TWO PATHS TO GOLDEN SUSTAINABLE HOMES

prepared for

City of Golden, Colorado
Community Sustainability Advisory Board

by

Peter J. Ewers, AIA, LEED AP
Michael Haughey, PE, LEED AP

special thanks to

Golden Community Sustainability Advisory Board

Paul Kriescher, Lightly Treading

Steve Stevens

Well Home, Inc.

TABLE OF CONTENTS

INTRODUCTION

Welcome to the City of Golden's guide to making your home more energy efficient and comfortable.

The mission and goal of Golden's Community Sustainability Advisory Board is to reduce energy usage within our city. With roughly 7000 existing homes, and very little space to build new homes, it is obvious that reducing the energy usage in these existing homes is the best way to affect the residential energy use of our city. The Task Force commissioned this study and report to help homeowners identify where they could make the most difference for the least cost. For those who wish to reduce their energy use all the way to zero, this report also provides a roadmap to reach that goal.

This report is tailored to the City of Golden in several ways. Data regarding existing homes in Golden were analyzed (in a previous report) and this data was used to formulate the strategies presented in this book. Four different types of residential construction typically found in Golden were analyzed (a solid masonry structure, an older wood-frame home that has moderate upgrades, a 10-year old home with no further upgrades, and a 30-year old home with extensive energy upgrades) and the information from those analyses were used in formulating the strategies in this report. The "typical Golden home" used in this report is loosely based on several different homes found in Golden, and the north direction for that home is rotated 35 degrees to reflect the rotation of Golden's street grid.

This report is designed as a holistic approach to upgrading your residence, but can also be used as a reference book for specific areas of home renovation.

The holistic approach in this study encourages homeowners to look at all aspects of their home's environment. The report is structured so that the most important upgrades, the work that should be performed first, is at the front of the report. Consider these examples:

> *When replacing a furnace with a higher efficiency model it is first important to reduce the heating load by repairing air leaks and increasing insulation. Reducing the amount of time that the furnace needs to run can save as much or more energy than installing a furnace that is 10 percent more efficient.*
>
> *…or…*
>
> *When considering installation of photovoltaic panels to generate electricity it is first important to minimize your home's electric usage. By installing efficient lighting and appliances you may reduce the amount of electricity used for less cost than installing photovoltaic panels.*

The reference aspect of the book is probably more obvious. If your furnace needs immediate replacement, the chapter on heating systems may provide useful information about your options. Or if you must buy a new refrigerator this week, the chapter on appliances may be helpful. We have attempted to include some order-of-magnitude cost opinions that might be helpful on a comparative basis. It is essential for any project that you do your own cost research before making any decisions.

Throughout the report we will follow two families to illustrate different methods of proceeding through a full home energy efficiency retrofit. Both of these fictitious families own a typical 2000-square foot home in Golden and both are embarking on substantial projects to improve the energy efficiency of their home. However, they often make different choices throughout the upgrade process.

Introducing The McFrugals…

The McFrugal family is budget-conscious. They want to make upgrades, but each upgrade must make financial sense as well as energy sense. Therefore they select systems and upgrades that will provide the largest energy benefits with the lowest up-front cost. They look carefully at the long-term cost savings versus the initial investment (this is also referred to as life-cycle cost analysis, or LCA). At the end of the renovations they will have a very energy efficient home.

Keeping up with the Jones…

The Jones family is very concerned with energy efficiency and they are dedicated to making their home "Net Zero". Regardless of what it costs (but within reason) they will select the most energy-efficient reasonable system in every category. At the end of the renovations they want to own a home that uses no more energy than can be produced on their property.

Neither family is right or wrong. Both families are commended for their dedication to energy-efficiency and the environment. The McFrugals and the Jones invite you to join them on their journey.

In order to study which upgrades will make the most difference, which upgrades will cost the most to implement, and how a home could reach the goal of Net Zero, some assumptions must be made. For the purpose of this report a "typical Golden home" has been created. Features of this home include:

- 2000 square feet of living space, not including the basement
- 2 stories
- 3 bedrooms, 2½ baths
- 2-car attached garage
- The front of the home faces southwest (angled 35 degrees to match the angle of the Golden grid)
- 2x4 wood-frame house over a concrete foundation with moderate levels of insulation

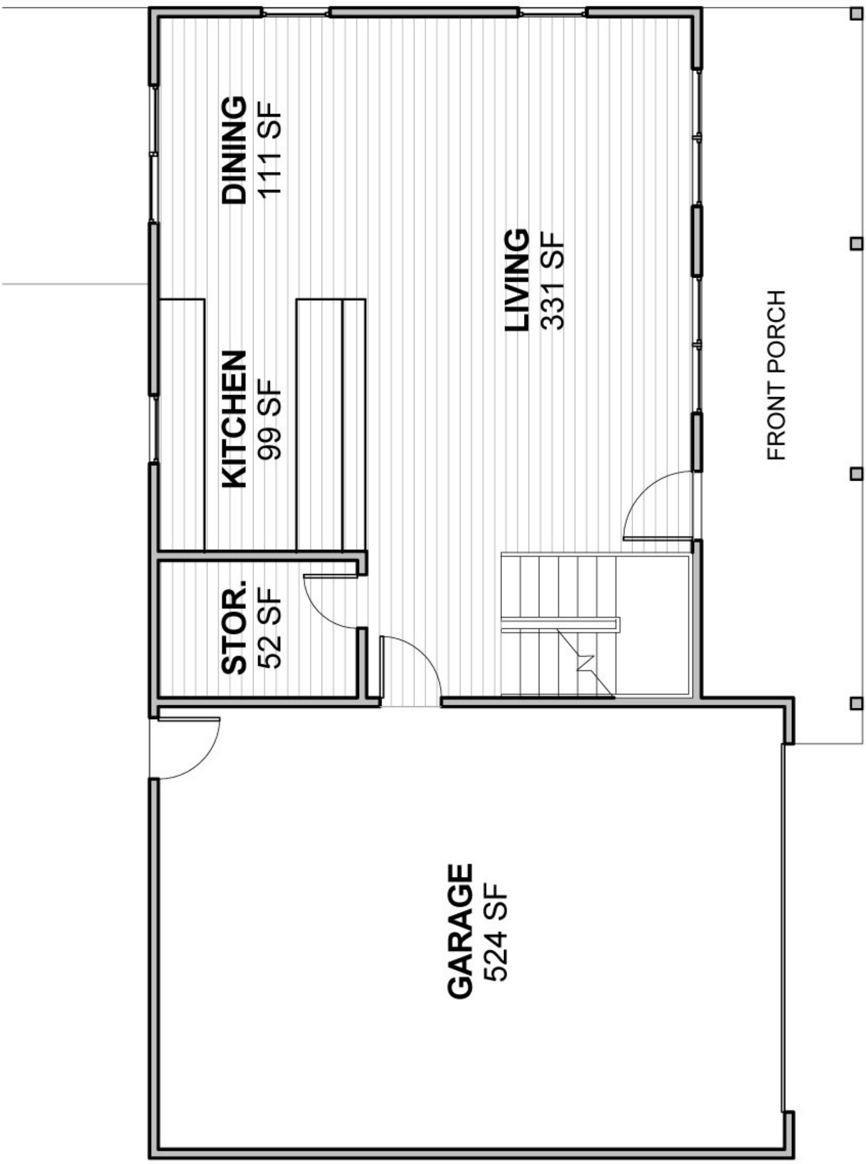
Your home may or may not be similar to this home, however many of the recommendations in this report will still be applicable to your home.

Throughout this report, when helpful, we use an image of this "typical home" to highlight the area that is being discussed in that chapter. The diagram to the left indicates that the roof is the current subject.

The following pages show more detail about this home…

TYPICAL GOLDEN HOME **perspective from southeast**

TYPICAL GOLDEN HOME **aerial view from southwest**



TYPICAL GOLDEN HOME **main floor plan**

TYPICAL GOLDEN HOME **upper floor plan**

CONTRACTOR TALK

Some of the projects discussed in this report can be do-it-yourself projects. However, many of the projects will require the involvement of a contractor. Throughout the report there is advice for when a contractor would be necessary, some good questions to ask contractors, and how to determine if the contractor is completing the work per your requirements.

Many terms are used casually these days, with definitions and interpretations varying greatly. What does “green” or “sustainable” really mean? Is a system sustainable just because it saves 10% more energy than another system? Those are questions being debated in the design and environmental community, but are not a part of this report (you are, however, encouraged to ponder these questions as you embark on this process).

Another term that is used frequently is “Net Zero”. There are many different definitions of this term as they pertain to homes, such as Net Zero electricity usage (but gas is used to heat the home), or Net Zero energy bills (where the onsite energy created through photovoltaics totally offsets all energy costs for the home). The definition used as a goal in this report is:

- All electric and gas energy used to operate the home is offset by renewable energies.
- Any natural gas used is converted to the energy equivalent in electricity.
- Renewable energy sources may include on-site photovoltaics, on-site wind turbine, on-site solar thermal collectors, community-wide solar gardens, or other nearby source of renewable energy that is directly attributable to the home.
- While Xcel’s Windsource program is a good tool for expanding renewable energy usage, this is not considered equal to on-site renewable for this report. The Windsource program allows users to pay a higher rate for electricity equal to the cost of providing all of the power for their home through Xcel’s wind farms.
- Net Zero as defined in this report may actually result in a net energy cost of less than $0 for an entire year. This is because the energy in one therm of natural gas is less expensive than the equivalent energy in electricity ($0.71 for natural gas energy vs. $2.93 for electric energy).

For those who wish to know more about how we arrived at the energy-efficient strategies and decisions presented in this book, this chapter provides a glimpse into the processes that were used in creating this report.

A study has been made of a Golden home that has already implemented many of the suggested upgrades. The analysis of this home has been helpful in fine-tuning the energy calculations for our typical home. The energy analyses for this report have been done using a simplified though complicated spread sheet methodology with many of the inputs being annually averaged data. The results are intended as comparative, not predicting actual results, but rather predicting which energy-saving strategy is better than the other strategies. Tools that are more predictive are in development by government agencies such as DOE and NREL and they may become available to the public over time. Similarly the cost opinions are just that – order of magnitude opinions. Actual costs will vary depending on many variables such as who does the work, market conditions, available rebates, credits, and incentives, and all the details of designing a modification for a particular home and owner.

We are only skimming the surface of possibilities in this report and by no means intend to suggest that all possibilities or even the best ones have been presented.

Two important concepts are embedded in this process for those of you thinking about a net zero home:

> **First** is that the home energy cost (or energy use) is reduced until it makes sense to the owner, for cost or other reasons, to provide the rest of the energy from renewable systems.

Second is that the decision about when to provide the rest of the energy from renewable sources can be influenced by the avoided cost of a renewable energy system.

To explain further, consider the scenario where you have decided to achieve net zero and are thinking about whether to add insulation on the wall exterior to reduce the amount of renewable energy needed or to just buy a little bigger renewable energy system. We have given some "avoided renewable energy system cost" ("avoided RE cost") opinions that may help in this process (again, only comparative). Adding insulation to the exterior wall will reduce the amount of heat needed. If you plan to provide heat from a solar system, that solar system can now be smaller. The difference between the solar thermal system cost with and without the wall insulation, in this example, is the "avoided RE cost".

This report assumes that photovoltaics (PV) will be the electrical renewable energy system and that solar thermal will be the renewable energy system for heating. The avoided RE cost opinions are based on a system that would be able to provide all the heat or electricity for the home. Since there is no "net metering" for natural gas, we have assumed that the solar thermal system has enough storage to ride through about 3 to 4 days of no solar heat gain from the collectors. Another approach would be to increase the PV system size to offset the gas energy purchased during cold periods.

This report gives some energy consumption estimates for the scenarios that we have examined. Those estimates are based on energy at the property line. Clearly there are other considerations, however we chose not to burden this book with the associated controversies and complexities. Just as a quick overview, here are some of those considerations for you to ponder:

- Electricity delivered to your home in Colorado has probably been produced by a power plant that uses coal or natural gas (mostly coal). There is some wind energy in the mix as well as hydroelectric power and soon there will be some concentrating solar power. The coal was mined, transported to the power plant, the wastes transported to some disposal or other re-use, and electricity was lost on the power lines, using diesel, oil, gasoline, and electricity. The equipment used in all these steps also has environmental and energy impacts. Each of these steps and others not mentioned has an energy-consumption impact as well as an environmental impact.
- Natural gas delivered to your home has similarly been made available by prospecting and drilling which uses equipment, energy, toxic chemicals, and water and also has environmental impacts. Delivering the gas uses electricity at compressor stations that force the gas through the pipelines. The pipelines themselves have an environmental impact. Again there are environmental and energy use impacts.
- The decision of when and how much to use renewable energy for your home can be made purely on a cost basis, which means energy delivered to your property, or you might want to include other considerations. In the later case it gets complicated and political and you will need to do a lot of independent research and judge the results based on your own personal values.

Deciding Between Options – A Little Basic (Uugghh!!) Math

Let’s say you are considering two options for saving energy and the contractor tells you both will save 40% on your energy bill. Does that mean the total energy savings will be 80%. The answers is, as you probably expected, “it depends”.

