Where energy matters

Pebble Ripple

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December 9, 2010

Mr. Jim Wilson
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Subject: Report for Home Energy Saving

Dear Mr. Wilson:

I am pleased to provide you the attached report for saving energy in your home.

The report addresses the critical topic of insulation for the crawl space, the exterior walls, and the attic. By implementing the recommendations, not only will you contribute to the environment and save money, but you and Alison will also enjoy significant improvements in energy consumption and in comfort.

If you have any questions or would like to discuss any of the future recommended work, feel free to contact me.

Yours sincerely,

Peter Carlson
Consulting Engineer

/pc

Enclosure: Home Energy Saving Report

Pebble
Ripple

Home Energy Saving Report

Prepared for: Jim and Alison Wilson

Prepared by: Peter Carlson

December 9, 2010

Table of Contents

List of Figures

List of Tables

Executive Summary

This report describes the recommendations to lower the energy consumption and improve the comfort of your home, addressing the more important recommendations from your energy audit. By following the suggestions in this report, you will alleviate one big problem: uncomfortable rooms because of temperature variations. The audit proposed many recommended actions. In this report we tackle two of them: insulating the crawl space and insulating the exterior walls. This report also addresses the health risks of fiberglass insulation.

In the research method, we consulted a wide range of material—books, journals and articles—from the web and from Southern Polytechnic State University. We checked the theory by using direct measurements within your home.

The results of the research resolved several unknowns. The crawl space issues include venting, moisture control, vapor barriers, and wall versus floor insulation. Even though the living room floor above the crawl space does not suffer big temperature swings, it seems prudent to insulate the crawl space roof and basement-side wall, with ventilation. The practice of insulating exterior walls with loose-fill insulation is well established. The exterior walls should have R-13 insulation. It was verified that your current insulation is very low and in winter this is contributing to cold wall surfaces, some 6 °F below the warmer walls in the house. The costs for insulating are small compared to your budget, especially after rebates. The predicted reduction is energy consumption is small. Fiberglass has been criticized for its health risks, but on balance it seems the risks are very low. The better insulation materials include cellulose and polystyrene, when we take multiple attributes into account. However, when sustainability is considered, polystyrene rates poorly.

In conclusion, insulating the crawl space and the exterior walls is worth your while. The current material in the attic poses little or no risk to your health. The percentage energy saving is significant, but not a huge amount. The rebates reduce your out of pocket costs considerably.

To achieve the benefits, we recommend that you should act on those two key items and consider authorizing further research on the remaining issues.

In a nutshell

- It is worthwhile to insulate the crawl space (with ventilation) and the exterior walls.
- The fiberglass in the attic poses little or no risk to your health.
- The predicted reduction in energy consumption is at least 13%.
- Your total rebates of $690 would pay for a significant portion of the $1140 cost.
- The recommended insulation methods for the floor above the vented crawlspace include either sprayed polyurethane foam, or polyisocyanurate rigid foam beneath the joists with fiberglass cavity insulation.
- The recommended insulation method for the exterior walls is loose-fill cellulose.

Introduction

This report describes the recommendations to lower the energy consumption and improve the comfort of your home. Although you do not spend much on energy, you want to make your home more energy efficient.

To realize these improvements, the report addresses the more important recommendations from your energy audit: insulating and sealing the crawl space; insulating the exterior walls; and insulating the attic with the best material. You see the results of the research in the analysis of the options and specific suggested solutions after balancing the complex trade-offs.

The Problem

You find some of the rooms uncomfortable because of temperature variations. As the seasons change, you're forced to rearrange your main bedroom: in winter you have to add more blankets and close the heavy drapes. You already made an excellent first step by organizing an energy audit under the Home Performance with ENERGY STAR® program ("Home performance," n.d.). The 20-page report was good (Wallace, 2010), but you are overwhelmed with the large number of recommended actions. How do you prioritize them? Are you sure they make sense for your particular situation?

The audit report (Wallace, 2010) provided the measured duct leakage and natural air change of the house. The natural air change was high, so the report recommended filling gaps (such as around windows and doors). The report also recommended insulating around the crawlspace to maintain a thermal barrier: "Complete crawl space vapor barrier and insulate floors. Crawlspace may be a candidate for sealing." (p. 3). Their tests indicated little or no exterior wall insulation, so the report suggested this be improved, but gave no specific recommendation except for the R-value (insulation's heat resistance level).

