THE ICEBOX BUNGALOW

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ABSTRACT

The assembly components of floors, wall and roof and thermal conduction of walls of a 1953, 732 square foot bungalow were evaluated using visual inspection, infrared digital thermometer, and infrared camera. The assessment was made to determine if the envelope met ASHRAE standards. Measurements were made with and without home heating on. Following initial measurements, a second assessment was carried out with insulating foam panels added against the east (inner) side of the living room wall. After calculating u values for the envelope and estimating heat loss, the opportunity costs of insulation purchase was evaluated against CO_2 production and natural gas heating costs. Indoor relative humidity exceeded ASHRAE indoor air quality levels. Fuel savings over 29 months and 50 months would cover the cost of installing additional insulation for the floor and wall respectively.

Fig. 1: The ice box bungalow

1. INTRODUCTION

Natural gas is a common home heating fuel. According to the Energy Information Administration of the US Department of Energy, 60.5 million households use natural gas for heating in the U.S., spending an average of $526 per household per year[i]. In Eugene, there is a large stock of 1950's bungalows, which most likely do not meet current ASHRAE standards for envelope U values, many of which use natural gas for space heating. The icebox bungalow is one such home. We chose to pursue this research topic because the homeowner (and team member) experienced an extremely low level of thermal comfort in the home she and her husband had recently purchased. The project goal was to indentify cost effective solutions to increase the thermal comfort in the house, decrease the heating costs and decrease the amount of CO_2 being released to the atmosphere from home heating.

2. HYPOTHESIS

The wall assembly of Jessie's house does not meet ASHRAE Standard 55-2004 for thermal comfort.

TABLE 1: ASHRAE STANDARD 55-2004
(MEEB Table G1)[ii]

Envelope Component	Maximum U-Value **Btu/ºF h ft^2**
Floor	0.066
Light Framed Wall	0.089
Fixed Window	1.22
Roof	0.081

3. METHODOLOGY

3.1 Preliminary tour and assessment

A preliminary assessment was carried out during a house tour. Cursory evaluation using a Ray-Tek® infrared thermometer indicated that significant heat transfer was occurring through the living room wall and window (data not included). Based on this information, we decided to inspect the floor, wall and roof assembly, and measure temperature differences between the interior and exterior wall surfaces in order to calculate the heat loss (q=Btu/h). Figure 2 shows the floor plan and measurement locations.

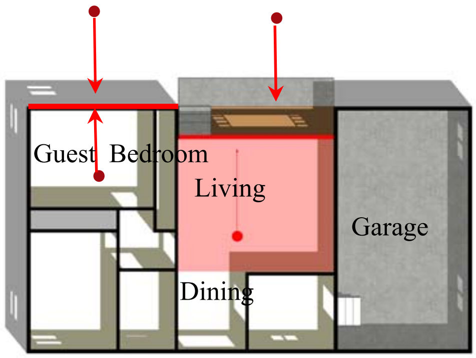


Fig. 2: Floor plan and measurement locations.

- Researcher position taking sling psychrometer and IR thermometer

3.2 <u>Envelope assembly</u>

The research team inspected the house exterior and interior including crawl space and attic. The assembly materials were recorded, and the house measured. U-values were calculated based on the materials and assembly of the home, as well as temperature differences between interior and exterior before and during heating.

3.3 <u>Thermal Integrity</u>

- Surface temperatures of the east walls of the living room and spare bedroom were measured using a Ray-Tek® infrared thermometer over a 2' x 3' grid. Eighteen and twelve locations were measured on the living room and bedroom walls, respectively.
- Air temperature (wet bulb and dry bulb) was taken using a sling psychrometer.
- Air temp, and surfaces temperatures were collected at T=0 indoors and outdoors for both rooms. Then the heating source (electric wall heater and gas fireplace) for the house were turned on, and measurements taken again in 20-minute intervals for a total of 6 readings.
- Thermal images using the Flir Thermacam B2® infrared camera were taken at the beginning, the mid and end point of the data collection.

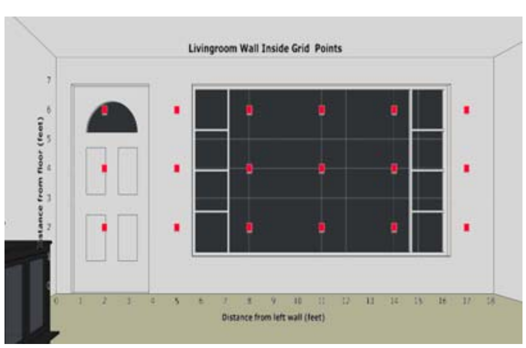


Fig. 3: Key to 2' by 3' living room wall grid

Measurements were taken in the early evening between 19:00 and 21:00 hours.

