The Golden Path to Net Zero Energy Homes

PHASE ONE REPORT
AUGUST 20, 2010

EWERS ARCHITECTURE

Silvertip Integrated Engineering Consultants

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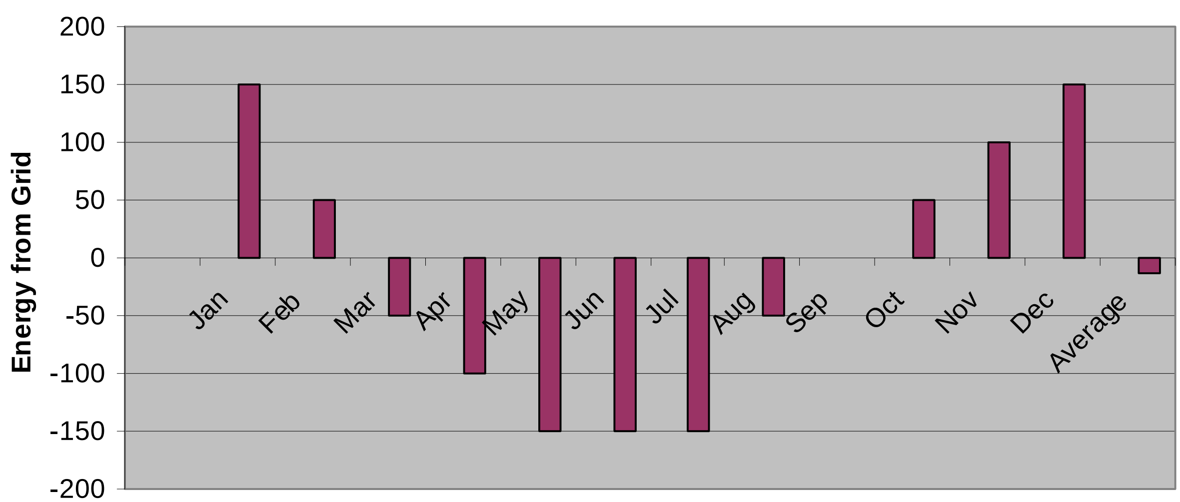


SAMPLE GRAPHIC OF MONTHLY ENERGY USAGE FOR A NET ZERO ENERGY HOME

Section A EXECUTIVE SUMMARY

OVERVIEW

Across the United States residential buildings use 21 percent of our primary energy and 36 percent of the nation's electricity. While it is important to build new homes that consume less, or even zero, offsite energy, we must address the energy usage of our existing homes if we are to reach the energy goals that have been set for our city, our nation and our world. If we, in Golden, Colorado, can learn how to greatly reduce the energy usage in our existing homes, then we can have a positive impact not only in our own town, but in towns across the country.

This study is the first phase of an investigation into the feasibility of upgrading a typical residence in Golden, Colorado, which uses a moderate amount of energy, to a home that uses no net energy. The ultimate goal is to create a prescribed path that any homeowner can use to transform their home into a house that has a net impact of zero on the nation's energy usage. This report is the first step in that journey, and the journey consists of at least three steps:

1. This report studies whether it is reasonably feasible to transform a typical home to a net zero home. If this seems an attainable goal, then…
2. The next step is to actually perform the design work and construction on one or more typical homes as a study and analysis tool for future homes, then…
3. Encourage more and more homes to follow these techniques to become net-zero or near-net-zero.

Wind turbine at the Renewable Energy Demonstration Center in Golden

The intent of this investigation is to gain a better understanding of the degree of success toward net zero that might be possible within a reasonable budget for a typical residence. This is intended to be a rough-cut first step outlining a simple spread-sheet evaluation methodology and a process for approaching net zero. Since it is possible to shift energy use from electricity to gas without actually saving significant energy, our recommendation is that the goal should be net zero for the entire energy use (rather than electricity alone excluding gas heat).

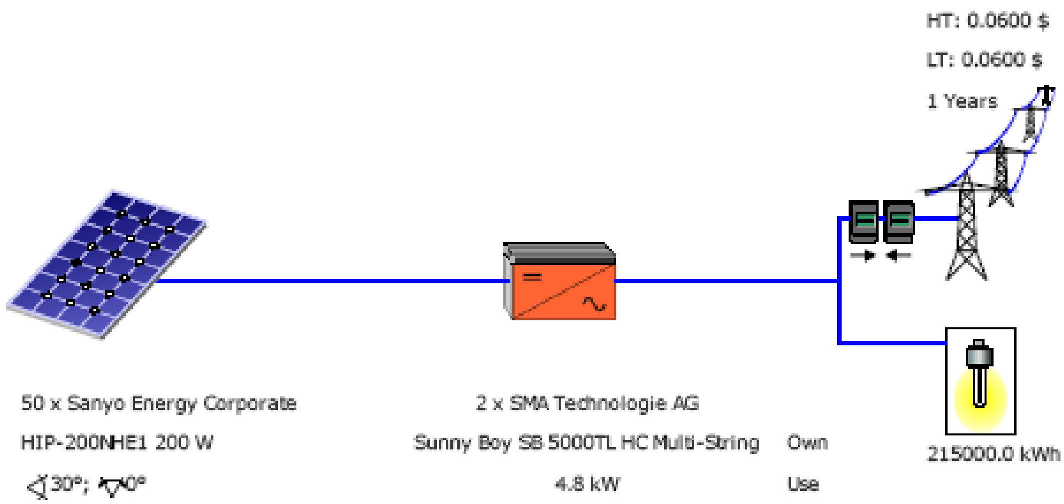
Therefore for the purposes of this report, net zero is defined as putting as much or more energy into the grid, including both electricity and gas, than is taken out. It remains to be decided in a future phase of this study whether to further define net zero in terms of energy at the building boundary or at the power plant or source or at another boundary.

The long-term goal of the investigation (phase three) is to evaluate the feasibility of providing standardized energy upgrade packages or designs for typical buildings in Golden, Colorado or to outline a process that can be site-adapted toward achieving net-zero.

WHO?

This study was commissioned by the Golden Community Sustainability Advisory Board (CSAB). Most notably, the authors of this report worked with:

- Theresa Worsham, Sustainability Coordinator for the City of Golden
- Gunter Ritter, CSAB member



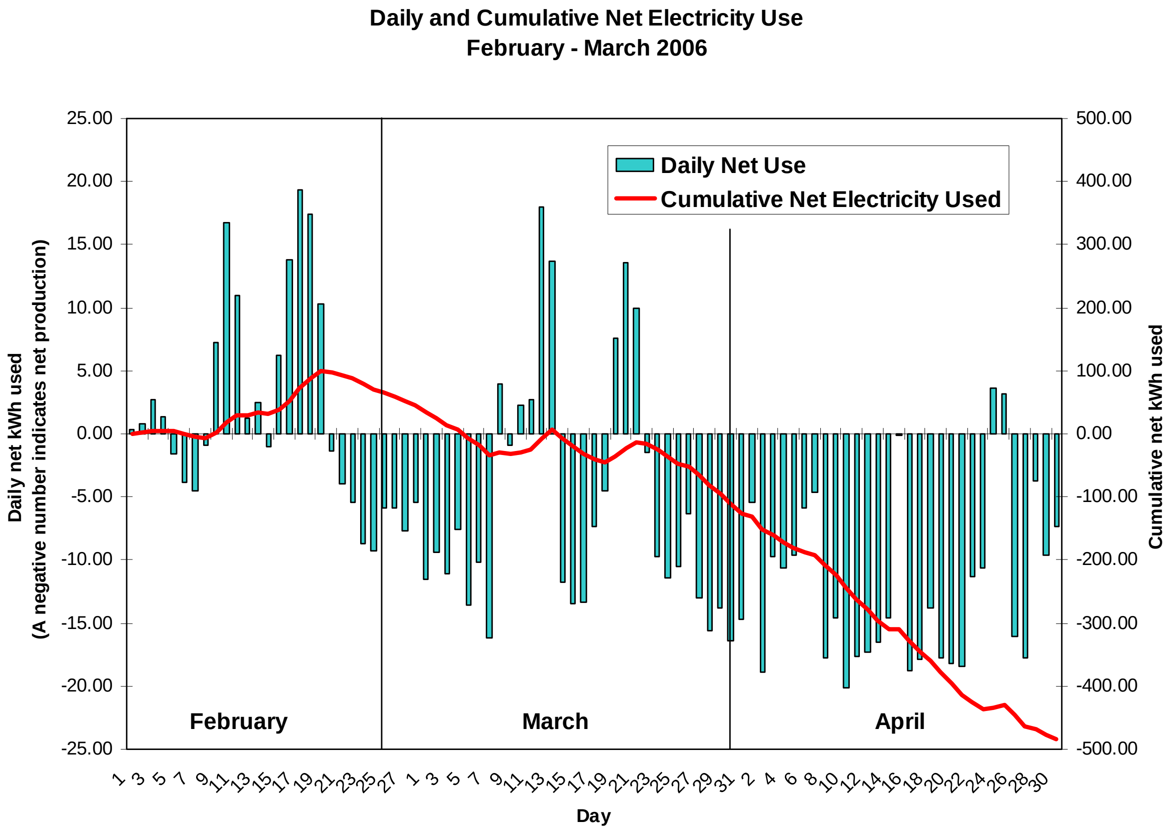
ENERGY DATA

Section B contains the results of our search for standard home and energy data. We found that:

- An average home in Golden is about 1,800 square feet and consumes $1,276 worth of energy each year.

- After translating the gas usage into the equivalent electricity, we realize that nearly 75% of the energy is used to heat the home. This means that reducing the need for heating is of utmost importance.

This data is important as we compare the energy cost savings to the potential cost of the upgrades. Assigning value to environmental impacts is left to the reader and to other studies.



(Graphic from NREL data on Denver Habitat for Humanity Net Zero Project)

COMFORTABLE IS GOOD

Section C contains information about comfort criteria. We believe that a net-zero energy home must be at least as comfortable, and hopefully even more so, than a standard home. If we ask people to sacrifice comfort (to live in a house that is too cold or too warm) this will be detrimental to the acceptance of these strategies by the general public. Conversely, if these strategies make the home even more comfortable, in addition to eliminating energy use, they are more likely to be accepted, implemented and even demanded by the general public.

WHO GETS THE FIRST UPGRADE?

Appendix 2 reviews some typical homes in Golden and shows the good and bad aspects of each, as it relates to upgrading to net zero. We found that probably less than 10% of homes in Golden are well-sited for roof-mounted solar panels (normally considered a requirement for net zero energy homes). Section D of this report looks at what criteria should be used for selecting the homes for the phase 2 study. We raise the question, "if we pick the best possible home for the phase 2 study (which is supposed to upgrade a "typical" home) to net zero, then is that really a typical home?" The answer to that question has two possible answers:

1. Don't pick the best home for the next phase, pick a home that has some real challenges. That way we can prove (or disprove) that upgrading a typical home to net zero is possible.
2. Perhaps a better option is to pick several homes for the second phase of the study – a home that has good solar access, a home that doesn't, plus a couple more homes with various difficulties or impediments. This would give us a much better view of the possibilities, and studying several homes at once would provide some much needed research into this realm of sustainability.