Indeed, the actions in the report are complex. Let's look at some of them.

One action involves insulating and possibly sealing the crawl space. This is controversial: research shows this is not always the best option, as you will see.

Another action was insulating all the exterior walls. You were surprised that the audit rated this at a low priority, giving it little attention. You can be assured, however, that the practice is well established (Lstiburek, 2010).

Another implied action was improving the attic insulation. You are concerned that the current fiberglass insulation has health risks.

Objectives

To help you to understand the complexities and decide what to do, the report tackles each of the selected actions from the audit. The report predicts the difference in energy consumption.

You can choose the best approaches. You see targets for the improvements, such as predicted changes in energy consumption. You see ways to prove that the improvements were successful, such as controlled measurements of temperature differences.

Methods

The research included access to varied knowledge sources, such as university libraries and detailed engineering handbooks. We checked the theory by using direct measurements within your home.

In the *secondary research*, not only was the theory behind the solutions investigated, but also that knowledge was applied in a practical way.

- Researched the current best practices for insulating crawl spaces and exterior walls, balancing the competing needs such as moisture control and insulation.
- Investigated whether fiberglass is a health risk and whether it is damaging to the environment. Investigated alternative insulation materials. The research avoided bias from vendors who may spin the facts.
- Analyzed multiple viewpoints, by looking at architecture journals; engineering journals and handbooks; medical journals and reports; and periodicals from the building industry. The analysis included calculations specific to your house.
- Gathered typical costs and rebates, including information from your local energy provider. We want to save as much money we can.

The focus was on the last 20 years for fundamental science facts, the last 10 years for the latest trends, and the current tax year (2010) for determining rebates.

The extensive library of Southern Polytechnic State University provided the research material. The following keywords were used: cancer, crawl space, embodied, energy, fiberglass, formaldehyde, furnace, insulation, polystyrene, R-value, and sustainability.

The following sources were included.

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and American Chemical Society publications
- U.S. Department of Energy (DOE) publications
- American Lung Association reports
- Epidemiology and occupational medicine journals
- Guidelines from university departments, applying ASHRAE and DOE principles
- Remodeling, building design, energy saving, and architecture magazines
- Your energy audit report

You also get the benefit of *primary research* when we measured the wall temperatures in your house, performed the calculations and verified the insulation levels. Using the infra-red thermometer that we had purchased, we followed the procedure by Pedersen and Hellevang (2010).

- We determined the outside air temperature.
- Inside the house, we determined the temperature of an interior wall that had both sides in the heated portion of the house.
- Inside the house, we determined the temperature of an exterior wall.
- We subtracted the inside temperature of the exterior wall from that of the interior wall.
- Using the outside air temperature and the difference in exterior and interior temperatures, we found the estimated R-value in the table provided by Pedersen and Hellevang.

Results

Overview

The crawl space issues include venting, moisture control, vapor barriers, and wall versus floor insulation. Even though the living room floor above the crawl space does not suffer big temperature swings, it seems prudent to insulate the crawl space roof and basement-side wall, with ventilation. The practice of insulating exterior walls with loose-fill insulation is well established. The exterior walls should have R-13 insulation. It was verified that your current insulation is very low and in winter this is contributing to cold wall surfaces, some 6 °F below the warmer walls in the house. The costs for insulating are small compared to your budget, especially when the generous rebates are taken into account. The predicted reduction in energy consumption is small. Fiberglass has been criticized for its health risks, but on balance it seems the risks are very low. The better insulation materials include cellulose and polystyrene, when we take multiple attributes into account. However, when sustainability is considered, polystyrene rates poorly because of its high embodied energy and large carbon footprint.

Crawl Space

Results indicate that the crawl space does not significantly affect the comfort of your living space above it. After identifying the issues regarding whether to vent or not, we describe the typical methods for insulation and moisture control, and provide typical costs.

Although you would save energy by insulating the floor over the crawl space, you should note that currently it has little effect on the comfort of your house. We found the upper surface of the floor above the crawl space to have only a 2.5 °F lower temperature than nearby inside walls, when the outside temperature was 34 °F. In comparison to the situation for the exterior walls, which we discuss in the next section, the perceived equivalent floor insulation is much better.

