HOUSE DOCTORING NEW SINGLE-FAMILY HOMES IN THE RESIDENTIAL CONSTRUCTION DEMONSTRATION PROGRAM

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In the Bonneville Power Administration's (BPA) Residential Construction Demonstration Project (RCDP), participating builders constructed over 300 homes to prescriptive infiltration control specifications. Blower door tests conducted after construction varied significantly, as did house tightening costs.

RCDP found that much of the variability in house tightness and costs was primarily due to the following:

- Use of a prescriptive standard without a performance standard for house tightness.
- Lack of preplanning of the air sealing process by the builder and subcontractors.

Further RCDP investigations were conducted on a self-selected subsample of 55 RCDP homes. These homes received blower door testing during construction. This testing is termed "house doctoring" because a blower door test diagnoses leaks that the house doctor and/or the builder seals. Historically, house doctor work has been limited to weatherization of existing homes. In RCDP, blower door tests were conducted and results recorded "before" and "after" house doctoring occurred. In many cases data regarding the materials and labor costs associated with house doctoring were also collected.

This paper summarizes RCDP house doctor blower door test results and house tightness cost data and presents estimated maximum house doctoring energy savings from increased house tightness. Cost estimates are based on the RCDP house doctor reported cost. The homebuyer's life cycle savings of RCDP house doctoring is also presented.

This paper presents case studies of builder/house doctor experiences, along with anecdotal information from builders and house doctors.

The results of this project are presented to further our understanding of the viability of house doctoring new residential construction, especially for those homebuyers and/or utilities who may be considering house doctoring.

INTRODUCTION

In Residential Construction Demonstration Project (RCDP) Cycles 1 & 2, 227 participating builders constructed 349 homes built to the Model Conservation Standards[1] and BPA's "advanced or standard infiltration" package prescriptive specifications.

The "advanced" goal was to tighten homes to a level of 1.8 air changes per hour (ACH) at a 50 Pascal indoor minus outdoor (negative) pressure difference (1.8 ACH @ 50 PA). The standard infiltration package had a tightness goal of 7.0 ACH @ 50 PA. (BPA 1987).

After construction was complete, all RCDP homes were blower door tested by a site visit technician. The builders' estimated incremental costs associated with house tightening were acquired via a builder cost survey.

The blower door and house tightness cost data indicated large differences in costs and house tightness from builder to builder. Some builders constructed tight homes at low tightening costs while others built tight homes at higher costs than expected. Leaky homes with low and high construction tightening costs were also observed (Barnett, Reiland, and Thor 1988) (Lubliner, Byers, and Young 1988).

Further investigations in RCDP revealed that much of the excess cost and air leakage in RCDP homes were primarily due to:

- Use of a prescriptive standard rather than a performance standard. A prescriptive standard requires that various penetrations be sealed, whereas a performance standard requires that each home be tested to comply with a target tightness level.

  In the BPA new residential construction programs, performance standards are not required and rarely used (Maloney 1988).

- Lack of preplanning of the air sealing process by the builder and subcontractors. This includes defining and coordinating which subcontractor will seal what envelope penetration, with what type of material, and at what point in the building process.

Quite often a lack of preplanning will translate into builders spending considerable time and using costly materials to tighten a home, only to find that they missed some large leaks, resulting in leakier than expected homes (Maloney 1988).

Innovations were developed in RCDP to improve the tightness level of the homes while minimizing costs. In RCDP Cycle 1, the house doctoring innovation provided a $200 cash incentive to 23 builders who hired private blower door contractors to test 35 homes, fix the leaks they find, and record "before" and "after" house doctor blower door test data. In RCDP Cycle 2, this effort was called the "Air Leakage Control" (ALC) innovation. The ALC innovation provided seven builders with $200 for house doctoring plus a $150 cash incentive to better preplan their house tightening process of 22 homes. An ALC manual was developed in RCDP to guide builders through the preplanning process. The manual included preplanning instructions, an ALC checklist, blower door test data forms, cost forms, and a builder evaluation survey of the ALC process (RCDP 1988).

SAMPLE POPULATION

The case study approach is taken because relative costs/benefits of house doctoring are based solely on the population of RCDP homes/builders who participated in the house doctoring innovation as shown in Table 1. These builders are self-selected from a larger self selected group of RCDP builders. Although perhaps not indicative of an accurate sample of all homes built in the Pacific Northwest, the group does include modular builders, small site-builders, and large volume site-builders. Therefore these homes represent a broad self selected spectrum of the single family building sector.

