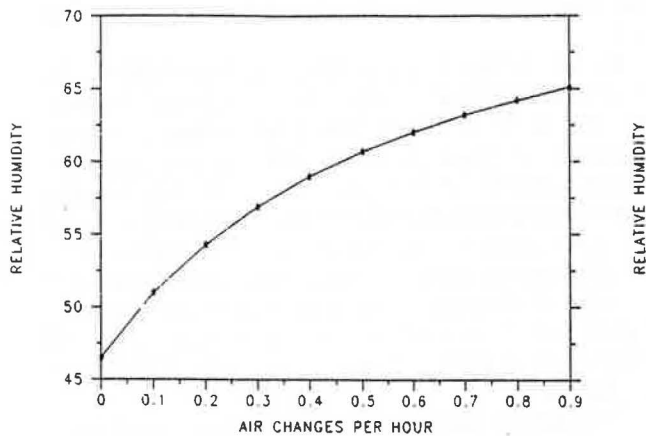
J.B. Cummings is Research Analyst, Research and Development, Florida Solar Energy Center; J.J. Tooley, Jr., is President, Natural Florida Retrofit, Inc., Orlando.



**Figure 1a** Annual cooling energy use in Orlando as a function of infiltration (78°F setpoint; 1500 ft<sup>2</sup> house)



**Figure 1b** Annual heating energy use in Orlando as a function of infiltration (72°F setpoint; 1500 ft<sup>2</sup> house)



**Figure 1c** Average July relative humidity in Orlando as a function of infiltration (78°F setpoint; 1500 ft<sup>2</sup> house)

kJ/kg) enthalpy, and the entering outdoor air is at about 39.5 Btu/lb (73.9 kJ/kg). Enthalpy gain is 8.5 Btu/lb (19.8 kJ/kg). In the case of supply duct losses, highly conditioned air with an enthalpy of about 24 Btu/lb (37.8 kJ/kg) is lost to the ambient, and outdoor air with an enthalpy of 39.5 Btu/lb (73.9 kJ/kg) is pulled into the house to make up for the loss. Enthalpy gain is 15.5 Btu/lb (36.1 kJ/kg). If half

of the air coming into the house is from the attic, where enthalpy may average 48 Btu/lb (93.6 kJ/kg), then the enthalpy gain may be 19.5 Btu/lb (45.4 kJ/kg).

What would be the impact of a 20% return leak upon cooling season energy use? If all the return leak is from the outdoors, the enthalpy gain may be the same as for natural infiltration—8.5 Btu/lb (19.8 kJ/kg). The 20% return leak times 8.5 Btu/lb (19.8 kJ/kg) enthalpy rise equals 1.7 Btu/lb (4.0 kJ/kg). However, from TARP simulations we find that because most of the added enthalpy is latent heat, producing an increase in indoor relative humidity (RH), only about 70% of the potential enthalpy becomes added load. Thus  $(0.70 \times 1.7 =) 1.19$  Btu/lb (2.77 kJ/kg) is added enthalpy. If the air conditioner provides cooling of 6.5 Btu/lb (15.1 kJ/kg) of (dry) air, then net air-conditioner efficiency is reduced by  $(1.19/6.5 =) 18\%$ , and energy use increases by 22%.

If the return leak is from the attic, where enthalpy may average 48 Btu/lb (93.6 kJ/kg), the enthalpy gain may be 16 Btu/lb (37.2 kJ/kg). A 20% return leak would add an average 3.2 Btu/lb (7.4 kJ/kg) to the air entering the evaporator coil. Since average cooling by the coil is 6.5 Btu/lb (15.1 kJ/kg), the return leak from the attic may cut the net efficiency of the air conditioner by about 50%  $(3.2/6.5)$  and nearly double the cooling energy consumption.