The big decision that needs to be made with crawl space insulation is whether to vent or not. Your crawl space is vented. Your furnace operating in the crawl space requires air, so ventilation is required at least for that purpose. To date there is no evidence of moisture damage in your crawl space. However, we should be aware that venting in summer might cause moisture problems from condensation.

Venting a crawlspace usually increases the humidity, according to Pass (2004). The outcome is opposite to what you would expect. “Building scientists have found consistently that when warm, moist outside air enters a crawl space, it instantly cools and drastically increases the relative humidity of the crawl space.” (p. 1). The author is a contributing editor to the magazine, one of several published by Scranton Gillette Communications (SGC) Horizon. This is a commercial magazine with advertising.

Vented crawlspaces suffer from moisture problems in hot climates (Lstiburek, 2009). How do you solve this? The basis of a solution is the "principle of eliminating condensation by keeping joists and subfloor warm" (p. 13). This update, provided by Aspen Publishers Inc., summarizes the Building Science Corporation article by Lstiburek.

The update describes two insulation methods to avoid condensation. The first method encapsulates the joists, subflooring, and rim joist in several inches of polyurethane foam. For example, the recommended shape of insulation under the floor is shown in Figure 1.

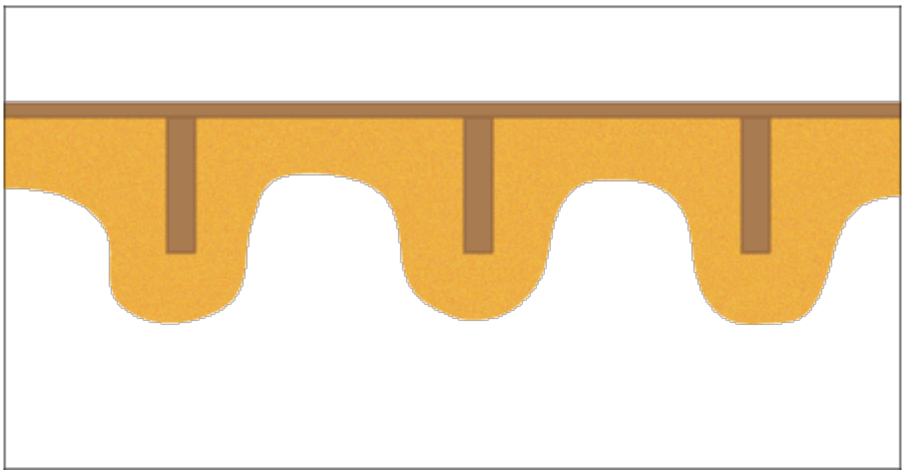

Figure 1. The insulation under the floor covers both floor and joists.

The second insulation method uses a layer of polyisocyanurate rigid foam beneath the joists and optionally fiberglass cavity insulation above the foam, but leaves an air gap above the fiberglass. This method is recommended for floors that do not allow water vapor to pass because they are so well sealed. See Figure 2.

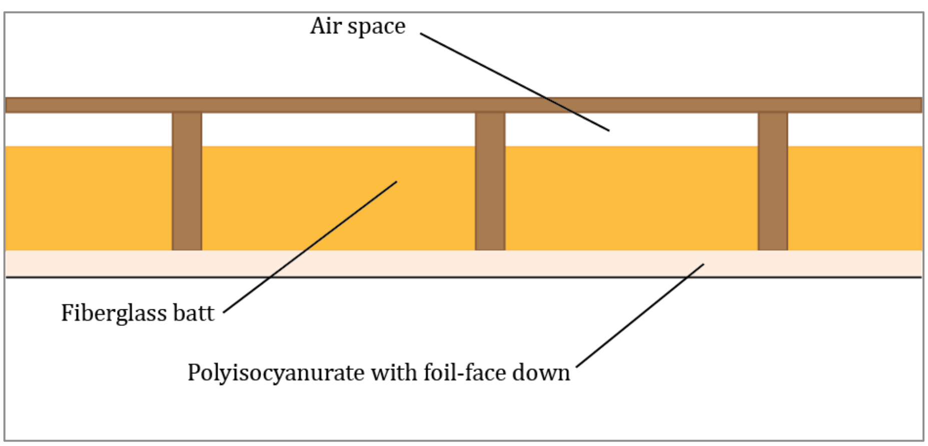

Figure 2. Rigid foam insulation is used for floors that are well sealed.

