4-17-1995

Assessment of Infiltration Practices in the Florida Energy Code

Florida Solar Energy Center

James Cummings
Florida Solar Energy Center

Reference Publication: Cummings, J., and Moyer, N., "Assessment of Infiltration Practices in the Florida Energy Code," Final Report No. FSEC-CR-1826-95, Florida Solar Energy Center, Cocoa, FL, April 17, 1995.

Assessment of Infiltration Practices in the Florida Energy Code

James B. Cummings and Neil Moyer
Florida Solar Energy Center (FSEC)

FSEC-CR-1826-95

1.0 Executive Summary

The Florida Department of Community Affairs has contracted with the Florida Solar Energy Center (FSEC) to review the current infiltration practices of the Florida Energy Code to determine, based on analysis of the best currently available infiltration data, whether there is need for three infiltration practices, and to make recommendations of what "point multipliers" should be applied to the infiltration practice(s). An advisory committee of industry, utility, and research representatives was formed to review the findings of the project and express opinions about the form the infiltration practices should take. This committee met twice, reviewed each of the reports produced by FSEC staff, and gave review and recommendations throughout. Views of the advisory committee are indicated in several places throughout this report.

Tracer gas infiltration data and blower door test data was found for 76 homes built within the past 10 years. Note that these homes were located in central Florida; there may be differences in housing located in northern and southern portions of the state. From this sample, infiltration practice was obtained from energy code compliance forms for 54 of these 76 houses. Eight houses claimed Practice 1 (least tight practice), 46 claimed Practice 2, and none claimed Practice 3 (the tightest practice). When the passive infiltration rates were compared for **one-story houses**, it was found that **both** practice 1 and practice 2 houses experienced 0.17 air changes per hour (ach). For two-story houses, practice 1 houses experienced 0.33 ach compared to 0.23 ach for practice 2 houses. Based on this analysis, it appears that there is no difference in infiltration between practice 1 and practice 2 one-story houses. The only noticeable difference between practice 1 and practice 2 houses is that 2-story Practice 2 houses appear to be tighter. In all cases, the sample sizes are too small to be conclusive.

Nevertheless, we can say with confidence that nearly all new Florida homes receive less ventilation air by means of natural infiltration than is called for by the ASHRAE 62-1989 ventilation standard (it calls for 0.35 ach or more). **Therefore, this report concludes that Florida houses should not be made tighter.** Blower door test data shows that Florida houses have become three times more airtight over the past 40 years, and that the majority of this airtightening occurred before the current infiltration practices came into effect in 1986. Reasons for this trend of tighter house construction is presented in the report.

This report proposes that the three infiltration practices be replaced by one infiltration practice. (It was the unanimous opinion of the advisory committee that the current infiltration practices should be replaced by one infiltration practice, and that separate duct multipliers be awarded to locating ducts in the conditioned space.) The new practice would place more emphasis upon tightening the ceiling plane of the house and less emphasis on tightening the wall planes of the house. We believe that by tightening the ceiling plane and loosening the wall plane, Florida houses built under the proposed infiltration practice will experience about the same infiltration as current Practice 2 (about 80% of Florida homes are now built to Practice 2). **It is our opinion, however, that many Florida homes built to the current or proposed new standards may experience poor indoor air quality under some conditions (e.g., if windows are kept closed, or in mechanical ventilation systems are not used). We recommend, therefore, that the State of Florida pursue an aggressive research program in the indoor air quality area to develop consumer guidelines and/or building codes in this area.**

The justification for having only one infiltration practice is that there is little energy savings which can be attributed to more tightening, and houses now receive less than the recommended amount of ventilation air. The justification for shifting the airtightening emphasis from wall plane to ceiling plane is that attic air is hotter, more humid, and more likely to be contaminated than air coming into the house through windows, doors, and walls. A line-by-line review of the measures of the current three infiltration practices is presented, and justification for including or excluding each from the new proposed infiltration practice is given.

Following is the propose infiltration practice to replace the current three infiltration practices.

1. A continuous air barrier shall separate the attic from the conditioned space.

    a) Joints, penetrations, or openings in the ceiling plane of the top floor of the building shall be caulked, gasketed, weather-stripped, or otherwise sealed so that air flow between the attic and conditioned space is stopped. Leak sites to be sealed include -- but are not limited to -- top plate penetrations, holes in the ceiling gypsum board, gaps around ceiling fixtures, gaps at registers and grills, open shafts, chases, space around fireplace chimneys, space around combustion and exhaust appliance vent pipes, and dropped ceiling areas, such as above kitchen cabinets, bathroom vanities, shower stalls, and closets. Large openings, such as shafts, chases, soffits, openings around chimneys, and dropped ceiling spaces, shall be sealed with an airtight panel or sheeting material and sealed to adjacent top plates (or other framing members) so that a continuous air barrier separates the spaces below and above the ceiling plane. Smaller penetrations, joints, and cracks shall be sealed with mastics, foams, or other sealants. Gaps between ceiling gypsum board and the top plate shall be sealed with a sealant to stop air flow between the attic and the interior of wall cavities.

b) As an alternative to 1,a), the builder may choose to install an infiltration barrier in the ceiling plane of the top floor of the house. The infiltration barrier shall create a continuous air barrier across the entire ceiling plane, shall be continuous across the tops of interior and exterior walls, and shall be sealed at the perimeter, at openings in the ceiling plane (grills, registers, attic access, plumbing penetrations, vent pipes, chimneys, etc.), and at seams between sections of infiltration barrier material.

c) Recessed lighting fixtures installed in ceilings that abut an attic space shall be sealed to the ceiling gypsum board in order to produce an airtight seal, shall have an airtight housing (unvented IC-rated fixtures), and shall be insulated and/or covered with insulation where local codes permit.

d) The attic access hatch, if located in the conditioned space, shall have an airtight seal.

2. The following are the requirements for exterior walls.

a) Penetrations, openings, and joints in the wall plane of the building envelope shall be caulked, foamed, gasketed, weather-stripped, or otherwise sealed.

b) Gaps or cavities around window and door frames shall be sealed.

c) In multi-story houses, the perimeter of the floor cavity (created by joists or trusses between floors) shall have an infiltration barrier to prevent air flow between this floor cavity and outdoors or buffer zones of the house (buffer zone, for example, could be an attic space over the garage). To make the floor cavity airtight, airtight panels, sheathing, or sheeting shall be installed at the perimeter of the floor cavity. The panels, sheathing, or sheeting material shall be sealed to the top plate of the lower wall and the bottom plate of the upper wall by mastic or other adhesive caulk, or otherwise bridge from the air barrier of the upper floor to the air barrier of the lower floor. Joints between sections of panels, sheathing, or sheeting shall be sealed.

d) In frame construction, the crack between exterior and adjacent wall bottom plates and floors shall be sealed with caulking or gasket material. Gypsum board or other wall panelling on the interior surface of exterior and adjacent walls shall be sealed to the floor.

3. Penetrations and openings in raised floors, greater than or equal to 1/8 inch in narrowest dimension, shall be sealed, unless backed by truss or joist members against which there is a tight fit. Alternatively, the builder may choose to install an infiltration barrier in the floor plane of houses with raised floors. The infiltration barrier shall create a continuous air barrier across the entire floor area, and shall be sealed at the perimeter, at openings in the floor plane (grills, registers, crawl space access, plumbing penetrations, etc.), and at seams between sections of infiltration barrier material.

4. All exhaust fans vented to unconditioned space shall have dampers.

5. Range hoods located in cooking zones shall be vented to outdoors and have a vent damper.

6. All combustion space heaters, furnaces, and water heaters must be provided with adequate combustion and dilution air, and combustion gases must be vented to outdoors.

7. All fireplaces shall have a flue damper.

Note that when the term "infiltration barrier" is used in this report, it refers to the specific definition provided in the 1993 Residential Instruction Manual (Florida Energy Code document), pp 58-60. This definition is lengthy and is not repeated in this report.

2.0 How Houses Leak Air

In order to assess the infiltration practices of the Florida Energy Code, it is important to understand how houses leak air. Section 2 of this report discusses the mechanisms by which infiltration occurs.

First, let's define infiltration. **Infiltration** is defined as air moving across the building envelope without the intent of ventilating for improved indoor air quality. **Ventilation** is defined as intentionally bringing air into a building in order to maintain acceptable indoor air quality. Infiltration can be caused by wind, temperature differentials (stack effect), leaks in the air distribution system, pressure imbalances caused by return air design problems, and the operation of exhaust fans and equipment.

A key concept: to get infiltration you need a hole and a driving force. A hole without pressure differential will result in virtually no air flow. A pressure differential without a hole will result in no air flow.

2.1 Infiltration requires a pathway (a hole)

In real houses, there will always be holes and there will almost always be driving forces. The extent of holes and driving forces varies considerably, however. Holes exist in the envelope of a house in the form of cracks, penetrations, and openings. They are created by the joining of various components; by putting openings in walls, floors, and ceilings; and by leaving openings in components of walls, floors, ceilings, and duct systems.

There are many things that can be done to make a building structure more airtight. These include sealing seams and joints with sealants or tapes, filling penetrations with sealants, covering the building with various types of air barrier sheeting, and use of airtight drywall techniques. The latter technique involves making sure that the gypsum board panels join tightly to other building sections, such as floors and framing members, and minimizing leaks at electrical fixtures and outlets.

Most building leaks are created when the buildings are constructed. However, some leaks develop over time. Duct systems are especially susceptible to development of leaks over time. The causes of developed duct leaks include:

1) failure of the closure system (i.e., drying of tape adhesives)

2) weight of a suspended duct pulling the duct away from its connection

3) people crawling over and around ducts can damage or disconnect ducts

4) animals -- such as rats, mice, raccoons, possums, squirrels, dogs, etc. -- have been known to tear open ducts, sometimes because the air inside the ducts provides welcome relief from inhospitable conditions in the attic, crawl-space, or other unconditioned space

5) the liners of flex ducts are occasionally exposed to sunlight, either in the attic or before installation, and the UV light can cause the outer and even the inner liner of the duct to disintegrate

6) moisture damage.

Houses also have intentional openings, such as combustion vent pipes and chimneys, combustion/dilution air openings for combustion appliances, vents on dryers and exhaust fans, outdoor air (on return side of duct system), and whole-house fans.

2.2 Infiltration requires a driving force

The driving forces of infiltration are pressure differentials. Pressure differentials are created by a number of factors, including **passive** -- wind and stack effect -- and **mechanical**. For the purposes of assessing the infiltration practices of the energy code, the driving forces of wind and stack effect are of primary interest, since they are a given for a specific house location. Mechanically driven infiltration will vary greatly from one house to another, depending upon construction and occupancy factors, and this infiltration is not greatly influenced by the building envelope airtightness.

2.2.1 Passive driving forces

As wind blows against a house it creates high pressure on the wind-ward side and negative pressure on the leeward side of the house. Wind also creates pressure differences when it blows across the top of the roof and orifices, such chimneys and various vents. Typically, wind across a chimney or vent pipe will induce a negative pressure which will cause air to be drawn from the house. Wind may also be caught by roof overhangs and pushed into the attic space. Generally this creates positive pressure in the attic space relative to the interior of the building, and can cause attic air, which is hot during much of Florida's cooling season, to be driven into the occupied space.

Temperature difference between indoors and outdoors creates pressure difference. In winter, house air is typically warmer than outdoors. Warm air is lighter than cold air, so house air tries to lift and rise out of the house through leak sites in the upper portion of the structure while cold outdoor air tries to come into the house through openings near ground level. In the summer, reverse stack may occur, where house air may try to leave lower portions of the house and outdoor or attic air may enter at the top of the house. Stack effect becomes stronger as the temperature difference between indoors and outdoors increases and as the height of the building increases.

In Florida, these natural driving forces of wind and stack do not create large rates of infiltration, compared to more northerly portions of the country, for the following reasons. First, wind speeds in Florida are typically lower than in colder portions of the United States. Second, temperature differentials are less in Florida than in other portions of the United States. Third, Florida houses tend to be shorter (a greater proportion are one-story without a basement) than in colder portions of the United States, and therefore cannot induce as much stack effect and are not as exposed to the wind. Fourth, newer Florida houses are, to a large extent, built on concrete slabs, so that there are relatively few leaks in the lower portions of the house, reducing stack effect infiltration (according to a University of Florida study [1993], only 8.4% of houses built in Florida during 1987-1993 have raised wood floors).

2.2.2 Mechanical driving forces

Sources of mechanically driven air flow include the central heating and cooling system air handler, kitchen and bath exhaust fans, cook-top grill exhaust fans, and clothes dryers. Combustion equipment may also be power vented, which can draw air out of the building. Attic exhaust fans can also depressurize the attic and the occupied space below, and thereby draw air out of the house.

Infiltration can be caused by duct leakage. Field testing has indicated that about 13% of the total house leaks (holes) are in the duct system. However, these leaks are under considerable pressure (often 10 to 100 pascals of pressure differential) and therefore much more than 13% of the house air infiltration occurs through duct leaks. When the ducts are located in unconditioned zones of the house, such as attics, crawl spaces, basements, garages, mechanical closets, and utility rooms, leaks in the return or supply ducts can move air from the house to outdoors and from outdoors into the house.

Closing of interior doors can also create pressure imbalances in the house which may substantially increase air flow across the building envelope. These pressure imbalances are created because returns grills are almost always located only in the central zone of Florida houses, while supply air is delivered to each room. The resulting high pressure in the closed rooms drives conditioned air from the house towards outdoors, and the resulting low pressure in the central zones draws air into the house from outdoors, the attic, the crawl space, and any other buffer zone.