The impact upon peak cooling electrical demand is even greater than the impact upon total cooling energy use. This is important to electric utilities because it may increase the electric utility's need to build new generating capacity. During hot afternoon hours, enthalpy in the attic can reach 61.5 Btu/lb (125.0 kJ/kg), or 30.5 Btu/lb (70.9 kJ/kg) higher than in the house. Calculation of the enthalpy of the air entering the air handler yields  $(0.20 \times 61.5 \text{ Btu/lb} + 0.80 \times 31.0 \text{ Btu/lb} =) 37.1$  Btu/lb (68.3 kJ/kg). This 6.1 Btu/lb (14.2 kJ/kg) enthalpy rise represents 95% of the air conditioner's capacity.

## PREVIOUS RESEARCH

Earlier research indicates that forced-air systems cause elevated infiltration rates in residences. Fourteen tracer gas tests were performed on a 1½-story townhouse in Cocoa, FL, with the air handler blower on and off under a number of wind conditions. Infiltration averaged about 0.57 ach with the air handler on and 0.22 ach with the air handler off (Cromer and Cummings 1986). Gammage et al. (1984) found from tracer gas testing in 31 Tennessee homes that infiltration averaged 0.78 ach when the air handler was running and 0.44 ach when the air handler was off. Tracer gas testing done on nine Florida single-family homes found infiltration of 0.62 ach with the air handler on and 0.22 ach with the air handler off (Cummings 1988).

Lower heating system efficiency in homes with forced-air systems was observed in a study done by the Northwest Power Planning Council (Parker 1987). It was found that forced-air electric heating systems used 28% more heat (normalized for house size) than baseboard and wall heating units. Evidence indicates that elevated infiltration is the primary cause of this added heating load. Long-term perfluorocarbon tracer gas tests found 0.41 ach in homes with duct systems, and only 0.24 ach for nonducted homes. This 74% higher infiltration occurs in spite of the



**TABLE 1**  
**Infiltration Rates and Return Leak Fraction with Air Handler on and off,**  
**Before and After Return Plenum Repair**

House	Floor Area (ft <sup>2</sup> )	Air Handler CFM	AIR HANDLER ON								AIR HANDLER OFF <sup>5</sup>			
			Before Repair				After Repair				Wind Speed		Air Temp.	
			ACH <sup>3</sup>	CFM	RLF <sup>4</sup>	CFM	ACH	CFM	RLF	CFM	ACH	(MPH)	in F	out F
F	1431	805 <sup>2</sup>	1.15	219	22.3%	180	.47	90	5.6%	45	.25	4-6	77	78
B	1376	1374	.91	173	10.8%	148	.32	68	1.3%	18	.08	7-10	76	59
D	1590	1301	.84	178	10.0%	130	.30	64	3.0%	39	.10	6-9	75	74
M	1686	1377	3.36	755	55.0%	757	.21	47	0.0%	0	.10	5-7	70	49
N	1050	1002	.82	125	9.8%	98	.24	37	2.0%	20	.18	2-4	75	65
Ave.	1427	1172	1.42	290	21.6%	263	.31	61	2.4%	24	.14	6		

House	Floor Area (m <sup>2</sup> )	Air Handler (m <sup>3</sup> /s)	AIR HANDLER ON						AIR HANDLER OFF <sup>5</sup>					
			Before Repair			After Repair			Wind Speed		Air Temp.			
			ACH <sup>3</sup>	m <sup>3</sup> /spc	RLF <sup>4</sup>	m <sup>3</sup> /s	ACH	m <sup>3</sup> /s	RLF	m <sup>3</sup> /s	ACH	(m/s)	in °C	out °C
F	133.0	0.382 <sup>2</sup>	1.15	0.103	22.3%	0.85	.47	.042	5.6%	.021	25	1.8-2.7	25.0	25.6
B	127.9	0.649	.91	0.082	10.8%	0.70	.32	.032	1.3%	.008	.08	3.1-4.5	24.4	15.0
D	147.8	0.614	.84	0.084	10.0%	0.61	.30	.032	3.0%	.018	.10	2.7-4.0	23.9	23.3
M	156.7	0.650	3.36	0.356	55.0%	0.375	.21	.022	0.0%	.000	.10	2.2-3.1	21.1	9.4
N	97.6	0.473	.82	0.059	9.8%	0.46	.24	.017	2.0%	.009	.18	0.9-1.8	23.9	18.3
Ave.	132.6	0.553	1.42	0.137	21.6%	0.124	.31	.029	2.4%	.011	.14	2.7		