Moisture also comes from the soil. If the soil of the crawl space is covered with a vapor barrier, the moisture is reduced, especially important in an unvented crawl space. The audit report recommended that your vapor barrier should be improved. However, it is difficult to install the cover because your crawlspace has a highly uneven surface.

Several factors affect the decision to vent the crawl space: drainage, water table height, adjacency to basement, climate, partial conditioning, radon gas exhaust, and termite protection (Carmody, Christian, & Labs, 1991). Although the observations in the report may now be outdated, the report remains a standard reference for the building industry, and provides an excellent review of the pros and cons. For a vented space, they recommend insulating the floor above the crawl space, not the sides: "Insulating the ceiling of an unconditioned basement is generally more cost-effective than insulating the walls of an unconditioned basement to an equivalent level." (p. 14).

The cost to insulate the crawlspace is $710, assuming you insulate the floor above the crawlspace and insulate the interior wall to the basement (to R-values of R-19 and R-11 respectively). This estimate is based on costs of insulation from Carmody, Christian, and Labs (1991), after allowing for inflation.

Exterior Walls

One common method of insulating exterior walls is using loose-fill insulation, but this requires potentially ugly holes in the walls. We identify what the ideal R-value should be, measure the current actual R-Value, verify this agrees with theory, predict the final R-value after insulation, and show that the final temperature difference of the walls is small. We provide a typical cost of installing the insulation.

It is a well-established practice to loose-fill cavity walls. The report from Lstiburek (2010) discusses packing cellulose fiber densely into existing frame walls. The air leakage is reduced by up to a factor of 10 or more. The report provides overall guidelines on where and how the insulation should be used. "One of the most effective ways of dealing with existing uninsulated frame walls is to blow cellulose into the wall cavities." (p. 54). The report does not provide the R-values of such walls, but the U.S. Department of Energy suggests dense packing *improves* the R-value. This report comes from the Building Science Corporation in Somerville, Mass. The corporation represents the knowledge of several consulting engineers. They offer practical advice. Despite the report's casual and humorous tone, the information appears to be trustworthy, based on author's extended experience in the field.

A typical installation method requires several large holes in the walls. Your exterior wall surface consists of wide wooden boards, which make it difficult to hide the hole coverings. This has a potential to be unsightly, especially to your neighbors.

The audit report recommends an R-value of R-13 for the insulation. This agrees with an independent recommendation for your location from an on-line tool provided by Building Envelope Research at Oak Ridge National Laboratory (www.ornl.gov).

To crosscheck the need for insulation, the calculated R-value was determined from a simple test where the surface temperatures were measured (Pedersen & Hellevang, 2010). The results (Table 1) show that the current insulation is very low: a quarter of what is recommended. In theory we would expect a value of 3.7 for a wood sheath, air gap, and Gypsum board using basic principles (Kuehn, et al., 2005, p. 23.3); that value is within 14% of our average measured value.

Table 1
R-value estimate based on measurements of inside temperature differences between interior and exterior walls for the north wall near the NE corner of the house in the study room.

			R-value	
Measurement number	**T1 - Outside temp. (°F)**	**T2 - Inside temp. diff. (°F)**	**Ra from ref.**	**Re extrapolated**
1	41	6.2	below 5	3.3
2	34	8.0	below 5	3.1

Note. T1 is the outside ambient temperature. T2 is the difference in temperature between the inside surfaces of an interior wall and an exterior wall. The R-values are listed as Ra which is directly from the reference table (Pedersen & Hellevang, 2010) and as Re which is the approximate value calculated by extrapolating from that table.

By filling the 4-inch air gap with loose-fill cellulose (U.S. Department of Energy, 2002), the added insulation would provide R-14, a level well above the recommended value. Using the calculator from Pedersen and Hellevang (2010), after insulation we expect the difference in wall temperatures to be negligible: T2 will be less than 2 °F.

The cost of wall insulation is not high. According to inflation-adjusted figures from U.S. Department of Energy (1995), to insulate the exterior walls with R-13 loose-fill cellulose, you would pay approximately $430, excluding any rebates. This DOE report provides guidelines for insulations using loose-fill technique, such as blowing into wall cavities. For loose-fill insulation the “average installed price per R-value per square foot was about 1.2 cents for blown-in cellulose and rock wool and 1.3 cents for fiberglass.” (p. 6). After inflation of 44% is included, the costs today are 1.7 and 1.9 cents respectively. The report is several years old, but the principles still apply.