Exhaust fans can depressurize the entire house, or specific zones of the house when the doors to those zones are closed. This negative pressure draws air into the house from outdoors, the attic, the crawl space, and any other buffer zone.

2.3 Where Florida houses leak

The majority of leak sites in Florida homes occur in the ceiling plane of a house. Based on inspections of hundreds of homes in Florida, we estimate that perhaps 70% or more of the leak area of homes is between the occupied zones and the attic. (If we exclude the slab floor, the ceiling represents about 55% of the exterior shell area of a one-story house. Even if the ceiling was only as leaky as the walls, then about 55% of the house leak area would be in the ceiling.)
As previously mentioned, most Florida homes are built on concrete slabs. The slabs themselves have almost no leaks. Typically, walls, windows, and doors in more recently built homes do not leak a great deal (see the discussion in Section 3.2 about why houses have been becoming more airtight). Therefore, the remaining opportunity for leaks is in the ceiling.

There are a number of factors that explain why ceilings tend to be more leaky. (Note that even though some of the following discussion refer to walls, especially interior walls, we consider them to be leaks in the ceiling plane because they provide pathways between the conditioned space and the attic.)

1) Interior walls are hollow, and therefore allow connection of air in the rooms to the air in the attic.

2) There are cracks between the gypsum board and the top-plates (typically a 2x4 at the top of the wall). These cracks can range from almost nil to a 1/4 inch in width. In a typical 1800 square foot house, there may be 400 lineal feet of top plate crack (recall that there is a crack on each side of the top plate).

3) Top plates also have penetrations by piping, plumbing stacks, electrical wiring, and control wiring (thermostats, door bells, etc.).

4) Ceiling gypsum board is penetrated at many places. These penetrations include duct registers, surface light fixtures, recessed light fixtures, smoke detectors, ceiling fans, and attic accesses. The insulation above the ceiling gypsum board normally provides little resistance to air flow through those ceiling penetrations.

5) Duct systems are leaky. In the typical Florida residence, duct leaks represent about 13% of the house's leak area. Even when the air handler is off, air can leak into or out of the house through the duct system, often by way of the attic.

6) It is common that wall gypsum board stops before reaching the floor, often leaving a gap of 1/2 inch or more. Though the gypsum board butts against the wall sole plate and the gap is generally covered by carpet/pad or floor molding, there are nevertheless pathways between the room and wall -- caused by irregularities in lumber dimension or offsetting of various member of the wall framing -- that allow air to move between the conditioned space and the attic when a pressure differential is exerted.

7) Walls have penetrations in them that allow air flow between the attic and room. These penetrations include electrical outlets, switch plates, phone jacks, light fixtures, and duct registers. Two of the largest holes in interior walls are 1) plumbing access areas in bathrooms and other sink areas and 2) the inside of return plenums created by enclosing an air handler support platform (also one of the largest forms of duct leakage).

8) Dropped ceilings, above kitchen cabinets, bathroom vanities, closets, and bathtub enclosures create a large opening between the attic and wall cavities, in effect by-passing the top-plate. These are fairly common in houses and create large pathways between attic and the occupied space.

9) Other building cavities, such as the space behind fireplaces, stairways, and inside plumbing chases, may be open from the attic to the slab, and sometimes represent very large pathways for air to pass between the attic and house.

10) Steel studs are being used more in house construction, especially on interior walls, thus allowing more free air flow through the wall cavities. (Note that the steel studs come from the factory with holes built in.)

Even if the attic plane were not more leaky than the wall/windows/doors plane, ventilation air from the attic is nevertheless much less desirable than air coming through the walls/windows/doors. This is true for three reasons; the air in the attic is 1) hotter during the cooling season, 2) air in the attic has a higher dewpoint temperature than outdoors, especially during the hot hours of the day, and 3) attic air may contain contaminants from insulation fibers, animals/bugs, dust, and pesticides.

3.0 How tight are Florida homes?

Field tests have been done on about 235 homes over the past 8 years by the Florida Solar Energy Center. In a sample of 160 houses with ages ranging new to 40+ years old, the infiltration rate was measured (tracer gas decay method) once with the air handler and all other mechanical air moving systems turned off, and once with the air handler turned on. With the air handler off, infiltration averaged 0.28 ach (ach is defined in the next paragraph). With the air handler turned on, infiltration more than tripled to 0.91 ach (Cummings, Tooley, and Moyer, 1991).

(Ach means air changes per hour. In this sample of 160 homes **with the mechanical systems off**, 28% of the house air volume leaves the house in one hour's time and is replaced with air from outside the conditioned space. **With the air handler on**, 91% of the house air volume leaves the house in one hour's time and is replaced with air from outside the conditioned space.)

3.1 Florida houses are getting tighter

In 89 of these 160 homes, blower door tests were done to characterize the airtightness of the building envelope. This data is presented in Figure 1. Note that the oldest homes have the highest ACH50 and the newest homes have the lowest ACH50 (ACH50 is a measurement of the leakiness of a building envelope and is air changes per hour when the building is depressurized to -50 pascals). Those 40+ years old (built before 1950) average about 22 ACH50 while those less than five years old (built 1985 - 1990) average about 6 ACH50.

A similar trend can be seen in a sample of homes from a different project -- the houses were built between 1985 and 1990. Figure 2 shows that the five-year-old houses were considerably more leaky than the one-year-old houses. The sample size for the specific years are too small to determine whether any significant changes in airtightness occurred when the three infiltration practices went into effect in 1986. Nevertheless, based on the data shown in Figures 1 and 2, it is clear that there is a strong trend toward tighter houses over the past 40 years.

3.2 Why are houses becoming more airtight?

There are a number of factors which have contributed to tighter houses.

1. The cost of energy jumped significantly in 1973 and again around 1980, spurring an increased emphasis on saving energy in houses, including methods for making houses more airtight.

2. Frame houses are built with panels now, whereas several decades ago they were primarily assembled with boards and plaster.

Exterior wall sheathing. Several decades ago, the exterior of frame houses was commonly clapboard siding. The clapboard siding was leaky (from an air passage point of view). The clapboard siding would act as a rain shield, and because it was leaky there would be little pressure drop across the siding, so rain water would not be driven into the wall. Often behind the clapboard siding was "tar paper" sheathing backed by "1 by" lumber to provide strength to the house structure. This exterior siding assembly was generally very leaky.

Current construction uses 4-foot by 8-foot sheets of plywood, oriented strand board, "denny board", or insulation board as exterior cladding. Because there is much less crack length in these large sheathing panels, total air leakage is considerably less. Since the joints between adjacent panels generally back onto framing members, leak paths are diminished even more.

Interior wall and ceiling sheathing. Current construction uses gypsum board to finish interior wall and ceiling surfaces. In general, sheet rock construction is more airtight than plaster construction.

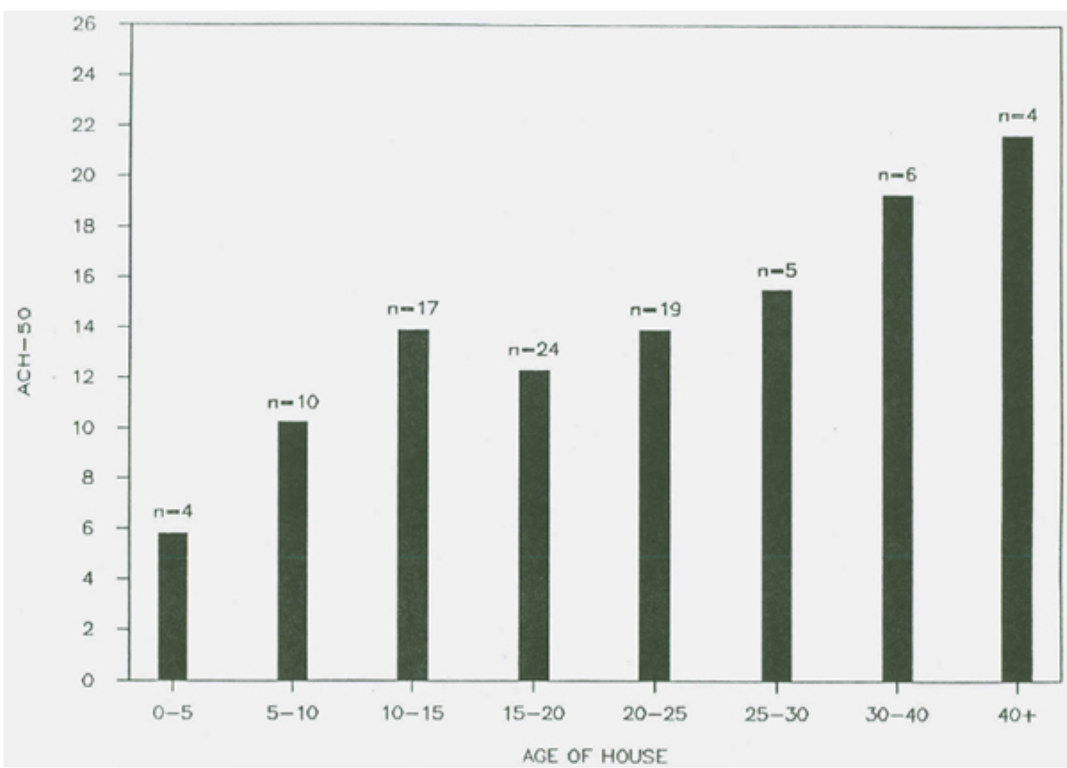

Figure 1. Airtightness of 89 homes as a function of age of house (n is sample size).
Source: Cummings, Tooley, Moyer, 990.

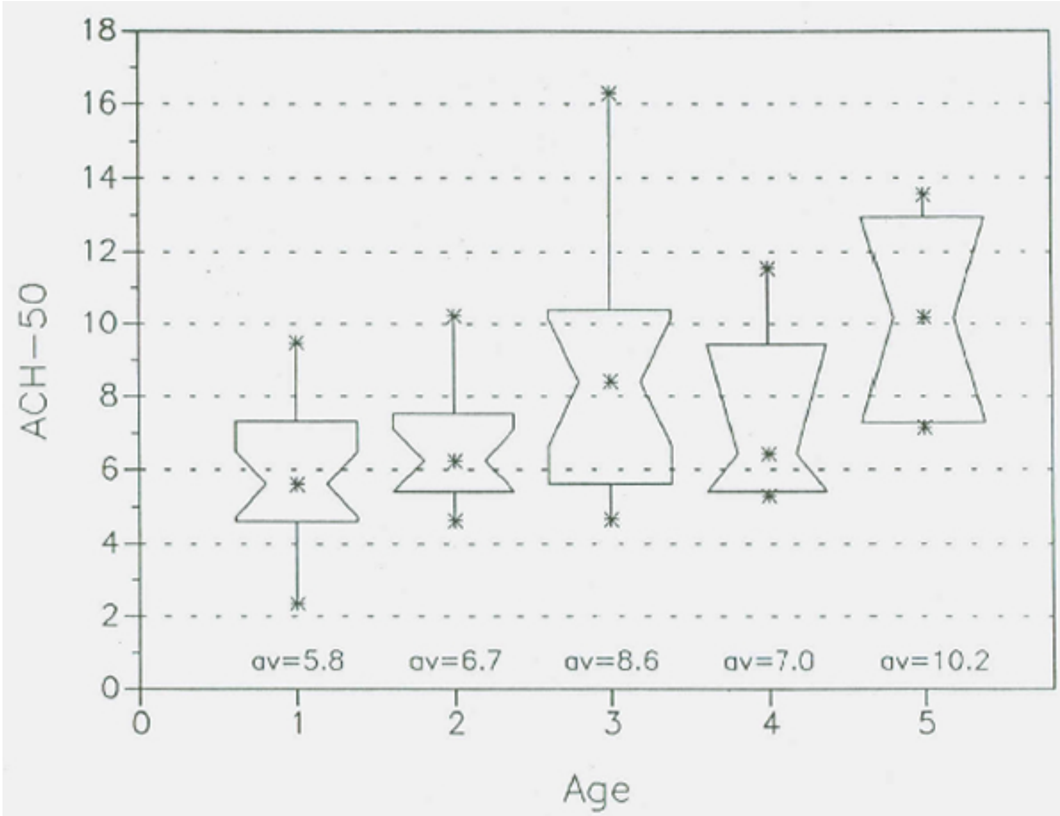

Figure 2. House airtightness of 70 houses built between 1985 and 1990 as a function of age.
Source: Cummings, Tooley, Moyer, 1990.

Having said that exterior sheathing has added to the airtightness of frame constructed houses, it should also be noted that the gypsum board on the **interior** surfaces of exterior walls is generally the primary air barrier in houses. This can be identified (in field testing) by checking pressures in exterior wall cavities when the building is depressurized by a blower door. In general, there is a greater pressure drop across the gypsum board than across the rest of the wall assembly. That is, when the house is depressurized to -50 pascals, the pressure in the wall cavity is closer to outdoor pressure than the pressure indoors.

Floor sheathing. Several decades ago, wood floors over crawl spaces and basements were constructed with "1 by" lumber which formed the subfloor. The subfloor members were intentionally spaced apart to reduce creaking noises when people walked across the floor. Depending upon the flooring material that was installed over the subfloor, the floor assembly could be anything from a little leaky to very leaky.

Current construction uses wood sheathing materials to form the floor. These 4 foot by 8 foot panels have much less leak area because they have cracks only where the panels meet, and these joints normally fall over floor truss, joist, or other framing members, so the leak path is obstructed.

