AIR INFILTRATION MEASUREMENT AND REDUCTION TECHNIQUES ON ELECTRICALLY HEATED HOMES

by

John O. Collins Jr.

ABSTRACT

Under the sponsorship of the Electric Power Research Institute, Johns-Manville undertook a two year program to evaluate the effect of air infiltration on the heating requirements of 29 electrically heated homes in the Denver, Colorado area. Following the measurement of the rate of induced air infiltration using the Super Sucker, the 29 homes were retrofitted specifically to minimize infiltration and subsequently retested. Thirty similar homes were also tested for infiltration and retained as controls.

The Public Service Company of Colorado, a major participant in the program, fitted all of the 59 homes with submeters measure the energy consumption associated solely with heat They have also undertaken the reading of these meters each the compilation of an energy profile for each house,

and the issuance of a monthly questionnaire to each homeowner relating to energy conservation methods or life style changes which might affect the measured heating energy usage. Their contribution to the program has been invaluable.

This paper describes the retrofit methods, their effect upon the induced air infiltration, the other data which are being collected, and the data analyses which are expected at the completion of the program.

INTRODUCTION

Background

Energy Conservation is rapidly becoming an everyday term with homeowners. Through the efforts of various Federal and State agencies and the utility companies, the homeowner is being educated on steps he or she may take. Major emphasis for retrofit has been on installation of additional attic insulation, and to a lesser extent, sidewall and crawl space insulation. In northern climates, installation of storm windows and storm doors or replacement of single glazed windows with double glazed windows is being recommended.

However, most homeowners do not appear to have an appreciation of the heating and cooling energy load which can be attributed to air infiltration. For example, one study (1) showed a 35 to 36 percent energy loss in a well insulated house under both heating and cooling modes due to air infiltration. In uninsulated houses, the values dropped to 19 and 27 percent for the heating and cooling modes respectively.

The commonly suggested means of retrofitting to reduce air infiltration is to caulk joints visible from the outside of the house. This is a step in the right direction, but often is not very effective, as the homeowner fails to locate many of the openings. Those unnoticed openings from the outside, the attic, or the crawl space can provide means for the air to flow directly into the living area or indirectly by passing into wall areas and then into the living area.

The Texas Power and Light Company has worked with new home builders in the Dallas area in studying the sources of air infiltration and means of reducing this during the construction process.(2) They have concluded that "unnecessary infiltration can attribute to 40 percent of the heating/cooling energy requirements of a typical home". Their study indicated that 1-1/2 air changes per hour were typical for new homes being constructed in the area. (The actual average measured value of 6 air changes per hour by the Super Sucker method was divided by 4 to relate to tracer gas studies.) They identified the major sources of air infiltration as being the sole plate (25 percent), wall outlets (20 percent), windows including frame (12 percent), and duct systems (14 percent).

Homeowners are responding to the use of added insulation to conserve energy. That technology is fairly well established. However, efforts to control air infiltration are limited because the technology as to how to accomplish this is not well known, and because there is a lack of information as to how much energy can be saved. There is need to demonstrate on a relatively large scale and under real world conditions the energy savings that can be achieved when air infiltration is reduced in both electrically heated and gas heated houses. This project is directed toward demonstrations in electrically heated houses.

This paper describes the retrofit methods, their effect upon the induced air infiltration, the other data which are being collected, and the data analyses which are expected at the completion of the program.

OBJECTIVE

Fifty-nine (59) owners/occupants of electrically heated houses in the Denver, Colorado area have, since the fall of 1978, been participating in a study sponsored by the Electric Power Research Institute (EPRI) to determine the effect of air infiltration on heating energy usage. The program is under the direction of the Johns-Manville Research and Development Center, with the active cooperation of the Public Service Company of Colorado. The primary objective of this program may be stated as follows:

> To demonstrate the energy savings that can be achieved when air infiltration is reduced in existing electrically heated homes.

STRATEGIES

Sixty (60) electrically heated houses in the immediate Denver area and served by the Public Service Company of Colorado were chosen for the study. Half of these houses (ultimately only 29 due to a withdrawl at the homeowners request) were retrofitted to reduce air infiltration, while half were retained as controls. All houses were measured for air infiltration using the Super Sucker technique, with the retrofit houses being tested before and after retrofit.