3.4 <u>Insulation Addition</u>

Four days following the initial evaluation, 2" poly-isocyanurate foam panels were placed against the living room wall. Measurements were repeated in the living room only. Data collection intervals were extended from 20 to 60 minutes. A total of three measurements were taken over two hours. Measurements were taken at the same time of day as previously.

4. <u>DATA ANALYSIS</u>

4.1 <u>Wall Assembly</u>

The construction of the house was determined from the physical inspection of the crawl space, walls and attic and documents from a professional home inspection service carried out as part of the home purchase. Figure 4 shows a typical section of the exterior wall.

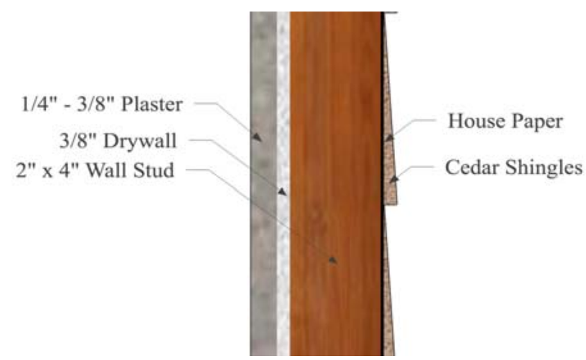


Fig. 4: Typical Exterior Wall Assembly

4.2 <u>Relative Humidity, Temperature, and Dew Point</u>

On both testing days, exterior temperature dropped over time and interior temperature increased when the electric and gas heaters were running. At time zero on each day relative humidity in house was above ASHRAE standard 55-2004 for thermal comfort. As the interior temperature increased, the relative humidity decreased to within the standard range. On day one, the interior dew point increased over time, yet stayed constant on the second test day when insulation was used. Overall, there was no correlation found between interior and exterior temperature. Ambient air conditions from day one are shown in figure 5a and 5b.

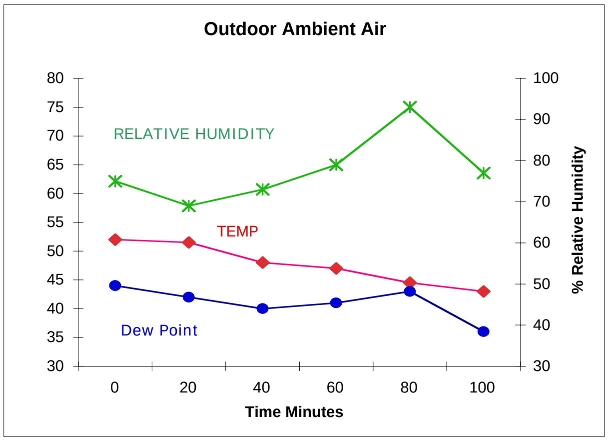


Fig. 5a: Ambient Living Room Temperatures (Day 1)