Insulation Materials

There appears to be little risk in leaving the existing fiberglass insulation in your attic. The cancer risk from fiberglass appears to be low, according to three different sources: American Lung Association (2008), Boffetta et al. (1997), and Checket-Hanks (2004). The traces of formaldehyde from fiberglass also present little risk. The risk of non-malignant respiratory disease is also low, according to Chiazze et al. (2002).

The 188-page report by the American Lung Association (2008) warns that “pollutants in the air in the home, school or workplace increasingly have been recognized as threats to lung health.” (p. 19). The report describes many indoor air pollutants, such as asbestos, tobacco smoke and radon. However, the report *does not mention* fiberglass.

Fiberglass has not been proven to cause lung cancer in at least in one study of a large population. The study by Boffetta et al. (1997) compared the mortality rates of workers in MMVF (Man-Made Vitreous Fiber) production. Glass wool, one of the glass fibers, is included in MMVF group. The study found that “results are not sufficient to conclude that the increased lung cancer risk is related specifically to exposure to MMVF" (p. 267). The analysis covered 22,002 workers.

Fiberglass is not considered to be a carcinogen. Checket-Hanks (2004) notes "In 1994, Health and Human Service's National Toxicology Program ... listed fiberglass as being 'reasonably anticipated to be a human carcinogen' based on animal test data." (p. 16). However, members of the manufacturing community have been waiting for the reclassification of fiberglass as not a carcinogen. "Fiberglass 'is currently considered not classifiable as a human carcinogen,' stated the American Lung Association (ALA)." (p. 16). This is a commercial magazine with advertising.

Fiberglass also has a very low risk of causing non-malignant respiratory disease. Chiazze et al. (2002) studied the cause of 30 deaths of long-term employees at the Kansas City plant operated by Owens Corning. The findings show no association between respirable glass fibers and non-malignant respiratory disease (excluding influenza and pneumonia). "Obviously a small study such as this cannot provide any definitive answers on the question . . . . On the other hand, given the paucity of literature on this subject, the current study adds some reassurance that no overwhelming risk is present." (p. 372).

Formaldehyde, possibly released in tiny quantities from the phenol-formaldehyde binder used in typical fiberglass insulation, is a confirmed human carcinogen, according to Wilson (2005). However, manufacturers of the insulation have since either switched to non-formaldehyde-based binders or have had their products certified as low emitting. This information is published by BuildingGreen, an independent company helping building-industry professionals and policy makers improve the environmental performance of buildings.

The better insulation materials include *cellulose* and *polystyrene*. Sotoropolis (2008) rated insulation materials using multiple characteristics and found that low-density polystyrene and cellulose ranked high for the climate zone of Ohio. *Fiberglass* was ranked considerably lower. This research, from the U.S. Air Force Institute of Technology, used a holistic approach to selecting thermal building insulation by developing a multi-attribute decision model.

The following attributes were used in the decision model.

- Effective thermal performance
- Sound attenuation
- Burn characteristic
- Smoke development
- Infiltration
- Hazardous materials
- Greenhouse gas emissions
- Recycled content
- Mold
- Exposure to particles

The rankings are shown in Figure 3.