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[1] *Model Conservation Standards were originally developed from the Northwest Conservation and Electric Plan Volume III - 1983.*

Table 1. Case Study Summary Information

Case	Builder ID#	House Doctor ID#	Number of Homes
A	3	2	8
B	6	3	4
C	24	13	10
D	25	13	7
E	1,2,4,5,7-23,26-30	1,4,5-12	26
Totals	30	13	55

House doctoring new residential construction is a relatively new phenomenon. Some of the 13 house doctors and many of the 30 builders had little or no experience with new construction house doctoring. Therefore, RCDP house doctoring results reflect what would be expected at the beginning of the learning curve. It is important that these results not be used to extrapolate the benefits of house doctoring to other house doctor programs where there is a more experienced and competitive house doctoring marketplace.

CASE STUDY ANALYSIS RESULTS

Case A

These eight RCDP Cycle 1 modular homes have basements. The homes were built and sited in Idaho by a builder with little energy efficient construction experience. The homes were equipped with air-to-air heat exchangers. Even with house doctoring they were not able to meet the 1.8 ACH @ 50 PA performance goal of the SGC advanced infiltration package. The house doctor was based in Montana and had the highest travel costs at $180 - $191, about half of the reported total cost. RCDP paperwork and reporting costs were $27 per house.

Case B

These four RCDP Cycle 1 homes were modular homes with basements. They were built by a builder with exceptional energy efficient construction experience. The homes were built and sited in Montana. This was the only case where the house doctor was also the builder. The builder normally blower door tests all the homes it builds. The homes were equipped with air to air heat exchangers and were able to meet the 1.8 ACH @ 50 PA performance goal of SGC advanced infiltration package "before" house doctoring. The builder reported total cost of $200 per house.

Case C

These 10 RCDP Cycle 2 homes were site-built, single-story homes without basements. They were built by a large-volume builder with energy efficient construction experience. The homes were built in Oregon, equipped with air to air heat exchangers, and built to the advanced infiltration package. None of the homes were able to meet either the 1.8 ACH @ 50 PA advanced infiltration package goal either "before" or "after" house doctoring, although they all met the "standard" goal "before" house doctoring. These homes were tested after construction and therefore difficult to seal. The house doctor was based near the site and reported $13 in travel costs and $27 in RCDP reporting costs per house. Total costs varied from $125 to $200 per house.

Case D

These seven RCDP Cycle 2 homes were site-built, single-story homes without basements. The homes were built in Oregon by a large-volume builder with little energy efficient construction experience and a negative attitude about air sealing. Subsequently they were the leakiest of all house doctored RCDP homes. The builder was quoted in the survey as saying "Why should we build tight homes and then cut holes in them?" However, the following comments indicate that he felt the doctoring experience was valuable: "The insulation contractors who were responsible for the ALC need some training from the house doctor," and "I found it interesting to learn where the leakage sites were from the blower door testing." The homes were equipped with non-heat-recovery ventilators using the furnace fan to supply air to the home. The homes were not able to meet their standard infiltration package design goal of 7.0 ACH @ 50 PA. The house doctor reported that these homes were tested after construction and therefore difficult to seal. The house doctor also reported $24 in travel costs per home and tested all homes on one visit. The RCDP reporting costs were $9 per home.

Case E

These 26 homes were built throughout Washington, Oregon, Montana, and Idaho by 26 different builders and tested by 10 house doctors. They were largely built by small-volume builders with varied energy experience. In all but two homes, house doctoring took place during construction. Three homes were equipped with non-heat-recovery ventilators and standard infiltration package. All of these were able to meet the 7.0 ACH @ 50 PA performance goal of SGC standard infiltration packages and one required no additional tightening. Twenty-three homes were equipped with heat recovery ventilators and advanced infiltration package; 10 of these were able to meet the 1.80 ACH @ 50 PA performance goal via house doctoring, and 7 others required no additional tightening. Six of the advanced infiltration package homes were not able to meet the 1.8 ACH @ 50 PA by house doctoring, although in two, house doctoring took place after construction.