HOW?

Section E contains information about how a home could be transformed from a mediocre energy user to a stellar home using only the energy it produces. This is an eye-opening look at what it will take to make this kind of drastic improvement. Some of the easy changes will include:

- Adding insulation to the attic
- Replacing some, or all, of the windows and doors
- Upgrading the heating system
- Purchasing energy efficient appliances
- Installing solar hot water panels to provide domestic hot water
- Installing solar photovoltaic panels to generate electricity
- Installing additional solar hot water panels to provide space heating

Some of the changes that are not so easy, but may be required, include:

- Making the exterior walls thicker – either by building a second wall on the interior and thereby reducing the size of the rooms, or by adding to the exterior which requires removing the exterior siding.
- Adding thermal mass
- Adding a sunroom

THE PROCESS
Changing a building to net zero is an intensive design and construction process. The design process suggested is outlined in Section F. This will entail gathering extensive data on the existing house, building an energy model of the home, and experimenting with various solutions using the energy model. It is important to establish the "balance point" where the reduction in energy for a given strategy is more expensive or more difficult than just adding more photovoltaic panels to offset the energy usage, and this design methodology will help establish that balance point for the various systems.

ROOFTOP SOLAR OR BUST?
Homes use power. That is a fact. That power has to come from somewhere. In order to create a net zero energy home, there has to be a source of power generation. At this time in our energy history, the easiest way to generate power is using photovoltaic (PV) panels, and the most accepted place for those panels is the roof of buildings. However, if less than 10 percent of houses in Golden are well suited for rooftop PV, this means that only 10 percent of our houses can become net zero. Therefore, we must explore as a community other ways to produce clean energy.

Photovoltaic panels on an off-grid home designed by Ewers Architecture

A 2009 study from the Pacific Northwest National Laboratory analyzed methods of neighborhood power generation and found that wind power on leased land was the most cost-effective, trumping a photovoltaic solar farm and concentrating photovoltaics. Of course, each neighborhood has different characteristics, and a variety of neighborhood power generation ideas could be explored. While the method will require more study, it is clear that community power generation will be required if the City of Golden is to be a community of net zero energy homes.

BABY STEPS OR GIANT LEAPS

As we compare the cost of upgrades of a home (see Section G) to the cost savings that would be realized from a net zero energy project, we find that the simple payback period for a project like this is extremely long. It is estimated that converting a home to net zero may cost in excess of $100,000, while the cost savings is merely $1,276 per year.

> Author's commentary: *Simple payback looks only at the actual out-of-pocket expenses vs. the actual cost of the power that could be purchased. However, the true costs of our power and environmental decisions should also take into account the cost of pollution reductions, tax incentives, health expenses associated with environmental concerns, natural disasters caused by global warming, cleanup from oil spills, wars cause by arguments over petroleum, and more. Only when all of these expenses are taken into account can our investment to reduce our environmental footprint be correctly measured.*

Many homeowners may desire to perform some of these upgrades but not all of the upgrades (and expenses) associated with true net zero. There can be many small steps, or phases, of a project that lead up to the giant step of a true net zero home. These steps may include the following scenarios:

- A house may not be a good candidate for roof-mounted solar photovoltaic panels. A homeowner may take all of the necessary steps toward net zero, and then purchase the remaining power needed from Xcel Energy's Windsource program, which provides electricity at the more expensive rate generated by Xcel's wind farms. In the future, neighborhood power generation may also become feasible, which can then replace the Windsource energy.
- Energy modeling may show that a home can reach net zero by installing 4 inches of exterior rigid insulation. However, this home has exterior siding that is in good condition and removing this siding would be a waste of natural resources. Therefore the homeowner may choose to perform all other work for net zero but leave the exterior insulation for completion when the exterior siding needs to be replaced.
- A homeowner may have a home that is well suited for all aspects of becoming a net zero building, but they do not have the financial means to pay for all of the upgrades. They may choose to complete the least expensive, or the most cost-effective upgrades, first, and then perform other upgrades as funds become available.

GUINEA PIGS COST THE MOST

The homes that are chosen for the Phase 2 study – to be the laboratory to study the best ways to attain net zero energy – will cost more to upgrade than subsequent homes. To be on the leading edge (or, as some would argue, the bleeding edge) of these efforts typically takes a greater financial investment, and the results are not guaranteed. Section H suggests some funding sources and partners that may be available to help defray these costs.

CONCLUSIONS AND RECOMMENDATIONS

This report endeavors to answer the following question:

Q: Is it possible to convert an average home to a net zero energy home?
A: Yes! The technology, expertise, materials, and systems exist, but at what cost? This second question requires more study.

It is the conclusion and strong recommendation of this report that the City of Golden move forward with Phase 2 of this quest to find the Golden Path to Net Zero Energy Homes.

RECOMMENDATIONS FOR PHASE TWO

This is where the difficulty of designing a solution for an actual typical home is examined by actually doing the design for one or more case studies and then going through a pricing exercise with contractors. Using real design data, it will be possible to further analyze some of the trade-offs that will be encountered. These trade-offs include the following examples:

- Evaluation of the comparative contribution to net zero of solar PV vs. solar thermal heating. This analysis can be done in the current market with the present subsidies and incentives as well as looking at a possible future case without the financial assistance. The comparative analysis without financial assistance will help gauge when the current common wisdom of using primarily PV may become outdated. It will also give some insight into the true environmental impacts.
- It is one thing to calculate the impact of adding an interior wall to improve insulation, and quite possibly another entirely to deal with all the details, such as deeper windows and other obstacles mentioned in this report. The exercise of applying creativity to solve such problems will be very useful.

Detailed modeling of windows and other alternatives is recommended for a net zero process. However, that is very expensive. Such detailed modeling might better be left for future studies with emphasis in this phase to investigating the practicality of implementation.

Another question that will need to be addressed is how to implement Net Zero on a wide scale. Most of the homes in Golden do not have adequate solar access. Even for those that do, the cost is high. This brings into the picture two areas to be addressed. One is some kind of community renewable energy generation such as the "solar gardens" concept. The other is how to justify the cost and find the funding through a long-term outlook. These investigations can be left for future studies but will eventually need resolution.

The next steps in this quest should include:

1. Identify one to four homes that are good candidates for Phase 2. If only one home is chosen (for cost reasons), that home should have good solar orientation for photovoltaics. If a study of multiple homes can be financed, then the homes should all have different qualities that are present in a multitude of Golden homes. Each home should start with a blower door test and a thermal imaging scan of the exterior. One possible home to consider is the Steve Stevens residence, which is already well on the way toward net zero. His approach may not be practical for wide application, so this should be one of a multitude of projects. Steve has used almost exclusively discard materials and his own labor, so the cost will not be representative of a typical project.
2. Find a partner organization (such as the National Renewable Energy Laboratory) to team with on this project. This partner may bring additional financial support, expertise, and marketing.
3. Execute a contract for the testing, analysis and design of the home's transformation to net zero. The contract consultants will use this report as a guide for this design phase. This study will implement a spread sheet analysis for comparison of alternatives and provide input on the predicted extent that the design might approach net zero. The homeowner(s) may or may not be asked to financially participate in this phase.
4. Hire a general contractor to perform the actual work on the home(s). It is extremely important to actually implement this second phase with actual construction – not just design and hypotheses. Carrying out 100% of the design recommendations will be the best way to obtain data that will be useful for future projects. The homeowner(s) should pay a portion of this work, since they will benefit, however, it would be prudent and fair to subsidize a significant portion of the cost.
5. Study the actual performance of the systems installed in the test home(s) over a period of at least two years. This will require additional support from the design team, plus monitoring equipment installed in the home.
6. Publish the results to the Golden community, encouraging other homeowners to take similar action. The partner organization should also help publicize this study to the global community, spreading the benefit of this study to a much larger audience.

If we follow these steps, then the City of Golden will be reaching toward the goal of being a leader in the national and international search for a sustainable future.

Respectfully submitted,

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Silvertip Integrated Engineering Consultants

A net-zero electric house designed by Ewers Architecture

Section B AVERAGE HOME AND ENERGY DATA

SQUARE FOOTAGE DATA (provided by City of Golden):
The following information regarding home sizes within the city limits of Golden was extracted from a database provided by the City of Golden.

- There are currently 3,630 single-family residences listed in this database.
- The total area of these homes (not counting garages and basements) is 6,500,576 square feet.
- The average home size is 1,790 square feet.
- There are an additional 486 multi-family housing units in Golden, and these are not included in the calculations above.

ENERGY USAGE DATA (provided by City of Golden):
The following information was extracted from a report by Xcel Energy of 2009 energy data, provided to the City of Golden.

- There are 7,526 residential units serviced by Xcel Energy in the City of Golden (note that this is roughly double the amount in the previous database, and the reason for this difference is not known).
  - 1,743 of these residences are serviced with electricity only.
  - 119 of these residences are serviced with gas only.
  - 378 of these residences subscribe to the Windsource program.
- The average electric usage for these homes is 6,840 kwh per year.
  - The average electric usage for homes enrolled in the Windsource program is 7,360 kwh.
- The average natural gas energy usage for the homes served with gas is 809 therms per year.

AVERAGE ENERGY USAGE (from Xcel Energy):
The following information is provided by Xcel Energy as their average residential customer in a 2,200-square foot home:

- 8,220 kwh electric usage per year.
- 828 therms of gas per year

AN AVERAGE GOLEN HOME - AN ANECDOTAL STUDY

One of the authors of this report owns a 1,800sf home in Golden. Information such as this will be important to receive for any home considering a net zero retrofit. Notes on this home and the energy usage:

- The home was built in 1889 and has had at least three additions.
- The home is 1½ stories (small upper floor tucked into the roof shape).
- The home has been updated in the past 15 years with:
  - Insulated low-e windows.
  - Wood frame exterior walls with R13 batt insulation between studs and R2.5 exterior rigid insulation.
  - R19 roof batt insulation.
  - Tankless gas water heater installed in late 2008
  - 1970's era gas-fired forced air heat
  - Programmable thermostat is set to 68 degrees with nighttime setback to 60
  - Evaporative cooler
  - Approximately ¼ of the lights are fluorescent and ¾ incandescent
- Natural gas is used for building heat (furnace), water heating, clothes drying, and oven/stove. All other appliances and systems are powered by electricity.
- The residence is home to two adults and two children (ages 11 and 14).
- One adult works outside the home.

