AIR LEAKAGE MEASUREMENT AND REDUCTION TECHNIQUES ON ELECTRICALLY HEATED HOMES

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ABSTRACT

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

The Public Service Company of Colorado, a major participant in the program, fitted all of the 59 homes with submeters to measure the energy consumption associated solely with heating. They have also undertaken the reading of these meters each month, 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 leakage, the other data which are being collected, and the data analyses which are expected at the completion of the program.

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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 leakage. 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 leakage. 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 leakage 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 leakage and means of reducing this during the construction process.[2] They have concluded that "unnecessary leakage can attribute to 40 percent of the heating/cooling energy requirements of a typical home". They identified the major sources of air leakage as being the sole plate (25 percent), wall outlets (20 percent), windows including frame (12 percent), and duct systems (14 percent). An air machine, coined the Super Sucker[2], was designed and built by Texas Power and Light and provided the appropriate pressure differential across the building envelope and air flow measuring mechanism to determine the leakiness of the test houses.

Homeowners are responding to the use of added insulation to conserve energy. That technology is fairly well established. However, efforts to control air leakage 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 leakage 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 leakage, 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 leakage 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 leakage 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 withdrawal at the homeowners request) were retrofitted to reduce air leakage, while half were retained as controls. All houses, ranging in age from 4 to 7 years, were measured for air leakage using the Super Sucker technique, developed by Texas Power and Light[2], 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 space 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 pre-retrofit data obtained from the Public Service Company data bank. Energy conservation practices and changes in life style were also noted through the use of a monthly Homeowner's Log.

SUPER SUCKER TESTING

The Super Sucker was used to measure induced air leakage. Three levels each of vacuum and pressure were applied across the envelope 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) 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 leakage.

TRACER GAS TESTS

Tracer gas tests were performed on two houses, before and after retrofit, using SF_6 and a portable electron-capture gas chromatograph. During the measurement period, site-specific meteorological data were obtained using a portable weather station.

To initiate an experiment, between 0.5 and 1.0 cc of pure SF_6 was introduced into the structure. This led to an initial SF_6 concentration of approximately one part per billion (10^{-9}). Usually the concentration decay experiment was terminated when a concentration of 5×10^{-11} (50 parts per trillion) was reached. Four fans in various rooms within the structure were used to homogenize the tracer gas concentration. Homogeneity usually occurred in 90 minutes. Glass syringes were used to sample the tracer gas in these tests from various rooms within the structure.

These samples were analyzed and were compared with values obtained utilizing the on-board pump in the gas chromatograph. When all values agreed to better than plus/minus four percent, homogeneity was assumed. Usually agreement to plus/minus one percent was easily obtained prior to onset of a decay run.

During a decay run, gas samples were drawn from opposite ends of the structure. One sample was drawn using the on-board sampling pump, the other was drawn using a disposable 12 cc polypropylene syringe. At 15-minute intervals living room gas samples were drawn utilizing the on-board sampling pump and were analyzed. Samples from the master bedroom were drawn by syringe utilizing an analysis interval of 30 minutes. Thus, every 30 minutes two spatially distinct samples were analyzed allowing close observation of the degree of homogeneity of gas concentration in the structure.

The runs generally lasted anywhere from 8 to 12 hours, and were repeated several times. The air leakage rates were then reduced to standard conditions of 10 miles per hour wind speed and 40°F inside-outside temperature difference. The results of these tests are compared to the induced air leakage 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 in spite 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.

While the opportunity existed for an extensive study comparing IACPH with ACPH, this secondary objective could not be justified on the basis of cost.

LEAK PATHS

Records were kept of the leaks which required treatment in each of the retrofit houses. Forty-five (45) different leak paths required treatment. Several paths occurred in only one house while several occurred in all, or nearly all houses. Table 4 lists the paths and the percent of the total number of retrofit houses requiring treatment for each path. Note that not all paths 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.