If each option is independent on the other, and the contractor calculated the energy savings of each and then divided by the present energy use, then the answer is "yes." *An example could be replacing the refrigerator with a more efficient one and then replacing the clothes washer. One does not affect the other.*

On the other hand, if the options are dependent, then the savings cannot be added. *An example of this could be adding insulation and then installing a more efficient furnace. For simplicity of the math, let's assume that the insulation option will save 40% and the furnace is also 40% more efficient on an annual basis. In this case if the insulation is done first, the amount of energy now used is only 60% of what it was before. The furnace will save 40% of that new energy use, which means the new energy use will be 60% of the new reduced amount. That is 60% times 60% which is a new energy use of 36% of the original (a savings of 64% … 100% minus 36%). So the furnace has saved 60% minus 36% which is 24% of the original energy use, not 40%. So the savings in this case is not 80% (40% insulation plus 40% furnace) but instead is 64% (40% insulation and 24% furnace) of the original energy use.*

If that wasn't complicated enough, consider if the furnace was replaced first and then the insulation done. In that case the furnace saves 40% and the insulation now saves 40% of the new use, or 24% of the total. So which one is the better investment? I think you know the answer: "it depends". If you are only going to do one thing, then you'll probably do the one that costs less. On the other hand, if you intend to eventually perform both upgrades, then the furnace will be smaller if you install the insulation first. If your intent is to eventually install a renewable energy system, then you might want to first reduce your energy use as much as possible because the RE system is so expensive.

When your final goal is a Net Zero Energy Home, then it is best to plan the whole process and decide how much needs to be saved at each step. And that is the point of this book – to show two examples. You may want to plot out a number of possibilities and see which reaches the end result for you at the best cost and best result.

There are presently some rebates, tax credits, utility company incentives, and other possible methods of reducing the cost of renewable energy and energy reduction measures. Those need to be considered in the decision process because they can be very significant.

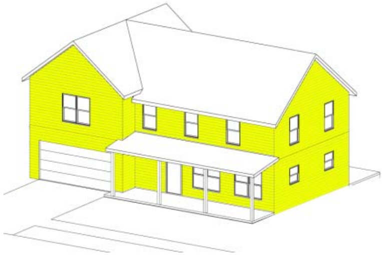
A Little Bit about "Savings"

Some of the annual energy savings just don't seem like much and in today's economy it is difficult to justify the installation cost to achieve them. So in addition to the avoided Renewable Energy Cost Savings, source energy, and environmental impacts, there is one more factor to consider. Fuel costs lately have been increasing faster than inflation. You can perform a web search for "peak oil", "peak coal", or peak just-about-anything and get pretty deep into some of the reasons. You might have noticed that the economy fell apart just after oil hit $140 per barrel (really high), and that the cost of oil dropped as the world economy slowed down. Now that the world economy seems to be picking up, so is the cost of oil. Knowing how much faster than inflation energy costs will rise is anyone's guess and probably impossible to determine with much reliability. So make your own guess. All the experts have often been wrong, so you may as well join them and make your own guess. Here are some potential calculations you can easily perform:

- If you think energy costs will increase 4% faster than inflation, then multiply the annual energy savings by 56 to get the 30-year energy savings (at present day dollars). Yes, that is correct … 4% annual increase, when compounded, will increase 56-fold in 30 years.
- For 8%, multiply by 113.
- For 12%, multiply by 241.
- For 16%, multiply by 530.

Notice it is not linear... you must use one of those fancy economic equations for the calculation. If you decide to assume an 8% difference between inflation and energy cost escalation, then your $100 per year savings (which may not sound like much) will actually result in a present-day dollar savings of $11,300 over 30 years (now that's some real savings).

While not real common yet, more and more mortgage companies are considering long-term financing of energy efficiency improvements right into the mortgage as well as lowering the qualification requirements for a mortgage on an energy-efficient home.



Houses leak. That may surprise you, but it is a fact. In fact, most houses are leaky enough to completely change the air inside the house in less than two hours on a day with "standard average" winds (this would be referred to as one-half air change per hour, or 0.50 ach). And many older homes have one air change per hour or more. If you are using energy to heat or cool the air that is leaking, then you are wasting energy and wasting money.

Air leaks typically occur at the junction between building materials – like around the edges of windows and doors, at the bottom or

top of walls, around a recessed light fixture, or at the roof eave. Some of the air leaks can be found easily (like if you can see outside light through a crack) and others can be hard to detect. Sealing the leaks can be similarly easy or difficult (some leaks occur in hard-to-reach places). There are several methods of sealing air leaks, but many can be done by the home owner. A Do-It-Yourself guide is available on the Energy Star website at energystar.gov/ia/partners/publications/pubdocs/DIY_Guide_May_2008.pdf.

Identifying the leak locations and which leaks are the most egregious is an important first step, and Xcel Energy has a low-cost tool that provides the easiest method for this. The Home Energy Audit provides testing on your home to identify leaks and more. A technician will install a blower door on your house (see photo at left) which will literally suck the air out of your house.

Then by using an infrared camera the technician will walk through your house and show you the sources of major air leaks. You can -obtain more information about these audits at xcelenergy.com/homeenergyaudit. The most beneficial audit will be the blower door test with infrared camera, currently $120. The audit will also include some additional information which is applicable to other areas of Two Paths to Golden Sustainable Homes.

CONTRACTOR CORNER

- Xcel Energy has a list of approved contractors that you must select from in order to receive their rebates.

tracking the McFRUGAL'S

The McFrugal family used the Xcel Home Energy Audit program to identify leaks in their home, then spent 6 hours with cans of expanding foam and a caulking gun sealing the air leaks that they could easily reach.

Cost: $100

Annual Savings: $92

keeping up with the JONES'S

The Jones family used the Xcel Home Energy Audit program and hired a contractor recommended by the auditor to seal all the leaks that were identified.

Cost: $700

Annual Savings: $92

Roof insulation is an important area when considering home energy upgrades. Because heat rises, this is an important wintertime barrier between heated indoor air and the cold outside air. In the summer roof insulation is also an important barrier to keep the sun from baking the interior of the home and causing an oven effect. Roof insulation is now required to be a minimum of R38 in new homes, but **R60 is a better target** for creating energy efficient homes. The good news is that adding insulation to a roof is often an easy and inexpensive project.

First, evaluate the existing insulation in your home. If you have an attic, you may easily measure the depth of the insulation. For existing insulation, use an R-value of 3.5 per inch of insulation. For the McFrugals and the Jones we have assumed an existing insulation depth of about 6", or R19. If you have vaulted ceilings, then the existing insulation probably matches the depth of the roof rafters, though it would be unusual to have more than R25 insulation for a home built before the mid-1970s.

LOOSE BLOWN INSULATION may be either cellulose or fiberglass, and is the most common material for insulation in open attic spaces, due to the fact that it is simple and inexpensive to install. For the do-it-yourself families, the equipment is available to rent at many building supply stores, or you may choose to hire an insulation contractor to perform the installation. One downside to this type of insulation is that the deep, soft, and sometimes skin-irritating insulation makes it difficult to use the attic for storage.

COOL ROOFS. When installing loose blown insulation it is imperative to allow air flow across the top of the insulation, from the roof eave to the ridge. This air flow creates a "cool roof". A cool roof is extremely important in our environment for two reasons:

1 During the summer the attic will become unbearably hot if there is no airflow. This heat will radiate down into the house, no matter how much insulation you have. A hot roof also may reduce the life of your roofing.

2 During the winter the warm moist interior air migrates up through the attic insulation and hits the cool dry air on the other side, condensing and creating moisture problems. Air flow in the attic helps keep the attic dry.

A successfully vented attic will have vents in the soffit at the base of the roof and vents at the top of the roof, encouraging continuous air flow. When installing new loose blown insulation be careful at the eaves to allow this air flow to be maintained. And if you don't have a well-ventilated attic (if you also can refer to the attic as "the oven" in the summer) this is a good time to correct that.

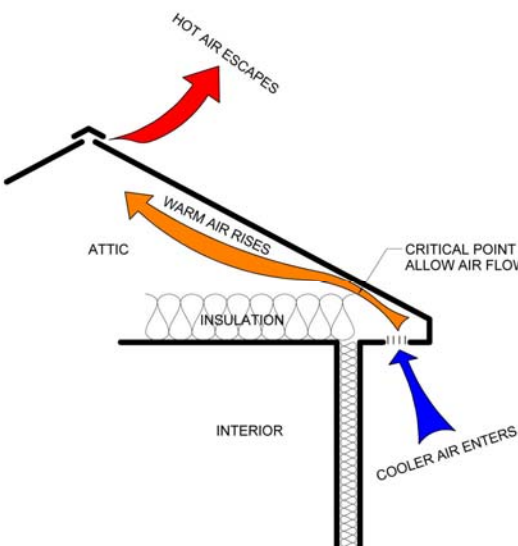


diagram of attic air flow to create a cool roof

Professional insulators may install a box, often made of cardboard, around the eve vents to make sure they are not covered by the new insulation. Or a corrugated product attached to the underside of the roof sheathing, between each roof rafter, will allow the air to flow.

EXPANDING FOAM is a newer product and is becoming more popular because it can provide a complete air seal, plus some products provide a higher R-value per inch. This insulation is also considerably more expensive and must be installed by a certified company. Expanding foam insulation is available in R-values of 3.8 to 5.3 per inch. (Note that some companies may claim that the effective R-value of expanding foam is higher than other types of insulation because of its air sealing properties, but this is not true…however, with expanding foam the quoted R-value is more likely to be obtained than with some other types of insulation where the quoted R-value may not actually be obtained because of gaps in the insulation and/or outside air leaking around the insulation effectively bypassing it). Some other facts:

- The insulation may be applied to the floor of the attic or to the underside of the roof, or both. This may allow easier use of the attic for storage.
- Because of the air and moisture sealing properties of some types of expanding foam insulation it may not be necessary to have air flow in the attic to create a cool roof, especially if the insulation is applied to the underside of the roof (rather than the floor of the attic). Some types of expanding foam provide a good air seal for reducing infiltration (air leaks) but are still permeable to moisture. For those insulations the attic ventilation is still required.
- An air and moisture sealing insulation may be preferable in vaulted ceiling areas where it is more difficult to create air flow over the top of the insulation. However, installing in an existing

house means removing all ceiling finishes and exposing the bare rafters.

- Be sure that the spray foam being used has water as the blowing agent. Carbon based blowing agents (such as any form of CFC's or HCFC's) have considerable global warming potential and therefore negate many of the benefits of reducing energy usage.

EXTERIOR RIGID INSULATION is also a possibility and is a very efficient way to insulate a roof. This insulation would be installed on top of the existing roof, between the roof sheathing and the finish roofing. The rigid Styrofoam boards may be polystyrene (just like Styrofoam packing material, which is about R5 per inch) or polyisocyanurate (about R6 per inch). Some of the properties of this insulation method are:

- The insulation needs to be installed with a re-roofing project and will add to the overall thickness of your roof, so new fascia and gutters will likely be required as well.
- This creates a uniform insulation across the entire roof, eliminating any thermal break at rafters, which is a great benefit.
- For vaulted ceilings this method may work extremely well, eliminating the need for removing the interior ceiling.
- Some rigid foams are available with an integral nailing board to make installation of the new roofing easier.
- By taping the joints between the boards a continuous vapor barrier can be created with some products, negating the need for a cool roof. Verify with the insulation manufacturer.
- If a cool roof is still desired, install furring strips across the top of the insulation to provide a path for air to travel from the bottom to the top of the roof.

CONTRACTOR CORNER

When hiring a contractor to install insulation in your attic:

- Be sure the contractor is experienced with the type of insulation you desire.
- Ask how they will ensure that you have adequate airflow across the top of the insulation to keep the roof cool.
- Ask for a cut sheet (product data sheet) for the insulation.
- Confirm whether the insulation product provides an air and moisture barrier, or just an air barrier
- For spray foam insulation, verify the blowing agent is water.
- Verify the depth of insulation installed is what you agreed, and that the depth is uniform.

tracking the McFRUGAL'S

The McFrugal family spent the weekend blowing in R20 cellulose over their existing R19 attic insulation. At the edges the thickness was less because of the roof slope. They then hired a contractor to install soffit vents and a ridge vent.

Cost: $1,500

Annual Savings: $37

keeping up with the JONES'S

The Jones family hired a contractor to install R-36 spray foam insulation on the underside of the entire roof, resulting in a new total R-56, and negating the need for a vented (cool) roof.

Cost: $6,000

Annual Savings: $55

Crawl spaces are often scary places where spiders and other critters hide. That may or may not be the case, but it can be a place where unwanted air and moisture can enter or leave your home. Our "typical Golden home" was not modeled with a crawl space, but the diagram shown here has been modified to show where a crawl space may be located in your home.

While there are differing thoughts from experts on the best ways to insulate the crawl space, all would agree that this is not a space to ignore.

Safety Precaution:
Some crawlspaces might have been treated with poison for insect or rodent control. If in doubt, wear protective clothing and breathing mask.

INSULATING THE FLOOR between the crawl space and the home above is historically the most common method of treating this space, if it is insulated at all. This provides a barrier between the warm air in the house and the cool air in the basement. The problem with that model is that moisture can condense on the bottom of the floor joists (between the insulation) and cause the structure to rot. The solution in this case is to provide ventilation in the crawl space (typically small openings in the center of each outside wall. If your house has a ventilated crawl space, and stays cool and dry, then insulating between the joists is a good option. R25 or greater insulation should be carefully installed as tightly as possible. Spray foam insulation will create a tight barrier at high costs while do-it-yourself fiberglass or cellulose batts must be installed carefully to avoid any gaps.

INSULATING THE WALLS of the crawl space is the recommendation of the Building Science Corporation (see "Conditioned Crawl Space Construction, Performance and Codes," Research Report 0401, November 2, 2004). In this scenario the exterior walls are sealed and insulated, and the space is heated just like the rest of the house. This creates a warmer floor for the room above the crawl space and significantly reduces the danger of moisture problems in the space. The wall insulation should be at least R25 and may be spray foam or vinyl-faced batts draped along the wall.

PROTECTING THE FLOOR of the crawl space is important to prevent moisture from migrating through the soil into the crawl space. Use a heavy vinyl, overlap and tape the joints, and carry the material at least 12 inches up the wall. You may also consider testing your home for radon (a gas which is present throughout Colorado and can be harmful when trapped in a tightly sealed home) and incorporate a radon ventilation system below the new vapor barrier.