The energy usage of the home is:

MONTH	2008		2009	
	NATURAL GAS (THERMS)	**ELECTRIC (kwh)**	**NATURAL GAS (THERMS)**	**ELECTRIC (kwh)**
JANUARY	155	556	132	569
FEBRUARY	192	584	141	619
MARCH	146	472	119	509
APRIL	94	379	81	476
MAY	76	385	82	414
JUNE	48	367	39	415
JULY	23	420	16	492
AUGUST	14	415	8	542
SEPTEMBER	10	490	6	480
OCTOBER	15	462	9	509
NOVEMBER	37	483	71	578
DECEMBER	60	466	82	523
TOTAL	**870**	**5479**	**786**	**6126**

SUMMARY OF ENERGY USE DATA

These three sets of energy use data (from Xcel's report to the City of Golden, from Xcel's standard for all their customers, and from one isolated average-sized Golden home) exhibit similar results. From this small sampling of data, we assume that an average home in Golden will use energy in this range. This is useful as test homes are considered, determining how much energy must be generated on site, and establishing how much energy consumption must be reduced through construction and energy upgrades.

For the purpose of this report, and with some rounding of this general data, we will use the following energy consumption parameters for a typical 2,000 sq. ft. home in Golden:

- Electrical usage = 7,000 kwh/year
- Natural gas usage = 800 therms/year

ENERGY CONVERSIONS AND EQUIVALENTS

As we consider the various methods possible to establish a definition of Net Zero, it will be necessary to convert one source of energy to another source for comparison purposes. For example, a home could consume some amount of natural gas energy and offset that energy usage by creating a surplus of electricity (presumably through photovoltaics or wind power).

There are many, many variables that may be taken into account when establishing a conversion method from natural gas to electricity. Line and transformer loss of electricity may account for as much as 30% of energy usage Homes that are further from the electrical generation plant require more power to be generated in order to deliver the same amount of power at the home's electric meter. Electrical energy use during the day will generally have higher line losses than use at night because there is more electricity flowing during the day. There are also differences in the mix of types of generation plant in operation from day to night, however those differences have not been evaluated for this report. The amount of energy needed to build an electrical generation plant and the associated distribution network vs. the power needed to drill and extract the natural gas, compress the gas for distribution, and build the piping distribution systems is part of the embodied energy of each unit of power. Other natural resources are consumed or disturbed during power generation (such as the large volume of water needed for electrical power generation or the land that is disturbed for transmission lines and piping), and this has additional impacts on our environment.

For this study each energy source will be considered separately in a simplified manner as follows:

- Natural gas will be compared using the fuel content of the gas as delivered at the site, ignoring gas compression energy (presumed to be relatively small).

- Electricity generated on site will be compared using the actual kWh generated since there are almost no line losses and transformer losses are small.

- Electricity delivered by the utility will be compared assuming a 30% line and transformer loss, a value typically used in such analyses.

The following are generally accepted standards for conversion between electrical power and natural gas power:

NATURAL GAS	ELECTRICITY
I Therm = 100,000 Btu	-----
3,412.1414799 Btu	1 kilowatt-hour (kWh)
1 Therm	29.30711 kWh
0.03412 Therm	1 kWh

From the information presented above, the following calculations show the average annual energy usage of a typical Golden home translated to on-site electrical power only:

- Electrical usage = 7,000 kWh
- Natural gas usage = 800 therms x 29.3 = 23,440 kWh
- Total energy usage in on-site electrical power equivalent = 7,000 + 23,440 = 30,440 kWh/year
- Converting to a common measurement unit for energy, this is also equivalent to on-site use of (30,440 x 3412)/2,000 = 51,931 Btu/Sq. Ft./Year

These calculations underscore the need to reduce the amount of energy used for heating a home. The primary use for natural gas is for building heat, and natural gas use accounts for more than 75% of the energy use of a typical home. If we can drastically reduce that amount of energy used, then we can begin to get into a range of energy usage that can be offset by onsite power generation.

ENERGY COSTS

Another key component of creating a Net Zero home will be establishing the cost of the upgrade project and comparing that to the energy savings. Using the current energy costs from Xcel Energy, the annual energy costs for a standard Golden home as defined above would be:

ENERGY USAGE/MONTH	RATE*	COST/MONTH	COST/YEAR
Electricity: • 7000 kWh/year • 583.3 kWh/month	$0.10/kWh	$58.33	$700.00
Natural Gas: • 800 therms/year • 66.6 therms/month	$ 0.60/CCF** = $ 0.72/therm	$ 47.95	$ 576.00
TOTAL		**$106.28**	**$1276.00**

* Includes taxes and fees, but not cost to provide basic service hookup.

** 1 CCF = 100 Cu.Ft. of gas. 1 Cu.Ft. of gas as delivered at 5,200-foot altitude in Colorado normally contains 830 Btu (0.0083 therm). Therefore, 1CCF = 0.83 therm and 1 therm = 1.2 CCF.

Section C COMFORT CRITERIA

One of the keys to acceptance of a new concept for buildings is to ensure that the building still provides the basic functions expected of it. One of those basic functions is comfort. The Achilles heel of the late 1970's energy codes and standards was the requirement that buildings be designed using no lower than 78°F for the indoor temperature during cooling. Many of those buildings became know as "energy code buildings", which was a euphemism for a building that doesn't work. The problem occurred because too little attention was paid to the many other factors that affect comfort as well as insufficient understanding of the impact of comfort on productivity. Another factor was that the resultant air distribution sizing was too small to allow for addition of future loads, such as computers.

A design that attempts to force a lifestyle change in the occupants for the building to succeed will probably meet with limited success. Conversely, a design that allows additional savings should lifestyle changes be adopted, but allows flexibility in such adoption, would seem likely to achieve a higher degree of success. The key to this is to give individual occupants control over the various comfort factors to the extent possible and feasible.

ASHRAE Standard 55 ("Thermal Environmental Conditions for Human Occupancy") addresses the conditions for comfort. It is fair to say that this standard addresses the conditions under which certain percentages of occupants will statistically not be un-comfortable. It is important to understand that humans are different and that it is basically impossible to achieve a building wherein more than about 70% to 80% of the occupants are thermally comfortable. The standard attempts to achieve 80% occupant thermal "acceptance".

> An important part of the concept is described in the standard states *"… people entering a space that meets the requirements of the standard (ASHRAE Standard 55) may not immediately find the conditions comfortable if they have experienced different environmental conditions just prior to entering the space. The effect of prior exposure or activity may affect comfort perceptions for approximately one hour."*
>
> The factors that affect thermal comfort include the following:
>
> - Air temperature
> - Mean Radiant Temperature (MRT)
> - Humidity
> - Air movement (draft or ventilation velocity)
> - Individual metabolism

- Individual clothing insulation

Thermal comfort, however, is not the only comfort criteria. Other factors that affect the success of the building in terms of comfort include:

- Acoustics
- Glare from the sun
- Glare from lighting
- Contrast ratio between surfaces with glare or brightness and darker surfaces
- Indoor air quality

The most forgotten of the above criteria is probably MRT (Mean Radiant Temperature). This is basically the combined effect of temperature differences between the human body and all the surfaces to which the body is exposed. Here are two explanatory examples:

> A room in a cooling situation with indoor temperature of 78°F that has dark-colored blinds heated by the sun can be very uncomfortable because the blinds will get hot and radiate heat to the occupant. A well-insulated room with light-colored (preferably white) blinds that reflect the sun, conversely, can be comfortable at 78°F.
>
> A room in a heating situation with an indoor temperature of 68°F and cold, un-insulated and/or drafty walls or single pane metal-frame windows when it is cold outside can be very uncomfortable because of the low MRT. Comparatively, a highly insulated wall with low U-value windows (those are good windows) and insulating window frames can be quite comfortable at 68°F.
>
> Because of the effect of MRT, it is not sufficient to merely specify room temperature.

The process described in this report will attempt to include comfort factors so that the likelihood of success is increased.

It is our recommendation that the modifications do not adversely affect comfort, to encourage adoption. In fact comfort should be increased to further encourage adoption and investment. Once word gets out that these buildings are actually more comfortable, the rate of adoption should increase.

Passive heating and cooling is strongly recommended as part of the process toward net zero. Also of great importance is consideration of the glare factors discussed above. These can be addressed using various means such as overhangs, light shelves, north-facing clerestory windows, and careful placement of light-admitting windows out of view and view windows with low light admitting coatings to limit glare. Systems such as Trombe walls, greenhouses, and sun-spaces can bring in heat to the main living spaces without the accompanying glare.

For the purposes of heating and cooling load calculations and energy estimates, the following indoor conditions are suggested:

- 72°F Winter; 75°F/40% RH Summer, plus consideration of the criteria discussed above in a subjective manner.

- 10% capacity increase to accommodate a cool-down from periods of temperature set-up in the cooling season. Without this, the building may not be able to cool back down to acceptable conditions and the occupants may not use the energy-saving set-up features.

- 20% to 35% capacity increase to accommodate a warm-up from periods of temperature set-back in the heating season. The percentage needs to be higher in buildings with more mass on the inside of the insulation. Without this, the building may not be able to warm up to acceptable conditions and the occupants may not use the energy-saving set-back features.

Section D CASE STUDY CRITERIA

This report is considered Phase One in the effort to make existing homes in Golden more sustainable, even to the point of using zero net energy. The second phase is to design, implement and study a small number of homes as test cases. The third phase envisions widespread implementation of the concepts and designs that result in a successful transition to net zero energy homes.

Selection of the most appropriate homes for the second phase of the study is paramount to the success of the entire project. In addition to the tangible, measurable criteria listed below, the City of Golden also will need to take into account some intangibles. Using a house that has the perfect orientation for active solar panels mounted on the roof could result in a skewed view of how easy it is to create a net zero home. Similarly, selecting a very large or very small home could create one-sided results that would not be applicable to a wide range of homes. And political issues could also be raised – such as subsidizing the project with public funds or grant money, and how the “winning” family is selected to be awarded such a project. Careful attention to all of these criteria will affect the perception of the project and the eventual success for widespread implementation of these concepts. Some form of economic assistance of incentive appears necessary in the present-day economic environment. Traditional gas and electicity costs are too low (perhaps artificially so) to offset the cost for achieving net-zero with an “attractive” rate of return on the investment.

For the most positive implementation as well as maximum benefit for a scientific-style study, the study of multiple homes would be most beneficial. If Phase Two could include several homes that each imbue a different aspect of typical Golden homes, this could create an atmosphere with the best chance for success on many levels. By studying homes of varying sizes, different solar orientation, a variety of family types, and other variables, this would create a meaningful laboratory environment for our entire community and beyond.

Criteria that should be considered when selecting the homes for case study include:

- Typical building for a common era in Golden
- Construction type
- Number of floors
- Insulation type and R-values
- Windows, type, R-values, SHGF
- Occupancy – possible conditions:

- Unoccupied daytime
- Kids/parent home daytime – full time
- Kids/parent home daytime – typical school schedule
- Work-at-home

- Good solar access (PV, solar thermal, passive solar heat)
  - Location for sun space for passive solar (or other options)
  - Good solar orientation
- Home is in need of major upgrades, including windows, exterior siding, etc.
- Owner is willing to make a major investment in the home.