Leak detection was accomplished simply by setting the Super Sucker to pull the maximum possible negative pressure on the house (up to 75 Pa), and feeling by hand where the air was entering the house. This procedure was used during the pre-retrofit tests, and also during the final caulking stage just prior to the post retrofit tests.

RETROFIT PROCEDURE

Preparation

The preparation steps were 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, in 7.6 cm, (3-inch), 10.2 cm (4-inch), and 1.22 m (48-inch) widths.
- Adhesive,
- Caulk, latex for interior exposure "self-skinning" or "paintable" meeting Federal Specification TT-C-00598C.
- Caulk, Curtain Wall Sealer for unexposed areas meeting NAAMM 5C-1.1.
- Rope putty,
- Paint, Latex wall paint,
- Electrical gaskets.

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-inch) 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 3 to 4 square meters per liter (120 to 150 square feet per gallon). The adhesive was also applied over the first glass mat application at the base of the wall, and out to the tack strip. A 1.2 m by 2.4 m (4 foot by 8 foot) piece of glass mat was then applied to the wall using conventional wallpaper hanging techniques. As before, the mat was pressed into the adhesive. The top and bottom edges were then trimmed, with the bottom cut made to permit the mat to run out to the tack strip. Cutouts around a window and an electrical outlet were made as appropriate.

At the joints, the adjoining strips of glass mat were overlapped, the two layers of mat were cut with a razor blade, and the resultant mating edges pressed together. After the adhesive had set for 15 to 30 minutes, and was holding the glass mat firmly in place, a second coat of adhesive was applied.

One coat of paint was applied normally 24 to 48 hours after application of the wall covering system.

It is appropriate to note that the moisture and air barrier was achieved by the adhesive and paint, while the fiber glass mat acted as the reinforcing medium. This combination has been found to have a perm rating of less than 1 when tested in accordance with ASTM E-92.

Electrical Outlets

One of the major sources of air leakage was through electrical outlets and switches. This was minimized with a resilient foam gasket which is precut to fit the variety of outlet types and sizes. They were placed directly beneath the cover plate on all outlets and switches, including those on the interior walls.

Caulking

While the caulking operation was not as regimented as the wall covering system or the electrical outlet gasket applications, it was not less important. As noted previously, the technicians "mapped" the house for obvious leaks during the initial testing of the house with the Super Sucker. These, in addition to the standard areas of treatment, were given primary attention. It became apparent, however, that the best caulking job was done while the Super Sucker was installed and operating. While the most obvious leaks noted during the inital test could be minimized satisfactorily, lesser leaks then became the major sources of air infiltration.[3] Had the Super Sucker not been operating at the time of the final caulking, the lesser leaks would have gone unnoticed and untreated.

With but two exceptions, all caulking was done from the interior of the house, basement or crawl space. Both of these instances required closure of large gaps between the facia and the siding where the main floor overhung the foundation. While this was not considered part of the retrofit program (in addition to weatherstripping doors, repairing flue dampers, etc.), the air leakage through these openings was sufficient to make the rest of the work almost useless if they were not corrected.

Table 4 showed a list of the major paths of leakage 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 leakage (and the tracer gas) measurements was considered to be significant. While only seven (7) of the retrofit houses had ducting, all of them were reported as major leakage paths. 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 path of air leakage as shown previously in Table 3. The effect was evident not only with the Super Sucker, but also with the tracer gas 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 operating. 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

Adhesive - \$8.70 per gallon

Fiber Glass Mat - \$4.94 per 100 square feet

Caulk - approximately \$25 per house.

The program was designed to treat each house essentially the same. Since we did not know the condition of the retrofit walls at the start of the program, it was decided to cover the entire interior surface of all exterior walls. 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 be applied only behind the baseboard and window and door trim. This would probably cut the retrofit costs in half. Caulking, taping and gasket application would still be necessary, however. Experience also indicates that additional effort might be appropriate in applying the air barrier system to all baseboard areas rather than just on the exterior walls. The extent to which the air leakage would be reduced still further is unknown based on this study.

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: pre-retrofit energy use data, post retrofit energy use data, and life style/physical changes information.