SEALING THE EDGES where the top of the foundation wall meets the floor joists and the wall above is also important. This is an area that is a common source of air leaks (this will probably show up during your Xcel energy audit discussed previously). Using cans of expanding foam to fill any cracks and gaps in this area will help reduce the air infiltration in your home. This should be done before any new insulation is added, because these areas will likely be covered with insulation.

Exterior walls make up the largest portion of the envelope protecting your home from the elements, so this is an area that is important to insulate correctly. For a new net-zero energy home the exterior walls are designed to R30 insulation or higher. Current codes require all new homes to have exterior walls with R20 insulation minimum. For existing homes it may be difficult to achieve levels of superinsulation, but there are some methods that are worth consideration.

Most homes built more than 20 years ago have 4" thick exterior walls with only R11 insulation, and that insulation often sags inside the wall so the top of the wall may have no insulation and there are probably other leaks where outside air "bypasses" the insulation. Older homes may have even less insulation, if any.

BLOWN-IN DENSE PACK CELLULOSE INSULATION is a common method of improving insulation in existing walls. This method involves drilling holes in the exterior or interior wall surface and using a high pressure blower to pack cellulose into the wall cavity. This works whether there is existing insulation in the wall or not.

- Installation by an experienced contractor is important to achieve the best results.
- The insulation only provides an R-value of about 3.4 per inch, so a 2x4 stud wall will yield an R11 wall, or a 2x6 wall obtain an R-value of 19.
- Dense packed insulation should not settle over time.
- Air infiltration will be reduced, and sound attenuation is improved.

NEW EXTERIOR INSULATION is one method of providing a much higher R-value for existing walls by adding insulation to the exterior of the existing wall. This method involves removing the existing siding from your home, adding several inches of rigid insulation (Styrofoam or polyisocyanurate) and then applying a new exterior finish. This is an extreme measure to increase insulation values, but may make sense for homes that are already in need of new exterior siding or if the homeowner desires a new look.

- By adding 4" of rigid insulation, the R-value will be increased by R20. If the existing walls had R11 batts, this gives a total R-value of 31.
- This insulation is continuous and does not have thermal breaks for studs, making it an excellent system.
- Tape the joints between the insulation panels to provide a tight installation and improve the air sealing of your home.
- Stucco works well as the finish over rigid insulation. Other types of siding such as fiber cement or wood requires furring strips recessed into the insulation to provide a nailing surface.

Polyisocyanurate boards added to the interior of an existing home.
Photo courtesy of Steve Stevens

NEW INTERIOR INSULATION is another option that can be very effective, but is difficult to achieve in an existing home. This method involves building a second wall inside the existing wall. The new wall may be studs (offset from the existing studs to provide a thermal break) or may be rigid insulation similar to the exterior rigid insulation discussed previously. Depending on the thickness of the new wall and the type of insulation used, an additional R13 to R20 or higher may be achieved. Some families may not like the result of diminishing the size of the rooms.

- This insulation will not be continuous throughout the entire house because some areas (such as bathrooms, stairs, or closets) cannot be reduced and still function or even meet code minimum sizes.
- The existing interior finish may remain or be removed. By removing the existing finish it may be easier to extend electrical outlets to the new surface, plus insulation in the existing wall cavity can be upgraded.
- When applying the new interior finish, consider two layers of 5/8" gypsum board to add thermal mass to the home (see the chapter on thermal mass).

CONTRACTOR CORNER

All options for adding insulation to existing exterior walls will likely require hiring a contractor.

- When several different contractors are involved (framers, insulators, stucco or other finishes, etc) it is best to hire a general contractor who will hire and oversee the subcontractors.
- Be sure the insulation subcontractor is experienced with the type of insulation you desire.
- Ask for a cut sheet (product data sheet) for the insulation and any other products that will be installed.
- Consider what other upgrades make sense to perform at the same time.

tracking the McFRUGAL'S

The McFrugal family considered dense-pack cellulose insulation for their existing walls and decided that the $4,000 cost and annual savings of $13/year did not meet their financial criteria. They decided to wait and perhaps perform this upgrade later.

keeping up with the JONES'S

The Jones family decided to go for a new look on their house. They hired a general contractor to install 4" exterior rigid insulation and a new stucco finish.

Cost: $25,000

Annual Savings: $37

Foundations are naturally insulated by the earth around them, which is both a benefit and a liability. Because of this natural insulation basements have been neglected over the years – many older homes have no additional insulation in the basement, and even though the ground is a moderate temperature, some insulation is still needed to buffer against the 50 to 55 degree earth on the other side. And that moderate earth temperature does not apply to the top three feet of soil – frost depth can reach close to three feet deep during a cold winter. Therefore, a well-insulated and energy-efficient home should provide R20 insulation in the basement.

INSULATION ON THE INSIDE SURFACE is the most common way to provide this insulation.

- Vinyl-faced fiberglass batts can be draped on the inside of a concrete wall, attached at the top and periodically attached along the face of the insulation. This provides a good layer of continuous insulation, but this vinyl face can easily become damaged in active basements with kids playing or adults wielding workshop tools. Also, if the basement will ever be fully finished as living space, that vinyl-faced insulation is often discarded creating unnecessary waste.
- A stud furring wall can be built inside of the concrete foundation, with any type of insulation applied between the studs. The stud space allows for current or future installation of electrical and plumbing components, plus allows easy installation of gypsum board for a finished basement.
- R20 insulation is suggested as a goal for this type of insulation.

INSULATION ON THE EXTERIOR of the foundation wall has many benefits, but is more difficult to achieve in an existing home.

- In this method, excavation around the entire house is necessary to place rigid insulation boards against the foundation wall.
- If moisture seeping into the basement has ever been a problem, this method presents an opportunity to solve this problem as well. Insulation & drainage boards are available to give a path for moisture to follow to the bottom of the wall. That moisture is then collected in a French drain and drained to daylight or to a sump pump.
- By placing the insulation on the exterior, the space in the basement is not reduced by furred walls, plus the concrete walls provide an excellent thermal mass for storing warmth or cooling (see chapter on thermal mass). Gluing gypsum board as a finish to the concrete, or a direct application of plaster, will provide a finished basement while maintaining the thermal mass properties.

tracking the McFRUGAL'S

The McFrugal family hired a contractor to build 2x6 furring walls in their basement, then they installed R21 Knauff EcoBatts between the studs.

Cost: $4,000

Annual Savings: $33

keeping up with the JONES'S

The Jones family hired a contractor to install Owens Corning Insuldrain R21 (4" thick) rigid insulation & drainage board plus a French drain and sump pump around their entire home.

Cost: $15,000

Annual Savings: $37

For a typical home, the windows and doors make up between 10 and 20 percent of the exterior wall surface (the Jones' and McFrugal's homes have about 2000 square feet of wall surface, not including the garage, and 300 square feet of that is windows and doors, for a total of 15% openings). If the R-value of those openings is 1 or less, that is a significant thermal hole in the house and is worthy of attention.

The technology for building more energy efficient windows and doors has grown significantly in the recent years. Most homes built in the past 30 years have insulated glazing with a U-factor of about 0.50 to 1.0 (the U-factor is used for windows and door ratings, and this is the inverse of the R-value – for instance, a U-factor of 0.50 equals an R-value of 2). Most homes built in 1960 or earlier will have single-pane windows and cold steel frames with a U-value greater than 1 (R-value of less than 1). Our current building code requires new homes to have windows and doors with a U-value of 0.35 or less.

New technologies include low-emissivity coatings (low-e), gas-filled space between the glazing (using argon or krypton), triple glazing, thermal breaks in the frame and more. U-values of 0.30 are easily attainable, and one window manufacturer is able to achieve a U-value as low as 0.09 (that is an R-value of 11).

In addition to the U-factor, glass is rated with a solar heat gain coefficient (SHGC) which measures the amount of heat that is transferred through the glazing. A SHGC of 0.0 means that no heat is transmitted, and a SHGC of 1.0 means that all of the sun's heat is allowed through the glass. For south-facing glazing that can be used to heat the home (meaning there is also adequate shading for the summer and adequate thermal mass to absorb the heat) a high SHGC is desirable, while east and west facing windows typically benefit from a low SHGC. Note that if you see SHGF (Solar Heat Gain Factor) instead of SHGC the values should include the window frames (which is good information to have!).

Windows on the south side of a home allow direct sun into the home – this can be a free source of heat, but can also be a source of overheating (even in the winter) or excessive glare. Large windows facing north are replacing a potentially well-insulated wall with a poorly insulated surface. Windows facing any direction provide free light during the day, but also may be a source of glare and eye strain if too bright. North-facing windows are best at bringing in free light without the glare most of the year. And all windows are a source of heat loss at night. Therefore, opportunities to enlarge windows that are beneficial or to reduce or remove (or add shading to) windows that are detrimental should be considered when embarking on a window replacement process.

The process of selecting the right glazing for each window is referred to as "tuning" the windows. Tuning the glazing is extremely important on a net zero energy building and is best done using energy modeling so that the results of different window selections can be studied.

For these reasons, replacement of some or all of the exterior windows and doors should be considered. Some of the factors and products to consider are:

- Vinyl (PVC) windows are usually the least expensive window option. However, these are typically not considered to be a high performing window and not the most aesthetically pleasing or most environmentally benign. Colors are only white or light beige/grey.

- Fiberglass windows are gaining popularity. They are generally considered stronger and more stable, have much better frame insulation value, yet can be as inexpensive as PVC. Many of the high-performing residential windows are fiberglass. These windows are also available in darker colors or they can be painted.
- Wood windows are often preferred for aesthetic reasons. Many wood windows have an exterior cladding of aluminum, PVC or fiberglass so that the exterior is virtually maintenance-free. These windows are usually more expensive than their PVC or fiberglass counterparts, and can be high-performing.
- Fixed windows (windows that do not open) typically have lower U-factors than operable windows (remember, the lower U-factor is better). Windows that have a crank (casement or awning) typically create a tighter seal and have a lower U-value than sliding (single-hung, double-hung and sliders) windows.

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- Visit a couple of window & door showrooms to see several different options.
- Ask how a broken window can be replaced – some windows must be totally removed and replaced while others can more easily have just the glass replaced.
- Not all windows are rated the same, although there is a move to more standardization. Be sure to verify that the ratings include the frames and are not simply glass-only ratings (the glass-only ratings will be higher than the whole-window ratings).
- Verify and compare warrantees, and what is covered under the warranty (glass seal failure, labor, etc).
- Be sure the contractor correctly seals around the edges of the windows using non-expanding foam (expanding foam puts pressure on the side of the window and can bend the frame).
- When replacing bedroom windows, be sure that the new window is rated to provide code-required egress.

tracking the McFRUGAL'S

The McFrugal family hired a contractor to install new double-pane low-e fiberglass windows with a U-value of 0.50.

Cost: $10,000

Annual Savings: $123

keeping up with the JONES'S

The Jones family installed state-of-the-art windows from Serious Windows (fiberglass windows, triple pane, two low-e coatings, gas filled) with a U-value of 0.15.

Cost: $25,000

Annual Savings: $262

Mechanical and solar systems are expensive. For that reason it is best to reduce the load on these systems by performing the work discussed in the previous chapters, because then a new mechanical system may be smaller and less expensive. Once insulation levels have been increased, air leaks sealed, and electrical appliances, lighting, and equipment replaced with more efficient options or controlled more efficiently, only then it is time to look at the mechanical systems.

Typically an existing residential heating system is a gravity gas-fired furnace with about 78% to 80% combustion efficiency. The real annual efficiency however is closer to 65% to 70% due to flue and standby losses. Here are a few ideas for replacement systems:

SEALED COMBUSTION FURNACES AND BOILERS. These use outside air ducted to the burner instead of room air. The result is the equivalent of reducing one big air leak in the home.

- The furnace (or boiler) is typically rated at 83% or higher due to advancements in design but without the old standby losses. The total reduction in

SYSTEM ZONING

When I ask a home owner if there are any mechanical issues, the most common response is that there are hot and cold areas and the upstairs is usually too hot in the summer. This is the natural result of having only one thermostat and only one system zone for a building that really has many thermal and use zones. Simply having a separate zone for each floor (this can be a separate furnace for each level) can save energy and improve comfort. Further zoning can also save energy and improve comfort to a lesser degree. Good zoning is helpful for heating and probably more so for cooling. None-the-less more than one zone is uncommon for small (and average) homes.

A common practice where two zones are installed is to put one furnace in the basement and one in the attic.

building heating energy use is then 8% to 19% or more.

- Note that mechanical room ventilation could still be needed if piping and ductwork are not adequately insulated. More on that later in this book.
- The furnaces are connected to ductwork and can probably re-use the existing ducts. These forced air systems can make the air feel dry to some individuals in our climate.
- Boilers are commonly used for baseboard radiators or in-floor radiant systems. While radiation can be put in walls and ceilings, that is much less common. An advantage to radiant systems is that they warm more of the surfaces and elements in the building (instead of the air) and as a result comfort can be improved at lower thermostat settings. The lower thermostat settings in turn save energy.

CONDENSING FURNACES AND BOILERS. Condensing furnaces and boilers extract more heat from the combustion process. Efficiencies as high as 94% to 99% are claimed for some of this equipment (be sure to read the fine print carefully). As a caution, condensing boilers are only condensing when the return water is below about 140 degrees F. Above that return temperature the efficiency is similar to or a little less than ahigh-efficiency boiler. As a result, condensing boilers are well-suited to radiant floor systems since those typically use circulating fluid of 120 degrees F or less.

Condensing boiler

- This type of equipment should also have the combustion air ducted directly from outside. With this upgrade the savings are now in the range of 19% to 33%.

- The flue gasses are ducted to outside using a PVC or CPVC pipe. The gasses are normally below 140 degrees F and there is a mostly water condensate that can be slightly corrosive.

Furnaces with **VARIABLE AIRFLOW FANS** are typically the highest efficiency furnaces and air conditioners.

