A Residential Duct Leakage Case Study on "Good Cents" Homes

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ABSTRACT

The "Good Cents" program has been adopted by many cities across the United States and has encouraged builders to employ aggressive energy conservation building techniques in residential applications. The program is well established and has been recognized for the added value it brings to homeowners. The primary energy using system in a residence is the heating and cooling system and in the hot and humid Southeast Texas climate, cooling is the predominant mode of operation for the HVAC system. This makes the system particularly susceptible to degraded performance if there are leaks in the air distribution system. Nine Good Cents homes in the College Station, Texas area were chosen for a study to determine the extent of HVAC air distribution leakage in the HVAC system. It was found that all the homes had significant measured leakage for the return-air side of the system. Houses with vertical sheet-rock lined plenums had significantly higher rates of return air leakage than homes with ducted returns.

INTRODUCTION AND BACKGROUND

According to Reliant Energy, a home's heating and cooling system is the single largest energy user, accounting for nearly sixty percent of its overall energy use (Reliant Energy, 2000). For many years, the air conditioning system ductwork was considered to be unimportant. Homeowners continued to complain about uncomfortable environments and increasingly high utility bills, paying little attention to the network of round or rectangular ducts running through their walls, ceilings, attics, and basements. According to the Electric Power Research Institute (EPRI), even energy experts once believed that air duct leakage was insignificant (EPRI, 1992).

In the late 1980s, researchers began to realize that a significant relationship existed between residential air duct systems and energy loss (EPRI, 1996). Previous studies showed that air duct losses on the order of 35% were typical in residential construction (Jump, et.al., 1994). Today, industry experts conclude that air duct leakage in existing homes increases a home's heating and cooling costs by 20 to 30 percent (Home Energy, 1993).

Research on energy efficiency in home building began even before the 1973 - 74 fuel embargo. The embargo taught that more aggressive methods to manage energy use at home needed to be considered. One of these alternatives has been adopted by the city of College Station, Texas. The Good Cents program was developed by the electric utility industry in 1976 to help make homeowners more comfortable in the hot, humid climate of the Florida Gulf Coast. The Good Cents program is a performance-based program that gives future homebuilders and owners the flexibility to choose combinations of energy efficient, thermal, and mechanical components to meet certain criteria. As stated earlier, duct leakage has a significant effect on heating and cooling costs. While programs like Good Cents have been developed to increase the energy efficiency of homes, there are no data that discuss how these programs affect the amount of air duct leakage.

The specific objectives of this study were; 1) determine if Good Cents homes had leakage into or out of the duct system, 2) to quantify duct leakage in selected Good Cents homes in College Station, and 3) determine if there were common factors that contributed to duct leakage. The study investigated single-family homes registered in the Good Cents program in the city of College Station, Texas.

REVIEW OF LITERATURE

<u>How an Air System Works</u>

A forced-air distribution system delivers conditioned air to a home from the air handler that is located either in the attic or in a mechanical closet in the home. The conditioned air absorbs heat and moisture from the interior of the home and is returned to the air handler to be cooled or heated and the cycle repeats. The distribution system (ductwork) is designed to be a balanced pressure loop and works, ideally, when leaks are non-existent. When leakage occurs in the system the different zones of supply or return can become pressurized or depressurized depending on the amount of leakage.

There are many types of ductwork that can be used in an air distribution system, such as metal duct, flexible duct, and ductboard. Stum's (1993) study showed that metal ducts have leakage problems at joints and where they attach to fittings. The study concluded that minimal leakage comes from longitudinal shop-bent joints in round and square ducts and from the factory swivel joints in metal elbows. In order to control leakage from these types of ducts, Stum recommended that sheet metal screws be installed at all fittings and connections.

Flexible ducts are very commonly used in residential systems. Unlike metal ducts, flex ducts have been found to leak at fittings and at the connection to the diffuser boot. The use of duct tape can reduce the amount of leakage. However, duct tape can fail and other remedies should be used to control leakage (installation of a nylon or metal band around the joints).

Air Duct Leakage

Leakage of air can waste energy dollars, raising a homeowner's heating and cooling costs by 20 – 40% (Reliant Energy, 2000). Duct systems can lose energy in three ways:

1. Through un-insulated or poorly insulated duct walls when ducts are located in attics.
2. Through holes in ducts or open spaces between poorly connected sections of ductwork and
3. From pressure differences caused by faulty ducts.