Pre-Retrofit Energy Use 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.

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 Energy Use Data

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

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 of Colorado 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 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 space 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 of Colorado 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 of Colorado. (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

Pre-Retrofit Versus Post Retrofit Data

The analysis effort will be centered first around the energy use data, both pre-retrofit and post retrofit. 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,

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 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 pre-retrofit total energy use data will be compared with the current space heating energy use data. This assumes that the pre-retrofit 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 pre-retrofit data for space heating energy usage alone.

However, post retrofit 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 pre-retrofit data as well. Therefore, the estimated pre-retrofit 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 space heating energy use versus change in induced air changes per hour.

2. Change in heating energy use versus change in induced air leakage (cfm).

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.

CONCLUSIONS

The determination of the extent to which the objective was achieved must await several winter seasons of data collection. However, it can be stated that the Super Sucker as designed by Texas Power and Light was effective in establishing the location and extent of air leakage in existing houses. It may also be concluded that air leakage, as measured by the Super Sucker, was reduced an average of 30 percent for all retrofit houses, and as much as 65 percent on an individual house basis.

REFERENCES

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

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.

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TABLE 1

LEAKAGE TESTS - RETROFIT HOUSES

RESULTS AT 25PA (0.1 In.) WATER COLUMN VACUUM

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

(1) IACPH = Induced Air Changes Per Hour using actual measured CFM.

TABLE 2

VARIATION OF IACPH WITH HOUSE STYLE

	Pre-Retrofit IACPH*	Post-Retrofit 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

TRACER GAS TESTS ON TWO HOUSES

	-----Pre-Retrofit-----		---Post-Retrofit----	
House No.	IACPH(1) 25Pa(0.1 In.)WC	ACPH(2)	IACPH 25Pa(0.1 In.)WC	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) Tracer Gas - 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 LEAKAGE LOCATIONS

Path or Location of Leakage	Percent 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

Session II - Questions and/or Comments

Keast & Pei

a. K. N. Patel, Argonne National Laboratory

Q: What is the accuracy of this method as compared to tracer techniques? Also please describe the equations.

A: The acoustic leak location method cannot be compared to the tracer-gas technique. The former is a qualitative means for locating some of the leaks in a building. The latter is a quantitative means for measuring infiltration rates.

The equations in the paper are regression fits to experimental data: a power-law fit of flow rate to differential pressure, and a fit of the sound-level increase at an opening to the logarithm of the local flow velocity at the same opening when the building is subsequently depressurized.

b. R. P. Tye, Dynatech R/D Company

Q: Has this technique been used to investigate other types of "flaws" within an insulated system? For example, have you looked at systems where there are air pockets or other isolated regions where one may not get direct infiltration but where there is a possibility of convective air movement, etc.? Could this technique then be used in a similar way to thermography for qualitative measurements on building components?

A: We did not evaluate the use of acoustic location to identify insulation voids in walls. Based upon theory and other data regarding the acoustic properties of walls, it is unlikely that such an effort would be successful in most cases. As a result, acoustic location probably cannot be used, like thermography, to locate insulation voids.

c. Gary Gillette, National Fenestration Council

Q: Why did you locate the sound source indoors? Did you make any attempt at calibrating your readings, and if so, how was this done? What advantages do you see in this type of method over infiltration methods currently in use?

A: It is not necessary to locate the sound source indoors when doing acoustic leak location. We did some tests using natural traffic noise out of doors, and some using an artificial outdoor sound source. However, in residential neighborhoods the operation of an artificial outdoor sound source is an effective attractant for curious youngsters, dogs, etc., that tend to reduce the productivity of the field crew!

The acoustic-location method involves a comparison of the sound level at a suspected leak with that at a nearby sealed location. Hence calibrated readings are unnecessary.

The acoustic leak-location method involves less-costly and/or less cumbersome equipment than thermography or pressure-testing of buildings. Often much of the equipment necessary is already available in the home. The acoustic method does not require a pressure or temperature differential across the building envelope.

d. S. J. Gordon, Flourcity Architectural Metals

Q: Have you obtained any correlation between the volume of sound and magnitude of air infiltration on a measurement basis (meter reading vs. cubic feet of air/time/pressure differential)?