- These can automatically reduce airflow for part load conditions, thus saving fan energy and improving the efficiency of the cooling system if there is one.
- The fan savings are included in the high efficiency ratings.

HIGH EFFICIENCY BOILERS. There are a number of types, however most of these have finned copper tube, low mass heat exchangers and sealed combustion. Annual efficiencies are typically up to about 87%.

GROUND SOURCE HEAT PUMPS (also known as Ground Coupled Heat Pumps and sometimes not too accurately as "geothermal"). This equipment uses compressors and a refrigerant to extract heat from the ground when heating and to "pump" heat into the ground when cooling. COP (coefficient of performance) is the ratio of the heating output, in Btu/hour to the energy input of the unit in Btu/hour and is typically used to rate heat pumps for heating capacity.

- The system is more cost-effective and could be more efficient when it is needed for both heating and cooling. It may need a larger ground "loop field" if only used for heating or if the heating energy extracted in a year is more than twice the cooling energy pumped into the ground.
- When the loop field is sized adequately (large enough) ground source heat pumps can be one of the most efficient

systems presently available short of solar systems discussed below or other renewable energy systems.

- When the loop field is undersized (for a heating system) the ground can get colder and colder until the system eventually shuts itself down to protect the compressor. A similar effect, overheating, can occur with an undersized system used primarily for cooling. In addition, energy costs can actually increase if the loop field is too small.
- Installing a GSHP system to replace an existing furnace is an expensive proposition. If the existing furnace uses natural gas for fuel, the change will save relatively little energy cost even though it will save energy at the property boundary. In the case below for the Jones' this system saves about 50% of the energy at the site boundary but only about $50 per year of energy cost. The cost savings are not greater because there is a switch from using natural gas for heat (relatively inexpensive) to using electricity (much more expensive) to run the heat pump and associated glycol circulating pumps. This is a good example to illustrate whether to use energy at the site boundary, at the power plant, or to attempt a holistic evaluation of all environmental impacts (refer to discussion earlier in this report).
- There are many types of GSHPs. A common type for residences is **water to air**. Water is a bit of a misnomer since the fluid circulating in the in-ground pipes is usually an antifreeze (glycol) solution. This system uses ductwork much like a common forced air furnace. There is a good chance that the existing ductwork can be reused (after it is inspected for leaks). This system can both heat and cool.
- A **water to water** system (again really an anti-freeze solution) is commonly used with a hot water floor radiant heating system. The inside water can alternatively be piped to a coil

in ductwork and used for heating and cooling. When strict precautions are taken, this system can use the radiant floor heating for cooling as well. The precautions are essential, not inexpensive, and should be designed by an engineering professional. The precautions involve adding controls, automatic valves, a house-side pump, and in-floor dew point sensors and house air humidity sensors. The water circulating in the radiant system must never get colder than the temperature at which water condenses out of the air to avoid serious moisture and mold problems in floors, carpets, etc.

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- Once you have reduced the home energy use by implementing strategies in the previous chapters you can install a smaller furnace. However, make sure you still have enough spare capacity to re-warm the home after a night temperature setback. 30% spare capacity is suggested for "morning warm-up".
- Ground Source Heat Pump systems require larger loop fields to achieve their efficiency potential, which adds cost. They also need to have a larger loop field if the system has no cooling or very little cooling use. Be sure your contractor (and engineer) understands these concepts. Beware if the contractor is recommending a smaller loop than you engineer.

tracking the McFRUGAL'S

The McFrugal family decided to replace their furnace with an ultra-high efficiency sealed combustion condensing furnace and re-use the existing ductwork.

Cost: $6,000

Annual Savings: $78

keeping up with the JONES'S

The Jones family installed a Ground Source Heat Pump system to reduce the energy use even though at current rates the energy cost may not change much.

Cost: $40,000

Annual Savings: $47

SOLAR THERMAL (heating) systems can save a lot of energy when properly designed and installed. Our climate has an abundance of solar energy, and since we are more than a mile high there is less atmosphere in the way. As a result we get about 17% more solar energy on a clear day than at sea level. There is a much wider variety of solar thermal system types than can be discussed here, so we will mention only some of the more common ones.

All solar systems need sunlight, so it is best if the collectors face nearly south. There are systems facing east and some a little toward the west, but they are less common and require extra attention. They also work best if tilted up to face more directly toward the sun. The amount of tilt can vary and is an important part of the design. If it will be used more in the winter, tilt it more. If the use will be more in the summer, then tilt it less (more horizontal).

- **FLAT PLATE COLLECTORS** used to be the dominant type of solar collections equipment. A special black surface coating absorbs heat from the sun and specially coated glass traps the heat in the collector. Normally one pane of glass is used for very low temperature systems and two panes of specially coated glass is used for moderately low temperature systems. Good sealing is needed to keep moisture, dirt, and weather out. When attaching to the roof, be very careful to properly seal and flash the supports and make sure everything drains well. There are both hot air collectors and hot water collectors (and hot antifreeze collectors).
    - o Hot air systems need ductwork and a means to store the heat. Usually a bin full of washed river rocks, as round as possible and about 1½ to 2 inches in diameter, is used for storage.

- A hot water system uses a tank to store the heat. The tank can be a manufactured pressure vessel or a field-built tank of structural walls and a water-tight single sheet EPDM liner. A pump circulates the water or anti-freeze to the collector and another pump circulates the water in the tank, or a secondary fluid, to the heating system.
- Flat plate collectors are low-temperature collectors. Their efficiency drops the greater the difference between the circulating fluid (water or air) and the outdoor air (ambient air). Normally their efficiency in our climate drops quickly above about 120 to 140 degrees F circulating fluid. This makes them suitable for radiant floor heating systems, but not for normal radiant baseboard systems.
- This author believes the risk of failure is much higher with "**DRAIN-BACK**" systems that use only water and no anti-freeze. While a simpler system in some respects, there is quite a lot that can go wrong. None-the-less they were popular in the 1970s and are still in use. Possible failure modes, generally leading to pipes bursting from freezing, include:
    - A stuck, frozen, or corroded air vent, preventing proper system drainage.
    - Pipes sagging over time leading to loss of drainage
    - Control sensor failure
    - Controller failure
    - Drain valve stuck closed
    - Differential settling of the foundation leading to loss of pipe slope required for drainage

- A **CLOSED LOOP** system uses anti-freeze in our climate. There is generally a heat exchanger and expansion tank included with this system. There is a science to designing the best ratio of ant-freeze to water and this should be permanently marked by the fill valves. The anti-freeze/water mixture should always be pre-mixed to this exact percentage and then added to the system. Never add anti-freeze and water alternatively hoping that the mixture will be about right (it won't). The anti-freeze provides added protection against freezing and bursting pipes and the resultant potentially extensive damage.

Evacuated tube solar hot water collectors

- **EVACUATED TUBE COLLECTORS** have recently become very popular. A glass tube about 2 inches in diameter has a vacuum inside that substantially reduces heat loss from the circulating fluid which in many cases is a refrigerant in the tube with a small heat exchanger at the top of each tube. These systems can collect heat at good efficiencies with fluid temperatures as high as 180 degrees F. This is a significant advantage that now allows use of solar heating efficiently in many more systems types such as standard baseboard radiators as well as in special absorption-type air conditioners. This year's ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) Annual Winter Meeting and Trade Show displayed an astounding number of manufacturers of evacuated tube collectors. Clearly the market has taken a turn in that direction.

- One problem these collectors have had is a loss of vacuum. Moisture then gets in the tube and the combination substantially reduces the efficiency. The manufacturers have been replacing the failed units under warranty, however most warranties do not cover the installer's time.
- Another issue is overheating during stagnant conditions. If the pump stops or power fails or for other reasons the circulation stops while solar energy is still being collected, or the storage tank is already at the maximum temperature, these collectors can get so hot they damage themselves. For this reason a reliable fail-safe design addition is necessary. A design professional should provide a method for rejecting heat in these circumstances.

- **CONCENTRATING TRACKING TUBE COLLECTORS** are relatively new to the market over the past few years. They use a non-evacuated tube, avoiding failure from loss of vacuum. A sensor tracks the sun's position and moves the parabolic reflector to focus the sun's energy on a pipe running down the middle of the tube. Temperatures and efficiency are comparable to the evacuated tube collectors. The electronic controls can move the focus away from the pipe quickly cooling it to prevent overheat. A power failure should result in the sun moving away in a short period of time, also protecting the system from overheating. Since these systems are relatively new there are questions about longevity relating to the motor, linkage, electronics, and the seal where the linkage passes into the tube.

- There are many kinds of **TRACKING CONCENTRATING SOLAR COLLECTORS** as well as **NON-TRACKING PARBOLIC CONCENTRATING COLLECTORS** that are beyond the scope of this report, but keep an eye out for new products.

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- Typically a system is sized to provide about 50% to 70% of the heating needs. Going beyond that requires a very effective passive home with extensive thermal mass and/or a very large thermal storage system for multiple days without sun and a small storage system for daily use.
- A system that truly provides all the heat would not need a backup system. This is very difficult to achieve and you will probably have a difficult time convincing the building officials to allow it.

tracking the McFRUGAL'S

The McFrugal family decided that a solar thermal system is just too expensive for now. They might reconsider when energy costs rise or there are better incentives.

keeping up with the JONES'S

The Jones family also considered a solar thermal system in addition to their GSHP. This system would theoretically cover all their heating needs using tracking concentrating tube collectors and a very large storage tank. It would cost $50,000 to $70,000 and save about $180/year.

VENTILATION is now a critical component of low-energy residences. Once leaks have been sealed and the air changes are reduced to about 0.25 per hour or less, then toxic fumes from off-gassing of furniture, cleaning chemicals, cooking, and so forth can build up to unhealthy levels. There can also be a shortage of fresh air.

The solution is a heat (or energy) recovery ventilator. There are two basic types depending on whether you want to recover moisture in the air or not. Most use what is called a cross-flow heat exchanger at its core plus an intake fan and an exhaust fan. These allow efficient heat transfer from the exhaust air to the intake air. They can not only preheat incoming air in the winter, but also have the inherent capability to pre-cool incoming air in the summer.

- If you are humidifying the home, then you should probably recover the moisture. The device that does that is an **ENERGY RECOVERY VENTILATOR (ERV)**. These often have a rotating wheel coated with a material such as bentonite that absorbs moisture in the moist air stream and releases moisture in the drier air stream.
- Often moisture accumulates too much in tight homes from showers, cooking, and other activities, and in that case not recovering moisture may be the better option. The device for that is a **HEAT RECOVERY VENTILATOR (HRV)**. If you like Colorado's dry climate, you may prefer a HRV.
- In our cold climate a heat recovery device will freeze and plug the exhaust air stream if precautions are not taken. The result is that the device is no longer doing its job. When freezing air enters the intake side, the exhaust side can freeze

and then moisture condenses and freezes until the entire airflow is blocked.

  - The solution is a little different with each manufacturer, but they all use some method of periodically warming the exhaust side to thaw out accumulated ice. While this is occurring the device is not ventilating.
  - Another method is to preheat the incoming outside air. This can be done with an electric heater or by using heated glycol from a boiler or solar system. When using heated glycol (never use just plain water), Murphy's Law requires that more than one scheme be employed to reduce the risk of freeze damage. It is recommended to employ at least three such "safeties". The glycol, at least 35%, is one (use relatively non-toxic propylene glycol). A second is a freeze-stat – basically a thermostat designed to sense near freezing temperature (in the intake air stream downstream of the preheat coil) and shut off the fan and close a damper and sound an alarm. A third safety could be a three-way valve, coil pump, and controls that keep circulation in the coil at all times and a control that turns the pump on when the outdoor temperature is near or below freezing.

- Currently manufacturers are offering EC Motors (Electrically Commutated), which are much more efficient than the standard fractional horsepower motors. They will save additional energy.

- Generally size the device for 5 CFM per person plus 0.06 CFM per square foot of occupied home. Then have the contractor make sure the equipment selected has sufficient static pressure capability for the proposed ductwork. Try to locate supply and exhaust grilles where you will provide good flow across the various spaces in the house.

Because we live in a mild climate many families do not feel they need a cooling system for their home, especially with one-story houses that are well shaded from large trees. However, if your home needs a cooling system to stay comfortable during the warm July and August days here are some good options for using as little energy as possible.

NIGHT FLUSHING refers to ventilating the house at night using cool outside air. This can be done using the furnace fan, a whole house fan, or other methods. By cooling the indoor building materials (walls, furniture, etc.), "coolness" is stored in the mass and can reduce cooling needs the following day. Night flush effectiveness can be improved by adding thermal mass (see discussion later in this pamphlet) as well as keeping the temperature from getting too cold.

HIGH EFFICIENCY CONDENSING UNITS AND EVAPORATOR COILS for air conditioning (a.k.a. "split systems"). Residential cooling equipment is available with EERs (Energy Efficiency Ratios) as high as 21 or more (older models have an EER of about 9), although the choices are limited at these high efficiencies. These achieve their high efficiency with variable speed indoor fans, high efficiency compressors, lots of finned area on the coils, and better control of the refrigeration process. The EER is the measure of air conditioner efficiency at maximum air conditioning load. It is the ratio of Btu/hour of cooling output to watts of electrical power input. The SEER (Seasonal Energy Efficiency Ratio) is calculated to approximate real-world conditions where the system is not at full design condition all the time. The SEER is determined through averaging performance at different conditions to represent typical use air conditioner efficiency throughout the season.

ADDING COOLING TO AN EXISTING FURNACE is common. This is done by installing a cooling coil in the furnace supply ductwork (which has to be enlarged for a few feet) and then an air-cooled condensing unit outdoors. Refrigerant piping is installed between the two. As a general rule the existing ductwork is too small for cooling and the fan and fan motor are also too small. The result is some cooling, but not as good as a new system installation. Following the recommendations in this report, however, will result in a much lower cooling requirement and in that case the existing ductwork and furnace fan may well be large enough. Refer to the paragraph above for information on a high efficiency condensing unit.