Leakage from supply air ducts (positive pressure) or leakage into return air ducts (negative pressure) has little impact on heating or cooling if they are from the conditioned space. However since most ductwork is found outside the conditioned envelope, any leakage will increase energy costs and reduce comfort (Stum, 1993).

There are several consequences that are the result of leaky ductwork:

1. Expensive cooled or heated air goes into unwanted areas such as the attic or garage
2. Return leaks induce outside air (hot/humid in summer, cold in winter) into the duct system, reducing both efficiency and capacity
3. Dust, mold, insulation fibers and other health contaminants are brought in as return leaks draw air into the home from crawlspaces, garages and attics (Retrotec Inc., 2000).

Approximately 30-40% of thermal energy delivered to ducts that are located in unconditioned spaces is lost through air leakage and conduction (Jump and Modera, 1996). Estimates are that approximately 2.5 quads of energy are lost annually through duct leakage and conduction. This translates to a loss of 30 billion-kilowatt hours of electrical energy (EPRI, 1996).

Past Studies on Air Duct Leakage

A study by Gammage conducted in East Tennessee was one of the first identifying air duct leakage in residential homes (Gammage, 1986). Researchers determined air leakage in homes by spraying a refrigerant (Freon-12) throughout the house. While the refrigerant was circulated through the house, the concentration decay was measured (note that the article was written in 1986 and Freon-12 emissions were not banned). For these homes, they concluded that the mean rate of "natural" or outside air exchange was nearly doubled when the central air-handler fan was operating.

Over the past ten years, EPRI has also completed a series of studies on air duct leakage. One study reviewed published papers on leakage of air into and out of residential duct systems, assessed current testing methods, and developed testing protocols. The three basic testing methods discussed in that study included the blower door method, flow-hood method, and the use of tracer gases (EPRI, 1992). Another study concluded that duct retrofits reduced leakage to the outside by more than 70 percent and improved heating efficiency by more than 16 percent (EPRI, 1995). Lastly, a 1996 study addressed duct design and installation, identified ways to improve duct energy efficiency, and summarized various testing procedures (EPRI, 1996).

Jump and Modera (1994) performed a study to separately measure the impacts of duct leak sealing and insulation retrofits and to optimize a retrofit protocol for utility demand side management programs. The researchers studied six winter and five summer season homes and concluded that duct retrofits reduced leakage by 64%. They also found that wrapping ducts with R-6 insulation reduced average flow-weighted conduction loss by 33%. Another study by Evans and Tsal (1996) discussed duct shape, fitting performance, leakage, and over sizing. They concluded that ducts should be round and sealed to the engineer-specified level so that pressure is lost in ducts and fittings rather than in dampers.

Rodriguez's (1996) study discussed the reduction in capacity and efficiency of an air conditioning unit subject to leakage from hot attic spaces. The study considered three attic conditions of humidity: low, moderate, and high. In high humidity attic areas, a 20% reduction in air conditioning capacity and efficiency occurred. In low humidity attic areas, the same percentage of air leakage resulted in a seven percent reduction. The study concluded that air leakage in high humidity attic conditions had a severe impact on equipment efficiency.

Hammarlund's (1992) study looked at 60 new apartments and 12 new homes with heat pumps and duct systems in the Los Angeles area. Each residence was tested for three major problem areas: duct leakage, improper airflow through the inside coil and improper refrigerant charge. The study showed significant deficiencies in all three areas, which resulted in higher levels of energy consumption.

Duct leakage was a major problem in single-family homes. Out of the 12 new homes tested, over 85% of the homes in the sample had supply duct leakage and 90% had return duct leakage. The study also showed that duct leakage was substantially less in multi-family homes due to shorter duct runs and lower pressure levels in the ducts, chases, and plenums.

HVAC industry experts, builders and architects have identified five major barriers to proper HVAC system installation: 1.) builder/HVAC contractor relationships are based on a low-bid, least-cost system and do not reward quality work, 2.) insufficient appreciation of HVAC building science principles by all parties, 3.) premium placed on living and storage space at the expense of adequate room for duct systems, 4.) lack of coordination among building trades resulting in dislocated or crushed ductwork, and 5.) codes and inspections that focus on products and rated efficiency levels on HVAC units rather than the actual performance of the systems (Hammarlund, 1992).