ECONOMIC ANALYSIS

Estimating Annual Energy Savings

Figure 1 presents the "before" and "after" house doctoring results in terms of ACH @ 50 PA for each case.

Estimated maximum annual energy cost savings from house doctoring is calculated using Equation (1). The overriding assumption of estimating annual savings is that the reduction in natural air exchange is not offset by the use of mechanical ventilation systems.

The maximum annual cost savings (MAXS) from house doctoring is estimated using Equation (1):

$$\mathrm{MAXS} = \frac{(\mathrm{ACH}_{bhd} - \mathrm{ACH}_{ahd})(\mathrm{Vol})(.018)(.05)(24)(\mathrm{DD55})}{(3413)\,(20)} \qquad (1)$$

where ACH_{bhd} = Air change rate @ 50 PA before HD
ACH_{ahd} = Air Change rate @ 50 PA after HD
ACH @ 50 PA is divided by 20 to acquire seasonal ACH
20 = RCDP average used to convert ACH @ 50 to seasonal ACH
Vol = Volume of building in cubic feet
.018 converts ACH to BTU/Hr at sea level
3413 convert Btu to KWh
$0.05 cost per kWh assumed
DD55 = Degree day @ base 55° (Zone 1 = 2393, Zone 2 = 4150, Zone 3 = 5023
24 hrs/day convert Btu/hr to Btu/day

An assumption that mechanical ventilation directly offsets the house doctored decreases in natural air exchange is a very conservative assumption for the following reasons:

1. If the house is not tight enough to require mechanical ventilation, there may be no need for mechanical ventilation. It is generally accepted in new residential BPA programs that homes with blower door tests that exceed 7.0 ACH @ 50 PA may not require mechanical ventilation. In this case (Case D), the actual energy savings is the maximum annual energy savings, as shown in Equation (1). Case D represents this situation because the "after" house doctor tests were in excess of 9.0 ACH @ 50 PA.
2. RCDP research has shown that in many homes tighter than 7.0 @ 50 PA, mechanical ventilation systems are rarely used and/or have little measurable effect on air exchange rates; (Lubliner 1988) (Palmiter 1990). Where this situation exists the energy savings may be close to the maximum as defined in Equation (1). It should be noted that some of this energy saving may be achieved at the expense of the indoor air quality.
3. Since mechanical ventilation effectiveness increases as the home gets tighter, it is important for mechanically ventilated homes to be tight. This is especially true for "balanced" ventilation systems, such as air- to-air heat exchangers. The term "build it tight and ventilate right" is quite often used by those involved in the Canadian R2000 energy efficient new home program. Mechanical ventilation is an efficient way of removing pollutants from the areas of the homes