GROUND SOURCE HEAT PUMPS (GSHPs) are discussed above under heating systems. Their cooling efficiency is rated using the EER discussed above. The system normally works better if it is providing both heating and cooling since that helps to stabilize the ground temperature over the year.

DIRECT EVAPORATIVE COOLING. The term "swamp cooler" is familiar to most people, and refers to very low effectiveness (similar to efficiency) direct evaporative coolers that typically use 1 inch thick Aspen pads as the evaporative media. Higher

effectiveness evaporative coolers using other media are available although not common for residential application. Evaporative cooling works better when outside air is drier, which makes Colorado a very good area to use evaporative cooling. None-the-less there are times of the year when the humidity is higher and the evaporative cooling will be less effective or do nothing at all. Direct evaporative cooling also raises humidity, and this needs consideration in some instances such as occupants who are less comfortable at the higher humidity (some are more comfortable at higher humidity) or in situations where the added humidity can cause damage, mold, or other problems.

MULTI-STAGE INDIRECT EVAPORATIVE COOLING is a process developed in Colorado that is capable of supplying air at lower temperatures than even high effectiveness indirect evaporative coolers. These systems still require two large duct systems when located indoors and are relatively expensive. Where the space and budget are available and dehumidification is not needed, these are worth consideration.

The ability to remotely set and read thermostats in a home has been around for a while, although the systems have required a specialty contractor to provide them. Simple web- and smart-phone applications are now under development and some are already available to remotely adjust thermostats, change schedules, and to check on house temperatures.

Simple furnace and boiler systems can be controlled using the controls in the equipment that is turned on and off by a wall thermostat. A programmable thermostat is recommended so that additional savings can be achieved with night setback. This simple measure can often save about 5% to 10% on the heating bill.

Low cost modern digital monitoring and control for small commercial and residential applications that have more capability remains elusive. Starting costs are quite high, typically adding at least about $5,000 to $10,000 or more for the digital controller and programming using a system that is relatively user-friendly and flexible. Lower cost systems usually have small screens and are difficult to navigate through the options even for a contractor who installs them regularly. None-the-less, here are some advantages to a small digital control system:

- Some systems require control features that are difficult to achieve and harder to maintain over the years using stand-alone relays and controls. When there are logical "if this then that" needs, a digital control system will be a better choice.
    - An example is a radiant cooling system where it is essential that fluid temperatures or surface temperatures be kept above dew point temperature so that mold is less likely to form on the radiant surface.

- By knowing how the system is performing through monitoring (beyond just the building meter), it is then possible to target improvements, repairs, and adjustments to the actual problem area. It also gives feedback to the occupant which often results in an incentive to save energy on the order of 10% to 15% just based on the real-time feedback.
    - As an example, by monitoring the temperature to a radiant floor heating system, it will become evident when the system is getting out of calibration and wasting energy.
- Automatic controls, when combined with a zoned system, can control the amount of energy used in each space as well as turn the system off in unoccupied areas. The result is improved comfort and reduced energy use.

If the system has the ability to keep logs of performance data, that information can be gathered and analyzed for use in improving future designs.

There are a lot of choices when it comes to heating water for domestic uses (showers, sinks, clothes washing, etc). We'll discuss briefly some of the more common ones. The fuel choices in Golden are generally gas, electricity, or solar. Most gas-fueled devices can be ordered with a kit to convert to propane if that is your source. Electricity and propane are expensive sources of energy in our area. If you don't have natural gas available, then your return on investment for using solar will be much higher. The first major division in system type is tank or tankless – or more accurately storage (tank-type) or instantaneous (generally tankless type). That leads to a hybrid which could be called "instantaneous with very small storage."

It takes a lot of heat in a short time to provide the hot water that we take for granted. We can either store it up over time (tank-type heater) or provide a very high capacity fuel burner that can provide the maximum heating rate required (instantaneous type).

STORAGE WATER HEATERS for homes generally have a tank with 30, 40, or 50 gallons of capacity plus a burner rated at about 30,000 to about 50,000 Btu/hour. There are more sizes, but those are the common ones. The ability to meet the hot water flow requirement is a combination of the stored hot water plus the burner capability. These are combined in "first hour" ratings.

- Don't forget that the burner rating is fuel input at sea level and the actual output capacity needs to be de-rated for both altitude and burner efficiency.
- Storage water heaters are inherently "forgiving" in that they can provide for large flow rates (subject to pipe size) if everything is on at the same time. The duration of course will be shorter in that instance.

- The storage tank has "standby" heat loss – basically conduction loss from the tank to the room air. If it is rarely used to near capacity, the standby losses can be a large percentage of the energy in hot water that is actually used. Wrapping your tank with insulation (kits are available) is a good idea to minimize these losses.
- Tank-type water heaters are also available in **HIGH EFFICIENCY** and **SEALED COMBUSTION** (very high efficiency) and **CONDENSING** (ultra high efficiency) versions. Generally these are very expensive in the current market, however watch for the prices to drop in time. A careful analysis can help determine if there are sufficient savings from the higher efficiency versions to provide sufficient return on investment. When your goal is a net zero home, these may have lower cost for the incremental savings than PV or solar thermal, however solar thermal can get you closer to net zero.

INSTANTANEOUS WATER HEATERS have large capacity modulating burners designed to provide the exact amount of hot water needed at any one time. These are sized by estimating the maximum amount of concurrent use that you want to be able to accommodate. The more concurrent use, the more expensive and the larger the gas line needed. Note that sometimes the gas company will not provide a larger gas line.

- Instantaneous water heaters have an advantage in very low to insignificant standby losses. Some also have very high efficiency burners.
- Two disadvantages of instantaneous heaters are low flow limits and high flow limits. If you turn on more uses than the capacity of the unit burner, the water will not heat to the intended temperature (or on some models will flow at a slower rate). When you try to use a low flow, such as a trickle flow in the kitchen sink, these devices typically cannot

modulate to below ½ gallons per minute (GPM) and the water comes out cold. These are adjustments in "lifestyle" that some people easily adapt to and others don't. Sometimes there is a real need for low flow beyond a lifestyle adaption.

HYBRID INSTANTANEOUS WATER HEATERS, or **SMALL TANK INSTANTANEOUS WATER HEATERS** are instantaneous water heaters with very small tanks, often as small as 1/5 gallon, but a few gallons works better. The purpose of the tank is to accommodate the very low flows and possibly a very brief high flow. This eliminates the "lifestyle" adjustment because now the combination can provide as low of a flow as you can adjust with the faucet. There is still a high flow limit beyond which the water comes out colder the more hot water faucets (or clothes dryers, dishwashers, etc.) are opened or turned on.

Hybrid system with on-demand gas water heater above a small electric water heater

SIDE-ARM WATER HEATERS are heat exchangers attached to a boiler that have flow internal to the boiler on the heating side. The advantage is having only one device to maintain that can be a very high efficiency device with large capacity. A disadvantage is the boiler has to be run in the summer for loads generally much smaller than its capability. There are also the potential disadvantages of low and high flow limits.

STORAGE TANKS WITH HEAT EXCHANGERS are tanks with heat exchangers inserted into them that are piped to a separate boiler or solar system. These allow the use of a boiler or solar system without the low and high flow limits of instantaneous and side-arm heaters.

SOLAR THERMAL DOMESTIC WATER HEATING SYSTEMS consist of solar collectors, tanks, heat exchangers, pumps, expansion tanks, controls, and sometimes a few other components. In our climate, if you have good solar access, these systems may easily provide 70% or more of your domestic hot water using solar energy with a good return on investment. This is also important if your goal is a net zero home. While solar systems almost disappeared after the 1970's tax credits expired, now the market, at least on the manufacturing side, seems to be growing exponentially... so there are a lot of choices.

- "**DRAIN-BACK**" and "**CLOSED LOOP**" systems are discussed in the earlier chapter on solar heating systems.
- An **OPEN TANK SYSTEM** can be field-built of framed lumber and lined with a single sheet of EPDM. These are normally used when the system serves space heating as well. Copper coils are set in the tank to function as heat exchangers, one piped to the solar collectors, one to the domestic hot water system, and one to the solar heating system.
- **CLOSED TANK SYSTEMS** can have single or multiple tanks. A single tank system can have the heat exchanger for the solar heat located in the lower part of the tank with the hot domestic water piped to the top of the tank. A common system would use a pre-heat tank that receives the solar heat from the collectors and has the cold water piped to it. The outlet from this tank then is piped to a back-up water heater that adds heat when the solar pre-heat tank is depleted below the temperature needed.

CONTRACTOR CORNER

- Remember to check for tax rebates and credits as well as local and State incentives. They can cover a significant portion of the system cost.
- Ask to see a few systems the contractor has installed. Look at the workmanship of the piping and insulation. Make sure you are comfortable with the way the collectors are installed on the roof, including the attachment method and the water-proofing and flashing. Talk to the Owner about how well it is working.

tracking the McFRUGAL'S

The McFrugal family is thinking about installing a two-panel (flat plate collector) domestic solar hot water system, but have not yet committed.

Cost would be: $7,000

Annual Savings: $100

keeping up with the JONES'S

The Jones family is thinking about installing a generously sized evacuated tube domestic solar hot water system.

Cost: $12,000

Annual Savings: $120

Lighting may easily account for 25% or more of the electricity used in your home, which creates a prime target for reducing energy usage. There are currently five primary types of lighting. Listed in descending order of energy usage they are:

- **Incandescent lights** were invented more than 100 years ago by Thomas Edison. These are the standard light bulbs we grew up with, creating light by sending an electrical charge through a filament. Nearly 90% of the energy, however, is wasted in creating heat rather than light. These light bulbs tend to last for about 1,000 hours.
  - PROS – inexpensive, easily dimmable, good color rendition
  - CONS – inefficient, create heat, burn out quickly
- **Halogen lights** are slightly more efficient than incandescent, working on similar principles of heating a tungsten filament in a sealed halogen bulb. They burn extremely bright, save about 20% electricity, and last for approximately 2,000 hours.
  - PROS – easily dimmable, bright white light
  - CONS – inefficient, create heat
- **Fluorescent lights** use a sealed glass tube that is coated with phosphors and filled with gases which get excited when stimulated with electricity, producing light. Fluorescent lights have been around for several decades and earned a poor reputation from their early days using magnetic ballasts. These older fixtures had a yellow hue to the light as well as a flicker that annoys some people and can cause headaches and other maladies. The newer fluorescent lights, however, contain electronic ballasts with a flicker rate 1000 times faster which is undetectable with the human eye. The newer lights also have much better color rendition. Dedicated fluorescent lights use long tubes or small bayonet-type bulbs (called

compact fluorescent), but screw-in type bulbs are increasingly available to directly replace incandescent bulbs in any light fixture. Dedicated fluorescent fixtures with dimming capabilities are expensive (typically adding $100 to the price of the light fixture), and the dimming capability of the screw-in type bulb is not very robust (they only dim to about 20% of the full capacity, which is often not enough dimming to be useful). Fluorescent lights typically last for 10,000 hours, ten times the life of an incandescent bulb, and waste very little of their energy in the form of heat. Fluorescent bulbs do contain some amount of mercury and should be disposed of through an approved recycler. For energy efficient lighting in a typical home, screw-in fluorescents are encouraged.

  - PROS – efficient, ease of installation, long lasting
  - CONS – dimming capabilities, mercury content

- **LED lights** are Light Emitting Diodes, which are semi-conductors. These lights use even less energy than fluorescents, typically saving about 25% compared to fluorescent lights. The quality of light can be very good, but cheap versions of these lights often give a bluish hue. Similarly, these lights are praised for their ultra-long life (50,000 hours is a typical claim) but cheap versions have been reported to fail in a fraction of that

ABOUT BULB LONGEVITY

Q: When one bulb burns out, should I just replace all of the bulbs in that room or in that light fixture? The other bulbs will burn out soon anyway, right?

A: NO! Light bulbs are rated for the number of hours they will burn. In order to determine the rating, the light bulb manufacturer burns a certain number of bulbs (we'll use 100 for this illustration). When the 50th bulb burns out, that is the number of hours that the bulb type is rated. One bulb may last twice as long as another identical bulb. So if you replace all the bulbs when the first one burns out, you will be wasting a lot of potential light from all the other bulbs.

time. These lights are becoming much more popular, but are still in their infancy of development. The best bet for reliable LED lighting is purchasing entire light fixtures developed specifically for LED lights from a reputable manufacturer, not just a screw-in replacement bulb.

  - PROS – very efficient, long lasting
  - CONS – high cost, even more expensive to dim, some cheap versions have bluish hues or burn out quickly

- **Daylighting** has been around since, well… the sun. It is free to everyone, has the best color rendition of any lighting, and is easily controlled by using window blinds or curtains. Designing daylighting well, however, is not as easy as one might think. There are a few things to take into account. One is to avoid direct sunlight on occupants, computers, etc. Another is to avoid glare. If the light is too bright or if there is too much contrast between the daylit area and an adjacent surface or surfaces, it will be difficult to see and especially difficult to read. The easiest way to introduce daylight without glare is to use a north-facing window or "clerestory" window that is recessed just a little for the times of the year when the sun is actually a little north of east (morning) or west (evening).
  - PROS – free, zero energy usage
  - CONS – not available at night

LIGHTING CONTROLS can also help reduce the amount of time the lights are on, which is an obvious benefit to the energy usage of lighting. Simple measures such as convenient wall switching, or more active measures such as timers and daylight or motion sensors may be implemented. Lighting for artwork would be a good application for motion sensors. If there is no one present to view the artwork, there is probably not a need for the lights to be on. Where there is more light than necessary for the task, installing lower wattage bulbs is often a sufficient solution. In some cases re-designing the lighting scheme is necessary.

tracking the
McFRUGAL'S

The McFrugal family replaced all screw-in light bulbs in their house with fluorescent bulbs.

