THE INFILTRATION STATION:
AIR LEAKS IN A 1924 HOUSE IN DOWNTOWN EUGENE

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ABSTRACT

Infiltration is a common source of heat loss, especially in older homes. This case study focused on a 1924 house in the downtown Eugene area. Infiltration in this home is excessive due to a basement door left open at all times, a fireplace lacking a damper, and vents left over from a defunct oil heater. We hypothesized that sealing these large leaks would reduce the infiltration by 50%. A blower door was used to test this hypothesis. The blower door was also used to identify additional air leaks after the implementation of solutions. This study found that these improvements reduced the infiltration by 43% and that the greatest contributor, by far, was the door left open to the basement. Further analysis revealed that this reduction in infiltration could lead to cost savings of up to $60 in a winter month.

1. INTRODUCTION

"When there is a fire in the fireplace, the room gets colder." This statement by homeowner and fellow student Rebecca Mann grabbed our attention and convinced us to study the temperature in her house during the winter months.

This case study was assigned in ARCH 491 Environmental Control Systems as a term project. It focuses on the physical performance of a historic home in the downtown Eugene area—owned by a fellow student—with the intent of improving the performance of its environmental control systems. During the process of the case study, we hoped to gain a better understanding of the building envelope, specifically the processes contributing to the heat loss from the building.

Rebecca shares the house with Sara and two cats, Nitro and Talula. The house was built in 1924. It is 1000 square feet, with two bedrooms and one bathroom. Most of the historic integrity is maintained. The original oil furnace remains below a large grate in the living room, but electric baseboard heaters are now the primary source of heat. The vents to the furnace have been partially plugged with cardboard. Other improvements include the addition of storm windows on the exterior of the original wood sash windows, caulking in the basement, and paint. The original chimney lacks a damper.

Figure 1: Reenactment of the problem

Figure 2: The house in winter

A cursory tour of the home revealed that air infiltration was the chief contributor to heat loss. This conclusion was reinforced by the *Handbook of Heating, Ventilation, and Air Conditioning*, which states that "infiltration is the dominant force" contributing to heat loss in single-family homes (1). Infiltration is defined as "unintended influx of outdoor air due to air leakage through the building skin" (2). The inspection report from the house purchase states that the insulation in the floor and ceilings is adequate, but that the chimney lacks a damper (3). Interviews revealed that the retired oil furnace system still punctured the floor in three places, and that the door to the uninsulated basement remains open at all times for pet traffic.

Figure 3: Vent to oil furnace

2. HYPOTHESIS

An inspection of the home revealed three contributors to infiltration that needed to be studied: the open basement door, the defunct oil furnace vents, and the fireplace.

The following solutions will significantly reduce the house's infiltration problem:

- Install a cat door into the basement door and keep the basement door closed.
- Plug the vents to the defunct oil heater with rigid insulation and foil tape.
- Install a damper in the chimney.

Closing the basement door, plugging the defunct oil furnace vents, and sealing the fireplace will result in a 50% reduction in infiltration in terms of CFM50.

Figure 4: Curtain separating heated space from uninsulated basement

3. METHOD & EQUIPMENT

3.1 Methodology

Two primary means of testing infiltration were identified: the blower door and tracer gas testing. Blower door testing was chosen for the following reasons:
- appropriateness to the small scale of the project
- low cost
- easy to understand method
- availability.

Air tightness is measured with a blower door by running a CFM50 test: The fan speed is increased until a pressure differential of 50 Pa from the outside air was reached. At this point the fan speed was read and converted to CFM. This reading is called CFM50 and can be used to compare the air tightness of the home before and after each solution is implemented.

3.2 Equipment and Set-Up

A blower door from Minneapolis Blower Doors was used to conduct testing. The blower door measures air tightness and can aid in determining the source of leaks.

Following the instructions from the blower door manual and information video, the blower door was installed in the main entrance door of the house and the gauges were tared for accurate measurement.

Figure 5: Blower door & Nitro.

The house was prepared for testing by ensuring that all doors and windows to the exterior were closed and that all interior doors were open.

3.3 Control

A one point CFM50 test was conducted following the instructions given by Minneapolis Blower Door. Fan speed was increased until the house pressure gauge read 50 Pa. The fan flow gauge was read, and this information was used to determine how many cubic feet per minute of air was required to flow through the fan to maintain a 50 Pa pressure within the house.