Each control and retofit house was submetered electrically to measure the amount of energy used just for heating. If the house had a heat pump system, energy used for summertime cooling was also included in this measurement. Total energy usage readings were also taken and compared with historical data obtained from the Public Service Company data bank. Energy conservation practices and changes in life style are also noted through the use of a monthly Homeowner's Log.

SUPER SUCKER TESTING

The Super Sucker[2] was used to measure induced air infiltration. Three levels each of vacuum and pressure were applied across the outside walls of every house. The goals of 75 Pa, 50 Pa and 25 Pa (0.3, 0.2 and 0.1-inch) water column pressure and vacuum were achieved in most cases. An occassionally very leaky house made it impossible to reach 75 Pa (0.3-inch). The prime goal of 25 Pa (0.1-inch), approximating a 24 km/h (15 mph) wind, was met in all cases. A pressure drop of 50 Pa (0.2-inch), the basis of the Swedish Standard, was met in almost all houses. The most notable exception was a house with an abandoned furnace vent.

The induced air changes per hour (IACPH) at 25 Pa (0.1-inch) water column vacuum for each retrofit house is shown in Table 1. The results are arranged by style of house architecture. Averages derived from Table 1 are shown in Table 2. Induced air changes per hour were calculated using the best judgement of volume in each house. For example, if a crawl space freely communicated air with the heated space in the house, this crawl space was included in the volume used to calculate IACPH.

It seems apparent that differences between house styles are not really significant. It is significant to note, however, that the retrofit workers consistently reported that bi- and tri-levels were the most difficult to treat for measurable reduction in induced air infiltration.

GAS DIFFUSION TESTING

Gas diffusion tests using SF_6 were performed on two houses, before and after retrofit. The results of these tests are compared to the induced air infiltration data at a pressure drop of 25 Pa (0.1-inch) in Table 3.

Note that the IACPH values reported for house R-15 in the "ducts open" configuration are lower than reported in Table 1. This is because total volume including crawl space, rather than heated volume, was used in the calculation. Total volume was selected for this specific comparison because the warm air ducts were found to provide communication between conditioned and unconditioned space. This communication continued inspite of attempts to repair the leaks in the ducts. The IACPH value after retrofit with the duct system sealed is based on the heated volume only.

SOURCES OF LEAKS

Records were kept of the leaks which required treatment in each of the retrofit houses. Forty-five (45) different leak sources required treatment. Several sources occurred in only one house while several occurred in all, or nearly all houses. Table 4 lists the sources and the percent of the total number of retrofit houses requiring treatment for each source. Note that not all sources were possible in all houses, and records were not kept to detail potential air leaks which did not require treatment. However, it was noted by the testing crew that every house having a forced air duct system demonstrated excessive leakage through the ducts. Thus, while only 24 percent of the houses had a duct system, 100 percent of those required correction for leakage during retrofitting.

RETROFIT PROCEDURE

Preparation

The preparation was conducted by both the homeowner and the retrofit crew. Prior to the arrival of the crew, the homeowner removed draperies, curtains, pictures, etc. from the walls, and relocated small nic-naks which could be inadvertantly knocked off of end tables, etc.

The retrofit crew completed the preparation by removing the trim from around windows (if it existed) and exterior doors, rolled back the carpet about 1-2 feet from the exterior walls, and removed the baseboard from exterior walls. Electric outlet and switch cover plates were removed as was any trim which abutted the wall(s) to be treated, i.e., paneling edge trim. Furniture was also moved, and baseboard electric heaters detached (mechanically but not electrically) from the walls, to provide clear access to the entire wall surface.

The materials used in this retrofit program included:

- Fiber Glass Mat, Johns-Manville Type 7115 in 7.6 cm, (3-inch), 10.2 cm (4-inch), and 1.22 m (48-inch) widths.

- Adhesive, Specification Chemicals, Inc., Boone, Iowa, No. 1300 White Plastic Adhesive (now designated No. 2500).

- Caulk, latex for interior exposure "self-skinning" or "paintable" meeting Federal Specification TT-C-00598C.

- Caulk, Tremco Curtain Wall Sealer for unexposed areas meeting NAAMM 5C-1.1.

- Rope putty, Tremco 440 Tape Black/Bronze.