Cost: $150

Annual Savings: $293

keeping up with the
JONES'S

The Jones family hired an electrician to replace most of the lights in their home with LED lights, and used screw-in fluorescent bulbs in storage areas.

Cost: $2,000

Annual Savings: $389

Passive solar design usually refers to using the sun's energy to naturally heat the home. In order to create a good passive solar design, three primary components are required:

1. **South facing windows** to allow the sun to enter the home.
2. **Adequate overhangs** or shading devices to cut out the summer sun, but allow the lower winter sun to shine in.
3. **Thermal mass** to store the sun's natural heat energy so that it can be used at night when it is most needed, and does not overheat the home during the daytime.

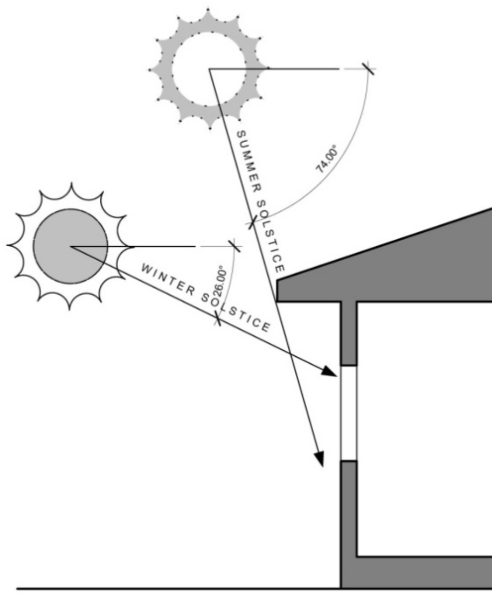
Let's look at each of these categories in a little more depth…

SOUTH FACING WINDOWS - Windows on the east and west side are not desirable for passive solar heating because the low sun angles (as the sun is rising and setting) tend to overheat the home in the summer months (and the west sun can even overheat the house in the winter months). North facing windows rarely receive any direct sun and are therefore not beneficial for passive solar heating, however they do provide a good source of natural low-glare daylight.

As long as the other two parts of the equation are satisfied, with adequate overhangs and thermal mass, then the windows on the south side should be specified with high solar heat gain coefficient (SHGC), which will maximize the energy from the sun that is allowed to penetrate the glass. The SHGC is a number from 0 (no heat gain allowed) to 1 (all heat allowed), and a high SHGC would be 0.40 or above.

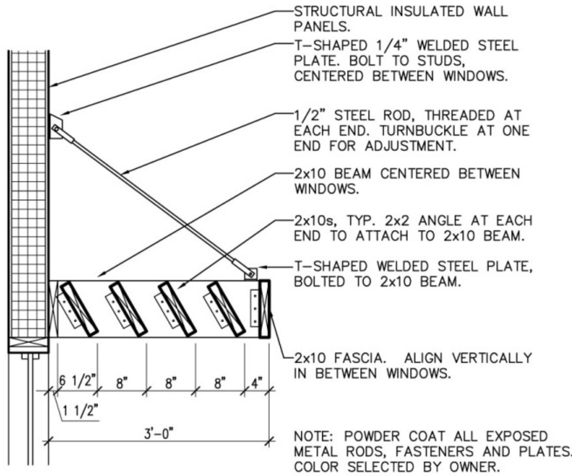
When designing a new passive solar home, a good design will include 15 to 20% of the floor area in glazing. If you perform a quick calculation comparing your floor area to the south-facing glazing you may determine if your home has too little or too much southern glass for passive solar benefits. In the McFrugal and Jones homes the upper floor south glazing is optimum for passive solar, but the front porch provides too much shade for the lower floor to benefit from the sun's energy.

ADEQUATE OVERHANGS - Shading is important as an energy-saving feature because without shading the home may require an abundance of energy to cool the home. Even if cooling is provided using an evaporative cooler, significant energy savings may be realized with proper shading designs. South-facing windows should have an overhang to protect the window from the summer sun, while allowing the winter sun to enter the home and provide warmth.



West facing windows are especially damaging because they provide abundant heat late in the day when the house is typically already warmed from the sun. For west-facing windows a large overhang, such as a covered porch, is often a good solution. If proper overhangs cannot be established, then the windows should have a very low solar heat gain coefficient (SHGC) as mentioned in the window chapter.

Shading may also be provided by landscaping. Deciduous trees on the south side of the home are efficient in blocking the summer sun while allowing some winter sun to filter through the leafless branches. Coniferous trees are valuable on the east and west sides to block sun throughout the year (as well as block winds from the northwest).



SHADING DEVICE DETAIL

If shading does not currently exist with roof overhangs, then shading devices may be added. These exterior devices may be made of wood, steel, fabric, or other materials.

THERMAL MASS - Of all the strategies, thermal mass is the most often forgotten or ignored. There are many examples (often in 1970s vintage homes) where a "passive solar" house has no thermal mass and therefore quickly overheats when the sun beats in, and then quickly becomes too cold at night because of the large windows which provide very little insulation from the cold night air.

Thermal mass is the materials inside a building that can absorb, store, and radiate warmth or coolness. This mass helps keep the interior temperature at a more constant level by cutting down on the extreme highs and lows. Mass in a net zero building (on the interior side of the insulation) serves two purposes. First is to store heat or cool from day to night (or vice versa) or from occupied to unoccupied periods (or vice versa). Second is to stabilize the space temperature to avoid the wide temperature swings that were (are) common to passive solar homes, in many cases making them quite uncomfortable.

- **Direct thermal mass** is the material that can absorb the sun's energy (warmth) when the sun directly hits the surface.
- **Indirect thermal mass** is the mass that occurs throughout the home that is not in the direct path of the sun, but can absorb or release the heat in the space.

Once there are properly shaded south-facing windows providing winter sun to the home, then the space must have a method to store that warmth. If the heat cannot be stored, then the space rapidly heats to an uncomfortable level, and then just as quickly turns cold at night when the sun is gone and the windows allow the cold to infiltrate. However, if the heat is stored then the energy is absorbed in the mass and is radiated back into the room when the room begins to cool.

- Indirect thermal mass helps the home stay warm in the winter, cool in the summer, and comfortable each day.
- Thermal mass may be added by adding:
    - Concrete floor topping
    - Stone wall finish
    - Masonry fireplace
    - Water feature
    - Water tubes embedded in a wall
    - Additional layers of gypsum board on as many surfaces as possible (choose walls that are easy add to – with fewer electrical fixtures, trim, etc).
    - Thickset stone or tile flooring
    - A large mass integrated with a heat exchange system, such as a rock bin like those used in air-type solar thermal systems or a water storage with a heat

exchanger similar to those used in water-type solar thermal systems

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- This is a good place to be creative. Perhaps there is a benefit for people who live amidst clutter and have stacks of magazines around their house.
- See the discussions in the interior wall insulation chapter regarding adding mass in the form of added layers of gyp board. Detailing around windows and doors can get tricky, and in some spaces there will be code limitations.

tracking the McFRUGAL'S

The McFrugal family looked at their house and decided that the upper roof overhangs and the front porch provides good shading, and decided adding thermal mass is too big of a project at this time.

keeping up with the JONES'S

The Jones family is considering adding a second layer of gypsum board in all the rooms of their house. At the time of this report they still have not made a final decision.

APPLIANCES AND ELECTRONICS use a surprising amount of electricity. At some point in the process of reducing the home energy use it will be important to look at the energy use of appliances.

- Appliances, such as refrigerators, dishwashers, and clothes washers are now available in a variety of energy-conserving models. A minimum these days is an **ENERGY STAR** label that both provides assurance that the product meets a minimum standard as well as giving typical energy use information on the label.
- In addition to using energy-efficient appliances and electronics when possible (some can be expensive), it is also important to look at ways to keep them off when they are not in use as well as to reduce "parasitic" or "phantom" energy use. A "parasitic" or "phantom" load is basically energy being used that is not obvious when the device is "off". Consider installing a switch or timer for the outlet that the appliance or electronic device is plugged into and turn it off when not in use, or use a power strip.
    - One common type of parasitic load is the little lights and clocks that are always on. When purchasing appliances, look for appliances that do not have these, or can be switched off at the appliance if some other part of the appliance has to stay on (such as a refrigerator).
    - Many electronics such as DVDs, TVs, microwave ovens, regular ovens, and similar equipment also have little lights and clocks that are always on.
    - Cable modems can use 40 watts just being ready to use even if they are not being used.
    - Chargers for cell phones, electric toothbrushes, laptop computers, electric screwdrivers, etc. all use electricity

when the device is fully charged as well as when it is empty. The transformer in the device uses electricity whenever it is plugged in.

- o If you have a blower door test and thermal imaging scan done, ask the auditor to scan for electrical hot spots. You'll be amazed at what is using electricity – even the ground-fault-interrupter electrical outlets that are required by code use electricity just sitting there with nothing plugged in.
- o Computer modems, routers, USB multi-ports, and so on also use electricity when not in use.

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- In many cases you can install a timer at an existing switch. If you are handy with simple tools and are not afraid of electricity, you may be able to install this yourself.
- Rewiring a circuit to have a switch or timer on just one outlet might better be done by a good electrician to make sure the result is safe and meets code.

tracking the McFRUGAL'S

The McFrugal family is still thinking about this one.

keeping up with the JONES'S

The Jones family installed several timers on their electronics and the cable box.

Cost: $200
Annual Savings: $15

They also purchased a new refrigerator that is the highest rated on the Energy Star website.

Cost: $2000
Annual Savings: $32

DUCT INSULATION serves many purposes. Some of the more important reasons for insulating ductwork are not always obvious. Duct insulation does add air resistance so it needs to be considered when sizing the duct and selecting the fan.

- Insulation reduces heat loss or gain. This can mean more of the conditioned air will reach the intended space. These losses are less important if the duct is in the space. It can also limit the overheating or overcooling of a space it passes through.
- Duct insulation, when applied to the interior of the duct, can reduce sound transmission result in quieter rooms as well as reduce the annoyance of hearing talking and other sounds from another room. Duct insulation applied to the exterior of the duct is not useful for sound control.
- Duct insulation can prevent condensation from a cold duct that passes through a warmer or more humid space.
- The most common insulation material is fiberglass. For a while duct liner was available that was made from recycled jeans, however the manufacturer no longer makes that product.

DUCT SEALING serves one primary purpose, reducing air leakage that can result in the conditioned air going to the wrong places.

- As with insulation, leakage is less important when the duct is in the conditioned space. When the duct is not in the conditioned space, or is in walls, ceilings, or other spaces, the losses from leakage can be significant, often as high as 40% or even more. Leakage reduces the system efficiency by making the fan work harder for the same effect. Leakage also results in the system not being able to keep the space comfortable because there is insufficient airflow, or even less comfortable if the system is undersized.

- Large gaps should be sealed with sheet metal rather than relying on tape or caulk to cover too big of a hole. Then caulk designed for ductwork, or special "mastics" designed for sealing ductwork, should be used. Oddly, "duct tape" is great for a great many projects except sealing ductwork. It tends to dry out over time and come undone. There are tapes specially designed for ductwork (such as aluminized duct sealing pressure-sensitive tape) that can do a good job. With all methods, it is of utmost importance that the ductwork be cleaned first, especially to remove any grease or oil, so that the sealant or tape will stick. Follow instructions on the product.

PIPE INSULATION also serves many purposes similar to those discussed above under duct insulation. In addition, pipe insulation prevents cold pipes from "sweating" (condensing water out of the air). Insulation on hot water piping is important for two more reasons: preventing injury from accidental contact and preventing overheating of the mechanical room (or closet).

- Residential pipe insulation is usually closed-cell foam. The reason for this is cost. While it does an adequate job of insulating and is easy to apply, it is also easily damaged and rarely installed properly (with all joints sealed and glued). When installed outdoors it will be deteriorated by direct sunlight as well as ozone in the air. Some products are rated as UV resistant (the damaging part of sunlight), however the damage will still occur – just more slowly.
- Fiberglass pipe insulation with a reinforced vapor-resistant kraft paper cover is more durable. For cold piping the edges and joints need to be sealed with mastic. Outdoor piping is protected with a variety of covers from aluminum or stainless steel to PVC or Hypalon (essentially the same material as used for membrane roofing). Fiberglass is more difficult to install so it should be done by a professional. Fiberglass will lose its insulating value if it is wet, so it needs to be protected and sealed when installed outdoors.

Generating power on site has become the symbol of sustainability. Photovoltaic (generating electricity from the sun) panels are popular, and installing them on a home or business broadcasts to the community that the building owner cares about the environment. However, many of the other strategies discussed in the previous chapters are actually more cost-effective and beneficial methods of reducing our environmental impact. **On-site power generation should only be considered after a homeowner has taken other strides to reduce their energy usage.** That being said, it is impossible to have a net zero energy home without generating your own power. The following methods are potential ways that may be considered for meeting the final step of net zero – providing the power that will be used after all loads have been reduced as far as practicable. The following list is a very short overview of each.

- **Solar electric using photovoltaic panels.** These panels are typically 3 feet by 5 feet and produce about 200-watts of electricity when the sun is hitting the panels at an optimum angle. In Colorado, an optimally-sited photovoltaic system will produce roughly 1,400 kWh of electricity per year for each 1.0 kW of rated panel (typically rated at peak output at optimal conditions).
- **Wind generation using small scale wind turbines.** These are often difficult to install in a typical neighborhood because of height limitations. Some turbines also have sound issues. Small wind turbines are still in their infancy in the development cycle and have received varying levels of endorsement from

professionals and critics. There are also no standards that can be quoted for the kilowatt output of devices, or the actual amount of power that would be generated by any given device.