Methods to Test for Air Duct Leakage

Several different methods have been developed to determine air duct leakage. Two approaches are commonly used, quantitative and qualitative measurement. A quantitative measurement will give air duct leakage in cubic feet per minute (CFM), while a qualitative measurement will measure a specific area and progress of repairs.

Quantitative measurements - Blower Door Subtraction Method.

The blower door subtraction method estimates flow through duct leaks with a house-to-outside pressure differential of 50 Pa. Two blower door flow readings are used to calculate the amount of duct leakage. The first reading is taken when the house is considered pressurized (when all duct openings are open). This reading obtains the total leakage of the house including any duct leaks. To obtain the second reading, the duct openings are covered revealing the envelope only leakage. Duct system leakage is obtained from the difference between the two readings (Proctor, et. al., 1993).

The two main advantages of this method are low cost and good control over duct pressure. The only piece of equipment that needs to be purchased or rented is a blower door. Additionally, this method measures only the leakage to the outside of the envelope. The disadvantages are, low repeatability under windy conditions or in very leaky homes and poor accuracy for low flows. The method also assumes that all leakage to the outside is eliminated when the registers are sealed (Proctor 1993).

Quantitative measurements - Flow Hood Method

The second quantitative method is the flow hood method which measures the flow through a calibrated hood used at each diffuser and grille in the system. To use this method, all the grilles except the largest and least restricted grille must be blocked and the house must be pressurized (or depressurized) with a blower door to 50 Pa. The duct leakage is then calculated by measuring the amount of air flowing through the open grille (Proctor, et.al., 1993).

This method has a high certainty of flow rate because the flow hood is used to take the measurement. However, there is difficulty in controlling the duct pressure and more equipment (blower door and flow hood) is needed.

Qualitative measurements

While the previous tests are used to determine the overall duct leakage in a system, other tests have been developed to assess specific areas of trouble. The smoke stick method and the pressure pan method are the two most common. The smoke stick method uses a blower door to pressurize the house between 10 - 15 Pa. Smoke is released at the registers and those that draw smoke the greatest represent a major leak. The pressure pan method uses a shallow pan, similar to a cake pan, to seal the supply or return registers. Once the blower door pressurizes the house at 50 Pa, the pan is used to seal the supply or return register. If the pressure drops from 2 - 5 Pa, this indicates a large leakage near that register. This test is conducted for all the registers in the house.

Good Cents Program

The Good Cents program in the city of College Station is a combination of performance-based design features, construction techniques and equipment selection that improve the energy efficiency of homes. The Good Cents program is divided into four areas: heat gain, system sizing, air infiltration, air conditioning and heating.

Heat Gain: The Energy Department of College Station performs a heat gain analysis using a proprietary software. This ensures that all homes accepted for the Good Cents program will have a heat gain of 12 BTU/hr per square foot or less.

System Sizing: Air conditioner system sizing may have an allowable maximum installed capacity of 600 square feet per ton of cooling capacity. Square footage is determined from the building plans.

Air Infiltration: Upon completion of construction, an air infiltration test is performed with a maximum allowable air change per hour (ACPH) of 0.75. The air conditioning and heating installer should take the following steps in order to reduce air infiltration problems through the HVAC ductwork:

- Seal diffuser grilles to ducts and ceiling or use gaskets.
- Use mastic compound to seal duct and plenum junctions.
- Seal return air ducts at ceiling penetration.
- Seal any upflow units around ceiling penetrations using ductboard and foil-backed tape.
- Seal return air chases at bottom plate, corners, and penetrations, or install ducted returns.

Air Conditioning and Heating: All Good Cents homes are required to have a 12 S.E.E.R unit on air conditioning and heating units or better.

EXPERIMENT DESIGN

In this study, the homes of interest consisted of one and two-story single family Good Cents homes in the College Station area. Currently, there are about 200 homes that are part of this program. According to the National Climatic Data Center, Texas had a total of 2850 cooling degree-days in 1999. That makes this area a key place for study due to its high demand for cooling.