- Paint, Kelly-Moore Latex wall paint.

- Electrical gaskets, the Vision Company, 2840 Singleton Boulevard, Dallas, Texas 75212.

Wall System Application

The first step was to apply the adhesive onto the base of the wall about 5 cm (2-inches) up from the floor, and onto the floor out to the carpet tack strip (about 2.5 cm). A strip of 7.6 cm wide glass mat was then laid with one edge against the tack strip, to the wall/floor intersection, and up the wall. After the glass mat was pressed firmly into the adhesive, a second coat of adhesive was applied over the mat and worked into the mat. A conventional paint brush was used to apply the adhesive in this area. Drying time between coats, sufficient for the mat to be set firmly, was 15 to 30 minutes.

If the windows did not have wooden trim, adhesive was applied to the sheetrock jamb surface around the window. The 10.2 cm (4-inches) glass mat was then pressed firmly into the adhesive, and a second coat of adhesive was applied. Excess mat which extended beyond the plane of the wall surface was trimmed with a razor blade. If the windows were the type which required interior wood trim (which had been removed during the preparation step), this step was bypassed.

The wall surface was then coated with the adhesive from ceiling to floor starting in one corner and extending outward slightly more than 1.22 m (4 feet). The adhesive was applied with a short-nap polyester paint roller at a rate of about

Table 4 showed a list of the major sources of infiltration in the 29 retrofit houses. Those areas which were caulked routinely included:

- plumbing wall penetrations,
- ceiling and wall light fixtures (between the box and the sheet rock),
- bathroom exhaust ducts,
- foundation/sill joint in both basements and crawl spaces,
- attic access.

Where mapping showed other specific infiltration areas, they were also treated. They included:

- window sill/dry wall intersection,
- stairs over unheated space,
- kitchen fan vent (between vent and wall or ceiling sheet rock),
- in-wall air conditioner,
- crawl space opening,

•baseboard heater,

•fireplace/sheet rock joint

The effect of forced air ducts on the induced infiltration (and the gas diffusion) measurements was considered to be significant. While only seven (7) of the retrofit houses had ducting, all of them were reported as major infiltration sources. Thus, an attempt was made to seal all openings in the ducting and transition pieces, and to seal between the registers and the subflooring. In spite of close attention to these areas, the ducts still represented a major source of air infiltration as shown previously in Table 3. The effect was evident not only with the Super Sucker, but also with the gas diffusion measurement method.

RETROFIT COSTS

The retrofit costs were accumulated in sufficient detail to permit an estimate of the average cost per house to complete the retrofit. This average was $1050 for materials and labor. This does not include the testing of the house with the Super Sucker, or the initial mapping of the leaks, but it does include the caulking done while the Super Sucker was in place. Considering that the average floor area was about 1600 square feet, the average cost works out to about $65 per 100 square feet. The average retrofit costs were based upon the following labor and material costs:

Labor - $6.50 per hour

No. 1300 White Plastic Adhesive - $8.70 per gallon

No. 7115 Fiber Glass Mat - $4.94 per 100 square feet

Caulk - approximately $25 per house.

Based on present knowledge and experience, the retrofit effort could probably be significantly reduced in houses where the walls are in good condition. Under these circumstances, the wall covering system should probably be applied only behind the baseboard and window and door trim. Caulking, taping and gasket application would still be necessary, however.

DATA COLLECTION

Public Service Company of Colorado, a major contributor to the program effort, has the responsibility for energy usage data, and life style information collection. These data fall into three categories: historical energy use data, current energy use data, and life style/physical changes information.

Homeowner's Log

Whereas the energy use data represent measured quantities, the effect of life style changes and house maintenance and alterations represent qualitative data. Each month the Public Service Company sends a questionnaire to each homeowner/occupant requesting information regarding changes in life style, family size, habits, energy saving alterations, additions, etc. which might alter the energy usage of the house. As a result of "awareness" generated by participation in the program, the coldest December 1978/January 1979 in history, and increasing utility rates, only seven (7) homeowners have reported no change whatsoever.

It is unclear at this stage how this information can be factored into the final analysis of energy usage before versus after the infiltration retrofit. It has been established however that the occupants play a very major role in determining how much energy they use[4,5]. As a result, the Homeowner's Log information cannot be ignored in the final analysis.