A: There were several leakage sources identified involving a number of houses which required relatively expensive or professional treatment. There were also numerous leakage areas which would be readily corrected by the homeowner. These areas, listed below, were not within the technical or budgetary scope of the project. Homeowners were advised of each leakage source and were encouraged to make or arrange to have made the corrections prior to the post retrofit retest. The homeowners action on these items was not universal, thus making it impossible to achieve optimum leakage reduction. Specific items included:
-install fireplace glass cover of good quality,
-weatherstrip doors between conditioned and unconditioned areas,
-install bottom and side garage door seals,
-repair or replace faulty dryer vent,
-recondition or replace sliding glass door,
-repair or replace faulty bathroom vent,
-remove and retrofit penetration by abandoned furnace vent,
-repair or replace faulty chimney damper.
These were also two areas which received our attention during retrofit, but which could not be fully corrected:
-the unexposed portions of the forced air ducts could not be properly sealed, and
-foundation sills were sometimes not accessible for inspection or treatment.

e. Mr. Gary C. Wobler, Allegheny Electric Cooperative Inc.

Q: Where heat pumps were the source of heat, were any of them using the crawl space as the plenum? If so, how were they retrofitted and what were the results?

A: None of the forced air systems evaluated utilized the crawl space as the plenum.

f. Mr. Jules Olsen, TMP Cons. Eng.

Q: Has there been any evidence that the reduced infiltration may contribute to problems of condensation?

A: We have received one comment from a homeowner in the test group that there seems to be significantly more condensation on the windows. Three or four other homeowners said they felt that their humidifier was not on as frequently, while one family thought it was drier.

g. Mr. F. Heller, Toronto Board of Education

Q: What was the brand name of the film applied to wall, does it act as a vapor barrier and where is it available?

A: The glass mat/adhesive system has a perm rating of just under 1, thus classifying it as a vapor barrier. The glass fiber mat was Johns-Manville Type 7115, and the adhesive was "White Plastic" made by Specification Chemicals, Inc., Boone, Iowa, who also handled the application. Glidden Paint Company is also marketing the system using their adhesive which I believe is essentially the same as that made by Specification Chemicals, Inc. Johns-Manville does not market or apply the system.

A: We have correlated the increase in sound levels at a crack (relative to a nearby sealed location) with the local air flow rate from the same crack when a separate pressurization test is done. See Figs. 6 and 7 of the paper.

e. Gordon Hart, Owens Corning Fiberglas

Q: It would seem that it would take a very long time to do a thorough energy audit on a home with this technique (with regards to finding leaks). How does the amount of time, using this acoustical method, compare to the amount of time using a pressurization - infra-red scanner technique?

A: Our experience is that a typical two-storage residence with basement and attic can be evaluated by the acoustic technique in about 1½ hours. Using an infra-red scanner with the building depressurized probably takes much less time. However, see my answer to Mr. Gillette's inquiry above.

f. Dr. Jamie P. Monat, Abcor, Inc.

Q: Have you considered trying to measure crack size by using, for example, electromagnetic radiation centered in the microwave region, and modulating the frequency while measuring the angle of diffraction due to the crack, with a detector?

A: We have done no work on RF measurements of cracks in buildings.

g. Robert O. Smith, Robert O. Smith & Associates

Q: What is a good kind of sound signal to use for testing purposes?

A: Most any kind of sound can be used, although the best performance is obtained with a sound that is high-pitched and readily distinguishable from the background. The sound you heard on the film is a rapidly-sweeping tone (2-3 sweeps/sec.) from about 800 Hz to 8000 Hz with 20 dB high-frequency pre-emphasis.

Sherman, Grimsrud, and Sonderegger

a. P. R. Achenbach, NBS

Q: Does not the poor mixing under pulsating pressure indicated by the tracer gas technique also have implications with respect to the actual heat loss under pulsating pressure conditions?