Selection of Study Homes

A list of potential participants was sorted by the year the houses were completed: 1992, 1997 and 1998. A random selection of 30 of these homes received a letter requesting their participation for the study. After the initial mailing and two follow up mailings nine participants were identified and an appointment for the duct leakage test was scheduled.

Duct Leakage Measurement Criteria

As discussed in the review of literature, most duct leakage methods require extensive set-up times, expensive equipment, and/or are inconvenient to the homeowner. For these reasons, a flow hood method was developed to quantify air measurements. To validate this method, sample homes were tested using the blower door subtraction method.

The flow hood method measured absolute flow for all registers in the house HVAC duct system. With continuity based on mass-flow, ideally, supply air should equal return air. First, volumetric flow at the return air grille was obtained then the supply diffusers were measured one at a time. If the supply air total was higher than the return flow, this would indicate a leak in the return system. Conversely, if the supply was lower than the return flow, this indicated a leak in the supply system.

EXPERIMENTAL METHOD

Blower Door vs. Flow Hood

The blower door subtraction method takes readings with the duct system openings uncovered and then again with duct openings sealed. The house was pressurized to 50 pascals with a blower door and the total air leak rate was recorded. The next step was to cover all the supply and return registers. Heavy plastic sheeting and masking tape were used to seal the duct diffusers. With all the registers covered a second measurement was taken using the blower door method.

Next, the same house was tested using the flow hood method. This flow hood method measured supply and return air flow through supply and return registers. This method was developed for the following reasons. There was no need to manually pressurize the house, data were easily gathered and the process did not interfere with the property and the flow hood could measure either supply or return air flow. This calibration procedure was repeated for five homes.

Measurement

To begin testing, the flow hood was placed on the supply or return register. Ten to fifteen seconds elapsed for the reading to settle before the CFM was reading was recorded. The same step was repeated for each diffuser using the same technique. Five homes were tested using both the blower door and flow hood methods to calibrate the measurement methodology. As Figure 1 illustrates, the flow hood and the blower door methods agree quite well. Table 1 shows that the five homes tested using both methods have a difference of no more than 5%.

These homes were selected because homeowners voluntarily allowed the study to be done. The testing method took several hours (approximately 4-5 hours). These homes were selected for the sole purpose of comparing the results of both methods and to validate use of the flow hood.

Homes that were tested with the flow hood only were numbered 1 – 9 for the Good Cents homes and T1 – T5 for the blower door vs. flow hood homes. In this study, all test homes had only one return register. Data recorded included supply diffuser flow, return grille flow, blower door setting and flow and conditions of the test. A sketch of the house floor plan and location of diffusers and grilles was used to note which registers had been tested.

DISCUSSION

The first objective of the study was to determine if Good Cents homes had traceable duct leakage amounts using the flow hood method. As Table 2 shows, there was a measurable amount of duct leakage in all homes tested. The intention of this study was to not find a solution to duct leakage. Modera's studies and others address this issue. This study compared existing building techniques adopted by the Good Cents program in College Station to average house building standards. Previous studies have determined that on average each house has 30-45% duct leakage. This study compared actual duct leakage in Good Cents homes with the estimated 30 – 45% benchmark from the literature.

