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CENTRAL AIR CONDITIONER IMPACT UPON INFILTRATION RATES IN FLORIDA HOMES

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ABSTRACT

Infiltration tests on nine residences in Florida found that infiltration rates are in the range of 0.20 to 0.60 air changes per hour (ACH). Tests were performed with the air conditioner blower on and off. Infiltration rates averaged 0.62 ACH when the blower was on and 0.22 ACH when the blower was off. Thus, the space conditioning system is generating infiltration at nearly twice the rate induced by weather conditions alone. If it is assumed that the air handler is running 35 percent of the time during the cooling and heating seasons, then the average infiltration rate for these residences can be estimated to be 0.36 ACH. This rate is smaller than values that are commonly assumed for simulation analysis of residential buildings. Additional tests were also performed on two of these residences when the interior doors were closed and the blower was running. Infiltration increased by 0.45 and 0.70 ACH in the two houses compared to when the doors were open and the air handler was on. These results have implications for:

1. building energy use,
2. peak electrical demand,
3. choosing between forced-air and alternative space conditioning systems,
4. modelling of building energy use and space conditioning equipment, and
5. how tracer gas infiltration tests should be performed.

1. INTRODUCTION

Infiltration of ambient air into houses represents a significant portion of the cooling and heating loads of homes in hot, humid climates. In Florida infiltration can represent 25 percent of the total air conditioning load, with latent heat being about 82 percent of this.[1] It has been common to assume that standard construction residences have infiltration rates of 0.5 to 1.0 ACH. To evaluate the magnitude of infiltration in Florida homes, eight single-family residences and one townhouse were tested. These buildings are all block construction, have forced air space conditioning systems, are in the range of 5 to 25 years old, and are probably typical of Florida concrete block housing. Because earlier research (discussed in Section 3) at the Florida Solar Energy Center (FSEC) found differences in infiltration rates when the air handler was on compared to when it was off, the tracer gas tests in this study were performed twice, with the blower running and with it stopped. In addition, tests were performed on two of the houses with interior doors closed to observe the impact of blocking the path for return air.

2. TEST METHOD

Nine residences were tested for air infiltration using the tracer gas method mostly during the period from July through September, 1986. The tests were generally performed during the daytime hours of 10 AM to 4 PM when summer winds are maximum in this coastal region. The tests normally required two to four hours. The house was prepared by closing any windows that might be open, opening all air conditioner vents not open, and opening all interior doors to rooms. Continuous air speed measurements were recorded at FSEC, which is generally within 10 miles of the tested homes.

Approximately 0.03 in^3 of sulfur hexafluoride (SF_6) was injected into the return air grill of the air conditioner (AC) with the fan on continuously, and was allowed to mix throughout the house for about one-half hour. Air samples were taken at approximately 15 minute intervals at a central location in the home using 10 cc syringes. Pieces of gum eraser were placed over the needle point to seal the syringe, and the samples were returned to the lab at FSEC for analysis. SF_6 concentrations were obtained using a gas chromatograph. The infiltration rate was obtained by:

$$ACH = \frac{60}{N} \ln \left[\frac{C_i}{C_f} \right]$$

where
- N is the number of minutes of the test
- C_i is the initial SF_6 concentration
- C_f is the final SF_6 concentration

3. OTHER RESEARCH

Previous research performed at FSEC on a townhouse (Rangewood Villas) in Cocoa, Florida showed a marked increase in infiltration when the AC blower was on (Figure 1). A series of 14 test were done in 1985 with the blower on and off under various wind conditions.[2] Wind speed was recorded continuously on a data-logger during the tests. Ceiling fans were turned on to insure mixing throughout the townhouse, which is a one and one-half story design and has a very open floor plan. Infiltration rates were about 0.35 ACH higher when the blower was on for all wind speeds. Under typical daytime wind speeds of 7 MPH, infiltration was about 0.57 ACH with the blower on and 0.22 ACH with the blower off.

Three hypotheses are presented to explain this induced infiltration:

1. leaks on the suction side of the air handler/duct system draw air from the attic (where the air handler and part of the duct system are located). More air is therefore pumped into the house than is taken out producing high pressure in the house and thus generating exfiltration.
2. leaks on the high pressure side of the air handler/duct system to the attic cause less air to be pumped into the house than is removed. The resulting low pressure in the house causes infiltration from the outdoors.
3. no leakage occurs in the air handler and duct system, but pressure differences within the building (higher than ambient in some locations and lower than ambient in others) causes infiltration through the building envelope.

It may be that some combination of these is at work. Whatever the cause, the AC air handler system acts as if it is providing make-up air to the residence. The 0.35 ACH increased infiltration represents 67 CFM, or 6.8 percent of the total 980 CFM capacity of the air handler unit.