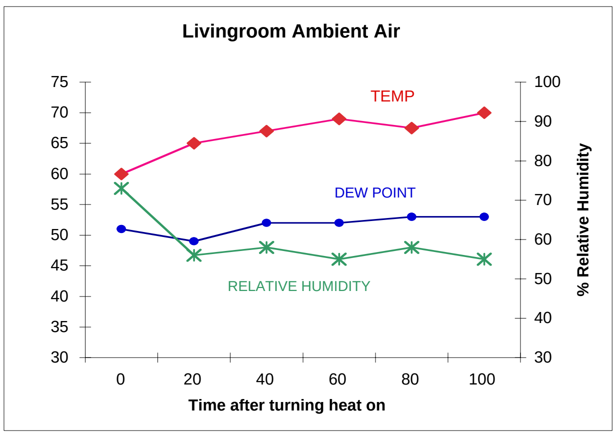
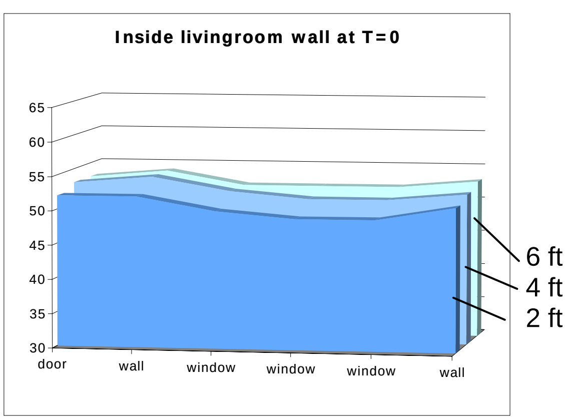
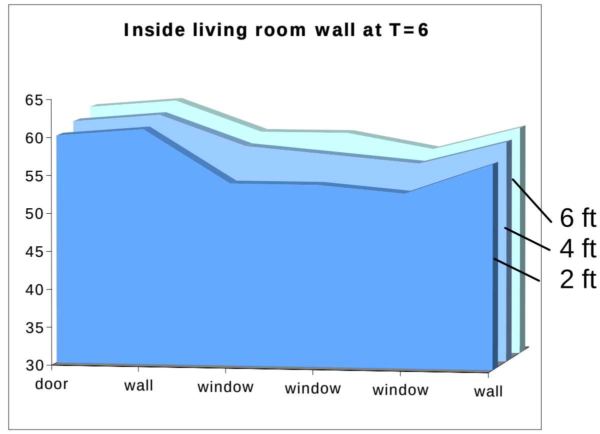


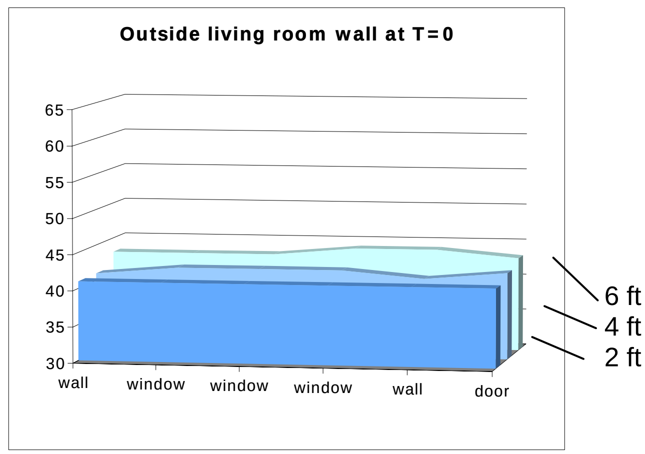
Fig. 5b: Outdoor Ambient temperatures (Day 1)

4.3 Wall Surface Temperatures

RayTek® measurements are summarized in figures 6 and 7. Figure 6 shows interior and exterior wall temperatures for the living room on day one. Figure 7 shows measurements for living room walls with insulation in place. Similar relationships to temperature and material were seen in the bedroom results on day one (not shown).