- **Advantageous Conditions**
  - Easy to add insulation
  - Easy to thicken exterior walls
  - Access for and adaptable to non-glare daylighting

- **Disadvantageous Conditions**
  - Poor solar access or site orientation
  - Difficult to add insulation
  - Slab on grade

INFORMATION NEEDED FOR NET ZERO PROJECT HOMES

The following information would be necessary for any home considered for a net zero project:

- Occupancy patterns (work-at-home, kids/parents at home – schedule, typical unoccupied schedules, typical sleep schedules)
- List of appliances from Owner
- Verify list of appliances provided by Owner and estimate degree of usage with input from Owner/Occupant
- Record and/or measure electrical draw of each appliance as possible
- Use Watt-meter to measure energy usage of appliances
- Estimate solar energy available on an annual basis for the available roof area
- Blower door test to determine air leakage areas
- Thermal imaging to determine areas of greatest heat loss (or gain)

Once this information has been obtained, analysis should include:

- Heating and Cooling (or ventilation) load calculation
  - Computerized heating and cooling load calculation. The computer calculation will be built to allow quick peak load evaluation of various combinations of wall and roof insulation as well as window performance and ventilation options.
    - Existing building as is
    - Renovated building with efficiency upgrades
    - Detailed computerized load calculation program criteria: equivalent to Elite or better
- Energy Analysis Methodology recommendations
  - Spread sheet evaluation criteria:
    - Account for all heat inputs and outputs:
    - Heat loss
    - Solar
    - Appliances
    - Lighting
    - Ventilation/infiltration
    - Motors
    - Fuel use and efficiency
    - Thermal Mass
  - Break analysis into bins of outside temperature and day, evening, and night
  - Analyze existing as well as a number of upgrade scenarios
  - Calibrate calculations by comparing existing energy use to annual energy bills.
  - Use this spread sheet to compare alternatives and to estimate the extent toward net zero which may be achieved

Section E OVERVIEW OF UPGRADE CONCEPTS

The specifics of construction for any net zero project need to be determined on a case-by-case basis. However, there are certain upgrades that will most likely apply to every project. The following is a partial list of upgrade concepts that may be utilized on projects.

BASIC CODE AND SAFETY UPGRADES
Super-insulating and sealing the building should tighten the building to the extent that fresh air needs to be introduced and combustion air must be ducted to the mechanical room. In many cases, it also means that a mechanical room needs to be constructed or enclosed. Otherwise the combustion air openings could become a big leak for the building.
Combustion air requirements need to be verified for each individual project. Normally there will be two ducts from the exterior to the mechanical room, one ducted to the ceiling and one to the floor. Typical size is 6” diameter each.
Fresh air can be provided with a fixed outside air duct to the furnace return air with relief air provisions provided in a few locations in the house. Another option is to provide exhaust fans that run whenever the building is occupied, and provide make-up air inlets such as the Aldes Airlets in a few locations. This later option is only advisable when any gas-fired mechanical equipment and water heaters are sealed combustion type and have fresh air ducted directly from outside.

- Heat Recovery Ventilators: there are two types, heat recovery (HRV) and energy recovery (ERV). These recover heat or energy from exhausted air, such as from bathrooms, and transfer it to the fresh air. Alternatively they can simply exhaust and supply fresh air without being tied to specific exhaust systems.
    - These devices are fairly large, about the size of a small refrigerator, and have four duct connections, so do require some space planning.
    - The ductwork should be installed so that a cross-flow is obtained through the entire residence

INSULATION
Increasing the insulation levels in a home is one of the first steps that must be considered. In order to take steps toward a net zero home the exterior envelope must be very well insulated and sealed. With high levels of insulation, the energy needed for the mechanical system to heat and cool the home are drastically reduced, and only with this reduction can net zero be attainable from a reasonable investment in renewable power generation.

ATTIC INSULATION is typically one of the easier areas to improve the quality and quantity of insulation. The goal for a net-zero energy home should be a minimum of R-60, and higher if possible.

- Attic insulation, blown in:
  - Blown-in attic insulation is generally the least expensive option and avoids issues with warm roofs and moisture in under-roof insulation.
  - Care must be taken around light fixtures and other electrical equipment.
  - Need to protect ventilation openings in the eaves for attic moisture removal to prevent ice and moisture build-up on the underside of the roof as well as ice damming on the exterior of the roof.
  - The ability of the ceiling below to support the added weight needs to be considered.
  - Future access to lighting, piping, plumbing, ductwork, etc. will be more difficult
  - Sometimes difficult to seal construction gaps (thermal or air leaks).
  - Substantial R-values can be achieved if there is sufficient height and if other issues can be addressed.
  - Products include blown cellulose and blown fiberglass. Cellulose is generally considered more sustainable because it is typically contains nearly 100% recycled content, however the added chemicals for flame retardance can be an issue.
- Attic insulation, spray foam on top of ceiling (floor of attic space):
  - Need to protect ventilation openings in the eves.
  - Care must be taken around light fixtures and other electrical equipment.
  - Need to protect ventilation openings in the eves for attic moisture removal to prevent ice and moisture build-up on the underside of the roof as well as ice damming on the exterior of the roof.
  - The ability of the ceiling below to support the added weight needs to be considered, although foams are very light.
  - Future access to lighting, piping, plumbing, ductwork, etc. will be more difficult
  - Substantial R-values can be achieved if there is sufficient height and if other issues can be addressed.
  - Does an excellent job of sealing construction gaps and openings, thus reducing infiltration losses. Claims are made that this results in effectively a higher R-value than loose fills. Independent analysis and verification of these claims is probably still needed.

  - Products include closed cell and open cell spray polyurethane foam (SPUF). Closed cell have a much higher R-value per inch, but have significant issues with the blowing agents used. For this reason only open cell SPUF should be considered except in rare cases where the required R-value cannot be achieved in other ways.

- Attic insulation, spray foam on underside of roof:
  - In conventional under-roof insulation there is a need to provide an air space between the roof and the insulation connected to the ventilation openings in the eaves or soffits for under-roof moisture removal to prevent ice and moisture build-up on then underside of the roof. Air-sealing foam insulations may not have this requirement, however this needs to be confirmed on a case-by case basis and approved by the local building department. See web link in appendix.
  - Access to plumbing, light fixtures, etc. can be improved if t here is sufficient attic area and height.
  - The foam adheres to the roof sheathing and is easily applied. Further investigation is needed to estimate the maximum R-value that can be achieved. R-60 typically requires about 15 inches of closed-cell foam.
  - Products include closed cell and open cell spray foam insulation. Common materials are Icynene and polyurethane foam (SPUF). Closed cell foams have a much higher R-value per inch, but most have issues with the HFC blowing agents used, in particular a high global warming impact. We recommend water-blown insulations for minimum environmental impact. The newer HFC blowing agents are not as environmentally harmful as the older CFC or HCFC agents, however the greenhouse impact makes it difficult to achieve a carbon-neutral result. New products are coming on the market and more research is needed. There are foams in development that are co-blown with JFC and water, however these need further investigation before they can be recommended for “green buildings”.

- Attic insulation, rigid insulation on exterior:
  - If there is no space available on the inside of a roof structure (such as with a vaulted ceiling), rigid insulation may be added above the existing roof sheathing. This will require removal of the existing roofing surface.
  - Products include expanded polystyrene (EPS) or polyisocyanurate, with an integral sheathing board attached to the top surface. Extruded polystyrene (XPS) should not be considered due environmental issues with the blowing agent.

WALL INSULATION may be one of the most difficult areas to add insulation, but is critically important to the steps toward net zero. Most homes will have either 2x4 or 2x6 wood studs for the structure of the exterior walls. However, this depth is not sufficient to obtain the R-values needed. Therefore, depth must be added to the wall either on the interior or exterior – and neither of these choices is easy. Either an entirely new exterior finish must be added to the building (when adding depth to the exterior), or interior space must be sacrificed (when adding depth to the interior). Adding depth to the interior is especially difficult in spaces like kitchens, bathrooms and stairways because a reduction of a few inches could mean that bathtub no longer fits, or the stair width no longer meets code. For these reasons, the increased depth on the interior may not be able to cover all rooms of the home, and therefore exterior insulation may be preferred.

The goal for a net-zero energy home should be a minimum of R-30, and much higher if possible.

- Wall insulation with furring to the inside:
  - If existing insulation is present and properly installed, and thermal imaging scans with a high-resolution camera during a blower door test show the wall to be very tight (low air leakage), then existing interior wall finish may be left in place and a new wall can be built on the inside of the existing. It may still be a good idea to remove a section of finish to verify the insulation and sealing. If the existing wall is 2x4 construction, then the existing insulation is probably R-13, and if existing wall is 2x6 construction then the existing insulation is most likely R-19.
  - If existing insulation is not present, has sagged, or has gaps, then the existing interior finish should be removed and new insulation installed.
  - Add a new 2x4 stud wall, with new studs offset from the existing studs, 24 inches on center with single top and bottom plates to maximize area of insulation. Spray insulation such as blown cellulose, blown fiberglass, or spray polyurethane foam should be used to ensure fully filling all cavities. Most of these insulations are between R-3.3 (fiberglass) and R-3.7 (cellulose or SPUF) per inch. Using these calculations, the approximate new wall insulation-only R-values would be:
    - R-26 for new 2x4 stud wall with an existing 2x4 stud wall.
    - R-32 for a new 2x4 stud wall with an existing 2x6 stud wall.
    - R-32 for a new 2x4 stud wall with a 2” gap between an existing 2x4 stud wall.
    - R-40 for a new 2x4 stud wall with a 2” gap between an existing 2x6 stud wall.

    - Note that all of these values are for the insulation only and do not take into account the loss of insulation where studs, plates and headers occur. A typical wall has an actual R-value of about 80% of the insulation value.
    - Also note that most likely furring to the inside will not be able to occur on 100% of the interior walls (per note above).

- Wall insulation with new insulation on the outside:
  - If the existing exterior finish of the home is deteriorating and in need of replacement, then adding insulation on the exterior of the home may be a perfect solution. However, if the exterior finish of the home is in good condition, or is a zero-maintenance finish such as stone or brick, then exterior insulation may not be an option.
  - Exterior insulation is typically applied using sheets of rigid insulation. This creates a uniform installation covering 100% of the wall surface. Therefore, the total-wall R-values for this insulation are inherently higher than for insulation applied between studs.
  - If existing insulation is present and properly installed, then that insulation should remain. If the existing wall is 2x4 construction, then the existing insulation is probably R-13, and if existing wall is 2x6 construction then the existing insulation is most likely R-19.
  - If existing insulation is not present, has sagged, or has gaps, then additional blown-in insulation should be installed. This may be done from the exterior by making small holes in the sheathing.
  - There are inherent difficulties in attaching siding through the insulation. If wood or similar appearing siding is desired as the new exterior finish, then furring channels or some means of siding attachment must be designed into the rigid insulation. If stucco is the preferred exterior finish, then this may be applied directly to the new insulation.
  - Exterior insulation boards will typically be expanded polystyrene (EPS – R-3.9 per inch) or polyisocyanurate (R-6.0 per inch). Extruded polystyrene (XPS) should not be used due to environmental issues with the blowing agent. Using these calculations, some possible wall configurations would be:
    - R-26.8 for new 2” EPS insulation over an existing 2x6 stud wall.
    - R-31 for new 3” polyiso insulation over an existing 2x4 stud wall.
    - R-34.6 for new 4” EPS insulation over an existing 2x6 stud wall.
    - R-37 for new 4” polyiso insulation over an existing 2x4 stud wall.