This reading became the control reading against which the solutions to the house's infiltration problems were tested.

Figure 6: Blower door fan pulling curtain into the main kitchen/living area.

Figure 7: Krystan blown away by open oil heating vent.

3.4 Testing of Hypothesis

Each solution was tested individually so that the solution provided the most reduction in infiltration could be determined.

The basement door was closed, then the one point CFM50 test was repeated, and the results were recorded.

The basement door was re-opened so that it would not influence the results when testing the effectiveness of the vent covers.

Next, the rigid insulation vent covers were installed in the main heating vent in the living room and the two ancillary heating registers in the hall and living room. The CFM50 test was repeated and the results were recorded.

The rigid insulation was removed from the vent covers so that they would not influence the results when testing the effectiveness of sealing the chimney.

The fireplace doors were then closed and sealed with duct tape. The CFM50 test was repeated and the results recorded.

Finally, all solutions were implemented and tested together.

3.5 Further Study

With all three solutions in place, the fan direction was reversed to find remaining air leaks. These leaks were found by feeling for them by hand and holding a burning stick of incense near them. The smoke from the incense follows the path of the leaks.

4. RESULTS

4.1 Testing of Hypothesis

Using the table provided in the blower door manual, the Fan Pressure readings from the gauges on the blower door were converted into CFM50. The percent reduction in CFM50 due to each change was then calculated. The percent reduction correlates with the amount of infiltration due to each source of infiltration.
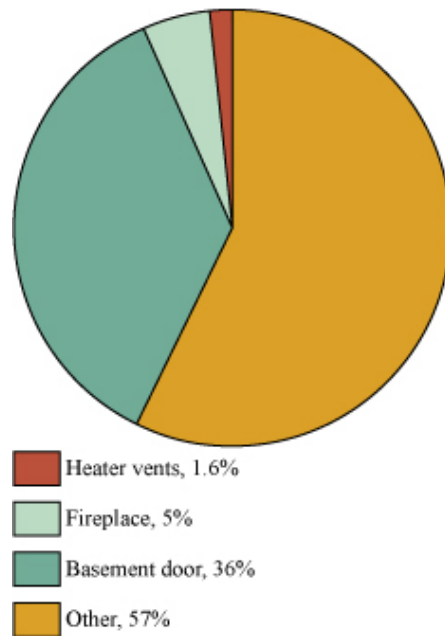

Heater vents, 1.6%
Fireplace, 5%
Basement door, 36%
Other, 57%

Figure 8: Percent of Infiltration Due to Each Source

Figure 9: Locations of Major Infiltration Sources

TABLE 1: PERCENT REDUCTION IN CFM50

TEST	DESCRIPTION	FAN PRESSURE (Pa)	CFM50	PERCENT REDUCTION
1	Control: All sites open	62.5	3773	-
2	Basement door closed	25	2407.5	36.19%
3	Heating vents plugged	60	3713	1.59%
4	Fireplace sealed	56	3588	4.90%
5	All solutions implemented	20	2156	42.86%

5. ANAYLYSIS

5.1 CFM50's Correlation with Actual Infiltration

CFM50 readings roughly correlate with actual infiltration. Average annual air changes per hour can be determined by dividing the ACH50 by a correlation factor, N. This correlation factor was developed by the Lawrence Berkeley Laboratory (LBL) in order to account for the following:

- *Climate:* Temperature and seasonal windiness affect the amount of infiltration into a building.
- *Stack effect:* A taller building experiences more infiltration because the stack effect draws more air in from the lower levels.
- *Windiness and wind shielding:* Higher winds force more air into a building and increase infiltration.
- *Type of leaks:* The size and shape of the holes affects the leakage behavior. For example, a round hole responds more to air pressure changes than a long thin crack does (4).

The correction factor N is determined by multiplying each influential condition's correction factor. The following table lists the LBL correction factors for this site.

TABLE 2: LBL CORRELATION FACTOR

INFLUENCE	CONDITION	CORRECTION FACTORS
Climate	Location: Oregon	23
Building Height	Single story house	1.0
Wind Shielding	Normal wind conditions	1.0
Leakiness	Old house	0.7

Therefore, the correction factor (N) used to find the average air changes during a year is 16.1.