Blind Controls

As a result of monthly heating energy use readings and Homeowner's Logs, the participating homeowners are very energy conservation conscious, possibly more so than the general public.

Thus, the control houses may not be as true a set of controls as desired. In an attempt to quantify this awareness effect, the Public Service Company has established thirty (30) blind controls. Since these homeowners are not aware that their energy consumption is being monitored, their identity must remain confidential with the Public Service Company. (The other participants have all provided written permission to utilize their energy use data.) Data collection and analysis will follow the exact pattern as discussed above except that the energy usage will be expressed as total energy usage, since no submetering will be done.

PROPOSED ANALYSIS

Historical Versus Current Data

The analysis effort will be centered first around the energy use data, both historical and current. Thus, the following specific analyses will be undertaken as they relate to the energy use data:

1. Each individual retrofit house before versus after retrofit,
2. Each individual control house before versus after the period of retrofit,
3. All retrofit houses combined before versus after retrofit,

•baseboard heater,

•fireplace/sheet rock joint

The effect of forced air ducts on the induced infiltration (and the gas diffusion) measurements was considered to be significant. While only seven (7) of the retrofit houses had ducting, all of them were reported as major infiltration sources. Thus, an attempt was made to seal all openings in the ducting and transition pieces, and to seal between the registers and the subflooring. In spite of close attention to these areas, the ducts still represented a major source of air infiltration as shown previously in Table 3. The effect was evident not only with the Super Sucker, but also with the gas diffusion measurement method.

RETROFIT COSTS

The retrofit costs were accumulated in sufficient detail to permit an estimate of the average cost per house to complete the retrofit. This average was $1050 for materials and labor. This does not include the testing of the house with the Super Sucker, or the initial mapping of the leaks, but it does include the caulking done while the Super Sucker was in place. Considering that the average floor area was about 1600 square feet, the average cost works out to about $65 per 100 square feet. The average retrofit costs were based upon the following labor and material costs:

Labor - $6.50 per hour

No. 1300 White Plastic Adhesive - $8.70 per gallon

No. 7115 Fiber Glass Mat - $4.94 per 100 square feet

Caulk - approximately $25 per house.

Based on present knowledge and experience, the retrofit effort could probably be significantly reduced in houses where the walls are in good condition. Under these circumstances, the wall covering system should probably be applied only behind the baseboard and window and door trim. Caulking, taping and gasket application would still be necessary, however.

DATA COLLECTION

Public Service Company of Colorado, a major contributor to the program effort, has the responsibility for energy usage data, and life style information collection. These data fall into three categories: historical energy use data, current energy use data, and life style/physical changes information.

2. When the house changed owners or occupants during 1977-1978, only the data from the most recent occupancy was used.

3. The period immediately after occupancy was discarded as not being typical for the energy usage for that family.

The remaining data were then plotted and a regression analysis conducted for each house separately. The model used was:

$$KWH = A + (B)(DD) + (C)(DD^2)$$

where: KWH = total electrical energy usage in average kilowatt hours per day,
DD = average degree days per day,
A, B, C = constants.

Each regression represents the base to which the post retrofit data will be compared.

Post Retrofit Data

Following retrofit, and subsequent to the installation of a submeter to record only the heating energy used in both the control and the retrofit houses, the Public Service Company has been collecting total energy usage, heating energy usage and degree day data on a regular monthly basis. These data are handled in the same manner as the historical data, and are currently being entered into the computer data bank for subsequent regression analysis at the conclusion of the program in mid 1980.

Historical Data

Total energy use data were collated for each house for the years 1977 and 1978. These data, which were generally monthly meter readings, were then reconstructed according to actual dates which allowed the determination of the number of days between readings, and the actual number of degree days during the period for each reading. The degree day information was obtained from the U.S. Weather Bureau at Stapleton International Airport in Denver.

The total energy usage for each period was then divided by the number of days in the period to yield an average energy use per day in kilowatt hours. The total number of degree days for the identical period was also divided by the number of days in the period giving the average degree days per day. These values were then plotted as dependent and independent variables respectively for each data period.

Certain criteria were established to determine if a point, or series of points, should be excluded from the regression analysis for each house. They were:

1. Data for periods less than 20 or more than 40 days in length were excluded as not representing an average or typical condition or circumstance.