WINDOWS AND DOORS

The technology for building more energy efficient windows and doors has grown significantly in the recent years. Most homes built 20 years ago or more will have insulated glazing with a U-factor of about 0.50 (the U-value is used for windows and door ratings, and this is the inverse of the R-value, so a U-value of 0.50 equals an R-value of 2). Most homes built in the 1960 or earlier will have single-pane windows with a U-value greater than 1.

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 some of today's windows achieve a U-value as low as 0.09 (that is an R-value of 11).

Windows and doors typically cover between 15 and 25 percent of the exterior walls of a home, so the insulation value of those openings is very important in a project approaching net zero energy.

Placement of windows is also of critical importance. 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) – see the notes on adding mass and on shading devices below. 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. And all windows are a source of heat loss at night. Therefore, opportunities to enlarge windows that are beneficial or reduce windows (or add shading) that are detrimental should be sought during the design process.

In addition to the U-factor, glass has 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 need a low SHGC.

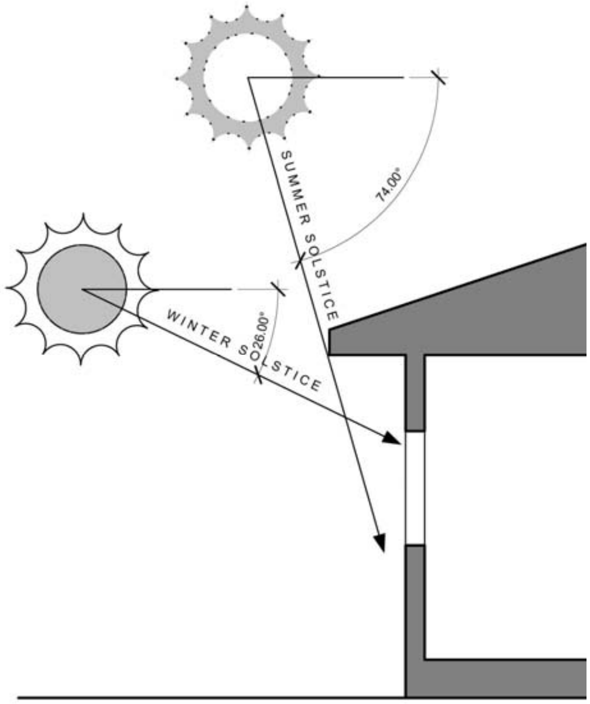
The process of selecting the right glazing for each window is referred to as "tuning" the windows. Tuning the glazing is extremely important on a net zero energy building and must be done using energy modeling so that the results of different window selections can be studied.

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:

- 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. 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.
- 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.
- Serious Windows (www.seriouswindows.com) is the only current manufacturer in the United States for ultra-high performing windows for the residential market.
- Fixed windows (windows that do not open) typically have lower U-values than operable windows. Windows that have a crank (casement or awning) typically have a lower U-value than sliding (single-hung, double-hung and sliders) windows.

PROPER SHADING DESIGN

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. Also, the goal of the net-zero home is also to provide a comfortable environment, and a home with proper shading will be inherently more comfortable than one without.

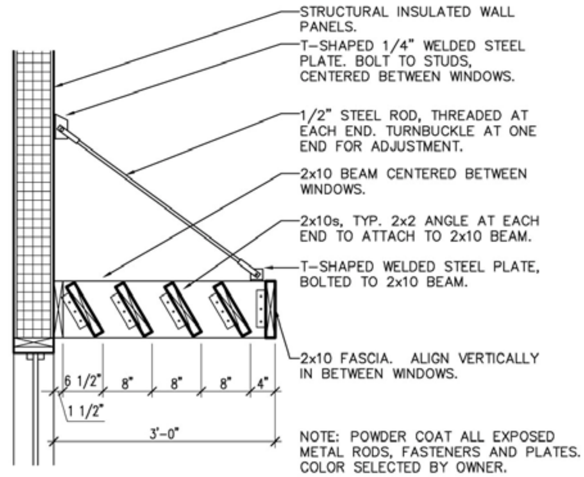


South-facing windows should have an overhang to protect the window from the summer sun, while allowing the winter sun to enter the home and provide warmth.

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 section.

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).

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.



SHADING DEVICE DETAIL

THERMAL MASS

Thermal mass is the materials inside a building that can absorb 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.

There are two types of thermal mass, and these can be identified as direct and indirect. Direct thermal mass is the material that can absorb the sun's energy (warmth) when the sun directly hits the surface. Indirect 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.

A successful alternative to mass interior to the insulation is mass integrated with the insulation, such as with straw-bale construction. Interior mass is still recommended, however less will be needed. For the renovation of existing homes such as those in Golden, adding straw bale insulation/mass is likely to be very difficult, although not necessarily to be completely ruled out.

In the absence of sufficient mass, there will be the temptation to use heating and cooling systems more than would seem necessary from annualized calculations that don't account for internal temperature comfort levels.

One of the key components of passive solar buildings, and the one that is most often forgotten or ignored, is direct thermal mass. 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 immediately 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. Direct thermal mass may be added by:

- Concrete floor topping
- Stone wall finish
- Adding a masonry fireplace
- Water feature
- Water tubes embedded in a wall
- Additional layers of gypsum board

If a home has the potential for passive solar heat, then direct thermal mass is an important area to address. However, all homes would benefit from indirect thermal mass. Indirect thermal mass helps the home stay warm in the winter, cool in the summer, and comfortable each day.

There are two associated requirements for the mass to be effective. First is to have sufficient mass to store a sufficient amount of heat or cool, ideally for multiple days. Second is to have sufficient surface area to be able to transfer or absorb the heat quickly. This thermal mass may be added by:

- 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

IMPROVE LIGHTING AND APPLIANCE EFFICIENCIES AND REDUCE PLUG LOADS

Lighting and appliances, particularly kitchen and laundry appliances, are major users of electricity in many homes. In addition, plug loads – basically anything plugged into an outlet – can also be major electrical consumers. Plug loads include anything from entertainment systems, TVs, clocks, and radios to computers and their accessories, security systems, and communications equipment. Some cable interface boxes use 40 watts of power and are on continuously whether the TV is on or not.

Both the type of lighting and the use of lighting are important factors.

- Incandescent lights are a type that consumes the most electricity, followed by halogen and other types. Fluorescent lighting uses significantly less electricity, however there are significant issues with their use of mercury. LED (Light Emitting Diodes) fixtures use less energy than even fluorescents and their costs are dropping. The biggest technological challenge with LEDs is the need for large heat sinks on the bigger fixtures. When preparing to pursue net zero for the home, conversion to LEDs wherever possible isrecommended.
- Use of lighting refers to how much the lights are on and whether there is more light than needed. Reduction in the amount of time the lights are on can be accomplished with simple measures such as convenient wall switching, or more active measures such as timers and daylight or motion sensors. 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.
- Reducing plus loads means surveying and measuring all the loads in the house to get an idea of where the loads are and then devising a strategy for turning off all power to the item when not needed. Many items consume power even when they are turned off. These devises have clocks, and other standby features that are not really necessary. As part of the survey, determine which loads need to be on together; for example the cable box and TV. Then run power to them as a group, perhaps through a power strip, and then the power strip can be turned off to turn off a group of items. Other strategies might include installing a wall switch for such grouped loads or a timer in a conveniently located wall plate so that the power is turned off if the occupant forgets to (even though the device itself, such as the TV, is turned off).
- Computer equipment is a special case and requires evaluation of any reduced life expectancy from turning the computers off when not in use instead of leaving them on continuously. Newer computers can generally be turned off, however verify with the manufacturer. Newer computers also have power-saving modes, so measuring the electricity use in that mode will tell you how effective it is. Computers also have many accessories that can usually be turned off, such as modems, routers, printers, monitors, etc., all of which consume power when idle and some even when turned off. A power strip or two can be used to turn everything off at once, and is more convenient (and thus more likely to be used) if the outlet for the power strip has a convenient wall switch.

IMPROVE SYSTEM EFFICIENCIES – HEATING, COOLING

The first and most important step in the process toward net zero is to reduce the energy needs of the house and appliances. Only after that is well underway does it typically make sense to address the mechanical heating, ventilation, and cooling systems. Improving the efficiencies of the heating and cooling systems can then make the final step to net zero possible.

Before proceeding, review the section above on basic code and safety upgrades. They are essential, and there may be others to add to the list.

One of the easiest and least expensive items to address is the water heater. An instantaneous tankless water heater can save energy, however it is not essential. There are now fairly high efficiency tank-type and hybrid tank-instantaneous water heaters. A new water heater that reduces stack and standby losses can make a significant difference. There is also a good return on investment from domestic hot water from solar thermal using a solar pre-heat tank (combined with a high-efficiency water heater if needed).

Evacuated tube solar hot water collectors

- The biggest savings, however, are likely to be from space heating. Many older homes still have gravity gas-fired furnaces with about 78% to 80% combustion efficiency, but closer to 65% to 70% annual efficiency due to stack and standby losses. Assuming the existing system is not already high-efficiency, here are some ideas:
    - Two basic options must be considered:
        - Replace the existing equipment only, but keep the system. This is clearly the lower cost, however there are limits to the efficiency that can be achieved. Many existing systems also have some significant problems, such as undersized or leaky ductwork, poor air distribution, etc.

    - Replace the entire system. The cost will be much higher and this option may only be practical when the house is already planned for a complete remodel.

- Sealed combustion furnaces. These furnaces use outside air ducted to the burner instead of room air. The primary advantage is that infiltration is reduced and therefore the overall energy used is reduced. The combustion process has a fan on it and also the ability to basically stop the airflow through the furnace when it is not firing. The result is a reduction in the standby heat loss that is common for natural draft furnaces. The furnace instantaneous efficiency is typically in the range of 80% to 83%. The total reduction can be as much as 15% to 20% of the building heating energy.

- Condensing furnaces. Similar to condensing boilers, a condensing furnace extracts more heat from the combustion process. Efficiencies as high as 94% to 98% are claimed for some of this equipment.