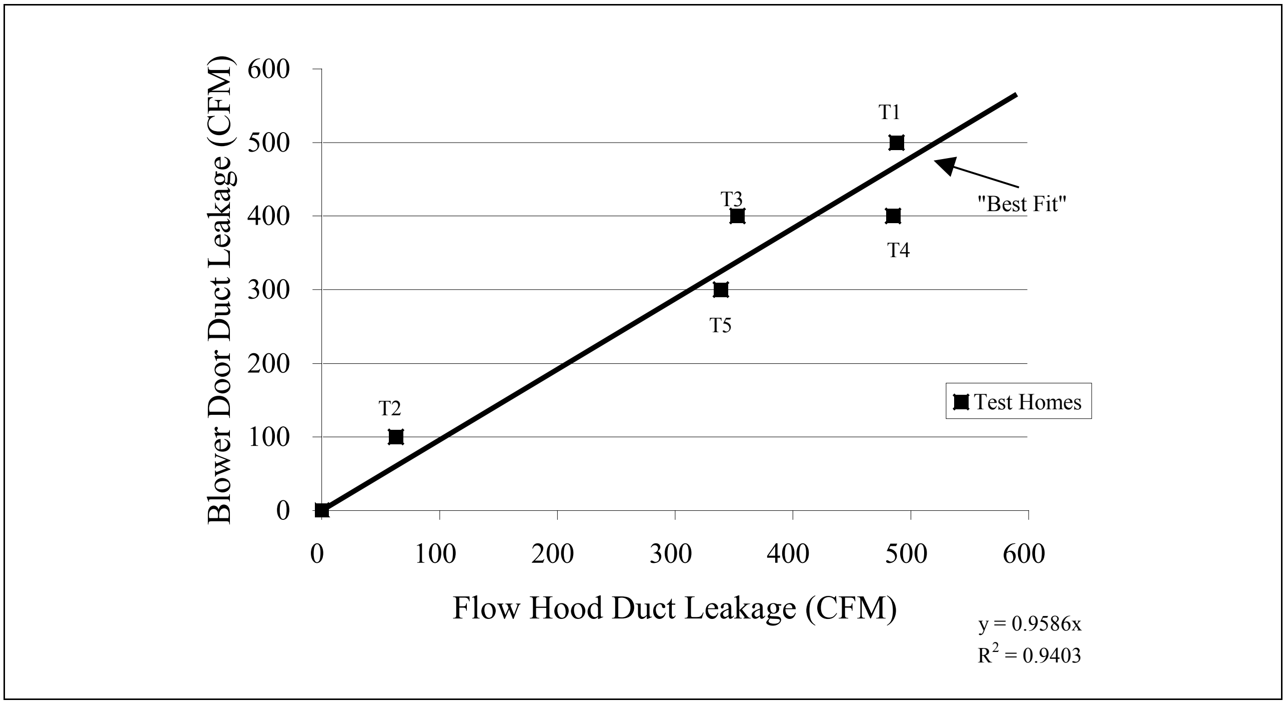

Figure 1. Comparison Results of Test Homes - Blower Door Subtraction Method vs. Flow Hood.

TABLE 1. Flow Hood and Blower Door results

Home	Flow Hood (CFM)	Blower Door CFM difference @ 50 pascals	Flow Hood - Blower Door @ 50 pascals	% of total supply volume from Flow Hood
T1	488	500	(12)	(1%)
T2	63	100	(37)	(2%)
T3	353	400	(47)	(2%)
T4	485	400	85	5%
T5	339	300	39	2%

Even though the Good Cents program emphasizes overall energy savings and more stringent construction practice, all of the homes tested showed air duct leakage. As shown in Table 2, air duct leakage was detected in all homes regardless of year built. Even using a five percentage plus or minus margin of error for the test measurements, there was a quantifiable amount of leakage. This was further supported by comparing the test homes with the Good Cents homes. Air duct leakage in Good Cents homes was lower than air duct leakage in the Test homes. Table 3 shows the amount of duct leakage in each Good Cents home tested. The quantity of duct leakage varies from 190 CFM to 716 CFM. Figure 2 shows a graphical view of Good Cents homes and their respective CFM leakage amounts.

Tables 4 and 5 presents actual and assumed leakage, respectively, for Good Cents homes. Table 5 includes actual leakage and estimated leakage, which is based on the 30% rate quoted in Jump's study. This shows that for the nine homes tested the actual duct leakage was found to be lower than the commonly quoted figure of 30% (except house 3).

Table 2. Occurrence of Duct Leakage in Tested Good Cents Homes

House	Year Built	% Leakage
1	1992	24%
2	1997	15%
3	1998	33%
4	1998	16%
5	1998	28%
6	1997	13%
7	1997	14%
8	1992	16%
9	1992	22%