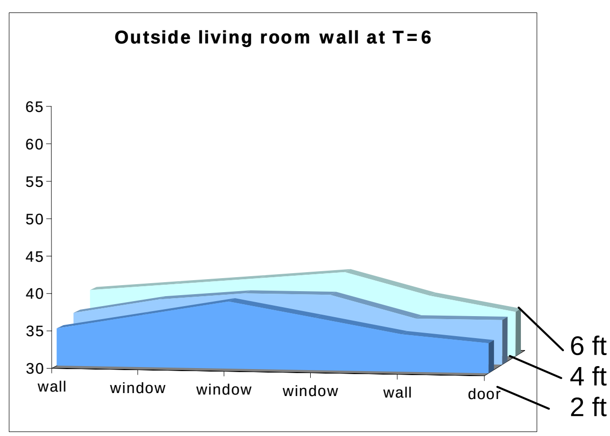
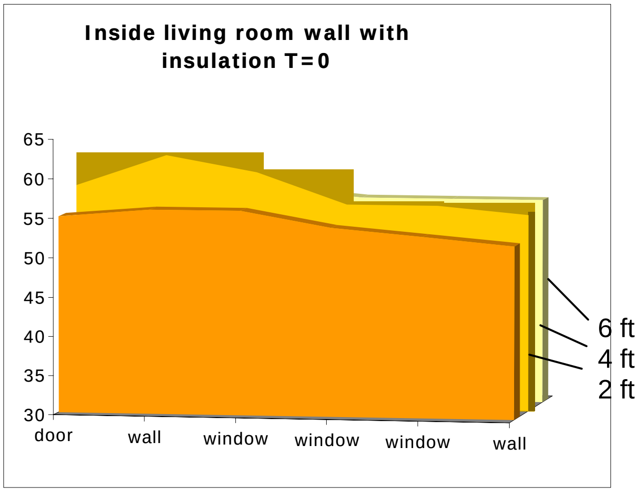
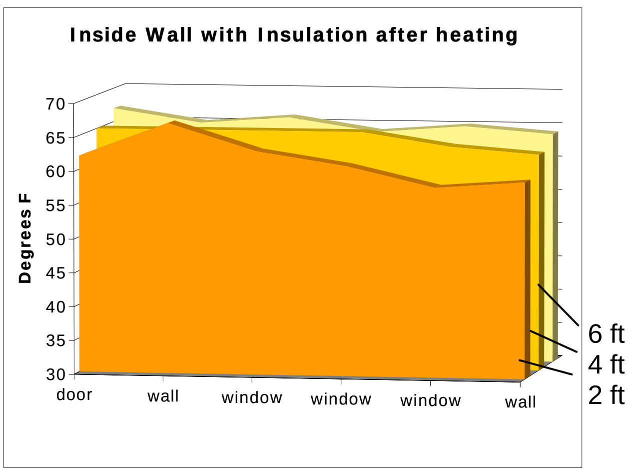
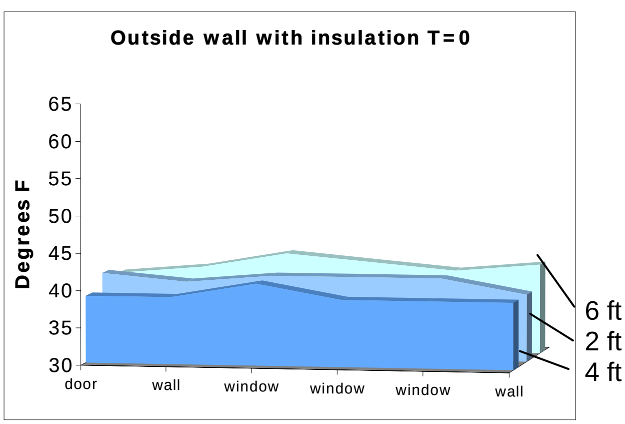


Fig. 6: Living room wall surface temperatures (Day 1)







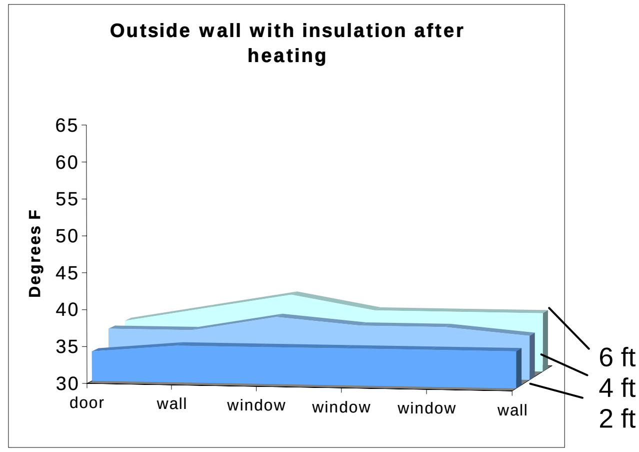


Figure 7: Living room wall surface temperatures with insulation

4.4 Image Analysis From Infrared Camera

The following images highlight the amount of heat loss occurring through the building envelope. Infra-red photographs from a properly insulated house are included for comparative analysis.