4. All control houses combined before versus after the period of retrofit,

5. All retrofit houses combined versus all control houses combined before retrofit, and

6. All retrofit houses combined versus all control houses combined after retrofit.

Analysis Number 5 above has already been completed using the historical (pre-retrofit) energy use data. This analysis showed that it is highly unlikely that the retrofit group and the control group were taken from different populations.

The previous section discussed how the historic energy use data will be compared with the current heating energy use data. This assumes that the historic base load (energy used for everything except heating) was represented by the "Y" axis intercept at "zero" degree days per day. It also assumes that the base load is constant regardless of the number of degree days per day. This assumption is necessary at this point in time since there are no historical data for heating energy usage alone.

However, current data permits the comparison of the baseload with degree days per day. Thus, with all else being equal, the relationship between base load and degree days per day should be appropriate for the historical data as well. Therefore, the estimated historical heating energy use curve for each house will be corrected still further based upon the results of the base load versus degree days per day relationship generated with the new energy data.

Total energy use by the blind control houses will be compared before and after the retrofit period. Any difference which might occur as a group will be taken into consideration when analyzing any difference which might occur in the regular control house group.

Comparison with Other Factors

The availability of other data and general information relating to each house and its occupants opens up numerous other comparisons which could be made, some quantitatively, others qualitatively. These include:

1. Change in heating energy use versus change in induced air changes per hour,

2. Change in heating energy use versus change in induced air infiltration,

3. Change in heating energy use versus house physical factors such as size, style, heating type, etc.

As mentioned previously, there are also other factors which can be brought into these analyses, if only in a qualitative way. The extent to which they will be considered will be determined at a later date.

REFERENCES

(1) Jones and Hendrix, "Residential Energy Requirements and Opportunities for Energy Conservation", Center for Energy Studies, University of Texas, September 1975.

(2) Caffey, G.E., "Residential Air Infiltration", ASHRAE TRANSACTIONS, 85, 1979.

(3) Harrje, D. T., Dutt, G. S., Beyea, J. "Locating and Eliminating Major Energy Losses In Residential Housing: Bypass Heat Losses", ASHRAE TRANSACTIONS, 85, 1979.

(4) Harrje, D.T., Socolow, R. H., Sonderegger, R. C., "Residential Energy Conservation - The Twin Rivers Project", ASHRAE TRANSACTIONS, 83, 1977.

(5) Sonderegger, R. C., "Movers and Stayers: The Resident's Contribution to Variation Across Houses In Every Consumption For Space Heating", ENERGY AND BUILDING, 1(1977/78) 313-324.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. Robert Mauro and The Electric Power Research Institute for their continuing technical support and sponsorship. Technical guidance which has been forthcoming from Mr. Urban Gibson of Texas Power and Light, Mr. David Grimsrud of Lawrence Berkeley Laboratory, Mr. George Reeves of GPU Service Corporation, Mr. Charles Robart of Edison Electric Institute, Mr. Jerry Kiel of Colorado Energy Research Institute and Mr. Ronald Cattany of Colorado Office of Energy Conservation is also appreciated. The Public Service Company of Colorado and the continuing efforts of Mr. David Davia, Mr. Frank Oliver, Ms. Mary Dobrinick and Mr. James Wakimura must be acknowledged for their essential cooperation and assistance. Finally, the Johns-Manville Professional Staff of Phillip Shepherd and Judith Gerharter, Technician Staff of Timothy Davis and Nicholas Mulnickel, Secretarial Staff of Lynn Hohnhorst and Sylvia Martin, and Consultant Dr. Paul Earle are recognized for their valuable contributions to the program.