Table 3. Duct Leakage in Good Cents Homes

House#	CFM Leakage
1	603
2	303
3	594
4	306
5	716
6	190
7	325
8	335
9	403

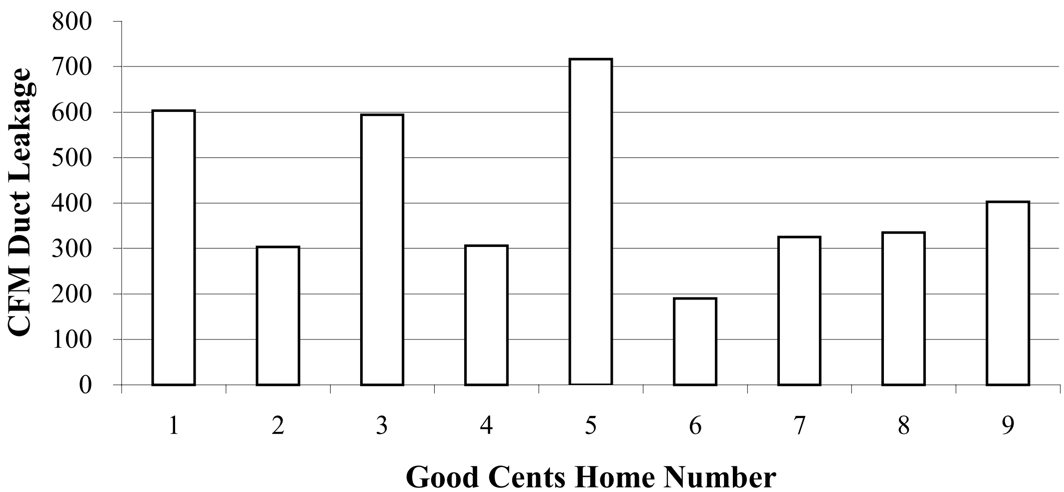

Figure 2. Histogram of CFM Duct Leakage for Good Cents Homes.

To better understand how duct leakage might contribute to energy losses in a house, the following analysis was developed.

Equation (1) gives an expression for airside energy transfer in HVAC equipment.

$$Q = 1.08 \times CFM \times \Delta T \qquad (1)$$

Q is defined as the amount of heat or cooling loss and is given by BTU/hr, 1.08 is a constant; and ΔT is the temperature difference. To determine the energy penalty because of duct leakage, it is assumed that: $\Delta T = T_{RA} - T_{SA}$, where T_{RA} is the return air temperature and T_{SA} is the supply air temperature.

This example is carried out using data from Table 5 regarding House 1. As shown, the total air flows was 2503 CFM with 603 CFM measured leakage on the return side of the system. For this example, a 5% attic duct leakage was assumed. Also, it was assumed that the attic air conditions were 140^{o} Fdb with a 70^{o} F dew point. While the study included readings for each supply and return register, it was not possible to determine if the air leaks were coming from conditioned or unconditioned areas. One of the limitations with using the flow hood was the inability to determine the source of the leak.

Table 4. Data For Good Cents Homes

House Number	Supply CFM	Return CFM	Difference	Leakage (%)	Year Built	Area
1	2503	1900	(603)	24%	1992	2504
2	1983	1680	(303)	15%	1997	1906
3	1794	1200	(594)	33%	1998	2429
4	1892	1586	(306)	16%	1998	2360
5	2566	1850	(716)	28%	1998	2837
6	1458	1268	(190)	13%	1997	1530
7	2335	2010	(325)	14%	1997	2000
8	2147	1812	(335)	16%	1992	2290
9	1801	1398	(403)	22%	1992	1808

Table 5. Good Cents Homes Compared To Jump's 30% Leakage Assumption

House Number	Supply CFM	Return CFM	Actual Leakage	30% Leakage	Year Built	Area
1	2503	1900	603	751	1992	2504
2	1983	1680	303	595	1997	1906
3	1794	1200	594	538	1998	2429
4	1892	1586	306	568	1998	2360
5	2566	1850	716	770	1998	2837
6	1458	1268	190	437	1997	1530
7	2335	2010	325	701	1997	2000
8	2147	1812	335	644	1992	2290
9	1801	1398	403	540	1992	1808

Figure 3 is a schematic for the mixing of two air streams showing how two mixed air streams flow into an HVAC unit and through to the supply side of the system. Point (1) is the return air, (2) is the estimated leak from the attic, and (3) is the total air going to the HVAC unit. In order to estimate the air conditions at (3), a combination analytical and graphical solution was used.