Gammage et. al. found similar results in tests on 31 Tennessee houses [3]. They found that there was a marked difference in the infiltration rate depending upon whether the central air handler was running. All 31 residences were tested with the air handler on and off, and the infiltration rates were found to be 0.78 ACH when on and 0.44 ACH when off. This difference of 0.34 ACH is very similar to the results from Rangewood Villas.

Inefficiencies related to air distribution heating were observed in a study by the Northwest Power Planning Council. In their study of 410 new conventional homes in the Pacific northwest it was found that forced air electric heating systems performed at only 78 percent ($\pm$7.1 percent) of the efficiency of baseboard and wall heating units.[4] When long term tracer gas infiltration tests were performed they found that residences with forced air heating systems averaged 0.41 ACH compared to 0.24 ACH for baseboard and radiant electric systems, even though blower door tests indicated little difference in leakage area. It appears, therefore, that induced infiltration is causing a significant decline in performance of forced-air space heating systems, since duct system conduction losses would not account for such large performance degradation.

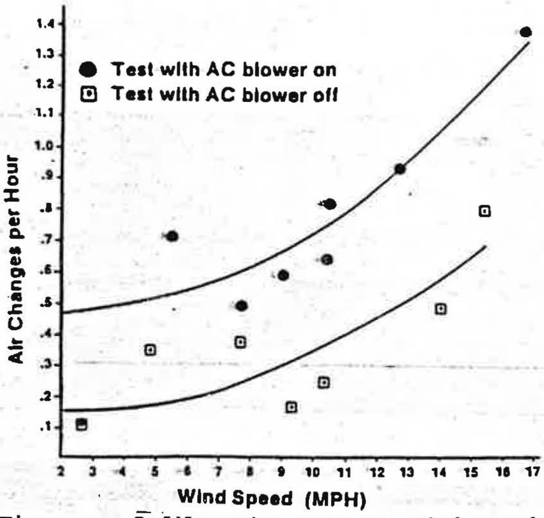

Figure 1. Infiltration rate vs. wind speed with air handler on and off at Rangewood Villas Townhouse

4. CURRENT INFILTRATION TESTS

Results from nine tested residences shows the same effect. Tracer gas tests were performed once with the AC blower on and once with the AC blower off. The results are shown in Table 1. Wind speed and ambient temperatures recorded at FSEC are presented. Differences in wind speed and air temperature are small between the blower on and blower off tests

TABLE 1. INFILTRATION RATE TESTS, 1986

House	Date	Time EST	AC Blower On ACH	AC Blower On Wind MPH[1]	AC Blower On Ambient Temp	AC Blower Off ACH	AC Blower Off Wind MPH	AC Blower Off Ambient Temp	Ratio ACH ON/OFF
A	12/29	9-12	1.40	21.9	54.1	.43	16.6	56.6	3.26
B	8/04	11-02	.73	5.1	88.3	.36	6.1	89.2	2.03
C	8/05	1-04	.42	7.7	91.2	.24	5.0	91.2	1.75
D	8/14	11-01	.79	6.1	83.1	.14	6.2	82.9	5.64
E	8/18	10-12	.27	4.3	81.6	.10	4.7	83.3	2.70
F	8/26	10-01	.41	4.4	84.6	.13	5.8	85.4	3.15
G	9/15	11-12	.88	<3	76.9	.25	<3	75.7	3.52
H	9/23	11-01	.31	<3	87.1	.16	<3	91.6	1.94
I	10/06	11-01	.38	<5	88.7	.16	<5	90.6	2.38
Ave.			.62	6.7	81.7	.22	6.2	82.9	2.82

[1] Wind speed data from FSEC weather station, except G,H, and I approximated from data from Rangewood Villas townhouse.

and thus cannot account for the major differences in infiltration resulting from the AC blower being on. With the blower on infiltration averaged 0.62 ACH and with the blower off it averaged 0.22 ACH. These averages are similar to the results found at Rangewood Villas (Rangewood Villas is also house I in Table 1.). The air handler nearly triples the average infiltration rate when it is on. In some cases the rate is less than twice as great while in other cases infiltration is nearly six times as high.

5. IMPLICATIONS

While the purpose of the AC system is to provide comfort conditions indoors, it is partially working against itself by inducing air infiltration. This can have a major impact upon total cooling and heating energy use and an even greater impact upon peak electricity demand, which is of importance to utilities.