TABLE 3: ESTIMATED AVERAGE INFILTRATION DUE TO EACH SOURCE

SOURCE	BASEMENT DOOR	HEATER VENTS	FIRE-PLACE	ALL SOURCES
CFM50	1365.5	60	185	3773
ACH50	9.10	0.40	1.23	25.15
Avg. ACH	0.57	0.02	0.08	1.56
Avg. CFM	84.81	3.73	11.49	234.35

According to ColoradoEnergy.org, the total infiltration for a typical old very leaky home is 1 ACH (5). The infiltration in this home contributed by the basement door, heater vents, and fireplace alone is more than %150 of the typical leaky home's total infiltration.

5.2 Costs of Infiltration

Rebecca uses electric heat during the winter. At these times, her electric bills average over $100 per month, nearly twice what she spends in warmer months, when she neither heats nor cools. Plug loads are low in comparison to the heating loads because both Rebecca and Sara are graduate architecture students, and the majority of their time is spent away from the home. Because the infiltration in the home is so much higher than typical, infiltration has a significant effect on the electricity costs for the home.

Using the average infiltration, the actual costs of infiltration at Rebecca's house can be determined. First, the estimated infiltration is converted to BTUs/hr, using the following equation (2):
$$Q \text{ (BTUs/hr)} = 1.1 * CFM * \Delta T$$

Rebecca says that she keeps her house at 70°F when she heats the house, and she only heats the house when the temperature outside is below 60°F. This analysis, therefore, includes only those months where the average temperature was below 60°F. According to EWEB, within the last year,

the monthly temperature averaged below 60°F during the months between November and April.

Comparing the infiltration heat loss before and after the solutions were implemented gives the savings in kilowatt-hours.

EWEB bills for electricity used during winter months as follows (6):

Basic Charge	$6.50 / month
Delivery Charge (all usage)	$0.02748 / kWh
First 800 kWh	$0.03996 / kWh
Next 2,200 kWh	$0.05641 / kWh
Over 3,000 kWh	$0.06860 / kWh

Plug loads and other non-infiltration loads were assumed to remain the same, and these generally contribute up to 800 kWh per month, at a total rate of $0.06696 / kWh. The electricity usage due to infiltration puts the total electricity usage over 800 kWh and into the next price bracket—a total rate of $0.08341 / kWh. Thus, the cost of electricity used due to infiltration is overrepresented in the bill by 25%, making the infiltration even more expensive.

5.3 Other Sources of Infiltration

After the tested solutions were implemented, an additional test was performed to find additional sources of infiltration. The remaining major sources of infiltration can be found on the following plan.
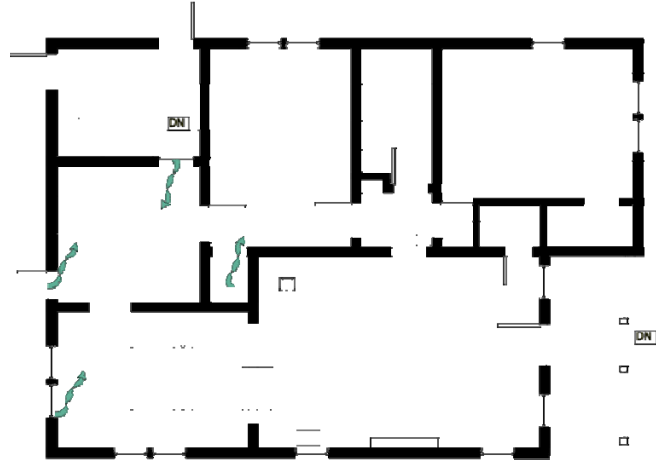