TABLE 1

INFILTRATION TESTS - RETROFIT HOUSES

Results at 25Pa (0.1-in.) Water Column Vacuum

House No.	Style	Initial CFM	Retrofit CFM	Initial IACPH (1)	Retro-fit IACPH	% Im-prove-ment	Retrofit IACPH at 0.2 In. (
5	Ranch	1300	720	10.4	5.9	44.6	7.5
6		1410	943	7.0	4.7	33.1	7.4
7		955	502	7.3	3.8	47.5	5.5
8		1020	722	8.2	5.5	32.5	7.4
10		930	<359	6.7	<2.6	>61.4	3.3
11		960	<500	3.8	<2.0	>47.9	<2.0
14		1740	1430	12.7	10.4	17.8	12.9
15		1300	709	10.4	5.7	45.5	6.7
16		<345	850	<3.6	5.6	N/A	9.5
19		722	727	3.4	3.5	0	3.8
20		1290	505	6.9	2.7	60.8	4.5
21		1240	958	6.6	5.1	22.7	6.8
22		1260	959	6.8	5.1	23.9	7.9
29		728	<507	3.3	<2.3	>35.8	3.3
30		<718	<719	<2.4	<2.4	0	<2.4
1	Bi-Level	2310	2200	17.3	16.4	4.8	Furnace Vent Ope
2		1360	1120	7.6	6.3	17.6	9.1
17		<719	<504	<3.3	<2.3	30.0	6.5
28		665	500	3.2	2.4	24.8	6.0
3	Tri-Level	1190	724	4.5	3.2	39.2	4.9
4		990	710	3.4	2.9	28.3	5.6
9		1790	1320	8.2	6.0	26.3	7.5
13		1440	<500	5.9	<2.1	>65.3	3.0
24		1440	1280	6.4	5.7	11.1	7.8
26		1880	1390	7.0	3.6	24.4	5.2
27		1440	<507	8.3	<2.8	>64.8	4.0
12	Two-Story	1560	950	10.3	6.3	39.1	8.3
18		2090	1660	8.2	6.5	20.6	8.7
25		1800	1650	10.1	9.2	8.3	13.7

(1) IACPH = Induced air changes per hour using actual measured CFM

(2) Swedish standard is 3.0 maximum

TABLE 2

VARIATION OF IACPH WITH HOUSE STYLE

	Initial IACPH*	Final IACPH*	Percent Improvement
Two Story	9.5	7.3	23
Bi-Level	7.8	6.8	13
Ranch	6.3	4.5	29
Tri-Level	6.2	3.8	39
All	7.0	4.9	30
Standard Deviation	3.3	3.0	

*IACPH = Induced Air Changes Per Hour

TABLE 3

COMPARISON OF SUPER SUCKER AND GAS DIFFUSION TESTS ON TWO HOUSES

House No.	Before Retrofit: IACPH[1] 25Pa (0.1in.)WC	Before Retrofit: ACPH[2]	After Retrofit: IACPH 25PA (0.1in.)WC	After Retrofit: ACPH
R-15 (ducts open)	6.7	0.70	3.6	0.50
R-15 (ducts closed)	-	0.33	2.5(3.93)[3]	0.20
R-10	6.7	0.45	<2.6	0.29

(1) Super Sucker - Induced Air Changes Per Hour.

(2) Gas Diffusion - Adjusted to 10 mph wind velocity and 40°F temperature difference.

(3) 3.93 IACPH based on volume of heated space only.

TABLE 4
FREQUENCY OF AIR INFILTRATION LOCATIONS

SOURCE OR LOCATION OF INFILTRATION	% OF HOUSES TREATED
Bottom of drywall	100
Window fit including sill	86
Plumbing fixtures, inside and outside walls	79
Electric fixtures including medicine cabinet	76
Bathroom vent	59
Outside door fit	55
Access to attic space	52
Basement door fit	48
Fireplace fit	45
Stair steps and risers over unheated space	45
Garage door fit	38
Clothes dryer vent	34
Garage-house connection	31
Fireplace damper	28
Heating ducts	24
Bathtub fit	24
Kitchen fan vent	24
Closet door trim	17
In-wall air conditioner	17
Sill plate	17
Door to unheated storage	14
Door bell	14
Smoke alarm	14
Crawl space opening	14
Baseboard heater	14
Crawl space vent	14
Shower stall fit	14
Closet door runners	10
Kitchen Cabinets, behind or on top	10
Philips control box	10
Sewer pipe penetration	7
Wood paneling on studs or furring	7
Intercom	7
Cellar floor drain	7
Toilet paper holder	7
Construction discontinuities	7
Telephone cord	7
Abandoned furnace flue	3
Soil pipe to basement	3
Bathroom cabinets, behind	3
Door latch	3
Sky light	3
Masonry seems porous	3
False ceiling beam	3
Stove damper	3