- Variable airflow furnace fans. The highest efficiency furnaces and air conditioners have variable speed fans. These can automatically reduce airflow for part load conditions, thus saving fan energy. 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. Efficiencies are typically up to about 87%. The annual efficiency is essentially the same as the instantaneous efficiency due to the very low standby losses.

- Condensing boilers. A condensing boiler extracts more heat from the combustion process by "condensing" the flue gas. Efficiencies as high as about 94% to 96% are claimed for some of this equipment. As a caution, the boiler is only condensing when the return water is below 140F. Above that return temperature the efficiency is similar to a high-efficiency boiler. Check with the manufacturer to obtain a chart of efficiency vs. return water temperature. As a result, condensing boilers are best applied to systems that use low temperature heating water, such as radiant floors.

- High efficiency condensing units and evaporator coils for air conditioning. Residential cooling equipment is available with EERs as high as 21 or more, 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 (energy efficiency ratio) 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) The SEER is determined through averaging readings of different air conditions to represent air conditioner efficiency throughout the season. 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.

- 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 the drier the entering air. Colorado is generally 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).

- Indirect evaporative cooling. Indirect evaporative cooling is done through a heat exchanger such that humidity is not added to the space. There is some loss of effectiveness due to the heat exchange. The advantage is that indoor humidity is not raised. This had been unusual for residential applications except for one product (developed in Colorado), however new products may emerge soon. As a general rule, the return on investment is not good for residential applications, but is much better for industrial applications needing lots of make-up air.

- Indirect-direct evaporative cooling combines indirect and direct evaporative cooling in one unit and can achieve lower supply air temperatures at the same outdoor conditions. This technology is rare in residential applications with only some use in large custom homes.

- Ice thermal storage. The primary advantage of ice thermal storage is to the utility company by moving electrical use for cooling from daytime to off-peak times. Often there is a financial benefit to the user as a result of the utility rate structure. There are some total source energy savings at the utility plant because the electricity is used when transmission line use is lower, thus lower electrical resistance and therefore less electrical energy lost in transmission. In some cases the utility also uses a higher efficiency base load generator during off-peak times which also provides some total source energy savings. Ice storage is not common for residential applications although there are some units in development (and maybe in production now).

- Ground-coupled heat pumps. When designed, installed, and applied for high-efficiency, ground-coupled heat pumps (or Ground Source Heat Pumps – GSHP) can be a very efficient source of heating and cooling. There is controversy over whether to consider GSHP to be a renewable energy source. I do not subscribe to this as it is merely an efficiency improvement technology through the use of a lower temperature differential heat exchange and there is no energy conversion process involved. The caveat about design for high efficiency is necessary because many designs and installations short-change the ground loop heat exchange surface resulting in low efficiency and ion many cases an out-of-temperature ground loop resulting in system shut-down. With good efficient design, a GSHP will out-perform most other systems. There are some cautions, as with condensing boilers. Particularly in heating, there are limits to the temperatures that can be efficiently achieved. Consequently the system performs much better when applied in conjunction with low-temperature heat distribution systems such as radiant floors.

- 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 can save energy and improve comfort. Further zoning can also save energy and improve comfort to a lesser degree.

- Monitoring and control systems. Low cost monitoring and control for small commercial and residential applications remains elusive. Starting costs are quite high, typically $20,000 and up for 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 then regularly. None-the less, here are some advantages:
    - 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.
    - Automatic controls, when combined with a zoned system, can control the amount of energy used in each space to just that needed 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.

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 top 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. 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 craw 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.

ELECTRIC POWER GENERATION

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 above 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 along a linear 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 are not 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).

IMPLEMENTATION OF STRATEGIES IN PHASE TWO
The strategies discussed above may now be considered for implementation into the second phase of this study – case study homes. Below are two possible implementation strategies for typical homes in Golden:

CONCEPT ONE (masonry)

- Assume brick or block construction, minimal insulation if any
- Blower-door test: identify all leaks and incorporate sealing into renovation
- Build 2nd wall inside with air space between and modify thresholds
- Foam the new wall and air space
  - Adds insulation AND seals many air leaks
- Install two layers of new 5/8 drywall for added mass AND finished surface
- Add sunroom with some mass (to moderate temperatures):
  - Fan, duct, and t-stat to transfer heat to rest of house (for absorption by added mass). Shut-off dampers to isolate at night.
  - Allow slightly higher daytime temperatures and typical lower evening and night set-back temperatures
- Consider Trombe Wall conversion if feasible (with shading for summer)
- Super-insulate and seal attics/roofs
- Replace window assemblies with high-performance
- Plug Load management
- Add power generation (photovoltaics or other form)

CONCEPT TWO (wood frame)

- Assume frame construction, minimal insulation if any
- Blower-door test: identify all leaks and incorporate sealing into renovation
- Remove exterior siding and add 2” minimum (4” preferred) rigid insulation, then add new exterior finish (stucco system would be the simplest)
- Add interior mass where possible (additional layer of 5/8” drywall , gypcrete flooring, etc).
- Add sunroom with some mass (to moderate temperatures):
  - Fan, duct, and t-stat to transfer heat to rest of house (for absorption by added mass). Shut-off dampers to isolate at night.
  - Allow slightly higher daytime temperatures and typical lower evening and night set-back temperatures
- Consider Trombe Wall conversion if feasible (with shading for summer)
- Super-insulate and seal attics/roofs
- Replace window assemblies with high-performance
- Add power generation (photovoltaics or other form)

Section F THE PROCESS TOWARD NET ZERO

We are recommending a "Process Toward Net Zero in this report. We have given considerable consideration to a number of possible approaches and believe this approach has significant advantages. For many reasons, a prescriptive one-size-fits-all approach to net zero has drawbacks. Those reasons include the fact that each person uses a building differently, and therefore the balance of net negative to net positive can vary considerably. Another reason is that each existing situation is different in many ways, and the resulting difficulty and expense of achieving net zero can also vary considerably. Each individual building, in fact, presents site and situation-specific challenges. Therefore this study recommends a *process toward achieving net zero* rather than attempt an impossible single prescription for all homes.

The process is deceptively simple in overview, and yet the details are probably more important in determining the degree of success. First, the process is described in the next part of this section. Following that, two concepts are explored to illustrate the process.

OVERVIEW

The Process toward Net Zero includes the following basic steps:

1. Reduce the building energy needs as much as feasible, essentially to the "balance point".

2. Incorporate high-efficiency or ultra high-efficiency mechanical and electrical systems and equipment, including appliances, again essentially to the "balance point".

3. Provide the remainder of the building energy needs using renewable energy sources.

The concept of a "balance point" is also deceptively simple. That would be the point at which it is economically and environmentally more effective to proceed to the next steps. Thus the building itself should be made as efficient as possible as long as the economic and environmental impacts are less than the impacts of more efficient systems or the use of renewable energy.

While the impacts are often simplified into life-cycle costs, the environmental impacts should also be considered. As a hypothetical example it may be more cost-effective even on a life-cycle basis to use more solar PV with storage batteries, however if there are serious environmental impacts from eventual disposal of the batteries or from mining or processing the raw materials for the batteries, that should be considered.

The steps below are highly informed by new building projects that have achieved net zero and more importantly, those that have attempted net zero and not quite gotten there.

An outline of the recommended simplified process is as follows:

1. **Determine the most cost-effective renewable energy source** or sources for the particular project and site. Then determine the incremental cost of adding more capacity. This will be used as the basis for determining when the balance point has been reached in comparing various measures to improve the efficiency of the building and its systems. Keep your notes about other sources because the situation may change as you get into the design and find some interesting integration possibilities.

   - For the purpose of this phase of the study, we will assume that community wind and on-site solar (PV for electricity and solar thermal for domestic hot water) are the two most likely renewable energy sources. On-site solar will be assumed where there is good solar access. Community wind will be the assumed alternative where solar access is poor.

2. **Determine the analysis tools that will be used.** There are a number of categories of tools that will be needed, including the following:

   - **Load calculation software** for determining peak heating and cooling requirements.

     For this we recommend using reasonably sophisticated computer software. There are many available and they have stood the test of time. It is not necessary to take shortcuts here. One that fits the bill well is “CHVAC Commercial HVAC Loads” by Elite Software, which we propose utilizing in future phases of this study. It has the sophistication needed to discern between small but important differences in building construction and systems.

   - **Energy analysis tools or software.** Some options are discussed elsewhere in this report. We are recommending using a spread sheet approach so that all the inputs and outputs can be viewed and adjusted rather than relying on the black box approach of most simplified residential analysis tools. The more sophisticated commercial software packages are complicated and require considerable expertise to achieve the level of discernment needed. Applying that level of expertise would most likely end up being far too costly as well. The factors to be included in the analysis are discussed in another section of this report.

- **Analysis tools for evaluating the comfort impact of thermal mass.** Again we recommend using a simple spread sheet evaluation. The software tools that might accomplish this are very complicated and in our judgment don't have the features needed sufficiently built in at this point. An outline of how to set up the spread sheet is discussed further in another section of this report.

  The primary reason to evaluate thermal mass is to keep the building within the comfort criteria as long as possible during occupied periods without having to turn on supplemental heating systems. If the indoor temperature average is within the recommended range, but there are swings of high and low temperatures that are outside of the comfort criteria, then the project success will be compromised. This is a common result in many passive solar buildings – too hot when the sun is out and possibly too cold when the sun is not out.

  Thermal mass will both store energy and level the high and low temperatures. The mass is most effective when is has sufficient surface area exposed to the space. That can be done with a few inches of drywall, concrete, or masonry on most of the interior wall, floor, and ceiling surfaces, or it can be accomplished with a rock box similar to the storage used in some air-type solar-thermal systems. Some buildings with super-insulation and sufficient thermal mass have been able to coast through a few days of no solar input even with very cold outdoor temperatures while dropping only a few degrees indoors.

  Thermal mass can also be effective in storing coolness without being too cold in passive cooling systems. In Golden, Colorado, most days of the year it gets cool enough at night to ventilate the building and remove heat from the mass. While natural ventilation will be sufficient many days, a mechanical ventilation option will be helpful when the outdoor temperature is barely below the desired indoor temperature. Simply put, if the intent is to cool the space to 75F, twice as much air must be moved when the outdoor air is 70F than when it is 65F.

- **Solar or renewable energy sizing software.** This can also be done with a spread sheet. The purpose is to size the solar system and have an output that includes the percentage of load that is provided, on an annual average basis, by the renewable energy system.

- **Develop a heating and cooling load calculation** for the building using the software discussed above. Do a cooling calculation even if mechanical cooling will not be used. The results will inform the natural ventilation strategies. Set up the program with sufficient detail to be able to evaluate many options as well as look at the variance in each room. A room-by-room calculation is recommended. As part of the calculation, calculate the R-value of each building component assembly using a separate spread sheet rather than use default values in the software. The default values won't have sufficient detail to evaluate small but important differences in insulation values and installation methods. List each window and each wall section separately to allow for subsequent quick evaluations. Once set up in this way, it is very quick to compare different insulation systems, wall constructions, windows, leakage rates, etc.