1. All homes are single-story slab-on-grade construction.
2. 805 CFM (0.382 m<sup>3</sup>/s) resulted from a very dirty filter. After testing was complete, we measured 1172 cfm (0.553 m<sup>3</sup>/s) with the filter removed.
3. Air changes per hour.
4. Return leak fraction. This is the proportion of the total air handler flow that is leaking into the return from outside the envelope.
5. Infiltration tests with the air handler off were only 30 minutes in duration; therefore, their accuracy is not as great as if a more lengthy test was performed.

fact that blower door testing predicted only 13% more infiltration in the ducted homes (Parker 1987). Given an average home size of 1600 ft<sup>2</sup> (148.7 m<sup>2</sup>) and 6000 heating degree days (3333 in °C), the difference in infiltration accounts for about 1.1 kWh/ft<sup>2</sup> (0.10 kWh/m<sup>2</sup>) of the total 1.5 kWh/ft<sup>2</sup> (0.14 kWh/m<sup>2</sup>) electricity use difference. Since air-handler-induced infiltration occurs more during hours when it is coldest outdoors, it is expected that this infiltration would cause more heating load than the calculated 1.1 kWh/ft<sup>2</sup> (0.10 kWh/m<sup>2</sup>).

### CURRENT TEST RESULTS

Five homes recently were tested for air-distribution leakage, and then repaired. The objectives were to:

1. Measure impact of duct leaks on infiltration.
2. Measure return and supply duct air leakage.
3. Measure leak area of house and duct system.
4. Observe the impact of duct system repair upon infiltration, duct-air leakage, and house and duct leak area.
5. Measure house pressures associated with duct leakage and closing of interior doors.

These five homes were not randomly selected, but were known or suspected of having air-distribution system leaks.

These five houses are all single-story slab-on-grade construction. Four are block construction; one is frame. The average floor area is 1427 ft<sup>2</sup> (132.6 m<sup>2</sup>) (Table 1). All homes have central forced-air heating and cooling systems. Four of the air handlers are located in closets within the conditioned space, and one is located in the garage. All of the supply ductwork is located in the attic.

There is no return ducting; a return plenum is located underneath the air handler. Air handler flow rates average 1172 cfm (0.553 m<sup>3</sup>/sec). Three of the homes are about 20 years old, one is 5 to 10 years old, and the frame house, which has the air handler in the garage, is only 6 months old.

Air distribution system leakage was measured in three ways:

1. House infiltration was measured once with the air handler on and again with the air handler off, using tracer gas.
2. Return leak fraction was determined using tracer gas.
3. Blower door measurement of the effective leak area of the air distribution system.

A description of the infiltration test, the return leak test, and the blower door test procedures is presented in Appendix A.

From test 1 two infiltration rates were obtained—when the duct blower was on, and when it was off (Table 1). For these five homes the average infiltration rate when the air handler was on was 1.42 ach, and when it was off averaged 0.14 ach. From test 2 we obtained the fraction of the return air originating from outside the envelope (Table 1). The average return leak fraction was 21.6%. From test 3 the ELA of the duct system was determined (Table 2). For the three homes tested it averaged 24.7 in<sup>2</sup> (0.0159 m<sup>2</sup>), or 19% of the total house ELA.