3. Over the past several decades, the use of board insulation materials has increased substantially. These materials not only insulate but can also act as an air barrier (unlike batts or loose fill insulation which is generally air permeable), depending upon how they are installed. In many cases, the exterior sheathing described in point number 2 above is board insulation. In other cases, board insulation materials are used on the interior (or sometimes exterior) surfaces of block walls, and therefore may increase the tightness of block houses as well.

4. Various types of caulks, foams, and gasketing materials have been developed over the past several decades which make sealing of joints and penetrations easier. The gasketing material used to seal the bottom plate to the slab or floor is a good example of a material which considerably reduces building leakage. Foam sprayed into a cavity between a window and the wall opening into which the window is positioned is another good example.

5. Duct systems are getting tighter, especially since 1991 when duct repair programs and training began in Florida. Even though the majority of duct leakage occurs when the air handler is on, there is some air leakage when the air handler is off, due to the pressures caused by wind and temperature.

6. There has been a trend toward a greater proportion of Florida homes being built by national builders. These builders bring their construction methods from northern houses to Florida. In northern portions of the United States the driving forces of stack effect and wind are much greater, and winter temperature differences are much greater, so that infiltration has a much greater potential impact on building energy use. Therefore, there is a strong impetus to build tight houses in the north and these practices are more and more being used in Florida construction.

7. Balloon framing versus platform construction. Forty years ago, many two-story houses were built with balloon framing. This framing requires longer lumber that can span two stories vertically. The wall cavity produced by balloon framing allows freer movement of air

from one floor to another and often between indoors and outdoors.

Balloon framing has been replaced by platform construction. In platform construction, the first floor walls terminate at the ceiling of the first floor and are separated from the walls of the second floor by a top-plate at the top of the first floor wall and by the floor sheathing for the second floor. Therefore, pathways for air to pass between the house and the attic (and outdoors) are significantly decreased.

3.3 Air exchange rates in recently built Florida homes

In a sample of 76 houses built between 1985 and 1992 (data base is attached as Appendix A), infiltration with the air handler off averaged 0.20 ach. Fifty-six of the 76 houses have passive infiltration rates between 0.1 and 0.25 ach. This data is presented graphically in Figure 3. Forty-nine of the houses come from a 1990 research project (Cummings, Moyer, and Tooley, 1990) and 27 of the houses come from a 1993 research project (Tyson and Withers, 1994).

In this sample of 76 houses, infiltration increased to an average 0.45 ach when the air handler was turned on. This is more than twice as much as with the air handler turned off. This data is also presented graphically in Figure 4. However, this 0.45 ach is only one-half the infiltration rate of the older-house sample of 160 homes (both samples with the air handlers operating -- see section 3.0). We can conclude from this data that both house envelopes and air distribution systems have become tighter in recent years. In a subset of these 76 homes, infiltration increased from 0.46 ach to 0.55 ach when interior doors were closed (air handler was on), indicating that the pressures produced by closed doors caused 20% more infiltration.

Exhaust fans also create significant infiltration (ventilation). In this sample of 76 houses, the average air change rate was 0.56 ach when only the exhaust fans (including clothes dryers) were operating.

3.4 Calculating overall infiltration

Mechanically induced infiltration does not occur continuously. Rather it is intermittent, depending upon which air moving equipment is operating and which interior doors are closed. During the cooling season, air handlers typically run 35% to 40% of the time and therefore duct leaks only occur during 35% to 40% of the day.

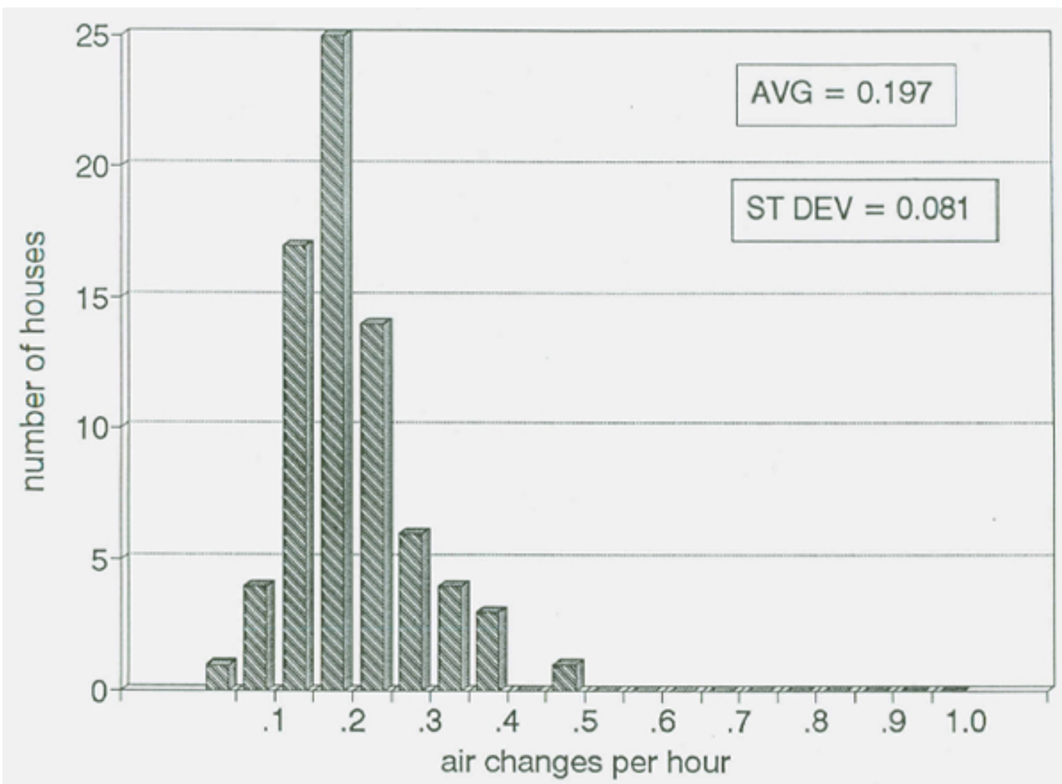

Figure 3. Infiltration rates measured in 76 central Florida homes built between 1985-1992 with air handler off.

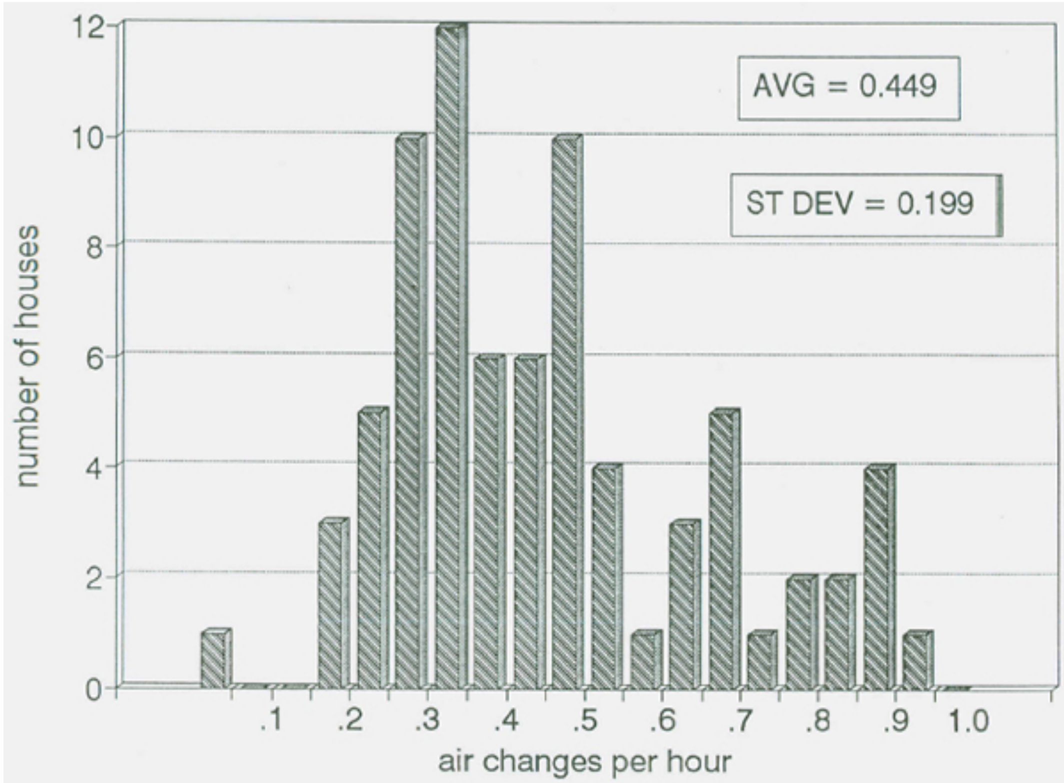

Figure 4. Infiltration rates measured in 76 central Florida homes built between 1985-1992 with air handler on.

Infiltration caused by closed doors can only occur when the air handler is operating, and only when interior doors are closed, and in proportion to the number of doors that are closed. In some homes, doors are closed much of the time. In other homes, doors are open most of the time so closed door infiltration is not really an issue.

Exhaust fans only operate a small portion of the time in most homes. Bathroom and kitchen exhaust fans typically run only a few hours per week. Cook-top grill exhaust fans run only during the time the appliance is used for cooking. Clothes dryers affect infiltration if located in the occupied space; they typically operate in the range of 2 to 8 hours per week. Consequently, even though they can produce significant infiltration (ventilation) when operating, exhaust fans and appliances only operate a small fraction of the time.

We can calculate a probable overall infiltration rate, if we take into account the amount of time various equipment is operating. Earlier we stated that in the sample of 76 newer homes, passive infiltration averaged 0.20 ach. However, the 27 houses built most recently, in 1991 and 1992, have a passive infiltration rate of 0.18 ach. If we also consider that the tracer gas tests were mostly done during the hours of 10 AM to 5 PM, when winds tend to be stronger in Florida, we can predict that infiltration will be less during the night when winds tend to diminish. Therefore, passive infiltration rates in new Florida homes may average no greater than 0.16 ach over a 24-hour day.

Since the air handler cycles according to the load and the requirements of the thermostat, and interior door closure and operation of exhaust equipment varies according to occupant use, infiltration fluctuates up and down in a largely random manner. We can approximate an average overall infiltration rate by assigning time-of-operation for the different house modes of operation. The following table shows the time-of-operation (expressed as a percent), the air change rate attributed to the various modes of operation, and the calculated overall infiltration rate. These numbers are based on testing from two different field studies; field testing of 70 new homes (Cummings, Moyer, and Tooley 1990) and field testing, repair, and monitoring of energy use and run time of 50 homes (Cummings, Tooley, and Moyer, 1991).

	time	ach
passive	60%	.16
air handler on (interior doors open)	34%	.45
air handler on (interior doors closed)	4%	.55
exhaust fans on	2%	.56
average weighted infiltration rate		.28

While the passive infiltration rate is only 0.16 ach, the actual (calculated) infiltration rate, including the mechanically driven infiltration, is nearly double at 0.28 ach.

It is important to remember, also, that the 0.28 ach is only an average for a large sample of homes. In many homes there are few or no duct leaks, and therefore the overall infiltration rate will be close to the passive rate. In some homes interior doors are closed a great deal, causing significant additional infiltration, while in others doors are kept open nearly all the time. The important point is that we cannot depend upon duct leakage, closed interior doors, and intermittent operation of exhaust equipment to boost house ventilation, because in some houses they have little effect or are used relatively little. Because of changes in the energy code and expanding education to HVAC contractors on how to produce airtight and durable duct systems, more and more homes will have little or no duct leakage, and therefore, the actual infiltration rates will fall below 0.2 ach in an increasing proportion of Florida homes.

In conclusion, we can say that most new Florida homes are receiving considerably less than the 0.35 ach (or greater) ventilation standard (ASHRAE 62-1989), even including mechanically-induced infiltration. (Note also that ventilation provided by duct leaks is often drawn from undesirable locations, from both a temperature and an air quality point of view, such as attics, garages, and crawl spaces.) Since duct leak infiltration will diminish over time, and since we cannot depend upon duct leakage to provide reliable ventilation in any given house, we must conclude that houses are already being built tighter than necessary from an air quality point of view.

It is important to achieve a balance between energy and indoor air quality. Florida homes have already reached a level of airtightness where additional airtightening may threaten to diminish indoor air quality, unless intentional passive or mechanical ventilation is provided. Considering that energy savings from additional airtightening will be small (e.g., dropping passive infiltration from 0.16 to 0.10 will only save about $20 per year), the case is strong that no additional airtightening should be done. **However, we believe the ceiling plane should be made more airtight, and in compensation, the wall plane should be more leaky.** The project advisory committee unanimously approved of this position.

4.0 History of infiltration practices in the Florida Energy Code

The Florida Energy Code came into existence in 1979. Requirements for airtightening the house envelope were few. By 1984 the code included the following airtightening measures.

1) for windows, maximum of 0.5 cfm per linear foot of operable sash crack.
2) for doors, maximum of 0.5 cfm per square foot of door area, including sliding glass doors.
3) caulk, gasket, weather-strip, or otherwise seal exterior joints and cracks.
4) ducts must be constructed in accordance with industry standards and local mechanical code.

In the 1986 revision, the Florida Energy Code was changed to include three infiltration practices. Builders could choose which of the three infiltration practices they wished to follow, and different summer and winter point multipliers were attached to each of the three practices. Practice 1 is a set of minimum airtightening requirements for all residences. Practices 2 and 3 include lists of additional airtightening measures which could be employed. Following are the 1986 infiltration practices in summary form.