Yes, indeed it does! There are two distinct processes that mitigate the heat loss due to pulsating flow.

The first, as noted in the question, is that infiltration under pulsating pressures is greatly reduced because of poor mixing near the exits of the leaks. The poor mixing occurs because most of the leaks are not simply orifices between inside and out, but rather are long, torturous paths: air leaking under the wall board may have to travel through an insulated cavity to find an opening to the outside; air that leaks into interior walls must travel first to the attic and crawlspace before it can exit, etc. If the pulsations are fast enough the air does not have a chance to leave the structure before the pressure pulse is reversed and the air is sucked back into the interior. As stated in the paper at about 1 cycle per second the measured infiltration increase due to the pulsations was only 20% of the expected value.

The situation concerning heat loss due to infiltration caused by pulsating pressures is even more interesting. Not only will the heat loss be smaller because of the effect mentioned above, but it will be smaller because of a heat exchanger effect. As the air passes from inside to out, it will give up some of its heat to the material it passes through (e.g. insulation or wall board) and it will exit at a temperature closer to outside temperature than inside. When outside air is pulled back into the structure it can regain the heat that was left behind on the previous half cycle and warms to a temperature approaching room temperature. This is a regenerative heat exchanger cycle using the envelope of the structure as the heat exchange medium. We have yet made no direct measurements of this effect, but we intend to, soon.

b. Paul Lewis, Florida Power Corporation

Q: What effect does utility holes (electrical & plumbing) in interior walls, which are covered with batt insulation have on air infiltration?

A: Infiltration through interior walls is usually quite hard to quantify. It is critically dependent on the communication between the internal cavity and the outside. If the top (and bottom) of the internal wall is sealed the effect of holes in interior partitions is minimal. If the interior of the partition is open to the attic (or crawlspace), a hole in the interior wall acts like a hole in the ceiling (or floor).

The best remedy for this is to seal the internal wall so there is no communication to the outside. However, if this is not possible it would be best to impede the flow caused by these holes (e.g. by stuffing insulation around the holes or by filling the interior cavity with insulation).

Steward, Jacob, and Winston

a. Frank S. Wang, Dow Chemical

Q: It appears to me that the difference among the houses were very little small, you are really splitting hairs trying to distinguish them. What is the reason that the <u>2x6 house</u> missed the tracer gas data in the winter season?

A: I agree, there was very little difference, but the differences needed to be identified as part of an overall program of research.

The 2x6 house was missing data because of equipment malfunctions.

b. David B. Goldstein, Lawrence Berkeley Laboratory

Q: Were the heating and cooling loads for the infiltration test homes measured? Are these results available?

A: The measurement of energy consumption was the primary goal of the project. The infiltration study was a support project. The results of the total energy study are the subject of a future presentation.

c. David Grimsrud, Lawrence Berkeley Laboratory

Q: Did you attempt to correlate the air leakage measured at a standard pressure (e.g., 50 Pa) with the infiltration adjusted to a standard weather condition? Did you attempt to find a correlation after subtracting the effect of the furnace blower on the infiltration measured in the three houses?

A: Although we did attempt to correlate pressure tests with natural infiltration, we found nothing conclusive. The pressure tests were done in three different configurations. The ranking of the houses and the magnitude of the differences between houses changed each time for various reasons. At this time, we feel that a correlation, such as that found by Jonny Kronvall in Sweden, would not be justified.

Yes, we did and with basically the same results.

d. Arranz Lopez - National Institute of Quality in Building

Q: Kindly send information about tests methods of infiltration using tracer gas, pressurization systems and infrared scans. In our country these methods have not been yet developed and we are interested to go into an in-depth knowledge about them. Please send the required information as soon as possible, we wouldn't like to wait to middle '80! Thank you very much.

A: No reply needed.

e. Frank W. Gery - St. Olaf College

Q: Why does blower swamp the results from leakage alone? What is the implication for constant flow air systems? Will the infiltration (or leakage) rate be vastly affected?