Leaks in the return plenum were repaired in all five homes and the testing was repeated. The average infiltration rate when the air handler was on decreased 78% from 1.42 to 0.31 ach. The return leak fraction decreased by

**TABLE 2**  
**Blower Door Test Results, Showing Air Change Rate at 0.20 in H<sub>2</sub>O (50 Pa) and the ELA of the House and the Air Distribution System, Before and After Repair**

House	Floor Area ft <sup>2</sup> m <sup>2</sup>		Constr. Type	Before Repair				After Repair					
				ACH50	ELA in <sup>2</sup>	ELA m <sup>2</sup>	ELA Ducts <sup>2</sup> in <sup>2</sup>	ELA m <sup>2</sup>	ACH50	ELA in <sup>2</sup>	ELA m <sup>2</sup>	ELA Ducts in <sup>2</sup>	ELA Ducts m <sup>2</sup>
F	1431	(133.3)	block	14.34	179.3	(.116)	21.1	(.014)	12.50	170.6	(.110)	12.4	(.008)
B	1376	(127.9)	block	8.70	80.6	(.052)	23.4	(.015)	6.86	68.0	(.044)	10.8	(.007)
D	1590	(147.8)	block	10.50	125.7	(.081)	29.5	(.019)	9.92	119.3	(.077)	19.4	(.013)
M <sup>1</sup>	1686	(156.7)	block	16.66	279.3	(.180)	NA	NA	9.37	100.4	(.065)	NA	NA
N	1050	( 97.6)	frame	8.76	86.1	(.056)	NA	NA	NA	NA	NA	NA	NA
5 Houses				11.79	150.2	(.097)	NA	NA	NA	NA	NA	NA	NA
4 Houses (F,B,D,M)				12.55	166.2	(.107)	NA	NA	9.66	114.6	(.074)	NA	NA
3 Houses (F,B,D)				11.18	128.5	(.083)	24.7	(.016)	9.76	119.3	(.077)	14.2	(.009)

1. In house M—in addition to sealing the return plenum, some other attic leaks were also sealed. It is estimated that 70% to 80% of the total 179 in<sup>2</sup> (.116 m<sup>2</sup>) that was sealed was in the return plenum.

2. ELA in the duct system was found by doing a blower door test once with supply and return grilles covered and then again with them uncovered.

**TABLE 3**  
**Impact of Closing Interior Doors on Infiltration When Air Handler is On**

House	Floor Area ft <sup>2</sup> m <sup>2</sup>		Air Handler <sup>1</sup> CFM    m <sup>3</sup> /5		ACH OFF	ACH ON	ACH <sup>3</sup> Doors Closed	Pressure Difference in H <sub>2</sub> O (Pa)		Rooms Main House <sup>4</sup>	
								House Outdoors	Rooms Main House <sup>4</sup>		
F	1431	(133.0)	805 <sup>5</sup>	(.382)	.25	.47	.58	NA	NA	.012	(.31) <sup>5</sup>
B	1376	(127.9)	1374	(.649)	.08	.32	.82	-.004	(-1)	.032	(8.1)
D	1590	(147.8)	1301	(.614)	.10	.30	.98	-.004	(-1)	.036	(9.1)
M	1686	(156.7)	1377	(.650)	.10	.21	1.27	NA	NA	.033	(8.2)
N	1050	( 97.6)	1002	(.473)	.18	.24	.88	-.008	(-2)	.010	(2.6)
	1427	(132.6)	1172	(.553)	.14	.31	.91			.025	(6.2)

1. Air handler air flow was measured at supply grilles by air flow hood.

2. Low flow rate is a consequence of a dirty filter. When the filter was removed, air flow increased to 1172 cfm (.553 m<sup>3</sup>/5).

3. Interior doors closed with air handler running.

4. "Rooms" means rooms behind closed doors. This is the average of the rooms.

5. 0.012 in H<sub>2</sub>O (3.1 Pa) average pressure across the interior doors with dirty filter in place. After filter was removed, delta pressure doubled to 0.026 in H<sub>2</sub>O (6.4 Pa).

89% from 21.6 to 2.4%.