Practice 1

1. Windows $\leq$ 0.5 cfm per lineal foot of operable sash crack.
2. Doors, including sliding doors, $\leq$ 0.50 cfm per square foot of door area.
3. Exterior joints or openings in the building envelope shall be caulked, gasketed, weather-stripped, or otherwise sealed in an approved manner.
4. HVAC ducts shall be constructed in accordance with industry standards and the local mechanical code. Ducts in unconditioned space shall be insulated to a minimum of R-4.2.

Practice 2

Meet all requirements of Practice 1, and the following:

1. All penetrations and joints in the top plates of exterior walls shall be sealed.
2. An infiltration barrier shall be installed in exterior walls and raised wood floors.
3. The crack between exterior and adjacent wall sole plates and floors in frame construction shall be sealed with caulking or gasket material.
4. All penetrations, joints, and cracks in interior surfaces of ceiling and exterior walls shall be sealed or gasketed including: window and door frames, electrical outlets and switches, baseboards, attic accesses, and recessed lighting cans.
5. All ducts in unconditioned space shall be sealed.
6. All fireplaces shall have flue dampers, glass or solid doors, and outside combustion air intakes.
7. All exhaust fans vented to unconditioned space shall have dampers.
8. In zones 1, 2, and 3 all combustion heating systems must be provided with outside combustion air from unconditioned spaces.

Practice 3

Meet all the requirements of Practice 2, and the following:

1. Infiltration barrier in the ceiling.
2. a) Seal all penetrations in top plates of interior walls, <u>or</u> b) Caulk, seal, or gasket penetrations, joints, and cracks on interior walls.
3. Recessed lighting in the ceiling shall be sealed from the conditioned space and covered with insulation where local codes permit.
4. Locate all ducts in the conditioned space.
5. All cooking appliances shall have a power ventilated range hood with damper that vents to outdoors.
6. Combustion devices such as space heaters, furnaces, and water heaters shall be
a) located in unconditioned space (except direct vent type)
b) supplied with combustion air
c) vented to outdoors.
7. Combustion cooking appliances shall have
a) a dampered combustion/ventilation air vent at lowest burner level
b) intermittent ignition device for each burner.

The infiltration practices remained unchanged from 1986 through 1993, except for the following modifications:

*the window airtightness standard was changed to $\leq$ 0.34 cfm per linear foot of operable window sash crack.
*ducts must be constructed and sealed to the requirements of section 610.1.ABC.3 of the Florida Energy Code.
*the requirement to seal the crack under sole plates was expanded to include adjacent walls.
*the Practice 2 requirement for combustion air for combustion heating systems was expanded to combustion space heaters, furnaces, and water heaters.

4.1 Assessment of infiltration rates which occur in houses built to the current infiltration practices

One task of this contract is to assess the actual infiltration rates that occur in houses built under the three practices. Therefore, we have made requests to obtain copies of the Energy Code compliance forms for the 76 houses in the study sample, so that we could identify the air infiltration practice claimed by the builder. Requests for these forms were mailed and FAXed to 13 county and city jurisdictions in central Florida. Energy code compliance forms were received for 54 of these 76 houses. Of these, 8 houses (15%) claimed air infiltration practice 1 and 46 (85%) claimed air infiltration practice 2. None claimed Practice 3. Note that in a University of Florida study (1993), 20% of a sample of 492 houses were Practice 1, 80% were Practice 2, and 0% were Practice 3. Therefore, it appears that our sample has a fairly representative distribution among the three infiltration practices.

When infiltration data for the 54 houses was examined, it was found that Practice 1 houses have 0.23 ach and Practice 2 houses have 0.18 ach. Based on this data, it would appear that Practice 1 houses have 0.05 ach more infiltration than Practice 2 houses. **However, upon closer examination, the difference between Practice 1 and Practice 2 diminishes.**

To understand this, we must look at the difference between one- and two-story houses. Two-story houses, which comprise 18 of the 76 houses, have substantially higher infiltration rates. While the 58 single-story houses averaged 0.18 ach, the 18 two-story houses averaged 0.26 ach. When the two-story houses are excluded from the samples, the difference between Practice 1 and Practice 2 houses all but disappears.

Table 1. Infiltration rates and blower door test results for a sample of 54 central Florida homes built between 1985 and 1992 as a function of height and infiltration practice (N = sample size).

	ONE STORY			TWO STORY		
	N	ach	ACH50	N	ach	ACH50
PRACTICE 1	5	0.173	6.88	3	0.333	9.41
PRACTICE 2	37	0.170	6.20	9	0.230	7.42
RATIO P1/P2		1.018	1.110		1.448	1.268

One-story Practice 1 houses averaged 0.173 ach. Practice 2 houses averaged 0.170 ach. Two-story Practice 1 houses averaged 0.333 ach, while Practice 2 houses averaged 0.230 ach. The sample sizes are too small (except one-story Practice 2) to make any definitive assessment of passive infiltration rates associated with the different infiltration practices. The most that can be said is that there does not appear to be any significant difference between the infiltration rate of one-story Practice 1 and Practice 2 homes. Practice 2 two-story houses appear to be tighter than Practice 1 two-story homes.

The blower door test results for these homes supports the evidence of the tracer gas test results. There is little difference between Practice 1 and Practice 2 one-story houses; ACH50 for Practice 1 one-story houses is 6.88 and ACH50 for Practice 2 one-story houses is 6.20, or only 9% less. There is greater difference between Practice 1 and Practice 2 two-story houses; ACH50 for Practice 1 two-story houses is 9.41 and ACH50 for Practice 2 two-story houses is 7.42, or 21% less.

Working under the assumption that 1 out of 5 new Florida houses is two story (as in our sample), we can calculate expected infiltration rates for Practice 1 and Practice 2 houses (both 1 and 2 story together). Practice 1 houses average 0.205 ach. Practice 2 houses average 0.182 ach. This is a difference of 0.023 ach.

4.2 Projected energy savings from current Practice 2

Energy savings associated with the additional airtightening of Practice 2 houses can be calculated, by comparing the passive infiltration rates of Practice 1 and Practice 2. To obtain these savings, we refer to computer simulation work done on software called TARP (Thermal Analysis Research Program) in 1988 (Cummings and Tooley, 1989). The simulations used a "standard" 1500 square foot house with R19 ceiling, R11 walls, single-pane windows, a standard air conditioning unit (8.0 SEER). Total cooling and heating energy use was characterized for a Typical Meteorological Year (Orlando) for the various infiltration rates, from zero to 0.9 ach.

Curves representing the annual cooling and heating energy use as a function of infiltration are presented as Figures 5 and 6 (Cummings and Tooley, 1989). (Note that the cooling energy use data has been modified to reflect a 10.5 SEER air conditioner.) From these curves, energy savings from reduced infiltration can be determined. Cooling season energy savings resulting from reducing infiltration from 0.205 to 0.186 ach is 30 kWh, or $2.40 (assume $0.08/kWh electricity).

However, the computer simulations assumed that the air entering the house came from outdoors. The cooling load associated with attic air produces about three times the cooling load of that coming from outdoors. While outdoor air averages about 80 degrees F (drybulb) and 71 degrees F dewpoint temperature over a typical cooling season, attic air often averages 88 degrees F (drybulb) and higher dewpoint temperature. If some of the reduction in infiltration related to adopting Practice 2 was infiltration of attic air, then the actual energy savings would be greater.
Though we estimate that 70% of the air leaking into the average Florida house comes from the attic, the measures of Practice 2 focus primarily on airtightening the wall plane (sealing the top plate of exterior walls is the exception). Therefore, perhaps only 30% of the

infiltration reduction (Practice 2 compared to Practice 1) would be attic air. Under this assumption, then total cooling energy savings increases to 48 kWh, or $3.84/year.

Heating season savings is 178,000 Btu (based on Figure 6). If this is electric resistance heat, then the savings are 52 kWh, or $4.16/year. If this is a heat pump operating at an average 2.2 COP, then the savings would be 24 kWh, or $1.92. If this is a gas furnace with a 0.65 efficiency, then the energy savings would be 2.6 therms, or $1.56 at a gas cost of $0.60/therm.

Data from a University of Florida study (U. of F., 1993) indicates that for housing built from 1987 through 1993 electric resistance represents 37% of heating systems and heat pumps and gas furnaces together represent 63% of Florida heating. Based on this distribution, the typical energy saving from upgrading from Practice 1 to Practice 2 is about $7 per year.

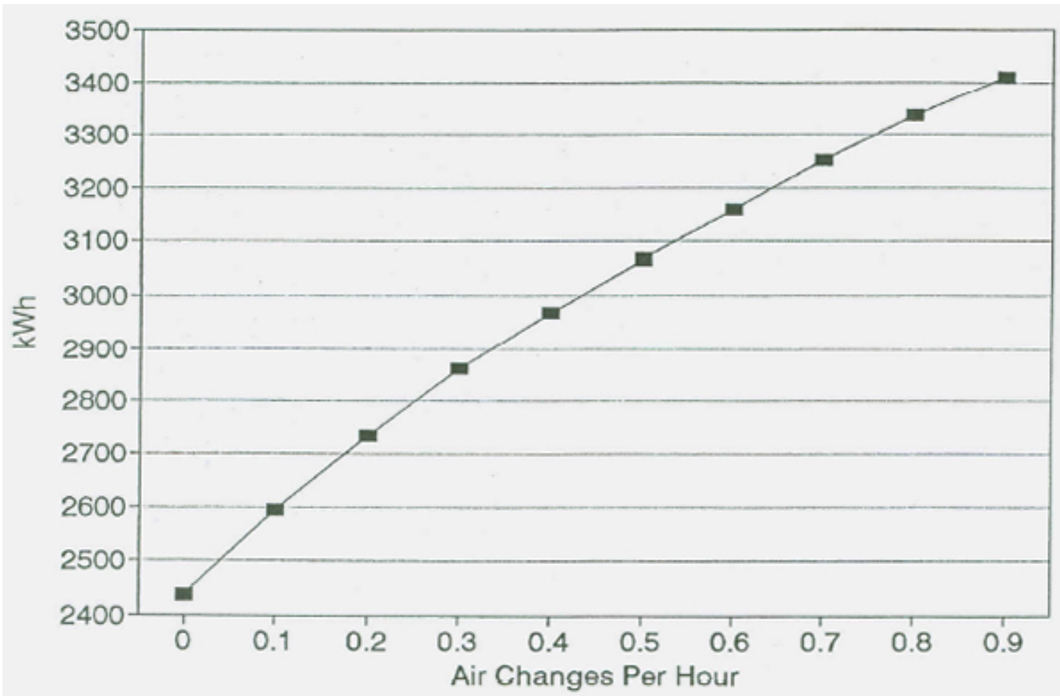

Figure 5. Cooling energy use in a standard 1500 ft2 house with 10.5 SEER air conditioner as a function of infiltration rate (in Orlando). *Source: Cummings and Tooley, 1989.*

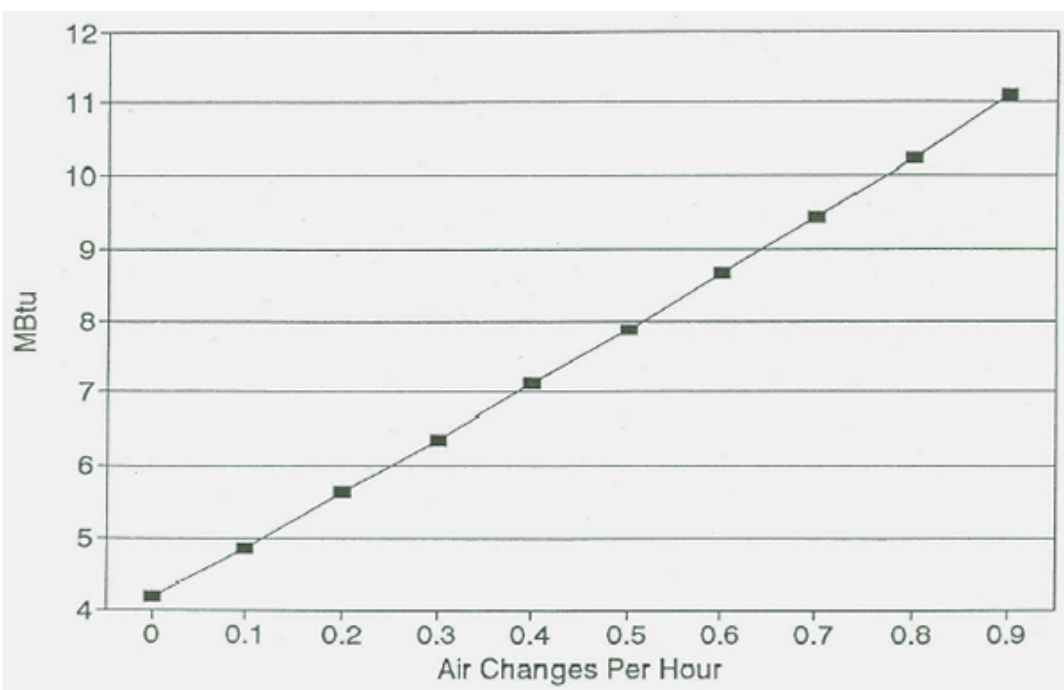

Figure 6. Heating energy use in a standard 1500 ft2 house as a function of infiltration rate (in Orlando). *Source: Cummings and Tooley, 1989.*

4.3 Block versus frame construction

Many people believe that frame construction is looser than block construction, because frame walls have more opportunities for leak pathways than block walls. This may have been true in the past, but based on our current database, there is relatively little difference between the two construction types. Looking only at Practice 2 houses (none of our Practice 1 houses are frame), blower door tests averaged 6.47 ACH50 for frame and 5.99 ACH50 for block. Tracer gas tests showed more of a difference; 0.198 ach for frame houses and 0.142 ach for block houses. Given that the block houses are 1.4 years newer than the frame houses, and we have seen that newer houses are generally more airtight than older houses, the difference may be even less than these numbers suggest.