It appeared that the more heavily insulated house (A) had a poorer performance than the lightly insulated one (B). (Did I misread the results?) How do you account for the differences?

Did you rotate the machinery; e.g., the sample injection machine in order to normalize results?

A: The point I wanted to make about the blower system in the furance of the house is that it can produce a component of infiltration independent of the weather conditions. If the blower is operated continuously, this component will be larger than if it is operated only on demand for heating or cooling. The magnitude of this component can exceed .1 air changes per hour. The blower operation can also influence pressurization testing as is shown in the paper.

I would like to point out that once the house is insulated, the level of insulation should have only a minor influence on infiltration. The houses were actually quite close to each other in terms of infiltration and the small difference can be attributed to random variation in construction quality.

We compared the monitoring devices at two times. First, we ran all three concurrently in the control house and compared results. Second, after the devices had been operating in the houses for a time, two of them were run in one house. The agreement between devices was very good both times.

f. Paul Lewis - Florida Power Corporation

Q: I would be interested in seeing test data results on AC and heat consumption for three test houses.

A: The energy consumption of the test houses was the primary goal of the project. These results will be the subject of future presentations. The air infiltration study presented here was a support project to help us understand the magnitude and nature of this portion of the energy load.

g. C. M. Hunt - National Bureau of Standards

Q: Did you have any complaints from the occupants due to the tightness of the houses?

A: These houses are located on the grounds of the Technical Center and are not occupied. The overall purpose of the project was to quantify the effect of insulation on energy usage and we felt that occupancy would introduce unwanted random variations.

Selkowitz and Weidt

a.

Q: If manufacturer's statements of laboratory tests are not an acceptable way of comparing one window product vs. another window product, what do you suggest that the architect/engineer/designer use to compare product or choose the one most acceptable to him?

A: We are not concluding that the laboratory test is not acceptable field tests of representative windows are preferable, if possible. But laboratory tests are frequently the only test data available.

b. Steve McCarney, Colorado Office of Energy Conservation

Q: At what frequency do individual manufacturers test their respective windows for air infiltration rates (as specified by ASTME 283, for example)? Is it a voluntary standard?

A: The frequency varies widely depending on the manufacturer. The ASTM test is a voluntary standard used by window manufacturers and private test laboratories.

c. S. J. Gordon, Flourcity Architectural Metals

Q: Was there any correlation between (1) structural performance (deflection), and (2) type of weather stripping and field performance?

A: This was not examined in the study.

d. M. Spicyn, Spicyn Associates

Q: If you were to design building today, assuming manufacturer claims 0.5 CFM/foot would you use this figure in your calculations? If not, what infiltration rate would you use?

A: I would use the manufacturers number if I used the "crack method." In addition a sensitivity study on the infiltration rate would indicate the effect on the building load calculation.

e. Patricia Brantingham, Schlegel Corp.

Q: You identified type of window as the most significant factor in performance variation, and manufacturer as the next most important factor. Did you consider the type and grade of weather stripping in your analysis? Was weather stripping a significant factor in the differences between manufacturers? What other differences existed?

A: We did not consider the type of weather stripping.

Hunt

a. Max Sherman, Lawrence Berkeley Laboratory

Q: In your presentation you stated that the infiltration was heavily influenced by the ventilation system. This should be reflected in a significant inside-outside pressure difference. Did you find this? If not, could you speculate why?

A: This observation is correct. One would expect an inside-outside pressure difference due to fan operation.

The main make up and relief (exhaust) dampers were sealed. Therefore these should not allow significant movement of air into or out of the building.

However, the tower was not operating as a closed system. As noted in Table 2, toilet and other exhausts as well as air diverted to the first floor withdraw air from the tower. If losses of this magnitude were made up by leakage through the tower envelope, a pressure drop of the order of 0.1 - 0.15 mm Hq would be expected. Observed pressure difference due to operation of all fans and exhausts was of the order of 0.01 mm Hq. We have no satisfactory explanation of this difference unless there are return pathways to the air haudling systems which are not indicated in the drawings.

b. Dr. Vladimir Bazjanac, University of California

Q: Is the building standing alone or is it a part of a cluster of high-rises (is it surrounded by high-rises)?