Blower door tests were available after repair on only four houses (Table 2). Ach50 for these four houses declined 31% as a result of return plenum repair. In house M, we estimate that about one-quarter of the sealed leak was other attic openings besides the return plenum. Correcting for this, return plenum repairs account for a 24% reduction in total house ELA.

Duct system ELA was measured on three houses after repair. ELA of the ducts fell from 24.7 in<sup>2</sup> (0.0159 m<sup>2</sup>) to 14.2 in<sup>2</sup> (0.0091 m<sup>2</sup>), a 43% decrease. Duct ELA declined from 19.2% of the house ELA to 11.9%. On these three homes, infiltration (measured by tracer gas test) with the air handler on decreased from an average 1.02 ach before repair to an average 0.36 after repair. Therefore, sealing 8.2% of the total leak area of the house, in the return duct system only, resulted in a 65% reduction in infiltration with the air handler on.

Following is a discussion of results from each house. Test results for the houses are summarized in Tables 1, 2, and 3.

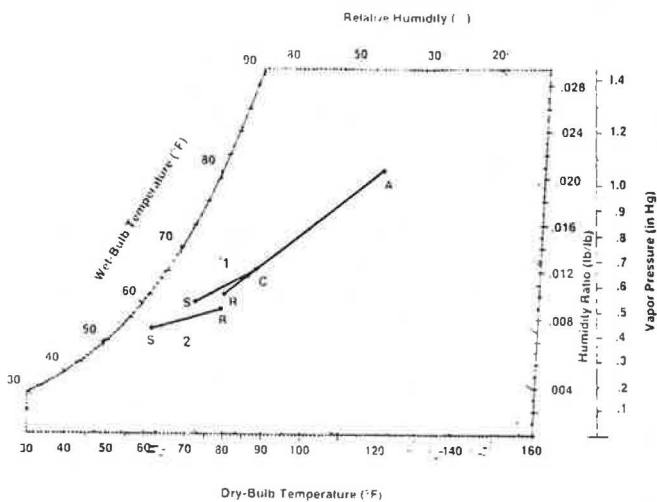
### House F

This 20-year-old block construction house has a relatively large leak area, 179.3 in<sup>2</sup> (0.116 m<sup>2</sup>) ELA, which yields 14.34 ach50. Of the five houses tested for naturally induced infiltration, this had the highest rate of 0.25 ach.

Only 12% of the leak area is associated with the duct system, but infiltration is dominated by air distribution leaks. When the air handler is running, infiltration rises to 1.15 ach, or an equivalent 219 cfm (0.1034 m<sup>3</sup>/sec). The return leak fraction was 22.3%, or 179 cfm (0.0845 m<sup>3</sup>/sec).

When the return plenum leaks were sealed, the total leak area of the house decreased by only 4.9%. Sealing this relatively small leak area caused infiltration in the house with the air handler on to drop 59% from 1.15 to 0.47 ach, and the return leak fraction fell 75% from 22.3% to 5.6%. The homeowner immediately noted that the house could be easily cooled on hot afternoons and that it cycled normally instead of running continuously. The remaining return leak is probably caused by leaks in the air handler, which is a gas furnace. Because the furnace requires combustion air, the ceiling of the air handler closet was not sealed.

The impact of a 22% return leak of attic air (assume 120°F [48.9°C] temperature and 80°F [26.7°C] dew point temperature) upon air-conditioner capacity can be seen in the psychrometric chart shown in Figure 2. The top line, labeled "A," shows room and attic conditions at points R and A, respectively, mixing to produce point C, which is the air conditions entering the evaporator coil. Point S is the condition of the cool air coming from the supply. The net temperature drop from R (room) to S (supply) is only about



**Figure 2** Impact of 22% return leak from 120°F attic upon the effective cooling capacity of an air conditioner

5°F (2.8°C). The lower line, labeled "B," shows the air conditioner cooling the air by 18°F (10°C) after the return leak is eliminated. Thus the net sensible cooling capacity of the air conditioner is reduced by 72% by the return leak. Figure 3 shows the impact of return leaks from the attic upon the effective EER of the air conditioner for various leak amounts during the peak cooling period of the day. A 15% return leak cuts EER in half and, with a 30% return leak, the capacity of the air conditioner is negated.