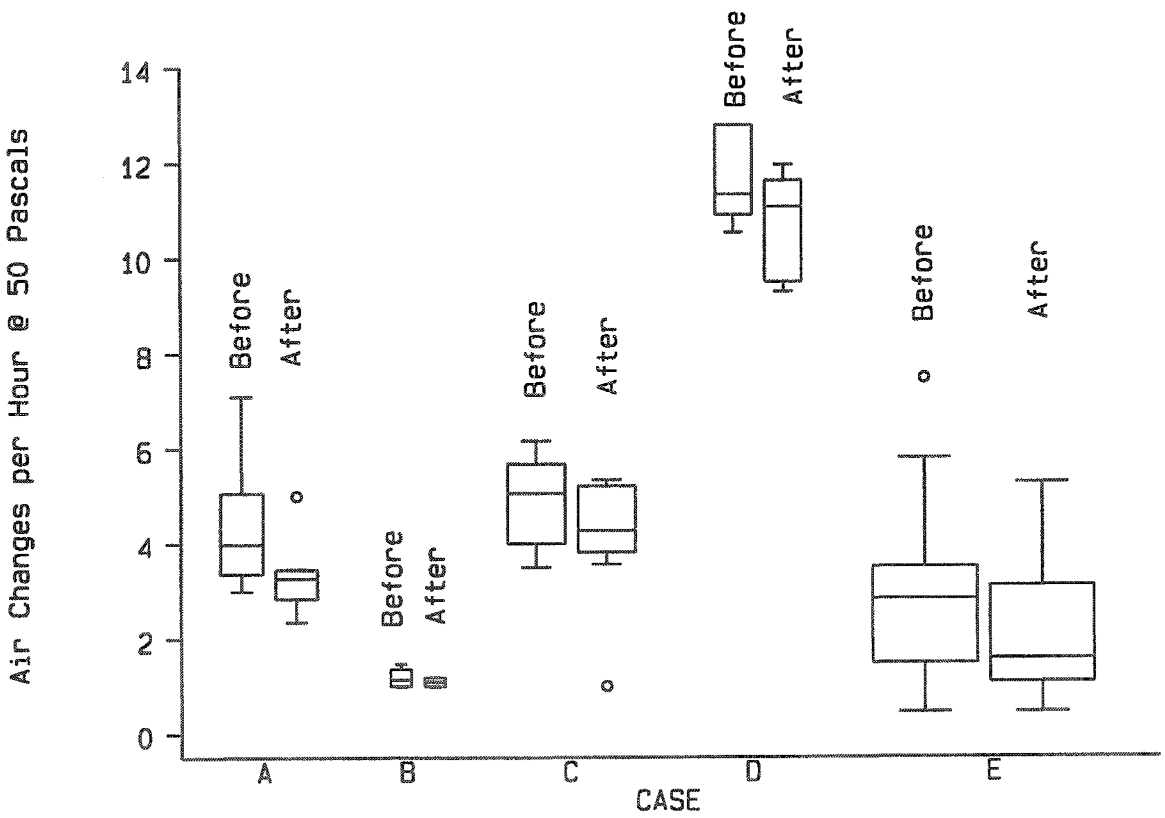

Figure 1. House Doctor Tightening Results

where the ventilation is needed. Mechanical ventilation is said to provide more uniform ventilation rates than natural ventilation and, thus, lower total airflow and improve indoor air quality (Feustel, Modera, and Rosenfeld 1986).

Mechanical ventilation of tighter homes also may improve the effectiveness of home ventilation because occupants have the ability to ventilate less at times when pollutant sources are low, or when the home is unoccupied (ASHRAE 1989). If mechanical ventilation systems in tight homes were to improve ventilation effectiveness, then the need to increase the mechanical ventilation rates to offset reductions in air exchange rates from house doctoring may be greatly reduced.

In this situation annual energy savings from house doctoring is a function of the ventilation effectiveness, although ventilation effectiveness is difficult to estimate. For this analysis report it was assumed that increases in ventilation effectiveness offset reductions in natural ventilation from house doctoring.

4. If the reader believes that increases in ventilation effectiveness do not justify the assumption that the actual energy saving is equivalent to the maximum energy savings as defined in Equation (1), then heat recover is required. Energy savings from heat recovery ventilation equipment that offset house doctored natural infiltration reductions would be the energy saved. A 60 percent heat recovery factor would be used to calculate these savings as shown in Equation (2) (NWPPC 1986). In all cases except Case D, heat recovery equipment was installed. Therefore Equation (2) would represent the minimum annual energy savings for cases A, B, C, and E.

The minimum annual cost savings (MAXS) from house doctoring is estimated using Equation 2. (2)

Heat recovery MINS = MAXS*60%
Where 60% is the assumed heat recovery efficiency.

House Doctor Cost

Figure 2 presents the cost for the house doctor service by case. These costs were acquired from the RCDP house doctor data forms (RCDP 1988). For some house doctors this cost was almost identical to the $200 house doctoring builder incentive that RCDP provided.

This raises a question regarding whether the incentive affected house tightness. In five cases house doctor #1 also acted as the subcontractor and was totally responsible for all air leakage control tasks and materials. In those instances the total costs reported by the house doctor were as high as $1500, and were not included in the cost analysis results.

The cost analysis is based on expenses such as material, labor, and travel. When costs are broken down by the house doctor they are provided separately. In many cases a good portion, from $100 to $200 of the house doctor costs, were used for completing work beyond normal house doctoring activities that were required for RCDP research, including extensive documentation and multiple blower door tests. Ninety-two dollars was the average reported cost associated with RCDP additional reporting and testing requirements.

After a phone debriefing with house doctors #1 and #13, the costs of the normal house doctoring service (the actual finding and sealing of leaks) were estimated for the analysis to be $50 less than the total reported in RCDP. In eight cases the homes were already tight and minimal house doctoring was conducted. In these cases the builders were still charged for travel and testing costs, yet there were no energy savings from house doctoring.