Thermal Analysis Research Program (TARP), in modified form to accommodate moisture adsorption and desorption into and out of building and furnishing materials (MADTARP), was used to assess the impact of increased infiltration upon cooling energy use. Simulations for Orlando using hourly TMY data for 0.43 and 0.64 ACH were available. This 0.21 ACH increase in infiltration increased cooling energy use for June through September by 8.3 percent. These results assume fairly constant infiltration throughout the day. When infiltration is assumed to vary based on air conditioner running time, and thus peaks during the hot afternoon hours, the 0.21 ACH infiltration increase produces a 10.0 percent increase in cooling energy use. Interior relative humidity also rose by about 2.5 percent.

An assessment is made of increased energy use based on building infiltration rates of 0.22 ACH with the air handler off and 0.62 ACH with the air handler on. If the air handler runs 35 percent of the time during a Florida cooling season, then the AC blower increases average infiltration from 0.22 to 0.36 ACH. Extrapolating from the TARP run described above, this 0.14 ACH increase in infiltration may increase the cooling season energy bill by 6.7 percent, or about $27/year. If some portion of the infiltration air originates in the attic, as we suspect it does, then the impact upon cooling will be even greater because the dry-bulb temperature is much higher in the attic than outdoors during the daytime when the AC-induced infiltration is greatest. If one-third of the infiltration is from the attic the increase in cooling season energy use resulting from a 0.14 ACH infiltration increase (assuming dry-bulb temperature of 105°F from 9 AM to 6 PM and 85°F from 6 PM to 9 AM — data from FSEC test attics) will be 11.3 percent, or $46/year.

Impacts upon heating energy use can be substantial in cold climates. In a climate averaging 35°F for six months, the added heating cost resulting from 0.14 ACH increase can be $39/year (furnace AFUE=.65 and gas cost is $0.50/therm).

Impacts on the peak electrical demand for Florida electric utilities are also quite substantial. This is because the air handler on-time is greatest at peak summer air conditioning and peak winter heating periods. If the air handler is on 80 percent of the time at the summer peak, then the infiltration rate would be 0.54 ACH compared to 0.22 ACH when it is off. This 0.32 ACH increase in infiltration elevates the peak load by 3773 Btu/hr, or 14.6 percent (assumes 25,840 Btu/hr peak load). Again, if a portion of the infiltration air is from the attic, the impact will be larger yet. If one-third of the infiltration is from the attic, the increase in the peak load will be 4947 Btu/hr, or 19.1 percent (assumes 115°F attic dry-bulb temperature).

Florida experiences winter peak electrical demand on cold winter mornings which is comparable to the summer peak. Either electric resistance heat or heat pump heating will produce elevated infiltration rates. If the ambient temperature is 20°F and the air handler is running 80 percent of the time, TARP simulation indicates that the increase of 0.32 ACH will increase the heating load 4010 Btu/hr. This may be about 20 percent of a typical peak heating load.

6. IMPACT OF CLOSING ROOM DOORS

The previous tests were performed with the interior doors to each room left open. When these doors are closed, the return air path to the central return is partially blocked. If the doors fit tightly and there is little crack at the bottom of the door, then the return air may be almost completely stopped. This will cause a pressure build-up in the rooms behind the closed doors, and produce low pressure in the remainder of the house. In areas of high pressure, exfiltration to the outdoors and attic will occur, and in areas of low pressure, infiltration from the outdoors and attic will occur.

Houses A and E from Table 1 were tested for infiltration with interior doors closed. (A Miran 101 Specific Vapor Analyzer designed to detect SF_6 in concentrations from 0.0 to 5.0 PPM was used for these tests.) In house A the infiltration rate increased from 1.40 to 1.85 (wind speed 21.9 and 19.6 MPH, respectively) when the doors were closed. These rates are the average from all the rooms.

Tests on house E, which had the lowest infiltration rates, experienced much more dramatic escalation of infiltration when interior doors were closed (Table 2.). When the AC blower was off, this house had infiltration rates of 0.10 and 0.21 ACH (Figure 2.) for wind speeds of 4 and 14 MPH, respectively. With the AC blower on and all room doors open, infiltration increased to about 0.42 ACH. With two doors closed it rose to 0.62 ACH. With three and four doors closed it was about 0.95 ACH, and with all six doors closed it increased to 1.15 ACH (Figure 3.).