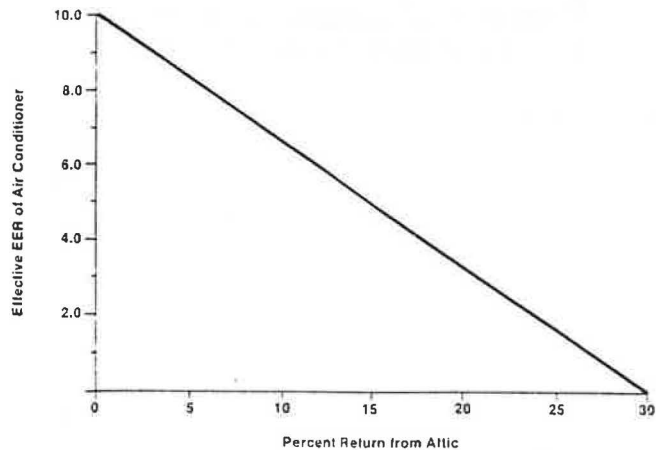
An additional infiltration test was performed with interior doors closed with the air handler on. Infiltration increased slightly to 0.58 ach from 0.47 ach (Table 3). This increase is small compared to other houses. The reason for this is that the total airflow to the bedrooms and baths, which have doors that can be closed, is relatively small. The crack size at the bottom of the doors is about 1/2 in. Pressure drop across the five doors averaged a relatively low 0.0124 in H<sub>2</sub>O (3.1 Pa). However, when the filter in the air handler was removed (it was very dirty) and the total system airflow increased from 805 to 1172 cfm (0.520 to 0.7565 m<sup>3</sup>/sec), the average pressure drop across the doors increased to 0.0256 in H<sub>2</sub>O (6.4 Pa).

### House B

This five-year-old, 1376 ft<sup>2</sup> (127.9 m<sup>2</sup>) block construction house is the tightest in the group, with only 80.6 in<sup>2</sup> (0.0520 m<sup>2</sup>) ELA and 8.7 ach<sub>50</sub>. This house also had the lowest naturally induced infiltration, 0.08 ach, even with the strongest winds of all the tests.

A rather large 29% of the ELA of the whole house is in the air distribution system. Infiltration is dominated by return leaks. When the air handler is running, infiltration rises to 0.91 ach, or an equivalent 173 cfm (0.0817 m<sup>3</sup>/sec). The return leak fraction is 10.8%, or 148 cfm (0.0699 m<sup>3</sup>/sec). With the air handler running, the house operated at +0.004 in H<sub>2</sub>O (+1 Pa) pressure, which is consistent with return leaks.

When the return leaks were repaired, the total leak area of the house decreased by 16%. Sealing 12.6 in<sup>2</sup> (0.0082 m<sup>2</sup>) of return leak lowered infiltration in the house when the air handler was on from 0.96 to 0.32 ach, and



**Figure 3** Performance degradation of air conditioner when attic air is drawn into air handler, assuming room is 78° and attic air is 120°F

reduced the return leak fraction from 10.8% to 1.3%. House pressure with the air handler running also decreased to neutral.

The air handler cabinet caused a portion of the return leak. In order to achieve 1.3% return leak, penetrations and cracks in the air handler were taped. Attic air could get into the air handler closet because the ceiling was not fully sealed. When the cracks were not sealed, the closet (immediately above the return plenum) operated under -0.004 in H<sub>2</sub>O (-1 Pa) pressure. When the cracks were sealed, pressure dropped to 0.0 in H<sub>2</sub>O (0 Pa).