5.0 Tight houses and indoor air quality

ASHRAE 62-1989 standard "Ventilation for Acceptable Indoor Air Quality" calls for minimum ventilation in homes of 0.35 ach or 15 cfm (cubic feet per minute) per person, whichever is greater. Number of persons, for purposes of this standard, is the number of bedrooms plus one.

It will be useful to look at a couple of examples. Let's say we have a 2000 square foot house with 8 foot ceilings and four bedrooms. The house volume is 16,000 cubic feet, so 0.35 ach is 93 cfm (16,000 cfm x 0.35/60 = 93 cfm). There are four bedrooms, so that represents five persons. Five persons times 15 cfm per person equals 75 cfm. Since 93 cfm is greater than 75 cfm, this house needs at least 93 cfm (0.35 ach) to meet the standard.

In a second example, we have a 1000 square foot house with three bedrooms. The house has 8000 cubic feet of volume, so 0.35 ach is 47 cfm. There are three bedrooms, so that represents four persons. Four persons times 15 cfm per person yields 60 cfm. Since 60 cfm is greater than 47 cfm, this house needs at least 60 cfm, also equal to 0.45 ach. Therefore, this house needs at least 60 cfm (0.45 ach) to meet the standard.

5.1 Control of indoor air quality requires control of air flows

Ventilation provides dilution of indoor air contaminants and thereby helps to improve and control indoor air quality. Dilution, however, is not the only method or most effective method to control air contamination. In most cases, control of sources is even more important.

Some pollution is related to occupancy. People give off carbon dioxide, moisture, and body odors. Activities of people also introduce moisture (cooking, showering, etc.), combustion products (cooking on a gas range/oven), and chemicals (cleaning, painting, etc.).

Some pollution is related to the building (materials) and is therefore largely independent of occupancy. Various products give off volatile organic compounds (VOCs), including paint, vinyl products, and carpets. Various types of wood products also give off formaldehyde. Pesticides are introduced into the building to control bugs. Buildings can also develop microbiological contamination, generally associated with high relative humidity or moist materials in the house, or both.

Some pollution problems are related to malfunctions of various systems.

Combustion equipment often relies on thermal draft to carry combustion products out of the house. This draft can be overcome by depressurization of the combustion appliance zone, blockage of the vent, inadequate combustion/dilution air, a very airtight building, improper vent design, and improper termination of the vent above the roof level. These conditions can result in backdrafting (reversal of flow in the vent pipe) or spillage (some goes up the vent and some spills into the room) of combustion gases.

Air flow problems related to the duct system, closing of interior doors, and operation of exhaust equipment, can result in pressure imbalances and elevated infiltration which can draw radon and sewer gases into the house, move moist air into the house, cause moisture condensation and accumulation (adsorption) in building cavities and construction materials, induce elevated indoor relative humidity, and produce microbiological infestations.

Condensate drainage problems (air handler) and condensation of moisture on cool duct surfaces can lead to materials damage and growth of microbiological organisms within the house.

Many of the indoor air quality problems which occur in Florida homes are related to moisture and microbial growth. For this reason, it is important to control relative humidity. A tight house is an important step toward adequate control of relative humidity and control over how humid outdoor air enters the house.

Figure 7 illustrates the affect of increasing infiltration upon relative humidity (RH). Based on computer modelling, RH increases from about 54% when infiltration is at 0.20 ach to about 58% when infiltration is at 0.35 ach and 61% RH when infiltration is at 0.50 ach (Cummings and Tooley, 1989). Since 70% is the minimum equilibrium RH (ERH) level at which fungi and dust mites can effectively grow, it is important to keep RH below this level and provide a margin for error. Most building scientists feel that humidity should be controlled to below 60%, from both a microorganism and comfort viewpoint.

Higher RH also decreases comfort during the cooling season. At elevated humidity levels, evaporative cooling from the skin slows so that a lower thermostat setting is required to achieve the same thermal comfort (this leads to higher energy consumption). Slower evaporation of skin moisture also tends to make the skin more uncomfortable. For this reason as well, it is good to maintain humidity below 60%.

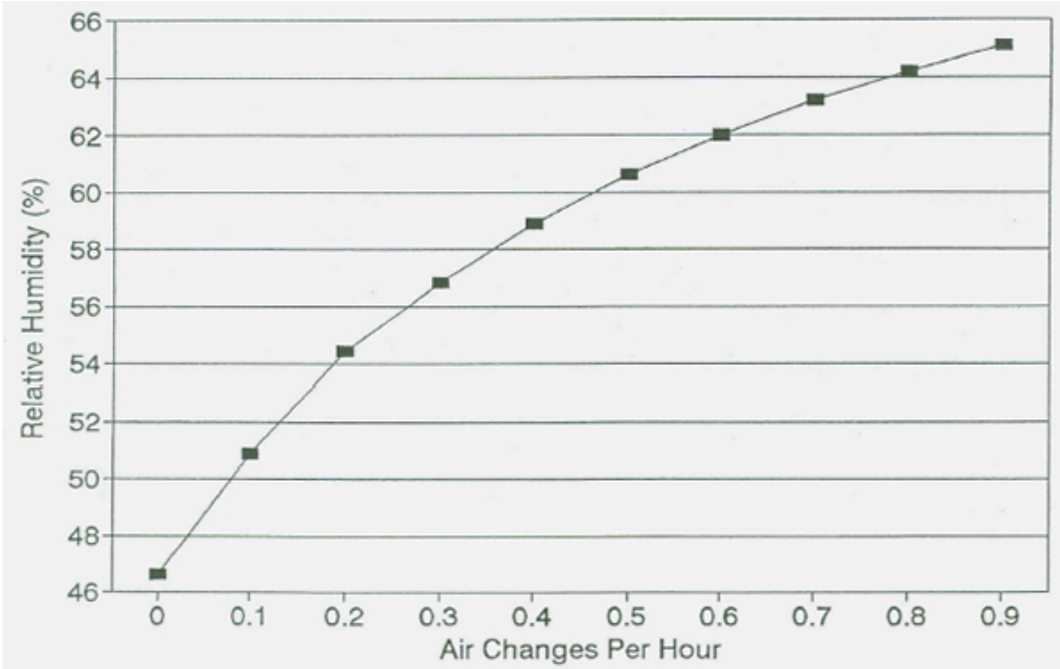

Figure 7. Indoor relative humidity over a typical Orlando summer in a standard 1500 ft2 house as a function of infiltration rate. *Source: Cummings and Tooley, 1989.*

In some cases, controlling indoor RH is not sufficient to control microbiological growth indoors. **Flow of humid outdoor air into building cavities** can create microbiological contamination problems even if the indoor RH is well below 60%. This can occur because of naturally or mechanically driven uncontrolled air flow.

In some buildings, wind can drive air into the house where inadequate air sealing of the building envelope has occurred. During the lengthy summer, this wind-driven air can pass through various building cavities (walls, floor sections on multi-story houses, chases, etc.) and cause moisture accumulation in wood and gypsum board materials, because these materials are cool from being in an air conditioned house.

More often, the air flow into interstitial building cavities is mechanically driven -- duct leaks, closed door pressure imbalance, and exhaust equipment. Whether the air flow is naturally or mechanically driven, fungal growth sometimes occurs on the inside surfaces of building cavities.

5.2 Arguments for and against building tight houses

There are arguments both for and against tight houses from energy and air quality points of view.

5.2.1 Arguments for tight houses

Tight houses use less energy for heating and cooling.

It is easier to control air flow across the envelope of a tight house, especially if a mechanical ventilation system is installed on the house.

Leaky houses can contribute to indoor air quality problems. Elevated infiltration, as previously discussed, can produce high RH, which in turn can create a humidity environment conducive to microbiological growth.

Additionally, a leaky house envelope may allow humid outdoor air to flow into interstitial cavities which can then, as previously discussed, create microbiological growth and damage building materials.

5.2.2 Arguments against tight houses

A tight house can reduce ventilation rates, diminish the dilution of air contaminants, and therefore contribute to indoor air quality problems.

A tight house can also more easily create high pressure differentials when mechanical systems operate. Duct leaks will produce greater positive or negative pressures in a tight house compared to a loose house. Closure of interior doors when the return is centrally located will produce greater positive or negative pressures in a tight house. Exhaust fan and clothes dryer operation will produce greater negative pressure in a tight house. The resulting strong negative pressure can cause backdrafting or spillage from combustion appliances. It can also lead to elevated entry rates of radon and sewer gases, if a source and pathway exist.

A tight house is more expensive to build.

5.3 Build the house very tight and put in a mechanical ventilation system

One solution, some argue, is to build houses extremely airtight and then install a mechanical ventilation system to achieve the air exchange and pressure differential desired. Mechanical ventilation (MV), which can be put into a tight or leaky house, has several advantages.

1) MV can deliver a specified rate of ventilation regardless of wind and temperature conditions
2) MV can generally control the direction of air flow, so that in this climate air can be forced from inside toward outside, thus helping to control moisture
3) MV can filter the air and draw it from a location having lower temperature, lower humidity, and fewer contaminants.

If MV is installed and the building shell is made very tight as well, then significant positive pressure can be produced in the house, helping to control moisture, reduce radon entry, and assist drafting in combustion equipment.

There are, as indicated above, some sound arguments against a very tight envelope. What follows is an argument against **very tight houses and depending upon mechanical ventilation**.
In this discussion, there are three issues; 1) the mechanical ventilation system, 2) the airtightness of the envelope, and 3) the difference in control between commercial and residential indoor environments.

1) On the first issue, **having** mechanical ventilation in houses is fine. **Depending upon** mechanical ventilation in houses may be a problem, because mechanical ventilation systems are likely to fail, over time, for a number of reasons.

Reasons why mechanical ventilation may fail in houses.

1. the motor may burn out
2. the occupants may turn it off
3. the filter may become very dirty and stop most of the air flow
4. the occupants may not know they have a ventilation system in their house, and thus 1, 2, or 3 (above) may happen largely because they are not aware of the need for maintenance or the need for the ventilator
5. the ventilation ducting may disconnect for a number of reasons: poor workmanship, failure of connections over time, or damage due to the activities of people or animals.

Based on research in over 300 residential and commercial buildings, we have observed that mechanical systems often fail to work or to perform up to expectations, for a number of reasons, including poor installation, poor maintenance, and failure due to age and extended use. Therefore, we feel that it is preferable that we not rely on mechanical systems unless essential. An important difference between commercial and residential buildings is that commercial buildings often have a person in charge of facilities, whose job it is to maintain and repair equipment, and generally observe when things are not working. There is no one in houses who has such a position, and therefore, problems often go undetected and unrepaired -- especially if the system is not perceived as essential by the occupants. (The heating and cooling system is usually perceived as essential by occupants -- a ventilation system would not necessarily be perceived in the same way.)

If the mechanical ventilation system fails, then the ventilation rate in a very tight house will drop to very low levels, perhaps down to the range of 0.05 ach to 0.1 ach, well below the accepted ventilation standards. Indoor air quality would suffer as a result.

2) If a mechanical ventilation system fails in a house that is built to current practice, then the average air change rate will be about 0.16 ach passive infiltration, or 0.28 when mechanical system operation is considered. While not up to the ASHRAE standard, it still provides a reasonable level of ventilation. If the mechanical ventilation system fails in a very tight house, then the average air change rate will drop to very low levels, perhaps down to the range of 0.05 ach to 0.1 ach passive infiltration, and perhaps 0.18 when mechanical system operation is considered. This is well below the accepted ventilation standards and indoor air quality would suffer as a result.

3) The third issue is that of individual control over the indoor environment. In most commercial buildings, occupants have almost no control over the ventilation rate of his or her space. Often the windows are inoperable, or if they are operable, the opinion of others in the space must be considered before ventilation is attempted. In residences, however, occupants have almost complete freedom over ventilation. That is, they have almost complete freedom over how much the windows are open, and they can more easily step outside for a "breath of fresh air" whenever they want.

In commercial buildings, occupants likewise have much less control over the sources of air contamination which may be in the space. In houses, occupants have more control over the types of materials brought into the building, when the garbage is taken out, what cleaners are used, how often pesticide is disbursed, etc.

So, given the large difference in control over ventilation and air contamination sources, it makes sense to require specific standards of mechanical ventilation in commercial buildings, but it would not make the same sense, in our opinion, to require mechanical ventilation for houses.

5.4 Tighten up the ceiling

As discussed earlier, air coming from the attic into the house is undesirable for several reasons; it is hot, it is humid, and it may be contaminated with dust, pesticides, insulation fibers, microbiological entities, and animal droppings. If we could keep attic air out of our houses and only allow air in from outdoors, then our utility bills would be lower and our air quality would probably be better.
Therefore, we suggest that the Florida Energy Code emphasize airtightening in the plane of the ceiling and make the

walls/windows more leaky. Note that the project Advisory Committee was in unanimous agreement that the recommended infiltration practice should emphasize a tighter ceiling plane and a looser wall plane.