- **Concentrating Solar Photovoltaics** is an emerging technology that may become available on a small scale in the near future. These systems use mirrors to reflect the sun's energy to a small photovoltaic element and are generally more efficient than standard PV systems. One such installation of a pole-mounted 8-foot square system may provide most of the power necessary for a home.
- There are several other types of on-site power generation which have very small market shares and should not be recommended for consideration at this time, but could merit examination on a case-by-case basis and as these systems improve. These systems could include small scale water generation (from flowing or falling water), methane gas (typically from waste material or manure), co-generation (electrical generation as a by-product of heat generation), fuel cells (though this is really only a method of storing energy), and growing algae for on-site fuel generation (more likely on a community scale).

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- The photovoltaic industry has seen tremendous growth in the past ten years, with several hundred companies in the Denver metro area now offering installation. Be sure to select a company that has experience and has s clients you can speak to.
- There are many rebates available for renewable energy installations. Many contractors will help you find the best available rebates, complete the paperwork for you, or even make the process seamless by incorporating the rebate in their price.

tracking the McFRUGAL'S

The McFrugals installed enough PV to get them half way to electric net zero (a 4-panel, ~ 1kw system). They will consider adding more panels when PV prices drop further and/or panels are more efficient.

Cost: $4,000 (after rebates)

Annual Savings: $140

keeping up with the JONES'S

The Jones family hired a contractor to install a 16-panel 3.7kw photovoltaic system to complete their quest for a net-zero home. Not all panels will fit on their roof, though, so some had to be mounted on a pole in their back yard.

Cost: $15,000 (after rebates)

Annual Savings: $500

As you probably have guessed, this report has not covered every possible sustainable upgrade or strategy. Other aspects of sustainable homes that have not been covered include water consumption and reduction, using healthy materials, recycled materials, recyclable and reusable materials, and more.

For those families who also would like a little more space in their home, there is one more strategy that you may consider…

ADD A SUNSPACE - A sunspace in a net zero home has a number of purposes and needs a number of features to be effective. It is primarily a means of collecting and distributing solar heat in the winter. It can also provide shade in the summer as well as assist with ventilation. Daylight can be introduced all year. A sunspace helps to make up for the fact that most residences simply don't have enough south-facing roof area to collect sufficient solar energy, and also allows more of the roof to be dedicated to PV and less to solar thermal.

In order to collect sufficient heat, the sunspace will need to cover a good portion of the south façade of the building. To prevent overheating of the building during the day and losing heat at night, the sunspace needs to be physically isolated and insulated from the building.

Distribution of the heat from the sunspace can be as simple as high and low registers that are opened when the heat is needed and available and closed when not needed or when the sunspace is cold. Alternatively, fans and ductwork can be used simply to move the heat to the north side of the house when it is available and needed. It is pretty easy to rig a heating and a cooling thermostat in series to automate this. The heating thermostat in the north end of the house determines if heat is needed, and the cooling thermostat in the sun space determines if heat is available. Having sufficient mass in the building that can absorb the heat also makes the sunspace distribution work better without overheating the space.

The sunspace can serve as an exhaust fan if the top is vented and there are low connections to the house. The heat will rise due to the chimney effect and that can draw air from the house through the low vents. Vents on the north side of the house can then let in fresh, cool air (when the outside air temperature is actually lower than the inside air temperature). Manual or automatic control is needed to operate the vents and fans.

The sunspace can also be a heat storage space if there is sufficient mass and also a means of insulating at night, such as closing insulating blinds. Having sufficient mass can also reduce the temperature when it is collecting solar energy, thus allowing the space to be used during some of that time.

tracking the McFRUGAL'S

The McFrugals have exhausted all their financial resources at this time. Perhaps as their savings grow from their reduced energy bills they will consider more strategies.

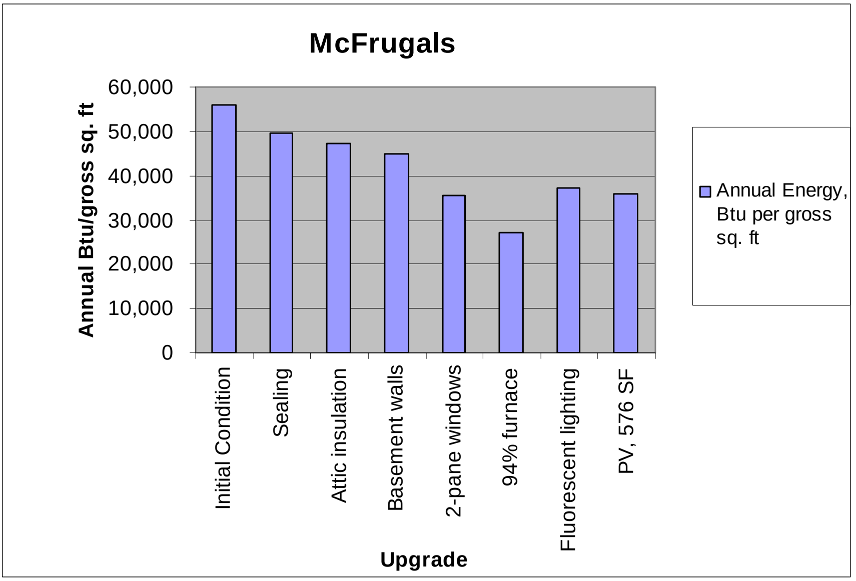
keeping up with the JONES'S

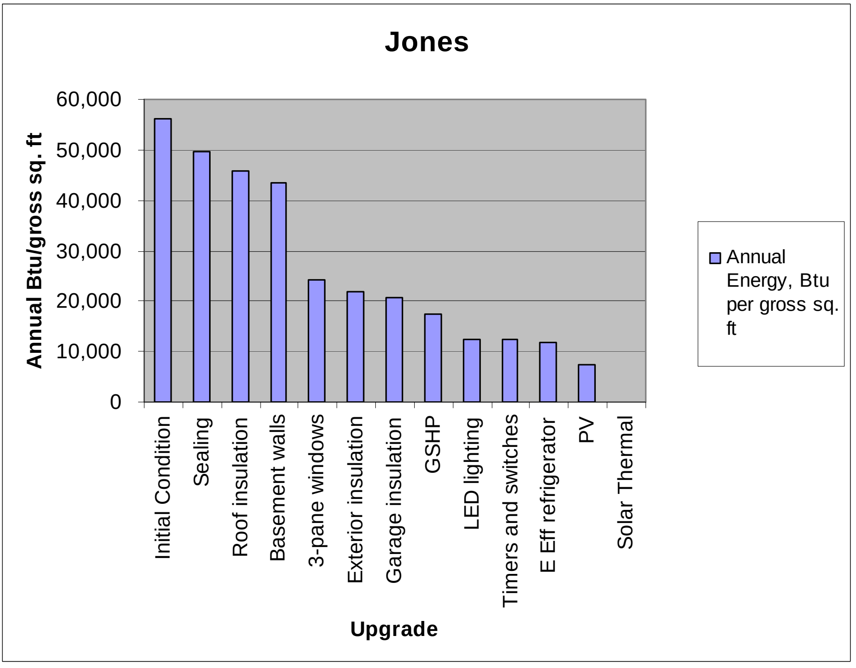
The Jones family just met with a contractor to look at turning their front porch into a sunroom where they can grow vegetables and herbs. They are not sure yet if they will embark on this project.

Both the McFrugals and the Jones embarked on paths to make their homes more energy efficient. Neither path is right or wrong, both paths represent excellent efforts to reduce their carbon footprint and help the City of Golden to reach the goal of reducing the overall use by 20% within ten years. Whether you are more like the McFrugals or you are trying to keep up with the Jones or you establish your own path, implementing some of the ideas in this report will help reduce our environmental impact.

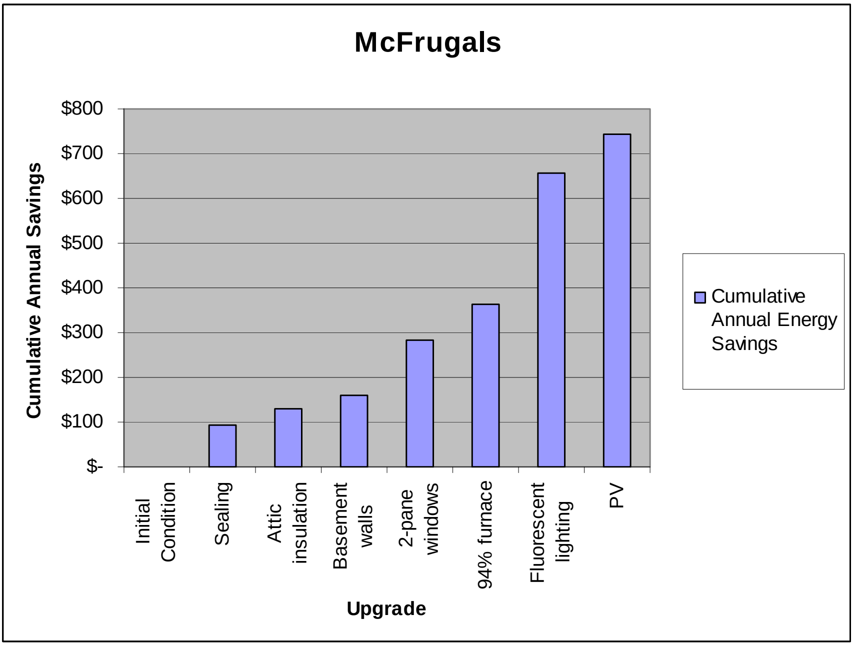
The following pages contain charts showing the energy savings as well as projected cost savings with varying increases in the cost of energy.