When interior doors were closed with the air handler running, the infiltration rate in the home increased to 0.82 ach (Table 3). Pressure drops across the four doors averaged 0.032 in H<sub>2</sub>O (8.1 Pa). Cracks at the bottom of the doors are about 1/2 in (0.013 m).

The master bedroom has a grille above the door to allow return airflow (it was closed during the testing reported above). When it was closed, the room pressure was 0.038 in H<sub>2</sub>O (9.5 Pa). When it was opened, pressure in the room dropped to 0.015 in H<sub>2</sub>O (3.8 Pa). This return path then helps reduce unwanted pressures in the house, but a larger opening would be even more desirable.

### House D

This 20-year-old, 1590 ft<sup>2</sup> (147.8 m<sup>2</sup>) block construction house has an ELA of 125.7 in<sup>2</sup> (0.0811 m<sup>2</sup>), which yields 10.50 ach<sub>50</sub>. Its naturally induced infiltration was measured at 0.10 ach.

A large 23.5% of the leak area of the house is in the duct/air handler system. Infiltration is dominated by air distribution leaks. When the air handler is running, infiltration rises to 0.78 ach, or an equivalent 178 cfm (0.0840 m<sup>3</sup>/sec). The return leak fraction is 10.0%, or 130 cfm (0.0614 m<sup>3</sup>/sec).

This house previously had a gas furnace in the hall closet. Several years ago a high-efficiency heat pump (SEER = 11) was installed in the closet, but the return plenum was not reconstructed. The whole closet was the return plenum. In order to seal this closet from the attic we had to put foam into numerous cracks and penetrations in the ceiling. Working in the attic, we used a smoke stick to

## Return leak pathways into return plenum from the attic

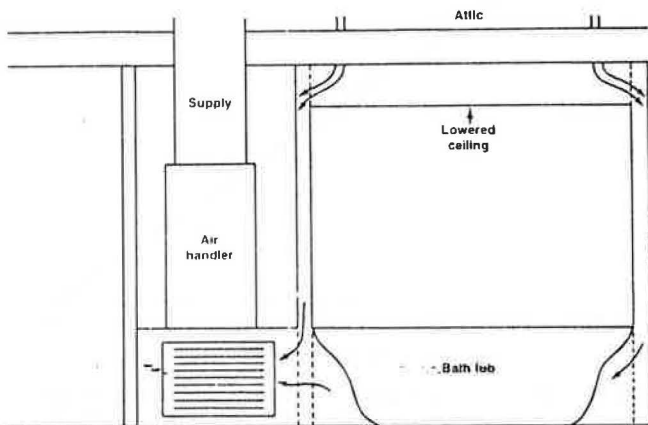


Figure 4 Return leak pathways into return plenum from the attic

identify where return air was being drawn into the closet. After sealing, the house ELA dropped about 5%. This resulted in infiltration being reduced from 0.84 to 0.30 ach with the air handler running, and the return leak fraction dropped from 10.0% to 3.0%.

When the interior doors were closed, the infiltration rate increased from 0.30 ach to 0.98 ach (Table 3). This increase is typical of what we have observed in a number of Florida homes. The crack size at the bottom of the doors is about  $\frac{1}{2}$  in (0.013 m). Pressure drop across the four closed doors averaged 0.036 in H<sub>2</sub>O (9.1 Pa), which is the highest of the five houses tested. The impact of this elevated infiltration was observed by the author at this house at a social event on a summer evening. The air conditioner did not shut off the whole period from 7 to 10 p.m., though it was not an unusually hot day and there were only about 10 people in the house. The apparent cause for the excessive run time was that three bedroom doors were closed, increasing infiltration and bringing in heat and humidity from outdoors and the attic.

When a pulse of humidity is introduced into the space, a good deal of the latent heat is converted to sensible heat as the moisture adsorbs into the materials in the house. Research done at the Florida Solar Energy Center has found that the furnishings of a house can store about 10 times as much moisture for a given RH change as the air in the house (Cummings and Kamel 1987). Therefore, when a large pulse of latent heat comes into the house, such as when the doors are closed, much of this latent heat converts to sensible heat.