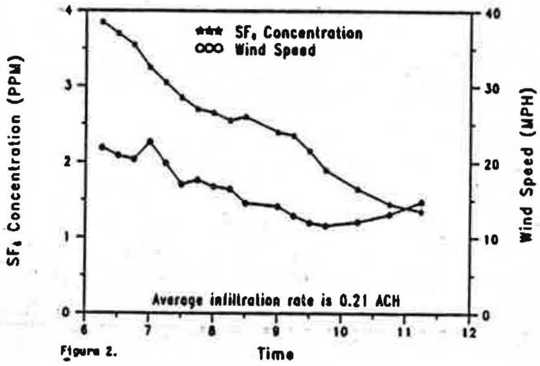

Figure 2.
Infiltration test with AC blower off and doors open (12-04-87)

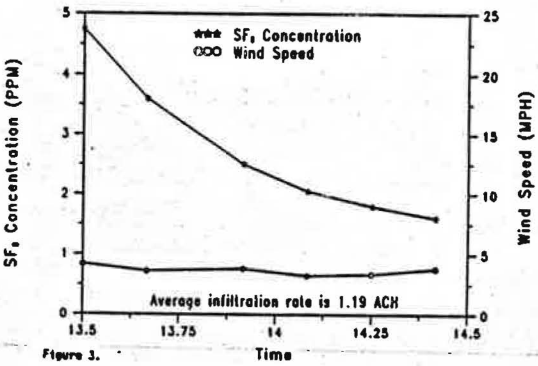

Figure 3.
Infiltration test with AC blower on and all doors closed (12-06-87)

TABLE 2. INFILTRATION TESTS AT ONE HOUSE WITH AC BLOWER OFF AND WITH AC BLOWER ON AND WITH VARIOUS NUMBERS OF INTERIOR DOORS CLOSED.

Date	AC Blower	Number of Doors Closed	Wind Speed (MPH)	Ambient Temperature	Air Change Rate
8-18	OFF	0	4.7	83.3°	.102
12-04	OFF	0	13.9	59.3	.210
12-06	ON	0	6.0	61.3	.444
12-08	ON	0	10.9	71.6	.394
12-08	ON	2	10.5	71.4	.563
12-06	ON	2	4.9	65.1	.671
12-08	ON	3	11.0	72.6	.976
12-08	ON	4	9.7	72.9	.935
12-06	ON	6(all)	6.3	67.7	1.187
12-03	ON	6(all)	5.4	66.1	1.120

Closing the doors increased the infiltration in houses A and E by 0.45 and 0.70 ACH, respectively. An explanation for the difference is that House E has very tight fitting doors while house A has more crack area, especially at the bottom of the doors.

7. IMPLICATIONS OF CLOSED DOORS

With interior doors open the air conditioning system generates increased infiltration that may add about 5 to 10 percent of annual energy use and 15 to 20 percent to peak electrical demand. When interior doors are closed the potential for increased energy use and electrical demand is increased. An assessment of the impact of having two doors closed is presented. If we assume that closing two doors increases infiltration by 0.15 ACH, cooling in Florida may cost an additional $10/year (2.5 percent increase), and annual heating costs may be an additional $15/year (natural gas) in a cold climate.

The impact upon peak cooling and heating demand in Florida will also be significant if two doors are closed in the average home. With the blower running 80 percent of the time and two doors closed, the peak cooling load may increase by 1886 Btu/hr (7.3 percent) and the peak heating load may be increased by 2005 Btu/hr (about 10 percent). The peak electrical demand in Florida in the heating season may be especially strongly impacted, because early in the morning a larger proportion of bedroom and bathroom doors may be closed while and before occupants are getting up.

8. CONCLUSIONS

The air handler of the space conditioning system is causing considerable infiltration in nine Florida residences. Tracer gas tests found that when the AC blower is off, infiltration averaged 0.22 ACH. When the AC blower was running, infiltration increased dramatically to an average 0.62 ACH. Assessments of the impact of this increased infiltration showed that annual cooling and heating loads may be 5 to 10 percent higher because of the forced air system. Space conditioning electrical demand during summer and winter peak demand periods may also be 15 to 20 percent higher because of this mechanically induced infiltration.

It was also found that closed interior room doors cause higher infiltration rates when the air handler is on. With the blower on, closing the interior doors increased infiltration by as much as 0.70 ACH. Annual cooling and heating loads may be two to five percent higher if two doors are closed. Space conditioning electrical demand during the summer and winter peak demand periods may be 5 to 10 percent higher when two doors are closed.

The findings described above have a number of important implications for residential energy conservation research:

- The causes of this elevation of infiltration resulting from the operation of the air handler needs to be more fully investigated. Studies need to determine whether these differences are caused by duct losses, or pressure differences in the conditioned space, or both.
- Methods to reduce infiltration caused by closed interior doors should be investigated.
- In light of reduced system efficiencies for forced air systems (resulting from increased infiltration conduction losses), baseboard and radiant electric heating systems should be considered as alternatives to forced air electric systems in order to reduce both energy use and peak electricity demand, especially considering the ease with zone heating can be achieved with these systems.
- Tracer gas infiltration testing should be done with the awareness that the space conditioner blower can more than double the infiltration rate. The best procedure is to perform the test both with the blower on and with the blower off.

9. ACKNOWLEDGEMENTS

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