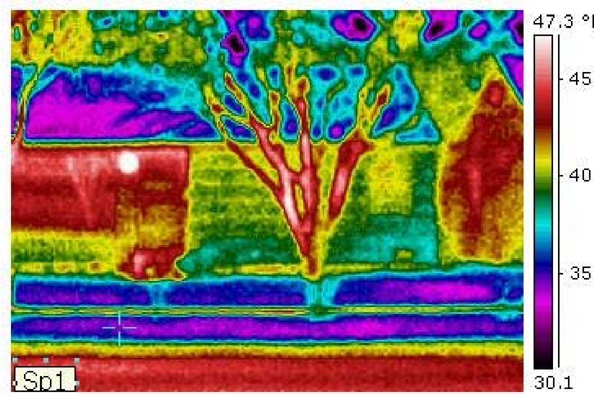


Fig. 8: Test House, Day 1 at T_0

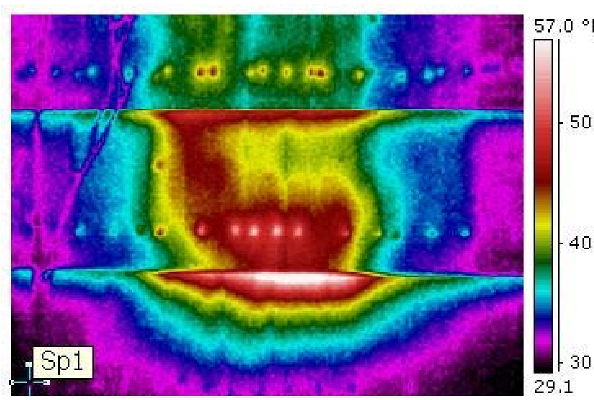


Fig. 9: Heat transfer from bedroom wall heating unit - Notice the thermal bridging of siding nails.

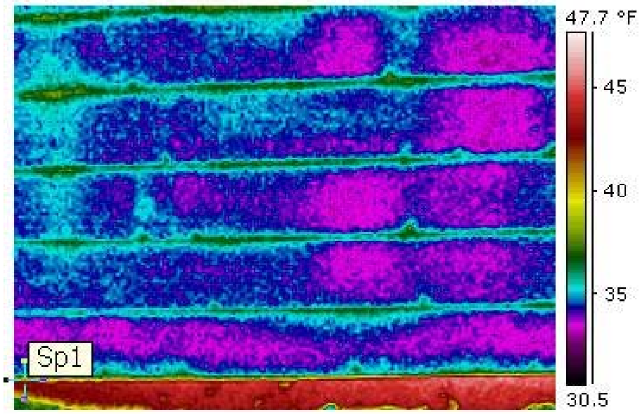


Fig. 10: Comparative IR photo of properly insulated wall

Fig. 11a: Test House, Day 1 at T_0

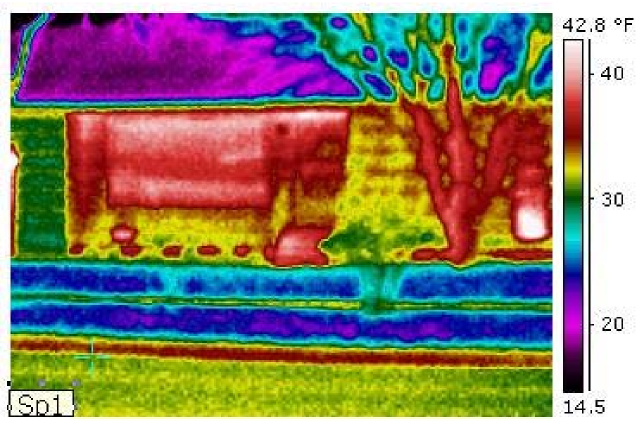


Fig. 11b: Test House, Day 1 at T_6 - Notice the wall-heating unit on the right.

4.4 <u>Total Design Heat Loss</u>

Assembly materials and R values of the unimproved thermal envelopes are calculated in Table 2. Table 3 below shows that the floors and walls of the bungalow did not meet ASHRAE standards for maximum U value.

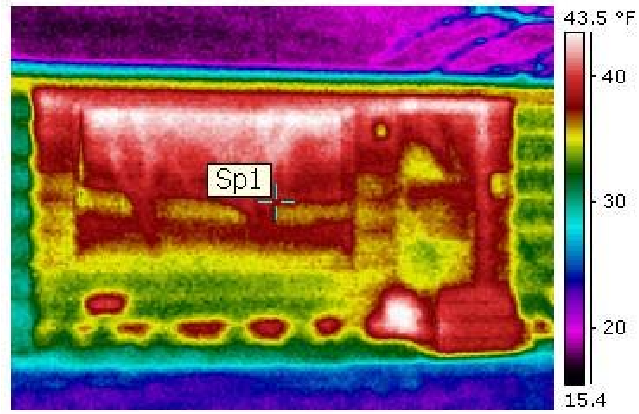


Fig. 12: Test house, Day 2 at T_6 - rigid foam insulation

4.5 <u>Economic And Environmental Costs</u>

According to the analysis of R, U and q values in Table 4, the total heat loss in the bungalow was 1.83 therms/ day. In a 19 day billing period with NW Natural the house used a total of 50 therms. Our theoretical heat loss of 1.83 therms/ day for 19 days is equal to 34.77 therms. Therefore, calculations show that approximately 70% of the heat energy used was lost through the thermal envelope.