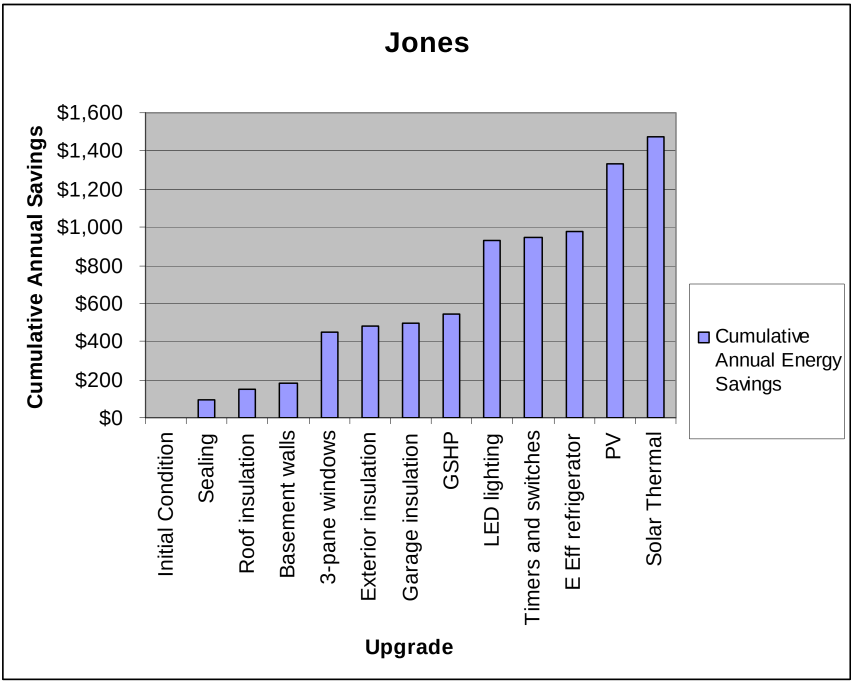
ANNUAL ENERGY USAGE



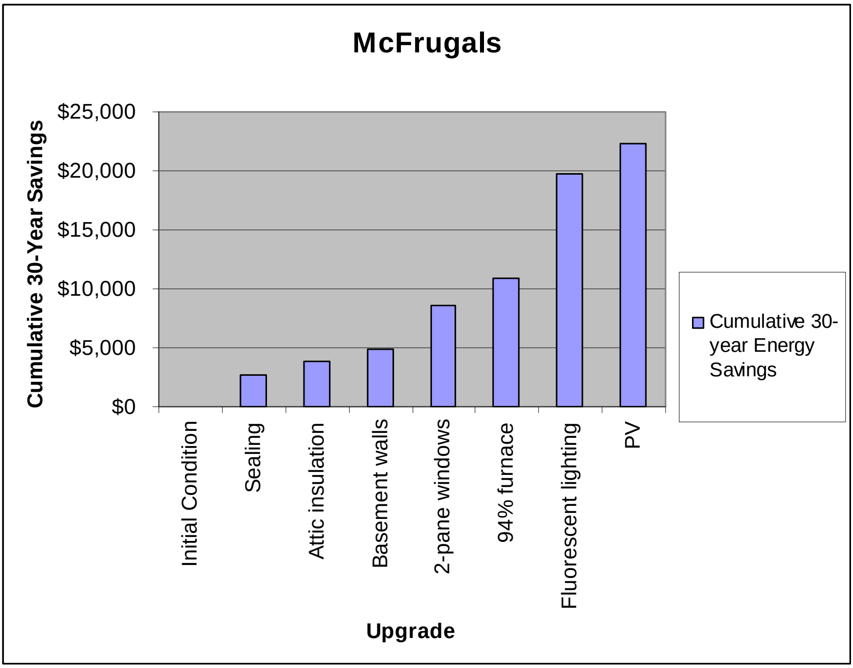


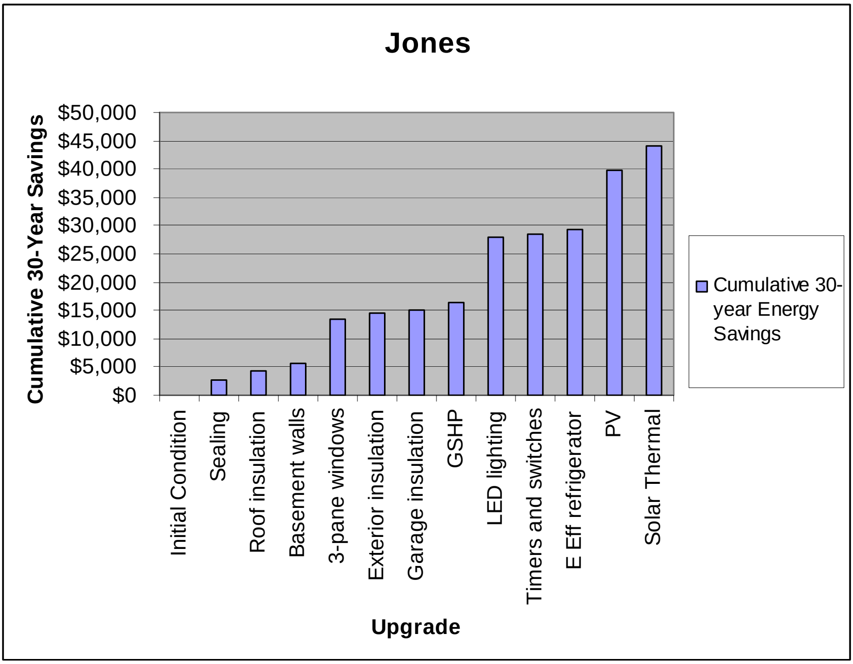
CUMULATIVE ANNUAL ENERGY SAVINGS



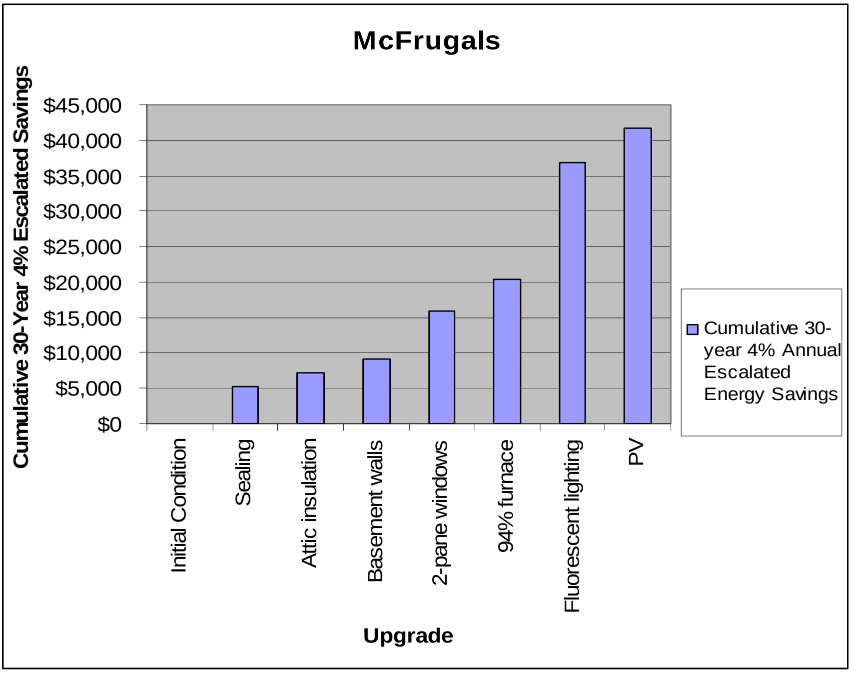


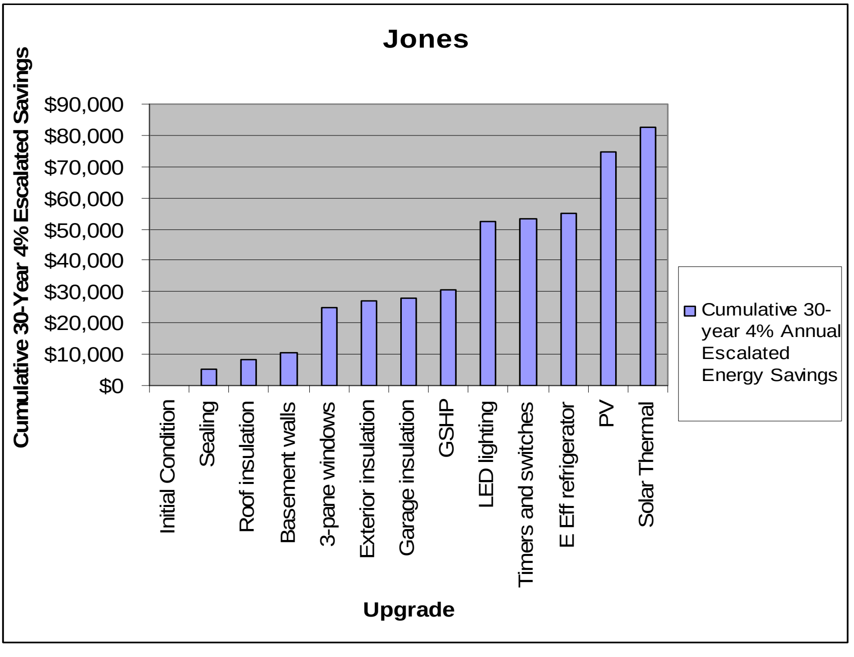
CUMULATIVE 30-YEAR ENERGY SAVINGS (no escalation)



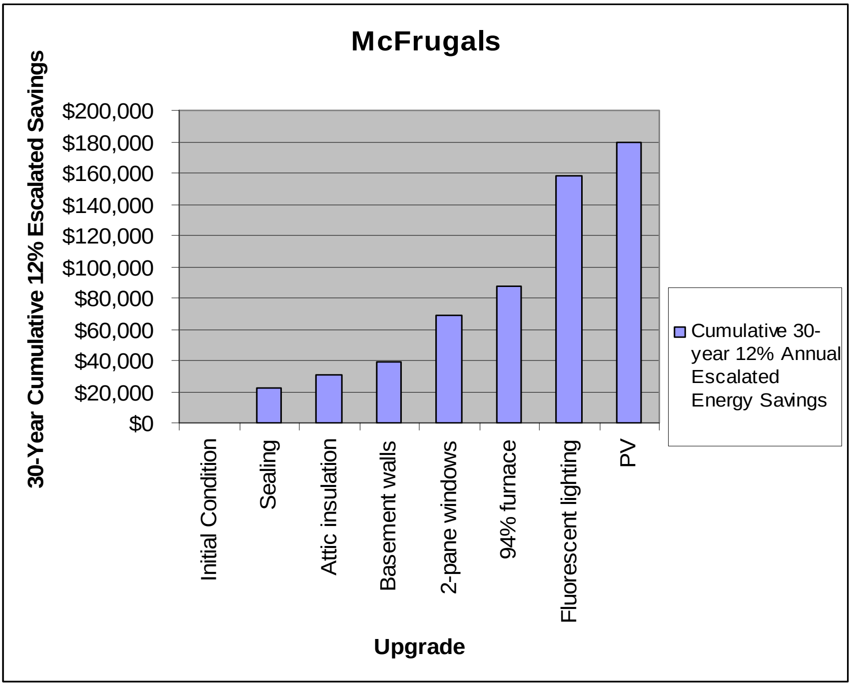


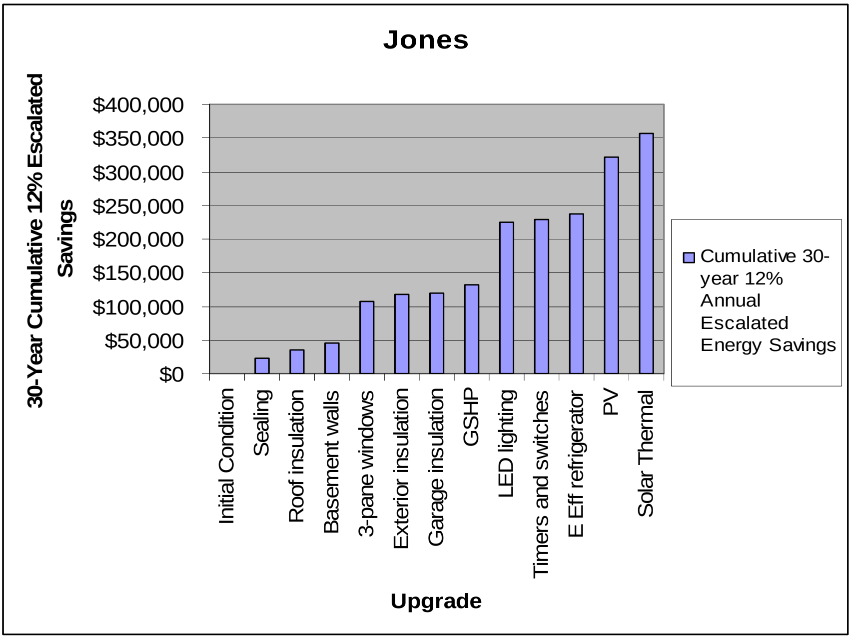
CUMULATIVE 30-YEAR ENERGY SAVINGS (4% escalation)





CUMULATIVE 30-YEAR ENERGY SAVINGS (12% escalation)





As you can see from these charts, only the Jones family was able to attain the goal of a Net-Zero Energy Home (ZEH). The Jones feel they have proven it is possible to change a typical Golden home into a ZEH, but the cost and commitment are high. They did run out of south-facing roof area for the photovoltaic and solar hot water panels and had to put some of the collectors on awning structures. An energy recovery ventilator, a few more efficiency upgrades, and a south-side sun room should lower the energy use enough that all the collectors will fit on the roof.

The following tables contain summaries of the strategies for each of our intrepid families. A more complete explanation of the four columns in these tables is:

- **Energy use** is a running total annual energy used for both electricity and natural gas (as reported by Xcel Energy) converted to BTU per square foot per year (BTU/sf/yr). The amount is reduced in each successive row for each successive strategy. GSF is gross heated square feet, including basement but not garage, which is 2,683 sq. ft.
- **Cost** is the estimated cost for implementing that single strategy, with the total for all construction costs reported in the bottom row.
- **Annual savings** is the estimated cost savings on a typical Xcel Energy bill for one year. Amounts in this column are a running total which include all upgrades listed above each row.
- **30-year savings** is the estimated cost savings over a 30-year period assuming no escalation in energy cost relative to inflation. If energy costs rise faster than inflation, then these cost savings will be greater. Amounts in this column are a running total which include all upgrades listed above each row.

- **30-year escalated savings** is the estimated cost savings over a 30-year period assuming energy cost escalates at a higher rate than inflation. Saving is based on energy cost increasing 4% per year more than inflation. The Consumer Price Index (CPI) for the U.S. was 168.8 in January 2000 and 220.223 in January 2011. That corresponds to an average inflation rate of about 2.5%. (data from http://inflationdata.com/inflation/Consumer_Price_Index/CurrentCPI.asp). The future cost of electricity and natural gas is unknown, and a search of the Internet doesn't give confidence in any cost projection. The coal and gas industries seem to say the cost will decline. A better measure might be the future cost of energy vs. your future income (since incomes seem to be declining lately). There is pressure to reduce use of carbon fuels, and if you are reading this you are probably concerned about reducing your use of energy from carbon fuels. There are indicators that the world is at peak oil and may be at peak coal and peak natural gas in the coming decades. Since we have no crystal ball, we thought it would be useful to give information on a "what-if" future scenario. We arbitrarily chose an energy cost escalation rate of 4% higher than inflation, which would mean about 6.5% per year if inflation remained at 2.5% per year. For other rates, refer to the section "A Little Bit About "Savings"" in the Introduction. Amounts in this column are a running total which include all upgrades listed above each row.

TRACKING THE McFRUGAL'S PATH

STRATEGY	ANNUAL ENERGY USE (btu/gsf)	POSSIBLE COST	CUMULATIVE ANNUAL SAVINGS	CUMULATIVE 30-YEAR SAVING	CUMULATIVE 30-YEAR 4% ESCALATED SAVING [1]
Starting point before any energy upgrades: 8,131 kwh electricity + 1,226 therms natural gas					
	56,022	$0	$0	$0	
Sealing air leaks	49,684	$100	$92	$2,750	$5,141
Roof/attic insulation	47,187	$1500	$129	$3,859	$7,214
Basemt & Foundation wall insulation	44,902	$4000	$162	$4,846	$9,060
Windows & doors upgrade	35,603	$10,000	$285	$8,546	$15,977
Sealed combustion furnace	27,194	$6,000	$363	$10,886	$20,351
Fluorescent Lighting	37,059	$150	$657	$19,710	$36,847
PV	35,967	$4,000	$743	$22,285	$41,662
TOTAL		$25,750			

KEEPING UP WITH THE JONES' PATH

STRATEGY	ANNUAL ENERGY USE (btu/gsf)	POSSIBLE COST	CUMULATIVE ANNUAL SAVINGS	CUMULATIVE 30-YEAR SAVING	CUMULATIVE 30-YEAR ESCALATED SAVING
Starting point before any energy upgrades: 8,131 kwh electricity + 1,226 therms natural gas					
	56,022	$0	$0	$0	
Sealing air leaks	49,684	$700	$92	$2,750	$5,141
Roof/attic insulation	45,893	$6000	$147	$4,418	$8,259
Basement & Foundation wall insulation	43,333	$15,000	$184	$5,533	$10,344
Windows & doors	24,128	$25,000	$446	$13,367	$24,990
Exterior wall insulation	21,772	$25,000	$483	$14,483	$27,077
Garage wall & ceiling insulation	20,808	$2,000	$498	$14,953	$27,955
Ground Source Heat Pump system	17,429	$40,000	$545	$16,343	$30,552
LED Lighting	12,482	$2,000	$934	$28,008	$52,361
Phantom load timers & switches	12,289	$200	$949	$28,463	$53,211
Efficient refrigerator	11,879	$2,000	$981	$29,431	$55,022
Photovoltaic system	7,437	$15,000	$1,330	$39,907	$74,605
Solar Thermal System	0	$12,000	$1,474	$44,216	$82,662
TOTAL		$144,900			

The Jones made it to Net Zero!