3. **Set up the energy evaluation spread sheet.** A recommended approach is a bin analysis wherein separate rows are used for 5 degree F temperature "bins" as well as separate columns for each occupancy/use period (for example: morning, day, evening, night).

   - Gather data about the use of the building and the hourly use profile of each energy-using appliance:
     - Lighting
     - Outlet plug loads
     - Computers
     - Refrigerators
     - Washers
     - Dryers
     - Dishwashers
     - Entertainment equipment
     - Communication equipment
     - Kitchen equipment
     - People (estimate heat output using ASHRAE data)
     - Anything else

   - Estimate the average energy use of each of the above and enter that into each of the temperature bins and occupancy columns.

   - Estimate the solar heat contribution from windows, walls, and the roof and enter that into each of the temperature bins and occupancy columns

   - Enter the heat loss (heating) and heat gain (cooling) for each of the temperature bins using the result of the load calculation. Note that this is done by calculating the heat loss or gain as Btu/hour (or equivalent metric units) per degree difference between the indoor design temperature and the peak load outdoor temperature and then pro-rating that to the temperature difference for each temperature bin.

   - Add a column for the energy used by the heating and cooling systems. This is typically pro-rated by the temperature bins.

   - Add all the rows and columns and calculate a single total annual energy use.

4. **Evaluate various options.** Note that now you can change the column variables in the energy spread sheet when evaluating different options and see the result in a single annual energy number. Now the cost of that change can be compared to the cost of providing the same amount of annual energy with the selected renewable energy source. In the simple case, the least cost wins. The "balance point" is where the two costs are equal. In a more complex consideration, environmental impacts or other values can now be evaluated and weighted.

   - **Evaluate insulation options.** As a starting point, successful net zero new buildings are using R-values similar to the following:
     - Walls: R30 to R50
     - Ceiling/roof assembly: R60 and higher
     - Foundation perimeter: Four inches of blueboard is common, for about R20
     - Windows: R7 or higher; SHGF: 0.30 or lower (be careful it does not get too dark); fiberglass frames (durable, better insulating, generally paintable)
   - **Evaluate window shading and daylighting options.** Effective use of windows can be key to achieving acceptable comfort without excessive glare. They are also an excellent source of "free" lighting during the day.
   - **Evaluate draft-sealing options.** Sealing drafts and dramatically reducing infiltration is essential to reducing the heating and cooling loads to the level where they can be reasonably addressed through renewable energy systems. This generally requires opening walls, ceilings, roofs, and sometimes foundations. An excellent first step is a thermal image scan performed when the indoor and outdoor temperatures are quite far apart.
   - **Evaluate passive solar and shading options. T**he best sources of renewable energy are passive solar heating and passive cooling. It is difficult to use this energy without overheating and glare issues, so very careful attention to details is essential.
   - **Evaluate mechanical system options.** After the building is made as efficient as possible, then it is time to look at high-efficiency or ultra-high efficiency systems. The systems will be much smaller once the building loads have been reduced, thus allowing some funding to be applied to higher efficiencies or improved control systems, or to offset some of the added cost to make the building more efficient. .
   - **Using the solar software or spread sheet, determine the solar system size** that will provide the remainder of the building energy needs. This may not be quite that simple, as most software will have a goal of some percentage that is

less than 100%. That is because the remaining percentage can be very expensive. Since we are considering a grid-connected system, one approach is to let the software determine a size for some percent, say 70%, and then increase the result by the unmet percentage. For example if the percentage provided is 70%, simply divide the result by 0.70.

- **Prepare design documents.** Clear documents are especially necessary on a project that is so much different than the traditional construction.
- **Carefully observe the construction process.** As with the design, heightened observation of construction will be necessary as contractors will be largely unfamiliar with how to achieve net zero.
- **Test, monitor, and adjust the final result.** Once completed, a monitoring and evaluation phase will be needed to understand the building performance and then to make adjustments to achieve the potential of the building. Then adjustments will be needed to fine tune the systems and for the occupants to learn how to achieve the best results from the building and its systems.

IMPLEMENTATION STRATEGY

The cost of taking an existing Golden residence all the way to net zero in today's market is likely to be high. Therefore a stepwise approach could make sense. In 5 to 10 years, the market could change, or there could be substantial rebates or incentives or other financial assistance. The first step taken, then needs to be such that it does not preclude eventually achieving net zero, or require significant undoing of what was done in the first step. An example of that would be the current approach in many if not almost all situations today. In those situations, an economical level of insulation is installed, perhaps blowing insulation into the existing wall and maybe furring in a few inches to add a few more inches, achieving about R19 or so. Windows might be replaced with triple pane windows with an R-value of about 3, which later turns out to only be center of glass and not include the frame, so really closer to R-2.5 or even R-2. When the next step occurs in this typical situation, it will be necessary to redo most of that, substantially increasing the wall R-value, putting in much better windows, and so on.

A wise first step implementation strategy from a longer point of view – that of eventually achieving net zero with minimal re-work along the way, might look like the following (keeping in mind that steps can be combined as budgets allow):

- Step 1 – wall envelope and space planning
  - Use an infrared scan to identify leaks in the insulation and sealing of the building envelope
  - Rebuild the exterior walls to achieve about R-50, sealing the exterior in the process

        - Be sure to include supports for future equipment and such things as future overhangs
    - Use sealants and foam to seal the wall and the wall to roof/ceiling interfaces
    - Plan the future space to identify a closed mechanical room and chases for heat recovery ductwork and future flues, combustion air, etc. Plan chases for solar thermal piping and for PV wiring. Plan spaces for PV panels, inverters, meters, etc. Install wiring or conduit for future control wiring and electrical wiring and any other electric or electronic systems envisioned for the future. Install conduit or wiring for future monitoring systems.
    - Install combustion air ductwork in this phase
    - Consider installing a small outside air duct to the furnace return connection
    - Install the PV system, or at least part of it, if financial incentives dictate
- Step 2 – Roof/Attic
    - Foam the roof if code allows (it should in the future) or the attic floor/spaces below ceiling if necessary
    - Be sure to continue the chases to the roof for any future equipment such as ERVs, solar PV, solar thermal, whole house attic fans, etc.
- Step 3 – windows
    - While this step could be taken earlier, there is likely to be better technology in the near future, so it might make sense to let this be an early phase budget cut as long as the new wall construction allows for future installation
- Step 4 – PV
    - Install the PV (this might be done earlier if financial incentives dictate)
- Step 5 – Solar Thermal
    - Install any solar thermal systems (this might be done earlier if financial incentives dictate)
- Step 6 – Appliances
    - This is really an on-going effort. Install the highest efficiency appliances that can be justified, and then maybe a little more, as they wear out.
- Step 7 – Electrical Controls and switching
    - This may also be ongoing with some being done in earlier phases.
    - Install switching to allow shutting off groups of outlets to control parasitic loads

- Consider controlled relays to allow a future computer control to shut off loads (present technologies are expensive, however the cost may drop as they become more widely used

- Step 8 – Efficient Mechanical Systems
  - Replace the water heater with a more efficient system when it fails, or do it at this time, or install provisions to allow quick installation of the new system when the old one fails
  - Replace the mechanical system with a more efficient system, or at least more efficient equipment. By this time there should be some prettyb good options on the market.
- Step 9 – Monitoring Equipment and Verification
  - Install sufficient monitoring equipment, temporary or permanent, to verify system performance
- Step 10 - Fine Tuning (Commissioning)
  - Make system and control adjustments and evaluate occupant usage patterns to fine-tune the system for performance and energy efficiency

Section G COST OPINIONS

Based on the obvious need for extensive renovations that will be required to transform an ordinary home into a net zero home, it should also be obvious that significant financial investment will be required. Of course, the actual cost of renovations will be determined on a case-by-case basis and will vary according to the actual construction, systems and finishes that are utilized in the project. The initial test homes, or case studies, will also likely be more expensive than subsequent projects due to higher design fees and using newer technologies. Full implementation of all construction needed to create a net zero home will likely exceed $100,000.

PHASING

One method of keeping costs lower would be to promote a phased installation of the materials and systems. In a phased approach, the upgrades could be completed as funds become available or as existing finishes and systems fail and need to be replaced.

For a phased approach to function properly, it is extremely important that the phases proceed in a proper sequence. For example, replacing an existing furnace with a new smaller furnace could only be done once the additional insulation and air sealing has occurred – otherwise the new furnace would not adequately heat the home. Some aspects of the project have logical order, but not absolute requirements – such as installing a new photovoltaic system for $20,000 only makes sense after investing $1,000 in more energy efficient lighting. Other aspects of the upgrade process may not have any needed order, such as when to replace an older refrigerator with a newer more efficient model (note that for these upgrades it is wise to keep in mind the embodied energy in existing appliances – taking a fully functioning refrigerator out of service and installing an energy efficient refrigerator may not save enough energy to offset the energy that it took to manufacture and deliver the more efficient model).

While some homeowners may benefit from this phased approach, it would be most beneficial if the case study homes for Phase Two of this study are constructed at one time, so that the full system can be studied and monitored. For this reason, grants or partner organizations may help offset the costs of ignoring potential cost savings through phasing as well as higher-than-normal costs for these initial projects.

Section H FUNDING SOURCES

The primary categories of funding sources to reduce the cost for energy retrofit projects include:

- Rebates/tax incentives
- Financing
- Grants

REBATES AND INCENTIVES

The first category, rebates and tax incentives, are available to all homeowners that are investing in their property through energy-saving projects and purchases. These incentives are usually offered by power companies to reduce the load on their systems so they do not need to construct expensive new power generation plants, or by government agencies in order to encourage their constituents to conserve natural resources. These incentives change over time, but some of the current offerings include:

- **Xcel Energy** offers rebates for the purchase and installation of energy saving appliances, systems, and more. These offerings currently include:
    - Energy audit for $60 to $120 (would normally cost $500 or more). Note that this audit is required in order to apply for the some of the following rebates…
    - Air sealing and weatherstripping ($100 rebate)
    - Attic insulation ($150 rebate)
    - Installing fluorescent light bulbs ($40 rebate)
    - Wall insulation ($250 rebate)
    - Setback thermostat ($10 rebate)
    - High efficiency furnace or boiler ($80 to $120 rebate)
    - High efficiency water heater ($60 to $100 rebate)
    - Energy Star appliances ($10 to $50 each rebate)
    - Evaporative cooler (up to $600 rebate)
    - See other potential rebates at www.xcelenergy.com/residential.
- **Xcel Energy Solar Rewards** program is specifically for installation of photovoltaic systems. These incentives include:
    - $2/watt rebate for installation of qualifying system.

  - Renewable Energy Credit (REC) which diminishes as more installations are placed. These RECs started at $2.50 per watt, but are currently at $0.45 per watt.