4.5.1 <u>Economic Cost</u>

Northwest Natural Gas charges $1.05 per therm. A typical heating period in Eugene is approximately 4785 heating degree-days[1] for a total of approximately 586 therms per year or $615.00.

4.5.2 <u>Environmental Cost</u>

One therm of natural gas emits 11.7 pounds of $C0_2$ when burned. If no improvements are made and the heating losses remain at 70%, a total of approximately 410 therms are lost, resulting in 2.4 tons of CO_2 produced without effectively heating the home.

4.6 <u>Cost - Benefit Analysis of Installing Insulation</u>

4.6.1 <u>Wall and Floor Insulation</u>
Ceiling and roof insulation was adequate and did not need augmentation. The walls and floor needed higher R values

to meet ASHRAE standards. Approximately 2/3 of the total floor area needs insulation. By installing R-19 fiberglass batt insulation the new R value would be 18.65 ^{0}F hft^{2}/Btu. Adding a cementitious foam insulation (R-19) through the wall membrane would increase the R value to 21.62^{o}F hft^{2}/Btu. The cost and benefit analysis is shown in Table 5.

4.6.3 Incentives from Northwest Natural Gas For Installing Insulation

Northwest Natural Gas provides incentives for improving home insulation. They provide a discount of $.45/sf for wall insulation and $.25/sf for floor insulation

TABLE 2: ASSEMBLY MATERIALS AND R VALUES OF THE UNIMPROVED THERMAL ENVELOPE (MEEB Table E.1)

Floor		Wall		Ceiling/Roof	
Materials	R*	Materials	R	Materials	R
0.75" hardwood decking	0.68	Interior air film	0.68	0.25" plaster	0.16
33.6 density tongue and groove	0.99	0.25" lightweight gypsum plaster	0.16	0.5" drywall	0.45
2 x 6 joists R-18 @ 12% framing	2.16	0.5" drywall	0.45	8" blown-in mineral fiber insulation	22.00
R 13 insulation @ .33 of floor	4.30	3.75" airspace (2 x 4 studs	1.10	2.5' average air space	8.80
Total R Value	**8.13**	2 x 4 joists R-18 @ 12% framing	1.32	Interior air film	0.68
		1953 tarpaper	0.5"	2 x 6 joists R-18 @ 12% framing	2.16
		Double layer cedar shingles	1.19	0.5" intermediate density sheathing	1.09
		Total R Value	**5.99**	Asphalt shingles	0.44
				Exterior air film	0.17
*R= ºF/ hft^{2}/Btu (I-P)				**Total R Value**	**35.95**

TABLE 3. ALLOWABLE AND MEASURED U VALUES

Envelope Component	Maximum U Value	Existing U Values	U Values With Insulation
Floor	0.066	0.12	0.054
Framed Wall	0.089	0.17	0.046
Fixed Window	1.22	0.51	No Change
Roof	0.081	0.028	No Change

TABLE 4. TOTAL HEAT LOSS OF THE UNIMPROVED THERMAL ENVELOPE INCLUDING WINDOWS AND DOORS

Materials	U *	Area ft^2	Q **
Door	0.25	40.50	202.50
Single pane window with storm	0.51	87.10	888.42
Double pane vinyl window	0.51	75.72	772.34
Floor Assembly	0.12	731.50	1755.6
Wall Assembly	0.17	624.20	2122.28
Ceiling/Roof Assembly	0.03	731.50	409.64
Infiltration (medium, (Δ T 28ºF, wind speed 15mph, 66.75 cfm, ACH 0.73)			1468.49
Sum of Q			7619.274
Total Heat Loss: Btu Per day (24 x Sum of Q)			182,862.58
Total Therms per day (99,954 Btu/therm)			1.83
*U=1/R or Btu/ºF hft^2 **Q=Btu/h Δ T = 20 ° F			

TABLE 5. HOMEOWNER COST/BENEFIT ANALYSIS OF INSTALLING INSULATION

	Material Added	Old Q	New Q*	% Savings in Btu	Cost ($/ft^2$)	NW Natural Rebate ($/ft^2$)	Total cost after rebate	Pay back time months **
Floor	R-19 fiberglass batt insulation	2457.84	790.38	68%	0.70	0.25	329.12	26
Wall	R-19 Cementitious foam insulation through wall membrane	3195.80	526.70	83%	1.80	0.45	842.64	41
*calculations not shown ** @ cost of $1.05/therm								