Homeowner Life Cycle Savings from House Doctoring

The calculated life cycle savings presented in Figure 3 are determined by taking the reported house doctor costs for each home, subtracting $50 for the RCDP programmatic reporting and additional blower door testing, and multiplying that cost by a 20 percent builder mark-up. The results are presented in Figure 4 for only those homes where house doctoring actually took place.

The economic assumptions included for the life cycle savings cost analysis are as follows:

loan period = 30 years
downpayment = 10%
real fuel escalation rate = 1.0%
real consumer discount rate 3.0%
expected life = 30 years
real mortgage rate = 6.2%

CONCLUSIONS

The following conclusions are based on the case study experiences of the house doctoring in RCDP and on analysis of the house doctor blower door tests and cost data.

House doctoring increased the house tightness significantly, on average from 3.49 to 2.78 ACH @ 50 PA for the advanced infiltration package homes (Cases A, B, C, and E). For the standard infiltration package homes, (Case D), significant differences were also found (house tightness went from 11.63 to 10.85 ACH @ 50 PA); however, this may be due to the small sample size for this case. These results indicate how house doctoring new residential construction can significantly tighten new energy efficient electrically heated homes.

For all cases RCDP per home house doctor house tightening costs varied from $100 to $391 and averaged $207 with a standard deviation of $81. This included costs incurred only for the actual finding and sealing of leaks. An estimated $50 was subtracted from the total cost to eliminate RCDP programmatic testing and reporting requirements. A 20 percent builder-to-homebuyer mark-up was also added to the costs. In addition, the cost did not include five homes with costs of $520 to $2500 where one house doctor performed all ALC work as a subcontractor.

Average life cycle savings for house doctoring where actual house doctoring took place was $162 with a standard deviation of $354. Life cycle savings for all homes averaged $109 with a standard deviation of $338.

Nine out of 32 advanced infiltration package homes that did not comply with the 1.8 @ 50 PA