- Tax incentives from the federal government are subject to annual change of the tax laws. Currently these incentives include:
  - The **Home Energy Efficiency Improvement Tax Credit** offers 30% of the installed cost (up to $1500) of window/door upgrades, insulation, efficient furnaces, etc.
  - The **Residential Renewable Energy Tax Credit** offers 30% of the installed cost (with no cap) for renewable energy systems such as photovoltaics, wind turbines, solar thermal, fuel cells, etc
  - The **Homestar Energy Efficiency Retrofit** program is pending legislation that could increase the cap on the energy efficiency improvements to $3000.
- The Colorado Governor's Energy Office (GEO) has also offered rebates in 2010, financed through the federal government's American Recovery and Reinvestment Act, but these rebates were quickly depleted.

FINANCING

Homeowners that are searching for financing options for their project may qualify for lower rates or lower down payments because their project is energy efficient. These options include:

- FHA 203K financing is available with lower down payments and interest rates, as well as offering a single loan for the construction cost and permanent financing.
- Some banks (Bank of Colorado is one) offer energy efficiency mortgages. These mortgages can take into account the lower utility bills for a homeowner and thus the homeowner may qualify for a higher mortgage.
- PACE (Property Assessed Clean Energy) financing may become available, depending upon federal and local legislation. PACEnow.org describes this financing as "a bond where the proceeds are provided to commercial and residential property owners to finance energy retrofits (efficiency measures and small renewable energy systems) and who then repay the financing over 20 years via an annual assessment on their property tax bill." One benefit of this type of financing is that the payments stay with the property – so an owner can sell the property, and the next owner would continue paying for the energy upgrades.

PARTNER ORGANIZATIONS

For the initial projects to study and implement net zero energy homes in the Golden area, it may be possible to partner with organizations that are devoted to energy efficiency, sustainability, construction, or other similar goals. Some possible partner organizations could include:

- National Renewable Energy Laboratory
- Xcel Energy
- Colorado Governor’s Energy Office
- Rocky Mountain Institute
- Building Science Corporation
- National Association of Home Builders
- American Solar Energy Society
- The Denver Post, 5280, or other local periodical
- Natural Home, Eco-Structure or other national periodical
- Manufacturers of photovoltaic or other technologies

GRANT ORGANIZATIONS

For the initial projects to study and implement net zero energy homes in the Golden area, it may also be possible to obtain a grant from various organizations. These organizations may be charitable organizations with an emphasis on sustainability. Grant writing and research is not the expertise of the authors of this report, however there are grant experts who may assist in finding such grants. Some possible organizations for these grants would include:

- US Department of Housing and Urban Development (HUD)
- ColoradoEnergy.org

Appendix 1 ENERGY ANALYSIS SOFTWARE

Energy Analysis Spread Sheet Recommendation
This appendix material is supplemental to the spread sheet description given in the report Section “The Process Toward Net Zero”.

Different families use their homes in different ways. Some families are home more during the days, some work from home, some are more nocturnal, etc. Also, some families are much more energy conscious and tend to use less energy. In order to have a successful project, this study should assume a certain level of activity and energy usage throughout the year, and the next phase of the study could recommend levels to assume. The spread sheet recommendation assumes that four occupancy periods will cover most applications: Morning, Day, Evening, and Night. The Day period will probably be an unoccupied time for residential applications where everyone in the household works during the day. It would be an occupied period for applications where someone is at home during the day or where the home is used for home business or self-employment during the day. The differences could be substantial both in terms of acceptable comfort range as well as possible cooling. If the use is different on the weekends (likely), then a second set of occupancy columns is recommended.

Commentary on Freeware and other Software
This appendix material is supplemental to the discussion of analysis tools in the Section “The Process Toward Net Zero”.

A good reference web site for both freeware and software for sale is http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=energy_simulation . This site lists software that is free and software that has a cost. There is also a summary of what the software is intended to do.

This section of necessity contains considerable opinion, so consider the comments here in combination with advice from other sources.

Energy simulation software has recently been developing quite rapidly after many decades of slow development due mostly to limited funding. Therefore anything said here should be verified as the situation can change quickly. Simulation software that does a good job of modeling buildings and systems and comparing options will of necessity use a significant level of detail. Either the options for different systems will be very limited, or the user will need to know how to correctly make modifications to accommodate the buildings and systems being analyzed. Up until now this has been quite complicated, and in general is expected to remain complicated for a while longer. Anything beyond the buildings and systems that are included in the pre-programmed options will require expertise in making modifications to the model parameters in an effort to make the model perform like the project building and system. Doing this successfully requires an extensive understanding of buildings and systems generally at an engineering level. This can be considered both an art and a science. The level of real success in such modifications is open to question even though frequent users have a high level of personal confidence. Recent studies have shown that individual building performance does not correlate well to expected performance in may LEED buildings even though on an average of many buildings the performance is relatively close. There are many possible reasons for this and more study is needed. One possibility is that the modifications to the software by the users are not as good as the modifiers think. Some experienced users have commented that perhaps as many as 80% of the simulations are seriously flawed due to lack of experience (both in energy modeling and in building and systems familiarity) and expertise of the modeler. The nature of construction these days, wherein the model is normally done during or preceding schematic design phases and then subsequent significant changes are made without the model being updated is another likely source of performance error. The modeler must assume usage patterns for the building, and there is considerable opportunity for the actual occupants to use the building much differently, and this can also have a significant effect on the predicted results. During construction there are changes made by the contractor or the Owner on some projects and these are sometimes not verified with the engineer or the modeler, again resulting in difference performance. Thus some caution is advised in treating the results of energy model as indisputable truth.

Simplified energy simulation software is also available, and of necessity this has many built-in assumptions. It is pretty unlikely that such software will have capability of modeling the current leading edge systems, or if it does, have the ability to compare subtle differences in approach. There is also a higher probability that such software uses more of a black box approach resulting in a significantly reduced ability to know exactly what has been modeled. These are good for very rough comparisons and possibly comparisons of very different concepts. However, significant caution is advised in treating the results of energy model as indisputable truth.

Most software requires a lot of time to set up initially regardless the size of the building. Therefore use of the more complex simulation software is generally cost-prohibitive on smaller buildings or smaller projects. The equivalent of at least a 100,000 square foot new building is generally needed for the cost to be reasonable. Some local codes that require simulation have exemptions for buildings less than about 20,000 square feet in area, and may have lesser requirements for buildings between about 20,000 sq. ft and 100,000 sq. ft. A residence is in an even less cost-effective category, both due to the building size and due to many residential buildings being very complex architecturally with shapes that are difficult to handle in most simulation software.

An option discussed above (under "*Energy Analysis Spread Sheet Recommendation*") is to use an excel spread sheet set up to compare the specific energy-consuming features that are different in the alternatives for the actual project. While it will not capture simulation effects, it can give a reasonable comparison of the important items. When combined with an accurate computerized heating and cooling peak load calculation and performed by an experienced engineer the results can be adequate.

Simulation of Net Zero performance is another level of sophistication that as far as I know has not been verified in an independent study for any software that might claim to have that capability. The complexity is immense. Not only is all the building and systems simulation capability needed, but also the ability to model the impact of mass and the time-dependent level of comfort within acceptable parameters.

For Net Zero evaluation, an excel spread sheet can also be a useful tool. It is necessary to include calculation of the impact of mass on the space temperature and have sufficient engineering experience to use those parameters reasonably.

Some common software (note we have only commented on a very few of the many software packages available, and due to the rapidly changing market these days, our comments may well be out of date):

DOE2 is a software package that has been used for a long time to perform energy analyses on relatively complex buildings and systems. It has considerable capability and requires considerable experience and expertise to use. Downloads are free.

eQuest is a Windows overlay for DOE2 that has many features of DOE2 made much more accessible. Modifications can also be made in DOE2 by an experienced user. Downloads are free.

EnergyPlus is rapidly gaining acceptance and is a powerful simulation tool. There is not as much pre-programmed material available yet; however third-party developers are closing the gap.

TRNSYS is a simulation tool often used for complex system comparisons. It requires considerable expertise.

Energy-10 is a good tool for schematic level comparisons as long as the building and systems are simple and are included in the software options. It has been a while since I've inquired about this software, however my expectation is that it has limited modification capability and limited zoning (perhaps only one zone for the residential version).

Appendix 2 OBSERVATIONS OF EXISTING GOLDEN HOMES

This brick home (may be double-wythe brick or wood frame with exterior brick finish) has a heavily shaded roof.

These two homes have south facing roofs. The house on the left has good solar access while the house on the right would not, due to the large tree.

These roof-mounted solar panels are rotated due south. It is preferable to keep panels closer to the roof surface for aesthetic reasons.

In an effort to evaluate and understand the existing stock of homes available in Golden for transition to zero energy homes, the authors of this report took a tour of the city in May, 2010. We drove through each neighborhood to understand what the primary home types are in Golden, and begin thinking about how to transition each home type to a net zero energy home.

We found great diversity in the types of homes, primarily because they homes are built over such a wide time period (1860's to present). Many of the older neighborhoods in the central core contain homes of solid masonry (usually double-wythe brick). These older homes also have been heavily modified over the years so there is little, if any, consistency from one home to the next. In the newer neighborhoods (such as Eagle Ridge, Heritage Dells, or Mountain Ridge) all of the homes are wood frame, many use the same or similar floor plan, and there has been very little modification to the homes in the few decades since they have been constructed. There are also neighborhoods such as Mesa Meadows where all of the homes are custom or semi-custom where there is no similarity between homes, but nearly all utilize standard wood frame construction.

Based on the criteria listed elsewhere in this report, we found that there were a great number of homes whose roofs are not well suited for active solar. Because of the large trees in the central core there are many homes that have shaded roofs, which also have benefits but makes them a poor candidate for rooftop solar. Many homes would have good solar orientation and access, but large dormers or complex roof shapes decrease the amount of roof area available for flat panels. And since Golden's grid is rotated approximately 35 degrees from true north-south, many homes on this grid have roofs that face 35 degrees east of south or 55 degrees west of south (a slight eastern orientation in Colorado is considered favorable because of afternoon cloudiness, though 35 degrees is more than is considered optimal).

Based upon these observations, we would estimate that less than 10 percent of homes in Golden are good candidates to be able to provide sufficient power to the home through use of roof-mounted photovoltaic systems. This leads us to search for other possible sources of power generation such as neighborhood solar or wind power systems or ground-mounted solar (if the land area is available).

These identical homes all have good south-facing roofs. The west facing large windows present overheating issues which can be mitigated through exterior shading devices.

While this is a good effort to provide on-site power, these photovoltaic panels are facing 35 degrees east of south per the Golden grid, and the limited number of panels would not provide a net-zero installation.

This near-optimal roof contains 42 panels (approx 8.4kW).

The closest home in this photo would have good solar orientation, but the large dormers significantly reduce the area of the south-facing roof planes.

These three homes have similar floor plans and varying amounts of south-facing roofs.

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