4.6.4 Payback Time

The payback time was calculated using the US Department of Energy's Consumer Guide for Estimating the Payback period of additional insulation. The equation for years to payback is
$(C(i) \times R(1) \times R(2) \times E) / (C(e) \times [R(2) - R(1)] \times HDD \times 24)$, where
C(i) is the cost of insulation /ft^2
R(1) and R(2) are the initial and final R-values of the section
E is the efficiency of the heating system
C(e) is the cost of energy expressed in $/Btu
HDD are the heating degree days /year
24 is the Multiplier to convert heating degree days to heating hours.

Payback for the floor and wall insulation would occur in 29 and 50 months respectively.

4.6.5 Environmental Benefits

Installation of both wall and floor insulation would improve thermal envelope efficiency by an average of 75% for walls and floor together. The heaters could be run less to accomplish the same thermal comfort. This would reduce the therms lost to approximately 103 therms or 0.60 tons of CO_2.

4.7 Analysis

Inspection of the house envelope revealed typical stick frame construction with minor upgrades since the house was built. Table 2 and 4 show the R, U and q values of the assembly. The house had a total of 2 metal doors with polyurethane cores, two large single-pane wooden windows with aluminum storm windows, and six double-pane vinyl windows. R, U and q values were calculated from MEEB. These numbers indicate there is a significant heat loss through the envelope.

Surface temperature measurements showed a stratification of heat on the interior of the living room wall from cooler to warmer from bottom to top. The measurements also indicated different temperatures (heat transfer) depending on component. When the reflective insulation was installed, warmer temperatures were found nearest the heating source.

The surface temperature measurements did not show the same the same significant heat flow through the wall envelope we had seen during the home tour. Where we expected to see the temperature of the exterior surface heat up over time, we actually measured a decrease in surface temperature. Over time indoor ambient temperature increased and outdoor ambient temperature decreased. This could have been due to a higher thermostat setting and a lower exterior temperature the day of the tour, which caused a higher Δ T and larger temperature gradient.

However, thermal camera images taken before the heat was turned on and at increments thereafter revealed the temperature of the wall assembly did increase over time. Overall, thermal images show significant heat transfer within the wall assembly, especially around the electric wall heater.

5. CONCLUSION

U value calculations of the envelope revealed the "ice box bungalow" lived up to its name and did not meet ASHRAE standards. This was further demonstrated through the thermal flow assessments. Although the in-wall electric heater in the bedroom heated the room rapidly, much of the heat production was lost to the outside. The gas heater in the living room lost much of its effectiveness through conduction of heat through the picture windows on the east and west walls. Thermal comfort and heating efficiency could be improved by bringing wall and floor insulation up to ASHRAE standards. Not only could the cost of insulation be paid back in fuel savings over the course of a few heating seasons, but carbon dioxide emissions could also be reduced because less natural gas would have to be used to heat the home to current thermal comfort levels. Improved envelope R values would help prevent very high humidity levels within the home and move the dew point out toward the cladding. This would reduce health risks to the residents by eliminating opportunities for condensation (and mold) inside rooms or within the walls and attic. Additional mitigation of heat losses could be obtained with insulated drapes closed over the windows during Eugene's coldest months.

6. DESIGN LESSONS LEARNED

The next steps in continued study of the Icebox Bungalow would be to install insulation and repeat the original experiment. Comparing measurements before and after insulation would quantify the increase in thermal envelope efficiency. If these steps were repeated for similar unimproved 1950's housing stock in Eugene, significant reduction in carbon dioxide production could be achieved. Certainly the ice-box bungalow would be thawed.

REFERENCES

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ACKNOWLEDGEMENTS

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[i] Energy Information Administration, Office of Energy Markets and End Use, "Table 1. Natural Gas Consumption and Expeditures in U.S. Households." 2001 Residential Energy Consumption Survey: Household Energy Consumption and Expenditures Tables (2001) 1. 16 Feb 2008 <http://www.eia.doe.gov/emeu/recs/byfuels/2001/byfuel_ng.pdf>.

[ii] Stein, Benjamin, J. Reynolds, W. T. Grondzik, A. Kwok. Mechanical and Electrical Equipment for Buildings. 10th ed. Hoboken, NJ: John Wiley & Sons, Inc., 2006.