Note that the benefit of a tighter ceiling plane not only affects passive infiltration, but mechanical infiltration as well. If interior doors are closed, thus depressurizing the central body of the house, considerable amounts of attic air can be drawn into the house. This would be especially true if a considerable number of vented, recessed lights were located in the main body of the house (say in the living room). Very substantial amounts of attic air could enter through these fixtures. The same is true for supply duct leaks and operation of exhaust fans. If we can make the ceiling plane of the house substantially airtight and the wall plane of the house more leaky, then the quality of the air entering the house can be substantially improved and considerable energy can be saved.

One way that walls/windows could be made more leaky is to install windows that have adjustable built-in vents. When the vents are closed the windows are tight. When the vents are opened, air can pass from outdoors into the rooms to provide passive ventilation without having to open the windows, thus reducing risks of break-in.

5.5 Suggested ventilation solution: medium tight house with the option of a mechanical ventilation system

Following from the previous discussion, this report proposes the following strategy with regard to infiltration practices and ventilation. **Build houses with a tighter ceiling plane and a looser walls plane, with ACH50 equal to about 6.0 (which is about where new Florida houses are now), and then optionally install a ventilation system that pumps air into the house at a rate consistent with ASHRAE 62-1989, thus creating positive pressure within the conditioned space relative to outdoors.** This positive pressure has the advantage, in the Florida climate, of having relatively dry indoor air flowing outward through the wall cavities and reducing the probabilities of moisture accumulation and microbiological contamination problems in wall cavities.

If house airtightness and ventilation rate are known, pressure differential can be predicted. The relationship between airtightness, air flow, and pressure differential is presented graphically in Figure 8. Consider an example.

A 2000 square foot house (8.5 foot average ceiling height) has an airtightness of 6.0 ACH50 or 1700 CFM50. The ASHRAE 62-1989 ventilation standard calls for 99 cfm of ventilation air. Looking at Figure 8, find the location where 1700 CFM50 (horizontal axis) and 99 cfm (vertical axis) cross -- at a location near 0.7 pascals. This means that 99 cfm of air blown into a house with airtightness of 1700 CFM50 will produce a positive pressure of 0.7 pascals in the absence of other driving forces.

Depending upon whether there are supply leaks, closed interior doors, exhaust fans, strong winds, or large temperature differences, air flow from in-to-out may not be maintained all the time. However, in most homes most of the time, air flow would be from indoors to outdoors.

Another alternative would be to build a tighter house, say 3.0 ACH50, and then install windows with built-in vents or some passive wall vent system that can be opened to increase the house's leakiness to say 7.0 ACH50. Then if the person chooses to install and operate a mechanical ventilation system, the house can be pressurized to 1.7 pascals with the passive vents closed. If, on the other hand, the house is ventilated passively with the window and wall vents open, then it should produce about 0.19 ach, or a level that many people find to be acceptable ventilation. With other ventilation provided intermittently by mechanical systems operating in the house and with the option of opening windows when air gets stale, acceptable air quality may be achieved in this way.

6.0 Suggested changes to the Florida Energy Code

As indicated, this report recommends that the three existing infiltration practices be reduced to one. Following is a listing of the current three infiltration practices. This listing will be a useful reference as the individual lines of the practices are reviewed in the following sections.

6.1 Infiltration practices in the current 1993 energy code

Currently the code offers the choice of three infiltration practices -- 1, 2, and 3. Following is a listing of the measures in the current 1993 infiltration practices.

Practice 1

1. Windows shall have a maximum of 0.34 cubic feet per minute (CFM) per linear foot of operable sash crack.
2. Doors (including sliding doors) shall have a maximum of 0.50 CFM per square foot of door area.
3. Exterior joints or openings in the building envelope shall be caulked, gasketed, weather-stripped, or otherwise sealed in an approved manner.

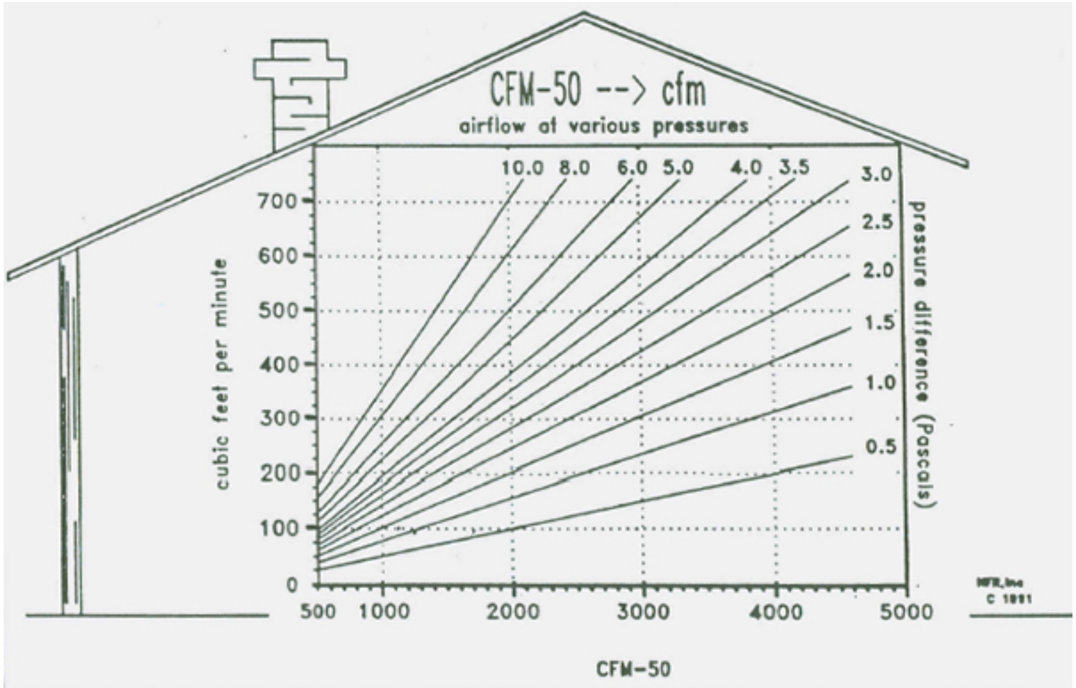

Figure 8. Air flow/pressure chart. If you know net air flow into a space and the space airtightness (CFM-50) then you can predict zone pressure. This chart is based on the air flow/pressure differential relationship Q = C (ΔP)n, where Q is flow in cfm, C is a constant, ΔP is pressure in pascals, and n is assumed to be 0.65.
Copyright Natural Florida Retrofit.

4. HVAC ducts shall be constructed and sealed in accordance with the requirements of section 610.1.ABC.3 of the Code. Ducts in attics shall be insulated to a minimum of R-6.0.

Practice 2

Meet all requirements of Practice 1, and the following:

1. All penetrations and joints in the top plates of exterior walls shall be sealed.
2. An infiltration barrier (see definitions in code) shall be installed in exterior walls and raised wood floors.
3. The crack between exterior and adjacent wall sole plates and floors in frame construction shall be sealed with caulking or gasket material.
4. All penetrations, joints, and cracks in interior surfaces of exterior and adjacent walls and ceilings shall be sealed or gasketed including the following components: window and door frames, electrical outlets and switches, baseboards, attic accesses, and recessed lighting cans.
5. All joints in ductwork in unconditioned space shall be sealed in accordance with section 610.1.ABC.3.
6. All fireplaces and wood stoves shall have flue dampers, glass or solid doors, and outside combustion and dilution air intakes.
7. All exhaust fans vented to unconditioned space shall have dampers.
8. In zones 1, 2, and 3 all combustion space heaters, furnaces, and water heaters must be provided with combustion and dilution air from unconditioned spaces.

Practice 3

Meet all the requirements of Practice 1 and Practice 2, and the following:

1. An infiltration barrier shall be installed in the ceiling. See code for definition of infiltration barrier.
2. Penetrations, joints, and cracks on interior walls, such as those around baseboards and electrical outlets and switches, shall be caulked, sealed or gasketed, or all penetrations through the top plates of interior walls shall be sealed.
3. Recessed lighting in the ceiling shall be sealed from the conditioned space and covered with insulation where local codes permit.
4. All ductwork shall be located in the conditioned space.
5. All cooking appliances shall be provided with power ventilated range hoods which vent to the outdoors and have a backflow prevention damper.
6. All combustion devices including space heaters, furnaces, and water heaters must:
a) be located in unconditioned spaces, weather-stripped, and sealed from conditioned spaces (this does not apply to combustion appliances of the direct vent types);
b) be supplied with vents which provide combustion air from unconditioned spaces; and
c) remove combustion by-products to the outdoors.
7. Combustion fuel cooking appliances located in the conditioned space must comply with the following additional requirements:
a) a dampered combustion/ventilation air vent to unconditioned space shall be provided at the lowest appliance burner level, and,
b) an intermittent ignition device shall be provided for each burner.

We propose that there be only one infiltration practice.

Justification: There are two reasons why we believe there should be only one infiltration practice.

First, there is almost no difference in cooling and heating energy use between Practice 1 and Practice 2. As indicated previously, the projected energy savings associated with going from Practice 1 to Practice 2 is only $7 per year for a 1500 square foot house. Even if Practice 2 saved three times that amount, it would still be difficult to justify use of the airtightening measures on a cost-effectiveness basis. If a Practice 2 was developed which would call for further tightening of wall and ceiling plane of the house, the point multipliers for this Practice 2 would only be slightly smaller than the multipliers for Practice 1. This would be a very small incentive to the builder or customer to adopt these tighter measures.

Second, nearly all Florida houses experience infiltration that is too low to meet the ventilation standards set by ASHRAE. It has been documented that Florida houses are much tighter than previously thought. When the three infiltration practices were developed, it was assumed that the associated infiltration rates would be 1.0 ach, 0.7 ach, and 0.4 ach, respectively for Practices 1, 2, and 3. We now know that passive infiltration rates average less than 0.2 ach, or less than half the projected air exchange rate of the current Practice 3. If the Florida Energy Code encourages building houses even tighter, by providing reduced point multipliers for tighter construction practices, this would be promoting small incremental energy savings at the cost of potentially reduced indoor air quality. If the code were to encourage tighter construction and then require mechanical ventilation, this may result in increased energy costs because of the electricity required to run the ventilation motor.

6.2 Current infiltration practices emphasize wall airtightness

The current code emphasizes airtightening the wall plane more than airtightening the ceiling plane. Most of the airtightening measures of Practices 1 and 2 apply to the wall plane, and very few apply to the ceiling plane. By contrast, Practice 3, to which very few houses are built, has a strong emphasis on tightening the ceiling plane. The following items in the current infiltration practices address airtightening of walls and ceilings.

In Practice 1,

wall: 1) tight standards for windows and doors
ceiling: 1) none

In Practice 2,

wall: 1) all penetrations, joints, and cracks in interior surfaces of exterior walls shall be sealed
2) install an infiltration barrier in exterior walls
3) caulk or gasket the crack between the sole plates and floors
ceiling: 1) seal all penetrations and joints in top plates of <u>exterior</u> walls

In Practice 3,

wall: 1) none
ceiling: 1) seal all penetrations and joints in top plates of <u>interior</u> walls, or seal all penetrations through interior walls (note that this measure is designed to stop air flow between the room and the attic by means of the wall cavities)
2) install an infiltration barrier in the ceiling
3) recessed lighting shall be sealed from the conditioned space
4) all ductwork shall be located in the conditioned space (note that most holes in the duct system allow air to pass between the room and attic

Attic air is the least desirable air that can enter a house from an **energy** point of view. It is hotter and more humid than outdoors, especially during the afternoon hours of the day when house infiltration rates are their greatest (because of stronger winds, greater temperature differences, and more air moving equipment operating).

Entry of attic air into houses has a disproportionately large impact on **peak electrical demand**, for two reasons. First, the attic becomes much hotter than outdoor only during the portion of the day when Florida utilities experience their summer peak demand. At night, the attic temperature is about the same as outdoors. Second, the driving forces of infiltration are generally greater during the afternoon hours of the day when the attic is hottest. These forces include duct leaks, wind, and stack effect. The peak demand impacts of attic air are important from an energy point of view because they create the need for construction of new electrical generating and distribution facilities, both of which consume considerable energy in the construction process.

Attic air is also undesirable from an **air quality** point of view. Attics often contain dust, animal and bug by-products, pesticide powders, and insulation fibers which can be transported through the air into the house. The high attic dewpoint temperatures, as much as 10 degrees higher than outdoors during the hot hours of the day, can result in moisture damage and microbiological contamination when negative pressure (caused by supply duct leaks or closed interior doors) draws this moisture laden air into wall cavities. The cool (inside the wall) surfaces of the gypsum board can cause moisture accumulation, the possibility of fungal growth, and indoor air quality problems in houses.
Crawl spaces (and to a lesser extent basements) also contain air which is undesirable from an air quality point of view. Possible contaminants include pesticides, microbiological growth because of moisture and/or high humidity in the crawl space, and radon. Therefore, our proposed infiltration practice also emphasizes airtightening of raised floors above crawl spaces and basements.

6.3 Discussion and justification of proposed infiltration practice

Following is a line-by-line review of the measures of the current 1993 infiltration practices. Justification is provided for each specific measure in the current infiltration practice -- why they are either included into or excluded from the proposed infiltration practice. In some cases, the project advisory committee voted on specific issues. In those cases, the vote of the committee is indicated.