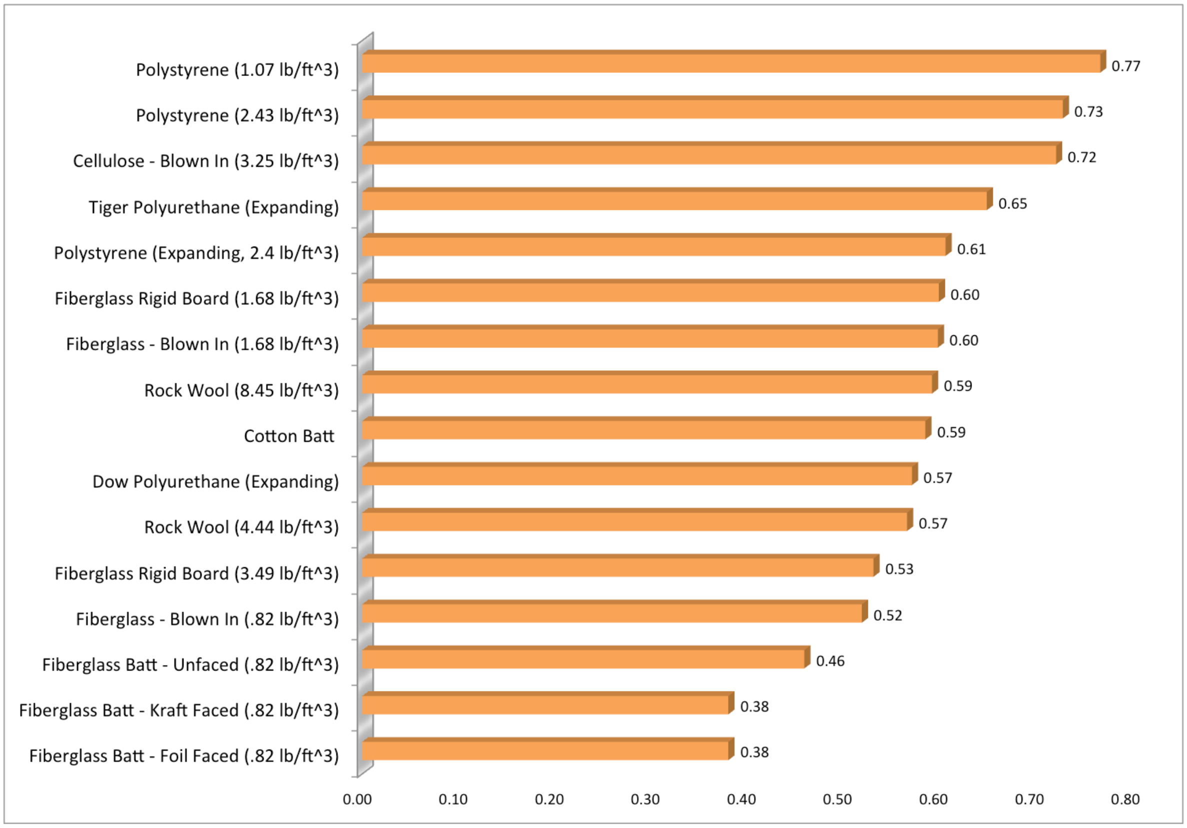

Figure 3. Insulation materials ranked for a climate as in Dayton, Ohio. Adapted from Sotoropolis (2008) p. 66.

Cellulose and polystyrene require flame-retardants, which lessen their environmental friendliness, even though cellulose is natural. Although the ranking by Sotoropolis accounts for environmental impact, it does not account for the impact of the product *itself* (Sotoropolis, 2008, p. 43). Polystyrene has been criticized as being not environmentally friendly because of the harmful substances it releases when it decomposes in the ocean (Bernstein, 2009). This news release from the American Chemical Society (ACS) reported that the researchers had found this discovery surprising.

The sustainability of the insulation materials can be gauged from their embodied energy (amount of energy needed to make insulation material) and carbon footprint. When comparing embodied energy, cellulose is a clear winner of the three, as shown in Table 2. Per volume, fiberglass requires nine times more energy than cellulose, and polystyrene requires 34 times more energy (Canadian Architect, n.d.). Canadian Architect is a magazine for architects and related professionals practicing in Canada. According to another source (GreenSpec, 2008), fiberglass requires twice as much energy as cellulose, and polystyrene requires 19 times more energy. Polystyrene also has a five times higher carbon footprint than fiberglass, according to GreenSpec®.

GreenSpec is a freely available directory of "green" building products in the UK, written by practicing building designers.

Table 2
The total primary energy consumed and carbon released over the life cycle of insulation materials.

	Energy (MJ/m^3)		Carbon ($kg\ CO_2/m^3$)
Material	**GreenSpec**	**Can. Arch.**	**GreenSpec**
Cellulose insulation (loose fill)	142	112	-
Glass fiber insulation (quilt)	336	970	16
Polystyrene insulation	2658	3770	75

Note. Where the measurements cover a range, the maxima are shown.

Reduction in Energy

After installing the insulation, you save significant amounts of energy with little expense when rebates are taken into account.