Solving for the unknown air condition entering the evaporator, the following formula was used:

$$W_3 = W_1 + \frac{\dot{m}_{a,2}}{\dot{m}_{a,1} + \dot{m}_{a,2}}(W_2 - W_1) \quad (2)$$

where

W : Humidity ratio $\left({lb_m}/{lb_a} \right)$

$\dot{m}$: Mass flow rate $\left({lb_a}/{\min} \right)$

The mass flow rate formula for $\dot{m}_{a,1}$ is given by:

$$\dot{m}_{a,1} = \frac{Total(CFM)\left({ft^3}/{\min} \right)}{SpecificVolume\left({ft^3}/{lb_a} \right)} \quad (3)$$

The mass flow rate formula for $\dot{m}_{a,2}$ is given by:

$$\dot{m}_{a,2} = \frac{Leakage(CFM)\left({ft^3}/{\min} \right)}{SpecificVolume\left({ft^3}/{lb_a} \right)} \quad (4)$$

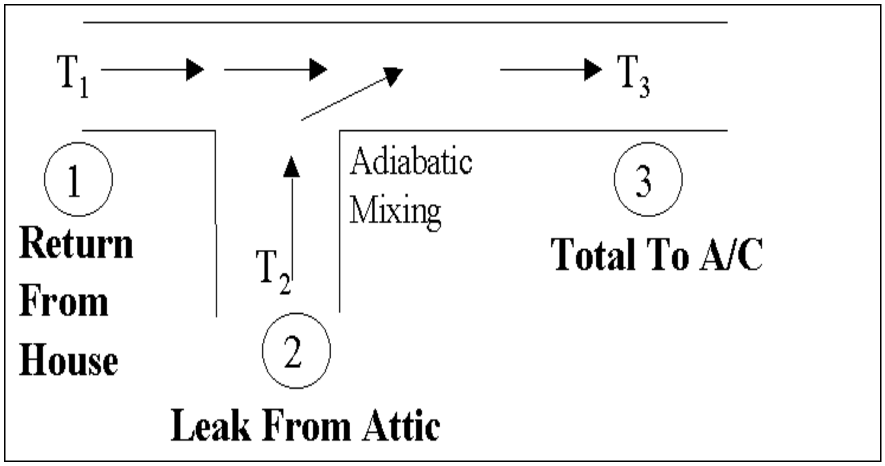

Figure 3. Schematic of Adiabatic Mixing of Two Air Streams

In order to compute the heat loss attributable to the leakage, a ΔT for the air conditioner had to be determined. Average high temperatures in the summer season in the attic are 140^o F with design return air temperatures of 80^o F, and an evaporator discharge temperature of 55^o F. It is obvious that mixing 140° and 80° air will result in a higher temperature. The following analysis is most likely a worst case for the energy impact for return leakage from unconditioned attic.
It was assumed that 5% of the total supplied air was leaking in from the attic which results in approximately 125 CFM of air leaking from the attic. Depending on season, conditions in the attic might be very different from these. Using this data, the following were calculated;

$$\dot{m}_{a,1} = \frac{2378}{13.87} \quad \dot{m}_{a,1} = 171.5\frac{lba}{\min}$$

$$\dot{m}_{a,2} = \frac{125}{15.51} \quad \dot{m}_{a,2} = 8.1\frac{lba}{\min}$$

From this point $\dot{m}$ is then substituted back into equation (2):

$$W_3 = 0.012 + \left(\frac{8.1}{171.5 + 8.1}\right)(0.016 - 0.12)$$

$$W_3 = 0.0122 \text{ (lbm/lba)}$$

This completed the analytical part of the solution. Now that the humidity ratio for the air entering the evaporator was known, a graphical technique was used to complete the solution. The first step was to plot the return air temperature and dew point and the attic air temperature and dew point. A line was drawn connecting these two points. A horizontal line was drawn using W_3 and intersecting this line. At the intersection of that line, a vertical line is drawn down to intersect with the dry bulb temperature line in the psychrometric chart. This determines the mixed air temperature that is entering the evaporator. For the example problem, the mixed air temperature was found to be approximately 83^o F.

Now that the temperature had been determined at T_3, the capacity required for these conditions was determined. From equation (1) it was determined that:
Q = 1.08 (2503) x (80-55)
Q = 67,581 BTU/hr or 5.6 tons

For the 5% attic leakage example;

Q = 1.08 (2503) x (83-55)
Q = 75,690 BTU/hr or 6.3 tons

Assuming that 5% of the leakage was coming from the attic, the load on the system increases by approximately 12%. This increase in load does not mean that a larger unit must be installed but that the homeowner will experience reduced capacity of the HVAC unit. As illustrated in the previous example, the additional 3^o F of temperature difference causes the HVAC unit to under perform. When this occurs a homeowner might comment that his/her unit was not cooling properly. If the same example is recalculated with a 10 % duct leakage, the load increases to 20%. As the example shows, the air leakage from the attic has a direct effect on the HVAC load capacity. These examples are in very good agreement with the study conducted by Rodriguez (1989).