Exclusion: Practice 1. Windows shall have a maximum of 0.34 cubic feet per minute (CFM) per linear foot of operable sash crack.

Justification: We have excluded the window airtightness standard for two reasons: 1) the energy savings from making windows so tight is extremely small and 2) we want to increase the amount of air entering the house through windows because we are going to make the ceiling plane of the house more airtight. Therefore, it would be good to loosen windows, if possible. The standard of 0.34 cfm/linear foot is based on a pressure differential of 75 pascals, the pressure presumed to be equal to the force of a 25 mile per hour wind. Most windows easily pass this standard, with some windows as low as 0.02 cfm/ft.

Pressure differentials across the house envelope averages much less than 75 pascals. In fact, the typical, the pressure differential between house and outdoors in Florida homes is 0.4 pascals, averaged over an entire year. If we assume that window cracks are more directly exposed to wind-induced pressure, and assume that the average pressure differential across window cracks is 1 pascal, then the leakage of 20 windows (3' x 3') matching the standard of 0.34 cfm/ft, would equal 2.5 cfm, or about 0.01 ach. The cost of this infiltration would be about $2 per year. Even if windows were 10 times more leaky, so that they were allowing 25 cfm of air into the house, this would add only 0.10 ach to houses that are averaging 0.16 ach under passive conditions. **Note: if windows do allow more air into the house this will improve house ventilation while having a minimal impact on house energy use.**

Exclusion: Practice 1. Doors (including sliding doors) shall have a maximum of 0.50 CFM per square foot of door area.

Discussion: We have excluded the door airtightness standard for the same two reasons that we excluded windows: 1) the energy savings from making doors so tight is extremely small and 2) we want to increase the amount of air entering the house through the wall plane because we are going to make the ceiling plane of the house more airtight. There may be other reasons for installing a threshold or weatherstripping on doors, such as to prevent bugs, lizards, etc. from entering the house, but energy savings is not a sufficient reason, especially since houses need more ventilation air.

The leakage of 80 square feet of door area in a house would equal about 1 cfm of infiltration, based on an average 1 pascal pressure differential. The cost of this infiltration would be about $1 per year. Even if the doors were 10 times more leaky, so that they were allowing 12 cfm of air into the house, this would only add 0.05 ach to houses that are averaging 0.16 ach under passive conditions.

Included: Practice 1. Exterior joints or openings in the building envelope shall be caulked, gasketed, weather-stripped or otherwise sealed in an approved manner.

Justification: In general we want houses to be reasonably airtight, so most of the joints and openings in the building envelope should be sealed.

Excluded: Practice 1. HVAC ducts shall be constructed and sealed in accordance with the requirements of section 610.1.ABC.3 of the Code. Ducts in attics shall be insulated to a minimum of R-6.0.

Justification: This is already a requirement for all construction. If it is useful as a reminder, there is no disadvantage in retaining this measure.

Included: Practice 2. All penetrations and joints in the top plates of exterior walls shall be sealed.

Justification: This measure tightens the ceiling plane.

Excluded: Practice 2. An infiltration barrier shall be installed in exterior walls and raised wood floors.

Justification: We have excluded this measure because it would tighten up the wall plane of the house. Since we are proposing that the ceiling plane be made more airtight, and Florida houses are already too airtight compared to the ASHRAE 62-1989 ventilation standard, the wall plane needs to be more leaky. We want the wall plane (including windows and walls) to be more leaky because the air entering through the wall plane is generally the best source of ventilation air.

Note, however, that we have called for an air barrier in walls that separate the conditioned space from garage or attic spaces, because the quality of air entering the house from those locations is not ideal from energy or air quality perspective.

We have excluded the air barrier requirement for the raised wood floors because typical construction with plywood subfloor generally creates a significantly airtight infiltration barrier between the crawl space and the conditioned space, and because the air coming from the crawl space by infiltration contributes only a small amount to the cooling or heating energy load of the building because the air temperature in the crawl space is not greatly different from indoor conditions. Thus it would not be a cost effective measure.

We have also excluded this measure because infiltration barriers are, in general, not cost-effective in the Florida climate given current construction practice. Because of limitations in our database -- all of our Practice 1 houses were block construction -- we do not know what impact the wall infiltration barrier has upon infiltration rates. Looking at Figure 1, we can see that houses built between 1980 and 1985 were averaging about 10 ACH50. Houses built between 1970 and 1980 averaged about 13 ACH50. Since dividing ACH50 by 40 provides a fairly accurate prediction of natural infiltration (Cummings, Moyer, and Tooley, 1990), we can project that passive infiltration rates in houses built between 1970 and 1985 averaged about 0.30 ach. If we assume that all of the reduction in natural infiltration that occurred those houses (1970 - 1985) and current houses, which average about 0.16 ach, the projected energy savings would only be $15 per year. Installation of wall infiltration barriers, which would typically cost $150 to $500 (labor and materials) depending upon the type of infiltration barrier installed, would not be cost-effective since the simple payback will be 10 to 30 years. Since it can be argued that the reduced infiltration, going from 0.30 ach to 0.16 ach, was needed to provide acceptable air quality in homes, the value of the energy savings is consequently brought into question.

Included: Practice 2. The crack between exterior and adjacent wall sole plates and floors in frame construction shall be sealed with caulking and gasket material.

Justification: Depending upon the evenness of the slab or foundation, there may be significant air leakage at the crack between the sole plate and the floor. Since this opening, if not sealed, is close to the ground and may be close to pesticides, radon, and microbiological contamination, it does not provide the best quality ventilation air. This measure is consistent with the next measure (it is also number 3 in the proposed infiltration practice) which gives general guidance to seal all joints or openings in the building envelope.

Included: Practice 2. All penetrations, joints, and cracks in interior surfaces of exterior and adjacent walls and ceilings shall be sealed or gasketed including the following components: window and door frames, electrical outlets and switches, baseboards, attic accesses, and recessed lighting cans.

Justification: Most of these measures are included in the proposed infiltration practice, in measures 1, 3, and 4. Emphasis on the electrical outlets and switches has been deleted.

Excluded: Practice 2. All joints in ductwork in unconditioned space shall be sealed in accordance with section 610.1.ABC.3.

Justification: This is already a requirement for all construction. If it is useful as a reminder, there is no disadvantage in retaining this measure.

Excluded: Practice 2. All fireplaces and wood stoves shall have flue dampers, glass or solid doors, and outside combustion and dilution air intakes.

Justification: Except for the requirement for flue dampers for only fireplaces, all of these measures are not cost-effective from an energy savings point-of-view.

The **flue damper in a fireplace** is justified because it closes a fairly large hole in the building which will cause infiltration throughout the year while not providing good quality ventilation air. (As a point of interest, note that flue dampers positioned on the top of the chimney generally produce a more airtight seal.)

Flue dampers in wood stoves should not be required. EPA rated wood stoves <u>should not</u> have flue dampers. The importance of a flue damper in older stoves (pre-EPA rated) is not the same as for fireplaces, since the wood stove is typically fairly airtight and thus the flue represents only a small hole in the building.

The requirement for **fireplace doors** cannot be justified based on energy savings. Based on personal communication with Paul Stegmeir, Technical Director of the North Central Hearth Products Association (St. Paul, Minnesota), the crossover point for closing the fireplace doors is 45 degrees. The crossover point is the outdoor temperature at which the fireplace efficiency is equal with the doors open or closed. The additional heat gain from radiation offsets the additional losses of larger amounts of house air going up the chimney. In Florida, the average fireplace fire will most likely occur when the outdoor temperature is about 45 degrees. Therefore, there will, on average, be no energy savings from having fireplace doors in Florida. When one considers the few number of hours that a typical Florida fireplace is used, the energy savings basis for fireplace doors is extremely weak.

The requirement for **combustion air** also cannot be justified based on energy savings. In fact, it will increase energy use in most Florida houses. Most fireplaces in Florida are operated very few hours per year. The combustion air inlet only saves energy during those hours when a fire is actually burning. During the vast majority of the year, the combustion air inlet is just a hole in the house letting outdoor air into the house, without providing the best quality air from a ventilation perspective (since the air passes over ashes to enter the house).

In the case of houses that are extremely airtight (say ACH50 = 2 or less), there might be a need for combustion/dilution air, but such tight houses are rare in Florida. If the fireplace or wood stove does have difficulty achieving good draft because the house is tight, a window can be cracked open to provide combustion/dilution air.

Included: Practice 2. All exhaust fans vented to unconditioned space shall have dampers.

Justification: This measure saves a lot of energy. Exhaust fans are off most of the time. Therefore, the open exhaust vent would be just a hole to outdoors, allowing outdoor air into the house all the time. However, the energy penalties are worse than just normal infiltration. The typical exhaust vent passes through the attic space and is aluminum. Therefore, air passing through the vent duct can pick up a great deal of heat from the attic, significantly adding to the cooling load during the summer.

Included: Practice 2. In zones 1, 2, and 3 (Florida's northern climate zone) all combustion space heaters, furnaces, and water heaters must be provided with combustion and dilution air from unconditioned space.

Justification: This measure was originally included in Practice 2 because tighter houses need to have provisions for combustion/dilution air in order for the combustion appliances to burn and draft properly. We have incorporated this into measure 9 in the proposed infiltration practice (and require it for the entire state), and combined it with the combustion device requirements from current Practice 3.

When the current code was developed, it was believed that infiltration practice 2 would produce about 0.7 ach of natural infiltration. Since houses are a good deal tighter than expected, it makes sense that combustion/dilution air should be required in all houses that have combustion appliances.

Excluded: Practice 3. An infiltration barrier shall be installed in the ceiling.

Justification: While it is desirable to keep attic air out of the house, the additional expense of creating or installing an infiltration barrier in the ceiling plane cannot be justified. If the requirements of measure 1 in the proposed infiltration practice are followed, the additional energy savings from an air barrier would be relatively small.

Included: Practice 3. Penetrations, joints, and cracks on interior walls, such as those around baseboards and electrical outlets and switches, shall be caulked, sealed or gasketed, or all penetrations through the top plates of interior walls shall be sealed.

Justification: A choice of two approaches is offered in the current code. Either approach is designed to stop air flow between the attic and conditioned space. The second approach has been adopted in our proposed infiltration practice. It is better to block the air flow pathways in the plane of the ceiling. If the air barriers are set up in the walls, some attic air can move into the hollow walls and give up its heat into the gypsum board of the walls. For this reason, sealing the walls at the ceiling plane is more energy efficient.

Included: Practice 3. Recessed lighting in the ceiling shall be sealed from the conditioned space and covered with insulation where local codes permit.

Justification: Basically this measure requires that recessed lights be the unvented IC (insulation covered) type, requires that they be sealed to the ceiling gypsum board, and requires that they be covered with insulation. We have changed the recommended wording to more explicitly state that unvented, IC type fixtures are required and that this applies only for ceilings that abut attic spaces. We recommend that Florida adopt the same standard for recessed light fixtures currently in place in the state of Washington. As of January 1994, four manufacturers sell airtight recessed light fixtures that meet the Washington state code requirements (Energy Design Update, January 1994).

This is a very cost-effective measure. A price check indicates that an unvented, IC rated recessed light fixture costs about $3.80 more than the vented, non-IC fixture. Blower door testing has indicated that typical vented canned lights have an associated leakiness of 20 to 50 CFM50. In a typical house, ten such lights could represent 20% to 25% of the entire house leak area. Since these lights connect the conditioned space to the attic, this is the type of infiltration which we would most like to eliminate. Note also, that the requirement for recessed light fixtures to be covered by insulation (in the attic), would significantly reduce heat gain and loss through the ceiling, because even small gaps in the attic thermal barrier can lead to a substantial reduction in overall effective R-value.

The project advisory committee voted on 3/17/95 about whether the single infiltration practice should require that recessed lights be unvented (airtight to the attic space). The vote was three in favor, two opposed, and one abstention.

Excluded: Practice 3. All ductwork shall be located in the conditioned space.

Justification: There is a separate Duct Multiplier which gives approximately a 10% credit for locating the ducts in the conditioned space. It can be argued that since the code requires that ducts be airtight, there should be no additional credit allowed for reduced infiltration as a result of locating the ducts in the conditioned space. Note, however, that we have recommended in section 6.3 of this report that the current duct multipliers be modified to take into account the energy savings which would occur because duct leaks would be to and from the conditioned space.

Note that the advisory committee voted unanimously that a second infiltration practice composed entirely of placing ducts in the conditioned space should be created, or the duct multipliers should be modified to account for the reduced infiltration.

Included: Practice 3. All cooking appliances shall be provided with power ventilated range hoods which vent to outdoors and have a backflow prevention damper.

Justification: This measure was included in the existing (1993) code to help remove pollutants from the house. Cooking can produce airborne water vapor, smoke, particulates, grease, carbon monoxide, nitrous oxide, and odors. Since it was assumed that following infiltration practice 3 would reduce infiltration to 0.4 ach, it was considered important to control sources of air contamination and odors, because the house was going to be airtight.
As it turns out, houses are actually considerably tighter than even Practice 3 was supposed to be. As noted previously, passive infiltration averages 0.16 ach, and even with duct leakage, exhaust equipment, and closed door pressure imbalances, this only increases to an average 0.28 ach.

Since Florida houses have low infiltration rates, well below the ASHRAE 62-1989 standard, it is important to control sources of indoor air contamination.