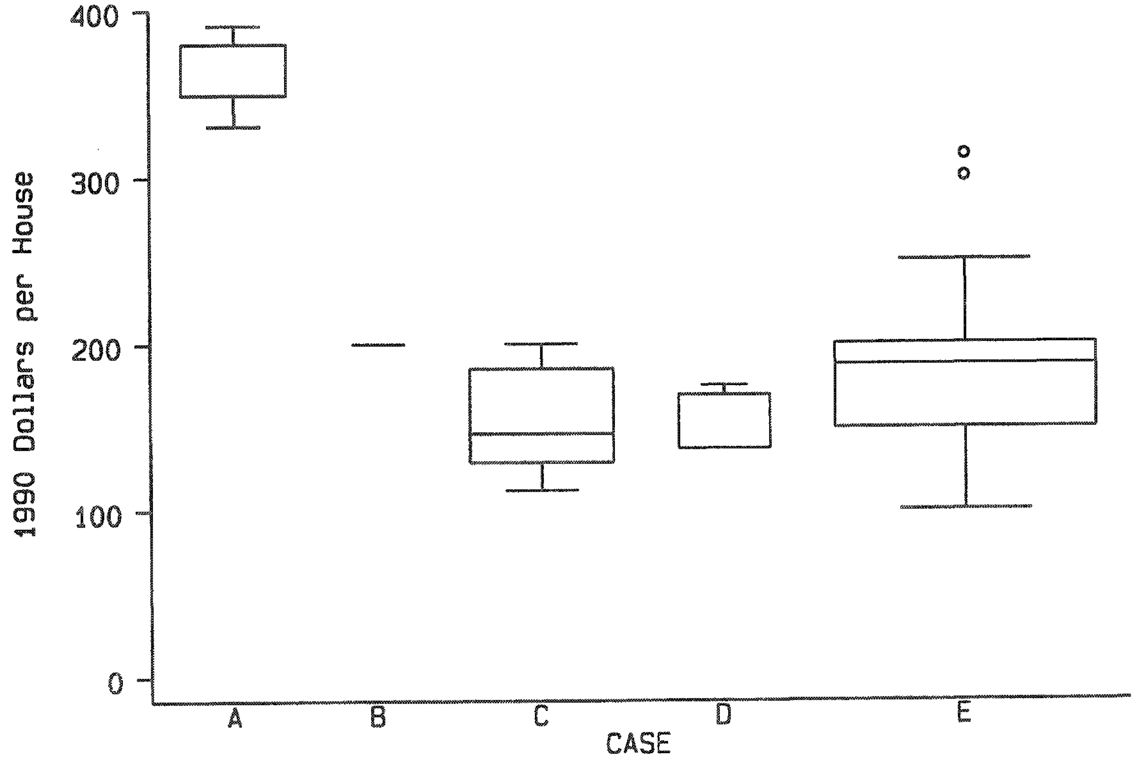

Figure 2. House Doctor Costs

performance goal "before" house doctoring were tightened by house doctors to comply with SGC house tightness performance standards (Case E). This suggests that house doctoring can be an effective tool in meeting the SGC advanced infiltration package goals.

Seven out of 45 advanced infiltration package homes required no house doctoring because they were found to be below 1.8 ACH @ 50 PA by the house doctor during the "before" house doctoring test (Cases B and E). Builders most experienced with energy efficient construction, air leakage control, and house doctoring may not need house doctoring to achieve SGC advanced infiltration package performance goals (Cases B and E).

Builders and their ALC subcontractors who experienced the benefits of house doctoring in one home may apply what they learned in future homes, thus producing ongoing energy savings.

Two out of 13 advanced infiltration package homes that were found to be below 1.8 ACH @ 50 PA by the house doctor during the "before" house doctoring test were tightened further by house doctors (Case B). This suggests that the specific goals of "how tight should the home be house doctored" need to be defined by the builder and doctor. It also suggests that further research investigations may be required regarding where the optimum cost/benefits of house doctoring exist.

The experiences of house doctors #13, #4, #9, and #1 indicate that house doctoring was more difficult when it occurred after occupancy. House doctor #1, who was most familiar with house doctoring new construction, reported that the ideal time to house doctor was after sheetrock, paint, and windows but before trim, carpets, and roof insulation.

Energy savings associated with house doctoring new residential energy efficient construction may not translate directly to energy savings if the increased tightness due to house doctoring is offset by an increased need to provide mechanical ventilation.