As shown in Table 6, the data were arranged to evaluate the effect of home size and duct leakage. For instance House 9 was the second smallest house in the sample yet it ranked sixth in leakage percentage. While House 9 was an exception to Table 6 in general, most homes fall under the assumption that a bigger house has a larger percentage in duct leakage.

Another factor to consider was the possibility that newer houses might have a lower occurrence of duct leakage. Table 7 shows the Good Cents homes ranked by percentage of duct leakage. As the data show, there is no direct correlation between the year the home was built and the amount of duct leakage. The home that had the smallest amount of duct leakage was built in 1997, while the home that had the largest amount of duct leakage was built in 1998.

Table 6. Good Cents Homes Sorted by Total Leakage

House	Area (ft^2)	Percentage Leakage	Total Leakage (CFM)
6	1452	13%	190
2	1906	15%	303
4	2360	16%	306
7	2015	14%	325
8	2290	16%	335
9	1808	22%	403
3	2429	33%	594
1	2504	24%	603
5	2837	28%	716

Table 7. Good Cents Homes Sorted By Percent Leakage

House	Year Built	% Leaking
6	1997	13%
7	1997	14%
2	1997	15%
8	1992	16%
4	1998	16%
1	1992	24%
9	1992	22%
5	1998	28%
3	1998	33%

To determine if there was a significant difference in duct leakage in Good Cents homes a t-test statistical model was performed. For this study, the population mean of 30% was taken from Jump's (1996) study. The 30% average takes into consideration homes of all years and sizes while this study considered only Good Cents homes and only houses built since 1990. For this study a t-test was conducted because of the small sample size and the ability to perform a one mean test. Table 8 shows that for nine homes included in this study, the average duct leakage was .20 or 20%.

Table 8. Sample Statistics for Duct Leakage

N	Mean	Std Dev.	Std Error
9	0.20	0.07	0.02

The data was computed using the assumption that the population mean of duct leakage was 30%. The data in Table 9 shows that the t statistic of the Good Cents homes is –4.223. This is lower than the .30 that was allowed. This indicates that the null hypothesis is rejected and the alternative hypothesis is accepted. The data suggests that Good Cents homes have a significant difference in duct leakage with the average 30% duct leakage assumption. The probability of 0.0015 from Table 9 indicates that there is a less that one percent chance that the tested Good Cents homes would have leakage as great as 30%.

Table 9. Hypothesis Test for Duct Leakage

Null Hypothesis:	Mean duct leakage => 0.30	
Alternative:	Mean duct leakage < 0.30	
t Statistic	Df	Prob > t
-4.223	8	0.0015

CONCLUSIONS

Homeowners spend millions of dollars annually to purchase efficient HVAC units with the highest affordable SEER. Numerous studies have shown that leaking duct systems may be negating the efficiency gains that should be realized. Previous studies have alerted the public about the significance of air duct leakage. Government programs have been developed to try to remedy the problem and new building programs have been established to try to make homes more energy efficient.

Good Cents homes were designed to meet stricter energy performance criteria. One key finding in this study of Good Cents homes was that all of the air duct leakage was apparently on the return air side. Most studies focused on studying, improving, and adopting new methods to control the supply air side of the ductwork. One element that should be further studied is controlling duct leakage on the return side.

This study showed that Good Cents homes fared better than a "standard" house or better than the commonly assumed 30% duct leakage figure. The study also demonstrated how the mixing of conditioned and unconditioned air could cause a significant decrease in system capacity. While all the Good Cents homes were found to have a measurable amount of duct leakage, the amounts were far less than the 30% average industry assumption. It would seem that the Good Cents program does have an effect on the quality of the duct system in residential construction.

Suggested topics for future studies include, developing a standard quantifying the amount of mixed air from the result of duct leakage, researching materials and construction methods that best work in hot and humid climates to reduce duct leakage, and comparing duct leakage testing equipment and how accurately they compare with each other.

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