A: The Administration Building is the only high-rise building on the 400 acre site. However, as shown in Figure 1, the first floor covers considerable area. Also, within 100 yards there are 3-story buildings to the north, west, south, and southeast.

7. Grot and Clark

a. D. N. Keast, Bolt Beranek and Newman Inc.

Q: Were weather data acquired at the time of the tracer-gas studies? If so, have results been adjusted in some way for the various weather ( ) conditions that probably existed during grab-sample results?

A: No response.

b. G. K. Yuill, UNIES Limited

Q: Please comment on the possible absorbtion of SF6 onto fabrics and other surfaces in the houses, and its effect on the accuracy of your tracer gas results.

Q: No response.

c. David Grimsrud, Lawrence Berkeley Laboratory

Q: We have made intercomparison measurements of infiltration rates use several tracer gases: C2H6, CH4, N2O, SF6. The techniques used were the same (concentration decay). Results will be reported at the LA ASHRAE meeting. Briefly, the intercomparison shows that the result obtained using one of the gases above agrees with a result measured simultaneously using another within 10%. The results for SF6 appeared to give

A: No response.

d. Gordon Hart, Owens Corning Fiberglas

Q: The percentage of homes with space leafers, 37%, was surprisingly large. I assume that these were mostly fueled by natural gas or propane. Of those that were vented, were the vents blocked off for the infiltration pressurization tests?

A: No response.

e. Doug Burch, NBS

Q: Did you find statistically significant differences in air infiltration rates attributable to type of heating plant, type of construction, number of stories, and geographic location?

A: No response.

f. Robert Sonderegger, Lawrence Berkeley Laboratory

Q: Could you see a city-by-city correlation between measured air infiltration rates and degree-days for each city? Could you see a city-by-city correlation between city-wide average air infiltration rates and city-wide average leakage rates?

A: No response.

g. Michael Core, Ohio Rural Electric Cooperatives

Q: What were costs (average each home) to correct infiltration problems. What were the paybacks? How or what extent was heating bill affected?

A: No response.

8. John O. Collins, Jr.

a. Max Sherman, Lawrence Berkeley Laboratory

Q: You used the term "gas diffusion" to refer to the infiltration monitoring technique. This is a common misnomer. Diffusion is a very slow process, the diffusion time for a house would be days rather than hours. The mechanism of infiltration is due to direct mass flow from convection, etc. A more acceptable term would be "gas dilution" to describe the tracer technique.

A: Mr. Sherman's point is well taken, and I stand corrected.

b. Paul Lewis, Florida Power

Q: We at Florida Power are spending countless hours looking at infiltration as well as other areas of reducing load and adding to conservation -- any additional data on your test results would be appreciated.

A: While we have collected data on heating energy used for one calendar year since completion of all of the retrofits, we and our sponsor, the Electric Power Research Institute, do not feel it appropriate to publish our preliminary results at this time. I will say however, that the data are encouraging.

c. Victor G. DeNunzio, Simplex Industries, Inc.

Q: Mr. Collins showed a chart attributing 20% heat loss to electrical outlets. While these outlets can be measured for air leakage the air must first leak into the wall cavity from outside. He made no mention of the effect of wall sheathing and siding. Wouldn't tight sheathing and siding products lower the air infiltration attributed to electrical outlets?

A: We believe the major cause of leakage through the electrical outlets are the large holes drilled through the soleplate, top plate, and the studs to accommodate the wires. These holes provide excellent air communication between unconditioned air and conditioned space, and this path of communication can involve interior walls as well as exterior walls. However, it is logical to assume that good, tight, well installed sheathing will tend to lower air leakage. Consideration of sheathing as a potential source of leakage was not within the scope of this project.

d. Mr. P. R. Achenbach, NBS

Q: Have you speculated on why you could only get a 30% reduction in air leakage by such an extensive retrofit?