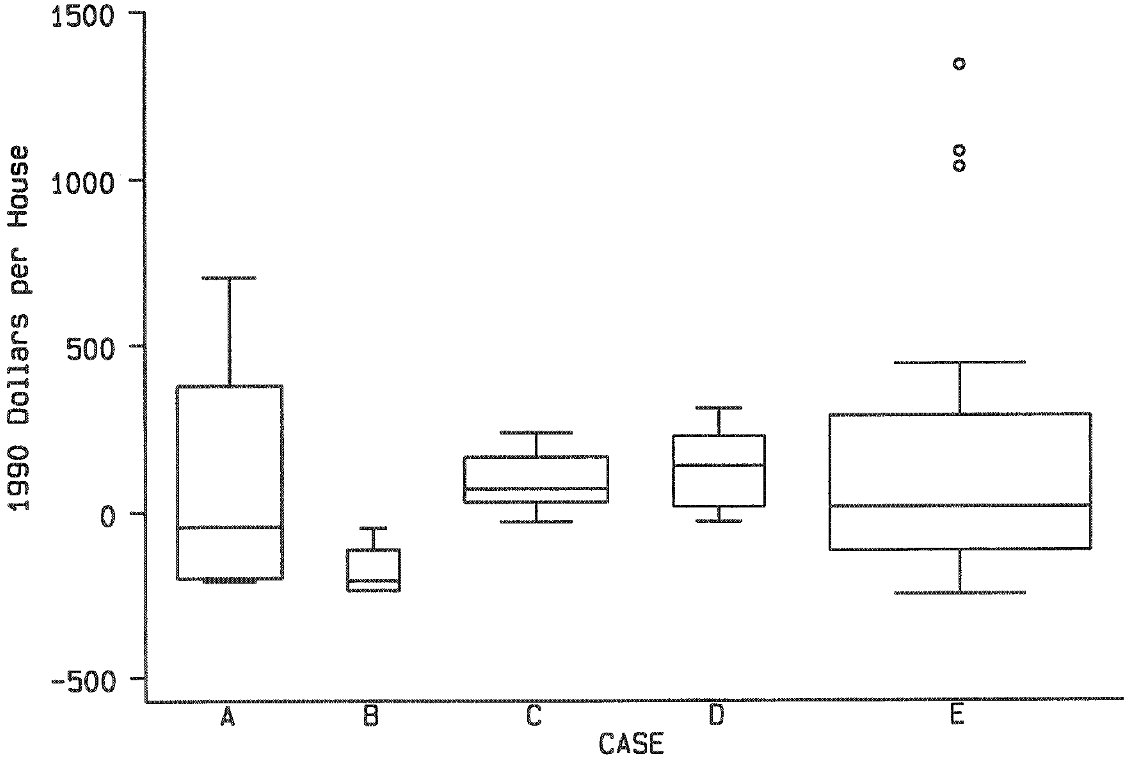

Figure 3. Life Cycle Savings - All Homes

This offset is reduced if heat recovery ventilation equipment is employed. However, if the house doctoring brings the home down to tightness levels that do not typically require mechanical ventilation, then an increase in house tightness from house doctoring may translate directly to energy savings.

Increasing the house tightness from house doctoring may improve the mechanical ventilation effectiveness (ability to supply sufficient amounts of outdoor air to each zone of the home when needed). Benefits from improved ventilation effectiveness may sufficiently offset any need for increased ventilation due to house tightness increases from house doctoring.

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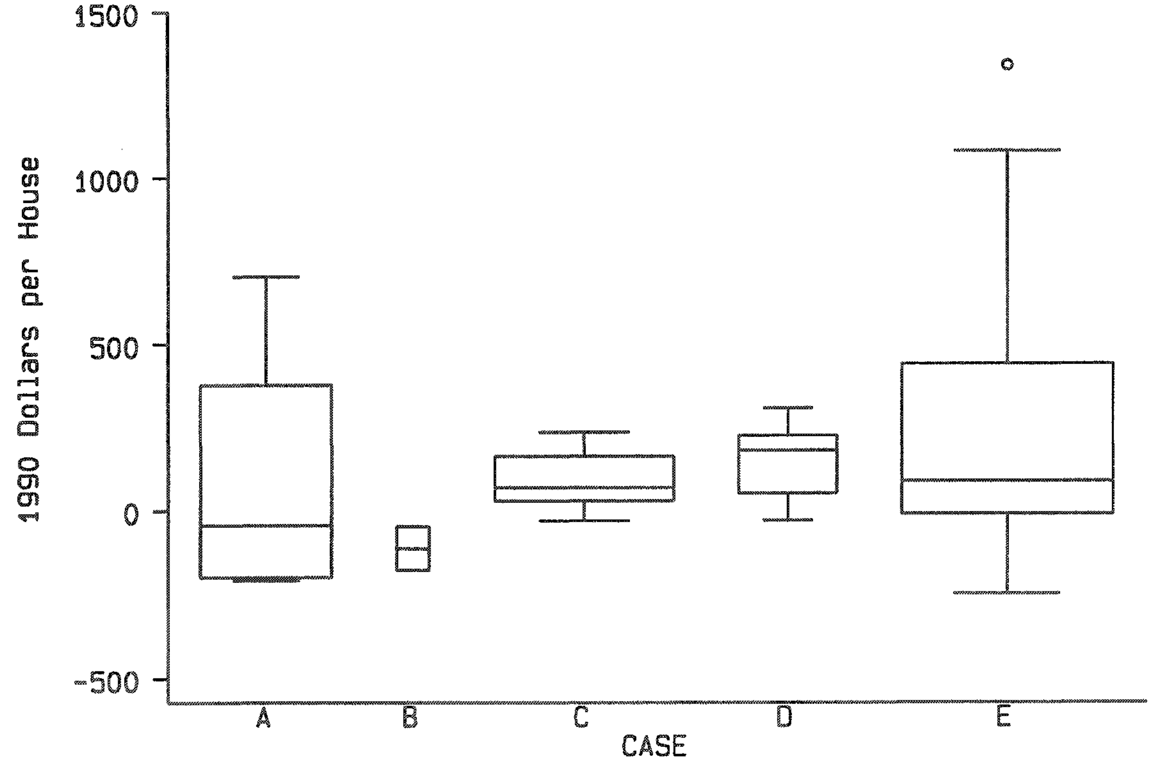

Figure 4. Life Cycle Savings - House Doctored Homes

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