Figure 10: Locations of Remaining Major Infiltration Sources

TABLE 4: REDUCTION OF INFILTRATION COSTS

YEAR	2008						2009
MONTH	Feb	Mar	Apr	May	Nov	Dec	Jan
AVERAGE TEMPURATURE (F)	39	47	51	56	50	39	39
KW HOURS	1658	1294	1143	979	1166	1698	1618
KWH SAVINGS	722	536	423	326	466	722	722
TOTAL KWH AFTER SAVINGS	936	758	720	653	700	976	896
ELECTRIC COSTS BEFORE ($)	132.42	101.88	89.22	75.45	91.16	135.79	129.07
ELECTRIC COSTS AFTER ($)	71.86	57.61	55.05	50.52	53.71	75.22	68.51
MONTHLY COST SAVINGS ($)	60.57	44.27	34.17	24.93	37.45	60.57	60.57
% COST SAVINGS	45.74	43.46	38.30	33.04	41.08	44.61	46.93
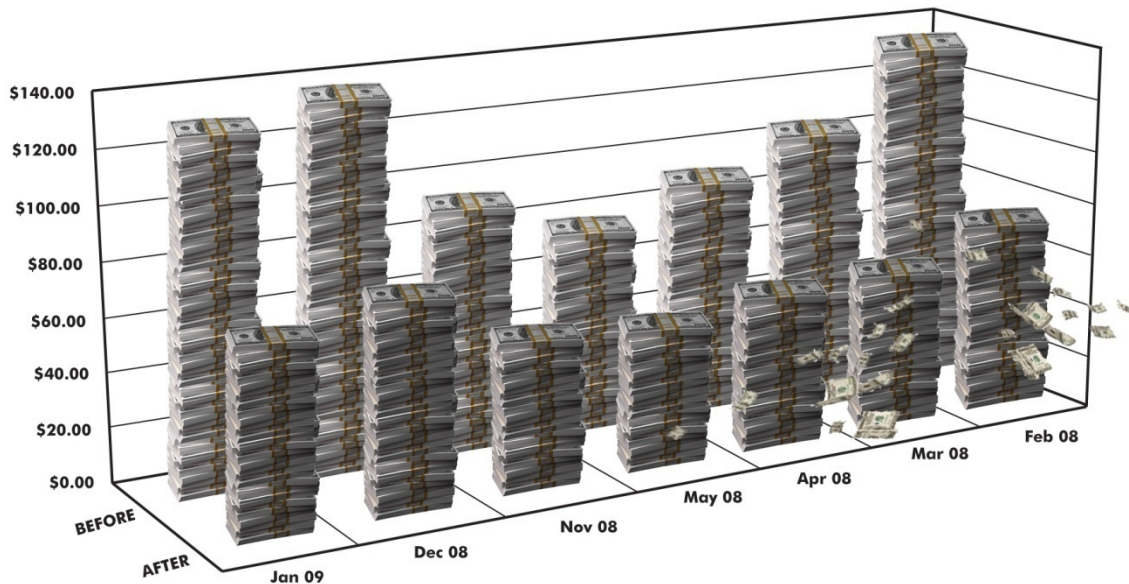
Figure 11: Estimated Cost Savings for Winter Months

6. CONCLUSIONS

6.1 Discussion

While the hypothesis predicting a CFM50 reduction of 50% was not fully realized, significant reductions in infiltration were still achieved. By sealing all three openings, the CFM50 was reduced by 42.86%.

The retired heating ductwork and floor openings contributed least to the infiltration in the tests, which indicates that the old system is more contained than initially anticipated. There were vent louvers in the cavity for the main furnace assembly, which were pushed closed by both the existing and new efforts to insulate that space.

The fireplace was more of an influence than the floor vents, which indicates that the fireplace is really a connector between the living space and the outside air, rather than the switch it pretends to be.

As anticipated, the primary connector was the open door to the basement, which connects the main living space to two outside doors, which are not well sealed, and the basement itself, which is not insulated at all.

Because of the duration of this study, the following month's power bill with the solutions in place cannot be analyzed, but estimated savings should be about $60.

6.2 Lessons Learned

While the projected reduction in infiltration was not met, the envelope's seal was significantly improved. Rebecca's house, like many old homes in Eugene, was constructed during a time when the extent of costs due to infiltration was not entirely understood, and energy costs were much lower. Even today, owners are most likely unaware of the amount of heat that is lost through a leaky envelope. Rebecca was amazed that making these three modifications to the house could potentially save 47% of her current heating bill (assuming a constant outdoor temperature of 30 degrees). It was also learned that precautions should be taken around open furnace pits when performing the infiltration smoke test.

Figure 12: Sara falling into the pit.

7. ACKNOWLEDGMENTS

8. REFERENCES

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