System imbalance caused by closed doors is typical in Florida homes. In a sample of 81 other homes with single returns that we tested in the Orlando area, the average pressure drop across the master bedroom door was 0.032 in H<sub>2</sub>O (8.0 Pa). In a sample of 16 homes that have multiple returns, pressure drop across the master bedroom door was only 0.006 in H<sub>2</sub>O (1.6 Pa). Providing multiple returns can help maintain even pressure throughout the house and reduce infiltration. Whether multiple returns, typically running through the attic, cause more problems from conduction heat gains and from return leaks than they solve is an issue still open to question.

## House M

This 20-year-old, 1686 ft<sup>2</sup> (156.7 m<sup>2</sup>) block construction house began as the loosest house of the five with 279.3 in<sup>2</sup> (0.1803 m<sup>2</sup>) ELA and 16.66 ach50. The naturally occurring infiltration rate was measured at 0.10 ach under calm wind conditions.

A blower door test with the registers covered was not performed, so the ELA of the air distribution system is not known. The return plenum leak was very large. One whole wall (about 5 ft<sup>2</sup> [0.46 m<sup>2</sup>]) of the return plenum had no sheet rock (Figure 4). This opening passed into the bath/shower enclosure, which also had no sheet rock below the top edge of the bathtub. Above the bath/shower was a lowered ceiling, thereby resulting in large pathways up the walls into the attic. With the air handler running, the infiltration rate rose to 3.36 ach, which is 755 cfm (0.356 m<sup>3</sup>/sec). The return leak fraction of 54.9% is in close agreement; it is equivalent to 757 cfm (0.357 m<sup>3</sup>/sec).

When the return plenum on this house was sealed, some additional sealing between the attic and the house was done. We estimate that 75% of the sealing was in the return plenum. The house ELA dropped from 279.3 to 100.4 in<sup>2</sup> (0.1803 to 0.0648 m<sup>2</sup>) (64% reduction), and ach50 dropped from 16.66 to 9.37 (44% reduction). The infiltration rate of the house dropped from 3.37 ach to 0.21 ach with the air handler on, a 94% reduction. The return leak fraction dropped from 54.9% to 0.0%. The final infiltration rate and return leak fraction are the lowest of the five houses. The homeowners were very pleased and wrote a complimentary letter to the electric utility. During the 16 years they had lived in the house they had called in air-conditioning contractors an estimated 12 times to repair the system and had been told that the equipment was working fine.

When the interior doors were closed with the air handler on, infiltration jumped from 0.21 to 1.27 ach. This is the largest increase in any of the homes. Pressure drop across the doors averaged 0.033 in H<sub>2</sub>O (8.2 Pa).

## House N

This is a six-month-old frame construction house with a fairly tight envelope. The house ELA was measured at 86.1 in<sup>2</sup> (0.0556 m<sup>2</sup>) and ach50 was 8.76 ach. This house had natural infiltration of 0.18 ach and 0.17 ach measured before and after repair.

A blower door test with the registers covered was not done, so the ELA of the air distribution system is not known. Infiltration tests on this house were done three times before the repairs were finally completed. In the first test, the infiltration rate was 0.94 ach with the air handler running, which is equivalent to 144 cfm (0.0680 m<sup>3</sup>/sec). The return leak fraction was measured at 11.3%, or 113 cfm (0.0533 m<sup>3</sup>/sec). Because this was a new house and was under warranty, the homeowner contacted the air-conditioning contractor to repair the leaks in the system. Based on our instructions he sealed the return plenum box joints where the air handler joins the plenum, and openings in the attic at the tops of walls. When a second test was performed it was found that the infiltration rate had dropped only slightly to 0.87 ach (133 cfm or 0.0628 m<sup>3</sup>/sec), and the return leak fraction was reduced to only 10.1% (101 cfm or 0.0477