After insulating the cavity of the exterior walls, the energy consumption would be 13% lower, based on figures from U.S. Department of Energy (2002) for a medium ranch house in Atlanta. The reduction in energy consumption from insulating the crawlspace is not easily predicted, but we would expect it to be in the single digit percentage range.

The rebates available to you (in 2010) and the approximate amount you could claim are summarized in Table 3. Out of your total cost of $1140, you could claim $688, a substantial portion. The large proportion comes from the state rebate.

Table 3
Rebates and claims for insulation

	Rebate	Your claim
Federal tax credit[1]		
Insulation	30% of the cost, up to $1,500	$68[3]
Georgia Power rebate[2]		
Insulate floor & foundation wall to R-5 (foam); R-13 in basement wall cavities (fiberglass acceptable)[4]	50% of the cost, up to $450	$355
Wall insulation improvements (conditioned space exterior walls)	50% of the cost, up to $550	$265
Total		**$688**

Note. 1. Does not include installation costs. 2. Individual rebate paid must not exceed 50% of related improvement cost. 3. Assumes installation labor makes up 80% of cost. 4. This applies to the crawl space.

Conclusions

Insulating the crawl space and the exterior walls is worth your while. The current material in the attic poses little or no risk to your health. The percentage energy saving is significant, although not a huge amount. The rebates reduce your out of pocket costs considerably.

For the *crawl space*,

- insulation is worth doing, as recommended by the energy audit;
- a typical insulation method involves insulating the floor *and* its joists;
- venting should be continued to be used; and
- dampness is unlikely to be an issue.

For the *exterior walls*,

- insulating all the exterior walls is effective;
- one of the better sustainable materials is loose fill cellulose;
- the cosmetic effect of the hole filling needs to be considered; and
- the walls in your rooms will be several degrees warmer on chilly days.

For the *attic*, the existing fiberglass insulation material poses little or no health risk.

The predicted reduction in *energy consumption* is at least 13%.

Your total *rebates* of nearly $690 would pay for a significant portion of the $1140 cost.

Recommendations

To achieve the benefits, we recommend that you should act on two key items and consider authorizing further research on the remaining issues.

It is recommended that you take the following actions.

- Improve the crawl space by insulating the floor above, and insulating the wall adjoining the basement, as shown in Figure 4.
- Insulate the exterior walls with loose fill cellulose.
- Do not remove the existing fiberglass insulation in the attic.

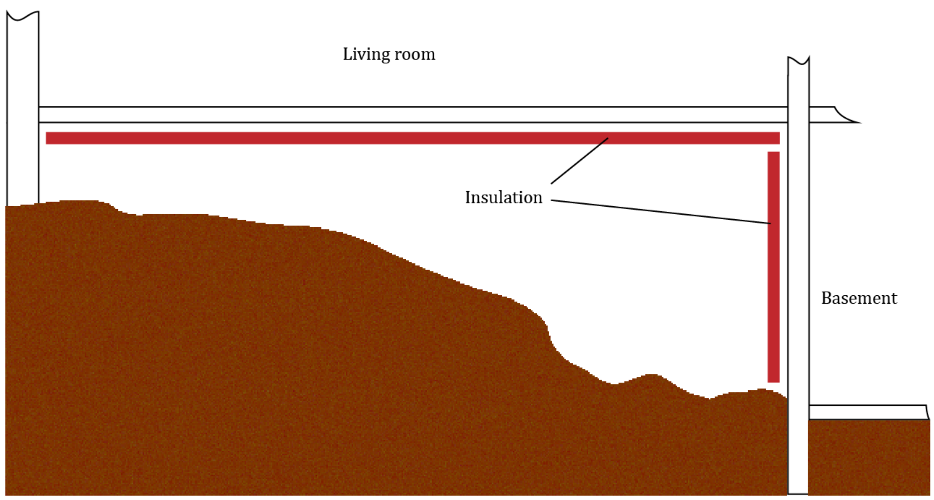

Figure 4. Insulation is applied to the floor above the crawl space and to the wall adjoining the basement.

To gain even more benefits, you should consider a next phase of research work.

- Prioritize the remaining recommendations from the audit report (37 in total), to make sure they really make sense for the particular situation.
- Identify suitable contractors by performing an analysis of consumer ratings and interviewing a subject matter expert.

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