Virtually all kitchens have a range hood, either vented or unvented. From the perspective of source control and improved ventilation, unvented range hoods provide almost no benefit to the customer. They do disburse the cooking vapors but they are not taken out of the house. In some cases, there is a charcoal filter, but unless these filters are maintained, they do little to control the sources. Vented range hoods, on the other hand, remove the cooking vapors and combustion by-products from the structure and bring fresh air into the house (by house depressurization). The incremental cost of a vented range hood is modest. Given that the unvented range hoods do not improve indoor air quality, it appears that requiring that range hoods vent to outdoors would provide a good service to the citizens of Florida.

The advisory committee voted four to two against requiring that "all cooking appliances shall have a power ventilated range hood with damper that discharges to outdoors". In written comments, one committee member voiced opposition to this item. "The wording for this item is too restrictive. The wording 'All cooking appliances ...' may be construed to mean coffee pots and counter-top toasters, and etc. Not all homes are constructed with range hoods in the kitchen. Currently homes are being built under the 1993 Code, Practice 2 and there is no evidence that there are any air quality problems related to cooking appliances under the current practice."

In respect to the committee's opinion, we have modified the wording to "Range hoods located in cooking zones shall be vented to outdoors and have a vent damper". Based on the revised wording, range hoods are not required. However, if one is installed it must be vented to outdoors. Our opinion is that it is not essential that all cooking spaces have a vented range hood. However, if a range hood is installed, it should be vented to outdoors so that the customer actually gets something that allows control of sources.

Practice 3. All combustion devices including space heaters, furnaces, and water heaters must:

Excluded: 1. Be located in unconditioned spaces, weatherstripped, and sealed from conditioned spaces (this does not apply to combustion appliances of the direct vent type);

Included: 2. Be supplied with vents which provide combustion air from unconditioned spaces; and

Included: 3. Remove combustion by-produce to the outdoors.

Justification: This measure was included in the current code to help reduce the amount of pollutants introduced into the house. Following are comments for each of the three items.

1) Even though Florida houses are tight, we do not fee that combustion appliances should be excluded from being inside the conditioned portions of the house. If the appliances are installed properly and the combustion zones are not depressurized so as to cause spillage or backdrafting, they should be safe even in a tight house. Therefore, part 1 of this measure is excluded from the proposed infiltration practice.

2) The requirement for combustion air makes sense since this insures that combustion appliances have sufficient air to achieve complete combustion of the fuel. Incomplete combustion, of course, can lead to higher levels of carbon monoxide and particulate production. This contributes to combustion inefficiency and the possibility of health problems if the combustion by-products are not completely vented.

3) The requirement for venting of combustion gases makes a great deal of sense. Unvented space heaters, for example, can produce considerable water vapor, particulates, carbon monoxide, and nitrous oxides. With Oxygen Depletion Sensors and catalytic converters, there is less likelihood of high carbon monoxide and nitrous oxide exposure. Nevertheless, the air change rate of Florida houses is very low, much lower than the 0.4 ach that infiltration practice 3 assumes, and the introduction of combustion by-products into the conditioned space does not appear to be reasonable.

The advisory committee voted five to one in favor of requiring space heaters, furnaces, and water heaters to be vented to outdoors. One member of the Advisory Committee who had voted in favor, stated that he would be willing to reverse his vote if a carbon monoxide detector was required when unvented space heaters were placed in a house. The committee was unanimously in favor of requiring combustion air.

The one member voting against this measure wrote: "Using the terminology "combustion space heaters" is over restrictive. Space heaters come in various size with inputs as low as 5000 Btus per hour. Space heaters are designed certified and listed by AGA for use in residential homes. This is no justification for claiming that these space heaters will cause any indoor air quality problems. This is a building code issue and is not energy related."

Our response: the justification for claiming that these space heaters may cause indoor air quality problems is that houses have become much tighter over the years, and Florida homes are receiving much less ventilation air than is called for by ASHRAE 62-1989. Building tight houses (as they are now being built) saves energy, allows better control over air flows in the building and building cavities, and helps control humidity and microbial growth in hot/humid climates like Florida's. But if we are to have tight houses, we must control sources of air contamination. To allow the combustion by-products of a space heater to be vented directly into the conditioned space could significantly reduce air quality in tight homes.

Practice 3. Combustion fuel cooking appliances located in the conditioned space must comply with the following additional requirements:

Excluded: 1. A dampered combustion/ventilation air vent to unconditioned space shall be provide at the lowest appliance burner level, and,

Included: 2. An intermittent ignition device shall be provided for each burner.

Justification: 1) A dampered combustion/ventilation air vent is not needed in houses unless they are very airtight. Therefore, we choose to exclude this measure.

2) Intermittent ignition makes sense for two reasons; energy and air quality. A pilot light consumer more energy, by burning continuously and by introducing additional heat and moisture into the space that must be removed by the air conditioner. A continuous pilot also adds air pollutants into the room requiring the house to have additional ventilation in order to achieve the same air quality.

There is one measure that has been added to the proposed infiltration practice which is not in the three existing infiltration practices.

Added: The floor cavity created between floors (space created by joists or trusses) in a multi-story house shall be sealed at the edges with a sealed infiltration barrier in order to stop air flow between the floor cavity and outdoors. Where a floor cavity opens into an attic space or other buffer zones of a multi-story house, a sealed infiltration barrier shall be located between the floor cavity and the buffer zone in order to stop air flow between the floor cavity and the buffer zone. (This is Line 2 of the proposed infiltration practice.)

Justification: Two story houses are considerably leakier than one-story houses, especially for Practice 1. This is especially true for Practice 1 houses, where infiltration is nearly twice as great in two story houses compared to one story houses. For Practice 2, two-story houses have 35% greater infiltration than one story houses. Based on our knowledge of house construction, the major source of leakage that occurs in two-story houses that does not exist in one-story houses is the large opening that exists between the interstitial floor cavities and outdoors (or attic spaces). In a majority of cases, the space between the first floor ceiling and the second story floor is at least partially unsealed at the edges. Especially in cases where attic spaces abut the side of the house (such as an attic space above the garage), the floor cavity is then open to the vented attic space, and the interior walls are open to the floor cavity. It is not uncommon during a blower door test (house at -50 pascals) to find that most of the interior wall cavities in a two-story house are closer to outdoor pressure than indoor pressure, because they are so well connected to outdoors by means of the inter-story floor cavity.

6.4 Proposed infiltration practice emphasizes airtightening the ceiling plane

Based on this line-by-line review of the current infiltration practices, we propose the following infiltration practice. This one infiltration practice places more emphasis on airtightening of the ceiling plane and less tightening of the wall planes. The logic is that attic air is hotter, more humid, and more contaminated than outdoor air. Air entering through the wall plane is, in general, the best quality air that can enter the house. By "best quality", we mean that entering through the walls is cooler, less humid, and less contaminated than attic air. It is also less contaminated than crawl space air.

Following is the recommended modified infiltration practice.

1. A continuous air barrier shall separate the attic from the conditioned space.

   a) Joints, penetrations, or openings in the ceiling plane of the top floor of the building shall be caulked, gasketed, weather-stripped, or otherwise sealed so that air flow between the attic and conditioned space is stopped. Leak sites to be sealed include -- but are not limited to -- top plate penetrations, holes in the ceiling gypsum board, gaps around ceiling fixtures, gaps at registers and grills, open shafts, chases, space around fireplace chimneys, space around combustion and exhaust appliance vent pipes, and dropped ceiling areas, such as above kitchen cabinets, bathroom vanities, shower stalls, and closets. Large openings, such as shafts, chases, soffits, openings around chimneys, and dropped ceiling spaces, shall be sealed with an airtight panel or sheeting material and sealed to adjacent top plates (or other framing members) so that a continuous air barrier separates the spaces below and above the ceiling plane. Smaller penetrations, joints, and cracks shall be sealed with mastics, foams, or other sealants. Gaps between ceiling gypsum board and the top plate shall be sealed with a sealant to stop air flow between the attic and the interior of wall cavities.

   b) As an alternative to 1,a), the builder may choose to install an infiltration barrier in the ceiling plane of the top floor of the house. The infiltration barrier shall create a continuous air barrier across the entire ceiling plane, shall be continuous across the tops of interior and exterior walls, and shall be sealed at the perimeter, at openings in the ceiling plane (grills, registers, attic access, plumbing penetrations, vent pipes, chimneys, etc.), and at seams between sections of infiltration barrier material.

   c) Recessed lighting fixtures installed in ceilings that abut an attic space shall be sealed to the ceiling gypsum board in order to produce an airtight seal, shall have an airtight housing (unvented IC-rated fixtures), and shall be insulated and/or covered with insulation where local codes permit.

   d) The attic access hatch, if located in the conditioned space, shall have an airtight seal.

2. The following are the requirements for exterior walls.

   a) Penetrations, openings, and joints in the wall plane of the building envelope shall be caulked, foamed, gasketed, weather-stripped, or otherwise sealed.

   b) Gaps or cavities around window and door frames shall be sealed.

   c) In multi-story houses, the perimeter of the floor cavity (created by joists or trusses between floors) shall have an infiltration barrier to prevent air flow between this floor cavity and outdoors or buffer zones of the house (buffer zone, for example, could be an attic space over the garage). To make the floor cavity airtight, airtight panels, sheathing, or sheeting shall be installed at the perimeter of the floor cavity. The panels, sheathing, or sheeting material shall be sealed to the top plate of the lower wall and the bottom plate of the upper wall by mastic or other adhesive caulk, or otherwise bridge from the air barrier of the upper floor to the air barrier of the lower floor. Joints between sections of panels, sheathing, or sheeting shall be sealed.

   d) In frame construction, the crack between exterior and adjacent wall bottom plates and floors shall be sealed with caulking or gasket material. Gypsum board or other wall panelling on the interior surface of exterior and adjacent walls shall be sealed to the floor.

3. Penetrations and openings in raised floors, greater than or equal to 1/8 inch in narrowest dimension, shall be sealed, unless backed by truss or joist members against which there is a tight fit. Alternatively, the builder may choose to install an infiltration barrier in the floor plane of houses with raised floors. The infiltration barrier shall create a continuous air barrier across the entire floor area, and shall be sealed at the perimeter, at openings in the floor plane (grills, registers, crawl space access, plumbing penetrations, etc.), and at seams between sections of infiltration barrier material.

4. All exhaust fans vented to unconditioned space shall have dampers.

5. Range hoods located in cooking zones shall be vented to outdoors and have a vent damper.

6. All combustion space heaters, furnaces, and water heaters must be provided with adequate combustion and dilution air, and combustion gases must be vented to outdoors.

7. All fireplaces shall have a flue damper.

Definitions: **ceiling plane** -- the boundary between the attic space and the conditioned space.

wall plane -- the vertical boundary between the conditioned space and any unconditioned space.

6.5 Energy credits for the proposed new infiltration practice

Analysis of the data available from our 76 house sample revealed that there is very little reduction in house airtightness associated with the infiltration practices. We could not, of course, make an assessment of Practice 3, because no houses in our sample claimed that practice. The difference in infiltration between the Practice 1 and Practice 2 houses was so small that project energy savings were only on the order of $7 per year in central Florida.

The infiltration practice that we are proposing should produce houses with tighter ceiling planes and looser wall planes. There is, however, no way to know, based on the data that we have, how much change in energy use will occur going from current Practice 2 (the one to which more than 80% of houses are now being built) to the proposed new practice. Since we believe that overall airtightness will be similar to the current Practice 2, we therefore propose that the Summer Point Multipliers and the Winter Point Multipliers be the same as is currently used for the Practice 2.

The point multipliers will then be as follows:

CLIMATE ZONE	SUMMER	WINTER
North (1,2,3)	8.0	7.4
Central (4,5,6)	10.9	4.1
South (7,8,9)	14.7	1.2

These multipliers are considerably larger than appropriate for just infiltration. They include, however, internal loads as well as infiltration loads. We recommend that internal loads be treated separately from infiltration. However, disaggregating internal loads from infiltration loads is beyond the scope of this project. We recommend, therefore, that the current Practice 2 multipliers continue to be used until new calculations for infiltration and accurate assessments of internal loads can be done.

In a separate research project at the Florida Solar Energy Center, computer modelling is to be done to characterize the appropriate energy savings credits that would apply to the infiltration practice (that is actually adopted) in the three climate zones of the state. When this analysis has been completed, appropriate adjustments can be made to the energy savings credits and to the question of how to deal with internals loads.

REFERENCES

Cummings, J.B. and Tooley, J.J., "Infiltration and Pressure Differences Induced by Forced Air Systems in Florida Residences," ASHRAE Transactions, 1989, Vol.95, Part 2.

Cummings, J.B., Tooley, J.J., and Moyer, N., "Radon Pressure Differential Project, Phase I," FSEC-CR-344-90, Florida Solar Energy Center, Cape Canaveral, FL 32920, November 1990.

Cummings, J.B., Moyer, N., and Tooley, J.J., "Radon Pressure Differential Project, Phase II: Infiltration," FSEC-CR-370-90, Florida Solar Energy Center, Cape Canaveral, FL 32920, November 1990.

Cummings, J.B., Tooley, J.J., and Moyer, N., "Investigation of Air Distribution System Leakage and Its Impact in Central Florida Homes," FSEC-CR-397-91, Florida Solar Energy Center, Cape Canaveral, FL, January 1991.

"Energy Code Compliance Form Analysis and Processing Methodology; Final Report", Shimberg Center for Affordable Housing, University of Florida, December, 1993.

Tyson, J.L. and Charles R. Withers, "Demonstration of Radon Resistant Construction Techniques; Phase II, Final Report, FSEC-CR-608-93, Florida Solar Energy Center, Cape Canaveral, FL, January 1994.